# Correcting pH-Induced Manganese Deficiency in Bermudagrass Turf[1]

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**ABSTRACT**

**Manganese deficiency of 'Tifgreen' bermudagrass (*Cynodon* × *magenissii* Hurcombe) turf has been observed in South Florida when soil pH exceeded 7 as a result of irrigation with alkaline water. A 2-year field study on Pompano fine sand (a siliceous, hyperthermic, typic Psammaquent) was designed to evaluate three approaches to correcting this deficiency: 1) soil pH reduction with acid forming N sources, 2) Mn fertilization at rates up to 5 g/m² using $MnSO_4$, a Mn-chelate, or a Mn-frit, and 3) $MnSO_4$ fertilization in combination with a series of fungicidal drenches for suppressing Mn-oxidizing soil fungi. Sulfate and chelate Mn sources provided short-term correction of the deficiency, but little response to the frit source was noted. Sustained correction was achieved with $MnSO_4$ in combination with the fungicidal drenches. However, adequate Mn nutrition was obtained even in the absence of Mn fertilization when soil pH was maintained below 7 with acid-forming N sources. This treatment appears most suitable for turfgrass, since considerable N commonly is used in turfgrass production.**

***Additional index words:*** ***Cynodon sp.*, Alkaline soil.**

MANGANESE deficiencies are well-documented in many plants, but few cases of Mn deficiency or responses to Mn have been reported for turfgrasses. In fact, turfgrasses are relatively insensitive to most micronutrient deficiencies other than Fe and Cu (4). Nevertheless, Mn deficiency was observed in Florida as early as 1948 (2), but the documenting evidence was not widely circulated or noted. We have observed Mn deficiency of 'Tifgreen' bermudagrass (*Cynodon* ×*magenissii* Hurcombe) on several occasions at the Agricultural Research Center in Ft. Lauderdale. For example, plots receiving N from CaN [$Ca(NO_3)_2$] were chlorotic and grew poorly compared to those fertilized with AS [$(NH_4)_2SO_4$] (13). Growth and color were improved when $MnSO_4$ was applied to the CaN plots, although growth remained inferior to AS plots receiving no Mn. Growth and color were nearly as good in CaN plots that received weekly fungicide drenches as in AS plots.

Manganese availability is inversely related to soil pH. The oxidation of divalent Mn to less soluble forms occurs in the pH range of 7 to 8 primarily as a result of microbial activity (10). Numerous fungal species have been implicated in this transformation (*Botrytis* spp., *Mycogone* spp., *Tricholadium* spp., *Papulospora manganica*).

Although the sand-textured Entisols and Spodosols of south Florida generally have very acid surface horizons, the pH of these poorly buffered soils can increase rapidly when irrigation water high in pH and calcium bicarbonate is used. In south Florida, limestone bedrock may be found at 1 to 2 m or less in depth. Drainage and irrigation canals and ponds often extend to or into this rock. Canal water near the Ft. Lauderdale Center had a pH of 7 to 8 and an alkalinity equivalent of about 250 mg $CaCO_3$/liter during a 14-month measurement period in 1974-75 (Lutz, J. 1977. Water quality characteristics of several southeast Florida canals. Tech. Publ. 77-4. South Florida Water Management District, West Palm Beach, FL 33402). Irrigation with this water would supply the equivalent of 25 kg $CaCO_3$/ha/cm, or 1 ton $CaCO_3$/ha/40 cm irrigation water. Since evapotranspiration from turfgrass in south Florida averages over 100 cm annually, considerable "liming" can result from required irrigations. Soil pH at the Ft. Lauderdale Center has increased from its native range of approximately 5.2 to over 7.0 as a result of irrigation since 1970. This increase is considered typical of many turfgrass areas in south Florida and no doubt occurs elsewhere when high-pH irrigation water is used.

The study described herein was conducted to determine the best methods for correcting pH-induced Mn deficiency in Tifgreen bermudagrass, and to assess the role of soil fungi.

## METHODS AND MATERIALS

The experiment began on 23 Dec. 1975, when N, from either AS or CaN, was applied with a drop-type spreader at the rate of 15 g/m² to plots 1.23 × 3.05 m. These plots were arranged in a randomized block design with five replications on an established stand of Tifgreen bermudagrass on Pompano fs, a siliceous hyperthermic typic Psammaquent (Entisol order), at the Ft. Lauderdale Center. Nitrogen was applied to the same plots at the rate of 10 g/m² at 4-week intervals through 20 Apr. 1978, using the same sources except that $NH_4NO_3$ was substituted for AS from March through July, 1977, and from November, 1977, to the end of the study in an attempt to keep soil pH above 5. For simplicity, this treatment is referred to as AS in spite of this substitution. Various uniform fertilizations (Table 1) were applied to the entire plot area to assure adequate plant nutrition (Mn excepted).

Starting with the second N application, fungicides were applied to one CaN-fertilized plot in each replication. The fungicides used were 1) captan (50 WP) at 6 g/m², 2) thiram (75 WP) at 7 g/m², Ortho Golf and Turf Fungicide[3] (60% folpet, 5% $CdCO_3$ and 10% thiram) at 2 1/2 g/m², and Dithane® A-40[4] (93 WP) at 1 g/m² (total material basis). One fungicide from this group of four was applied on a rotational basis each week, except that Ortho Golf and Turf was dropped in mid-1977 when it became unavailable. The fungicides were mixed in approximately 16 liters of water per plot and applied with a sprinkling can. From 0.5 to 1.0 cm of irrigation followed each fungicide application.

One CaN fertilized plot in each replication was divided into thirds and each subplot received Mn from $MnSO_4$ at 0.2, 0.6 or 2.0 g/m² on 16 Mar. 1976 and at 0.5, 1.5, or 5.0 g/m², respectively, on 9 Mar. 1977. The $MnSO_4$ was dissolved in 2 liters of water per subplot and applied with a hand sprayer. The applications were followed with 0.5 cm irrigation. Manganese from $MnSO_4$ was applied in a similar manner to one AS and to two

[1] Contribution from the Agric. Res. Ctr., Univ. of Florida Institute of Food and Agricultural Sciences. Florida Agric. Exp. Sta. Journal Series No. 1394. Received 27 Sept. 1978.

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[3] Chevron Chemical Co., Ortho Div., 200 Bush St., San Francisco, CA 94120. Mention of trade names is made for identification purposes and does not imply endorsement.

[4] Rohm and Haas Co., Independence Hall West, Philadelphia, PA 19105.

**Table 1. Fertilizer applications across all plots.**

| Nutrient | Source | Rate | Date |
|---|---|---|---|
| | | $g/m^2$ | month/year |
| P | Triple superphosphate | 6.1 | 1/77 |
| K | $K_2SO_4$ | 8.0 | 12/75, 8/76, 4/77, 7/77, 10/77, 2/78, 4/78 |
| Mg | $MgSO_4$ | 9.6 | 1/76, 3/77, 9/77, 2/78 |
| | | 0.4 | 8/76 |
| Fe | $FeSO_4$ | 0.46 | 3/76 |
| | | 0.11 | 8/76 |
| Zn | ZnO | 0.12 | 8/76 |
| B | $Na_2B_4O_7$ | 0.013 | 8/76 |
| Cu | $CuSO_4$ | 0.09 | 8/76 |

CaN-fertilized plots (including the plot which received fungicides) in each replication at the rate of 2.0 $g/m^2$ on 16 Apr. 1976, and at 5.0 $g/m^2$ on 19 May 1977. Manganese was also applied separately to CaN fertilized plots in the same manner at the same rates on the same dates using the sources a) THIS[5], a polyphenolic acid chelate and, b) Mn-glass frits,[6] except that the frits were applied with a sprinkling can in 1977. Irrigation followed these treatments. One AS and one CaN plot in each replication received no manganese during the study.

Turf appearance was rated periodically throughout the study, always 2 weeks after the N fertilizations. The ratings were based on a combination of color and density, with 10 being the best possible and 7 being just acceptable. Tissue samples were taken periodically in each plot with a greens mower set at 0.6 cm. The roller drive was disconnected from the engine so that the mower could be pushed by hand while taking the sample. The mower accurately cut a 56 cm wide by 262 cm long strip in each full plot or a 56 × 165 cm strip in the subplots. The tissue samples were dried at 70 C, weighed, and ground in a stainless steel Wiley mill. Various metal cations were analyzed in wet acid ($3HNO_3$:$2HClO_4$: 1HCl) digestates of the tissue using atomic absorption. Phosphorus was determined by the vanadomolybdophosphoric yellow color procedure and N was determined by Kjeldahl procedure (8). Chlorophyll was occasionally determined colorimetrically in methanol extracts of plant tissue (9).

Soil samples (0 to 10 cm) were taken from two AS and two CaN plots each month just prior to the N fertilizations. Samples were air-dried, screened, and pH was measured in water by the Univ. of Florida (Gainesville Campus) Soil Testing Laboratory.

Samples were taken from all plots in May of 1976, 1977, and 1978, air-dried, screened, and manganese extracted (2 g soil — 20 ml extractant) with the following reagents determined by atomic absorption: pH 7, *N* $NH_4OAc$ (6); pH 4.8, *N* $NH_4OAc$ (1); 0.1 *N* $NH_4OAc$ + 0.2% hydroquinone (12); and DTPA (7).

The plot area was managed as a golf green. It was treated for nematodes shortly before the study by injecting DBCP (5) and in April, 1977 using Nemacure[7] granules. Insecticide controls were used, particularly for sod webworms (*Herpetogramm* spp.) during the summer and fall. Fungicidal controls were generally unnecessary, and were avoided since fungicides constituted one treatment. However, the plots were sprayed twice with Dithane® M-45[4], which contains 16% Mn, at 0.9 $g/m^2$ during June, 1976, and with Daconil 2787[8] several times during August and September, 1977, to control dollar spot (*Sclerotinia homoeocarpa* Bennett). Partly because of fungus and worm injury, no evaluations were made from June, 1976 to February, 1977 or from September to November, 1977. The turf was mowed at 0.6 cm twice weekly during the spring, summer, and fall, and weekly during the winter. The turf was irrigated daily at 0.25 to 1.0 cm, except during the rainy periods, using alkaline water from a canal adjacent to the Ft. Lauderdale Center.

[5] Stoller Chemical Co., Inc., 8705 Katy Freeway, Houston, TX 77024.

[6] Frit 187. Frit Industries, Inc., Box 1324, Ozark, AL 36360.

[7] Chemagro Agricultural Chemicals Div., Mobay Chemical Corp., Box 4913, Kansas City, MO 64120.

[8] Diamond Shamrock Chemical Co., Agricultural Chemicals Div., 1100 Superior Avenue, Cleveland, OH 44114.

Data from qualitative treatments were subjected to analysis of variance, means were compared by the Duncan's Multiple Range Procedure (14). Regression analysis was used for data from quantitative treatments (14).

## RESULTS AND DISCUSSION

The AS N source caused a rapid drop in soil pH from greater than 7 to less than 5 (Fig. 1). The pH decreased about one unit during the first 2 months of AS fertilizations. Where CaN was used the soil pH remained near 7. Thus, relatively speaking, the CaN treatment can be thought of as the "high" pH treatment and the AS treatment can be thought of as the "low" pH treatment.

A difference in turf appearance which was related to the N source became clearly evident shortly after the first N application. The turf was much darker green in the AS plots. Tissue samples taken from CaN and AS fertilized plots just two weeks after the first N application yielded 3.7 and 6.4 $g/m^2$, respectively. Chlorophyll in these plots averaged 19.5 and 44.2 mg/$m^2$, respectively. Similar appearance, yield, and chlorophyll trends were noted in an evaluation taken 2 weeks after the second N fertilization. There were no appreciable differences related to N sources in the tissue analyses on these two dates for N (avg. 5.9%), P (avg. 0.5%), or K (avg. 1.8%), but Mn averaged 36 and 78 ppm in CaN and AS fertilized plots, respectively.

Similar visual results were observed in a test strip adjacent to the plot area. Small plots receiving N (15 $g/m^2$) from either AS or $NH_4Cl$ were darker green 2 weeks after application than those receiving CaN or $NaNO_3$.

Less than 2 months after the weekly fungicide drenches were started on CaN plots, the turf so treated was observed to be darker green than that in CaN plots which did not receive the fungicides.

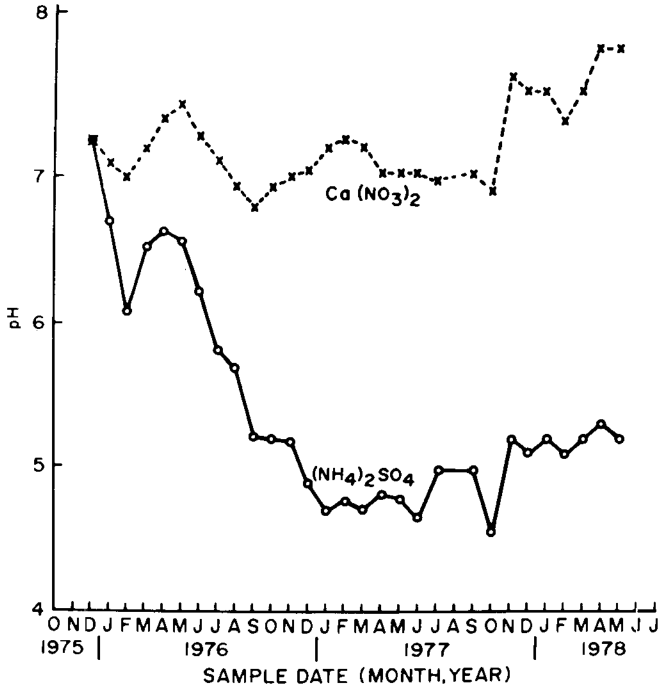


Fig. 1. Soil pH resulting from $(NH_4)_2SO_4$ and $Ca(NO_3)_2$ nitrogen sources.

Turf appearance improved considerably when CaN sub-plots were fertilized with Mn (Fig. 2). Significant ($P < 0.05$) linear responses were observed at 2 and 6 weeks. However, ratings decreased with time after Mn fertilization, and at 10 weeks there was no statistically significant response. Furthermore, at any level of Mn, CaN subplots rated lower than AS plots which received no Mn. These latter plots averaged 9.9, 9.8 and 9.9, for the 2, 6, and 10-week ratings, respectively. No statistical comparison can be properly made among all four treatments because of the plot design. In spite of the obvious color response to the three levels of Mn, there was no growth response (data not shown).

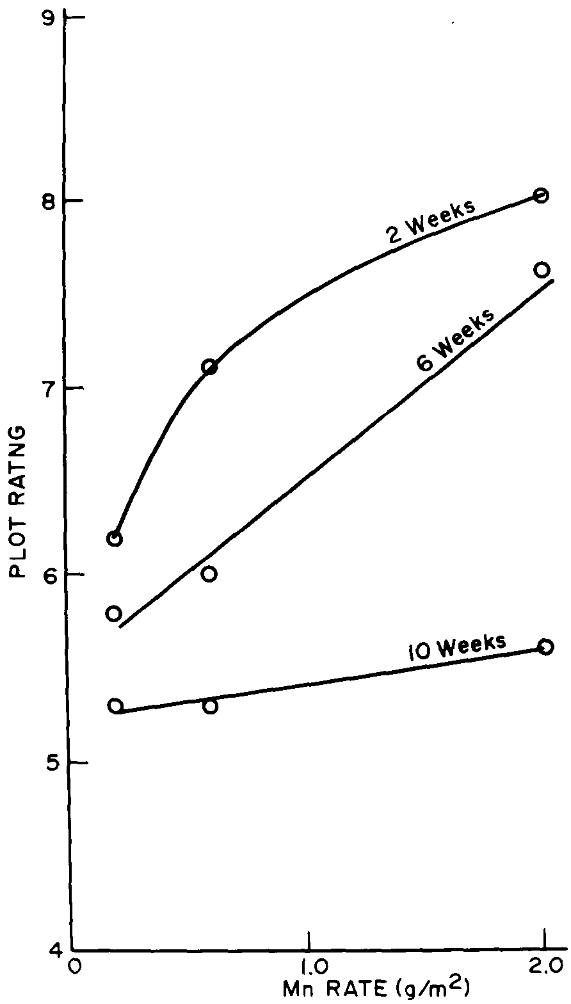


Fig. 2. 'Tifgreen' bermudagrass turf ratings resulting from Mn fertilizations ($MnSO_4$) of $Ca(NO_3)_2$ fertilized plots on 16 Mar. 1976.

Turf receiving the chelated and sulfate Mn forms generally had a higher rating for visual appearance than that receiving the frit source, when all were applied at 2.0 g/m$^2$ (Table 2). There were no differences in yield among these treatments, nor were they different from the check except that the chelate treatment was better than the check in April and May, 1977. Plots receiving N from AS generally had better visual appearance and frequently had greater yield, even without Mn fertilization, than CaN-fertilized plots which received Mn treatments. The exception was the CaN plot which received fungicidal drenches weekly. There were no significant differences in rating between this treatment and AS fertilization at 4 or more weeks after Mn application, although its yield was less through 6 weeks. Thirteen months after the Mn was applied, the CaN + fungicides treatment was superior in rating and yield to the other CaN treatments. Its yield was comparable to the AS treatments, and its appearance rating was somewhat better than the AS treatments. Most of these responses were very apparent visually (Fig. 3).

None of the four fungicides contained Mn as a part of the active ingredients. However, the captan, thiram, Golf and Turf, and A-40 materials were found to contain 300, 5, 12, and 0 ppm Mn, respectively. During the study less than 0.06 g Mn/m$^2$ was added with the fungicides. We consider this amount insufficient to account for the performance of the fungicide treatment, especially considering that this treatment emerged as one of the better ones within a few months after the study was initiated. The treatment effects were more likely due to suppression of Mn-oxidizing fungi (10).

Data obtained in the second year upon reapplication of the treatments at higher rates largely confirmed the first year results, though some important differences occurred. Following $MnSO_4$ application at 0.5, 2.0 and 5.0 g Mn/m$^2$ to CaN plots that had received Mn at 0.2, 1.5 and 2.0 g/m$^2$, respectively, the previous year, significant visual response was noted at 3 weeks (Fig. 4). The highest Mn application produced ratings in the same general ranges as those of AS-fertilized plots (9.4), i.e., better than in the first year. The CaN plots without Mn only rated about 5.0. Yield also was significantly increased by Mn (data not shown), which did not occur in the first year. Ratings continued to be significantly related to Mn fertilization for over a

**Table 2. Yields and ratings of 'Tifgreen' bermudagrass as affected by Mn sources applied 16 Apr. 1976 at 2 g Mn/m$^2$.**

| | | 1976 | | | | | | 1977 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 27 Apr. | | 11 May | | 25 May | | 30 Mar. | | 27 Apr. | | 19 May | |
| N source | Mn source | Yield | Rating | Yield | Rating | Yield | Rating | Yield | Rating | Yield | Rating | Yield | Rating |
| | | g/m$^2$ | | g/m$^2$ | | g/m$^2$ | | g/m$^2$ | | g/m$^2$ | | g/m$^2$ | |
| $(NH_4)_2SO_4$ | -- | 36 a* | 9.8 a | 24 b | 9.5 a | 50 a | 9.9 a | 22 abc | 9.5 a | 36 a | 9.8 a | 45 a | 9.2 b |
| $(NH_4)_2SO_4$ | $MnSO_4$ | 40 a | 9.9 a | 34 a | 9.6 a | 52 a | 9.6 a | 22 abc | 9.4 a | 34 abc | 9.8 a | 43 a | 9.2 b |
| $Ca(NO_3)_2$ | -- | 14 b | 5.4 e | 17 bc | 5.3 b | 22 b | 6.1 c | 15 bc | 5.0 c | 25 c | 5.8 c | 19 c | 5.5 e |
| $Ca(NO_3)_2$ | $MnSO_4$ | 12 b | 7.2 c | 10 c | 6.0 b | 25 b | 7.3 b | 24 abc | 6.0 b | 32 abc | 6.7 b | 27 bc | 6.4 c |
| $Ca(NO_3)_2$ | Chelate | 18 b | 7.8 c | 12 c | 6.8 b | 26 b | 7.7 b | 26 ab | 6.2 b | 35 ab | 6.7 b | 30 b | 6.2 cd |
| $Ca(NO_3)_2$ | Frits | 14 b | 6.3 d | 13 c | 6.1 b | 23 b | 6.3 c | 17 c | 5.1 c | 26 bc | 6.0 c | 21 bc | 5.7 de |
| $Ca(NO_3)_2$† | $MnSO_4$ | 19 b | 9.0 b | 17 bc | 9.3 a | 37 b | 9.1 a | 25 a | 9.3 a | 41 a | 9.5 a | 48 a | 9.9 a |

* Values within a column followed by the same letter are not significantly different at 0.05 level. † + Weekly fungicidal drenches.

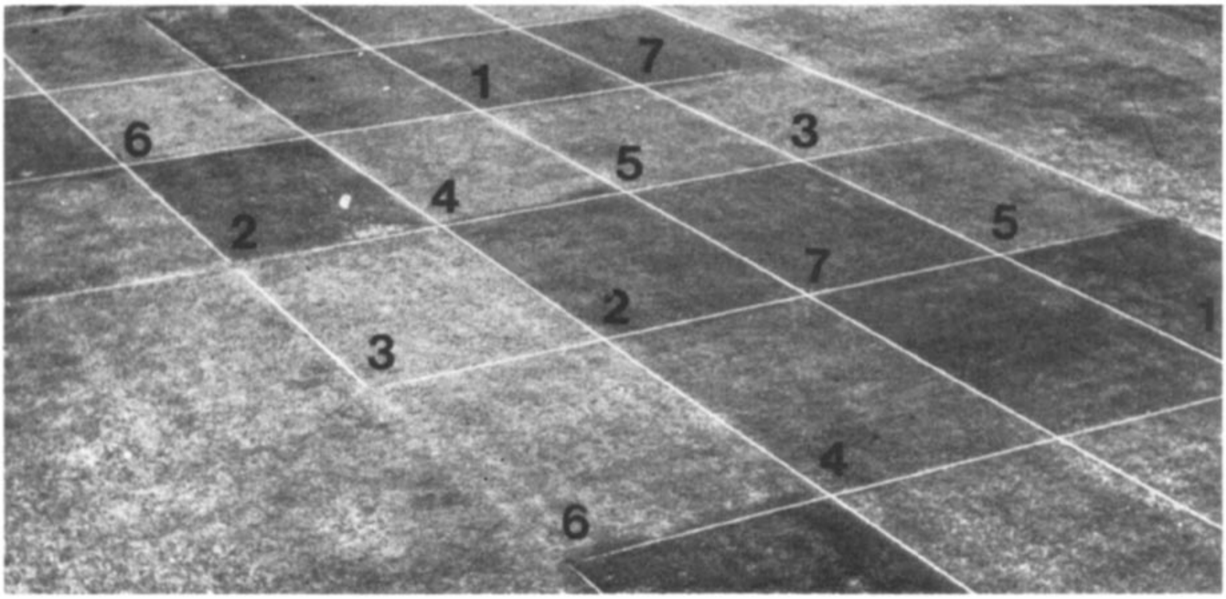


Fig. 3. Experimental plots on 24 Mar. 1977 (approx. 50 weeks after Mn sources were applied at 2.0 g Mn/m²). Treatments: 1) $(NH_4)_2SO_4$ + *no Mn*; 2) $(NH_4)_2SO_4$ + $MnSO_4$; 3) $Ca(NO_3)_2$ + *no Mn*; 4) $Ca(NO_3)_2$ + $MnSO_4$; 5) $Ca(NO_3)_2$ + Mn Chelate; 6) $Ca(NO_3)_2$ + Mn Frits; and 7) $Ca(NO_3)_2$ + $MnSO_4$ + fungicide drenches.

year (through May, 1978). Nevertheless, with time the ratings declined and beyond 7 weeks appeared to be substantially less than those of the AS fertilized treatments.

Yields and ratings following the second, but higher (5 g Mn/m²), application of the various Mn sources generally reinforced the first year data, though some exceptions occurred (Table 3). In contrast to the first year, CaN-fertilized plots receiving $MnSO_4$ and Mn-Chelate were essentially equivalent to AS plots in both yield and rating 3 weeks after Mn application, and in yield through the August 3 evaluation. This contrasts with the first year, when the lower (2 g Mn/m²) rate was used, in which both ratings and yields were usually inferior to those of the AS plots.

As in the first year, the frit source resulted in lower visual ratings than the other two sources. Yields of the fritted source treatment also were lower, except during the last few months of the study, when the fritted source and chelate source yields were equal, but lower than the sulfate source. There were no visual differences between the chelated and sulfate-Mn treatments.

The $MnSO_4$ + fungicides treatment resulted in ratings and yields equivalent to the AS plots, except for two evaluations in the spring of 1978 when an unexplained brownish-reddish dieback of many leaves in the fungicide plots occurred. By the last evaluation date the fungicide plots again were equivalent to the AS plots. The AS plots, with or without added Mn, always rated and yielded among the best.

Tissue Mn in mowed clipings taken over a 1-year period immediately before and after the 19 May 1977 Mn fertilizations at 5.0 g/m² are presented in Table 4. On the date of application there were no significant differences in tissue Mn among the CaN plots, but Mn was significantly lower in CaN plots than in AS plots. Additionally, tissue Mn was the same in AS plots regardless of whether or not Mn had been applied (2.0 g/m²) 13 months earlier (16 April 1976). The same observation held for the CaN plots.

**Table 3. Yields and ratings of 'Tifgreen' bermudagrass as affected by Mn sources applied 19 May 1977 at 5 g Mn/m².**

| | | 1977 | | | | | | | | 1978 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 7 June | | 5 July | | 3 Aug. | | 14 Dec. | | 8 Feb. | | 5 Apr. | | 10 May | |
| N source | Mn source | Yield | Rating | Yield | Rating | Yield | Rating | Yield | Rating | Yield | Rating | Yield | Rating | Yield | Rating |
| | | g/m² | | g/m² | | g/m² | | g/m² | | g/m² | | g/m² | | g/m² | |
| $(NH_4)_2SO_4$ | – | 43 ab* | 9.2 ab | 51 ab | 9.7 a | 51 a | 8.7 b | 39 a | 9.8 a | 17 a | 9.4 a | 49 a | 9.6 a | 114 a | 9.7 a |
| $(NH_4)_2SO_4$ | $MnSO_4$ | 46 a | 9.3 ab | 54 a | 9.5 ab | 54 a | 8.7 b | 36 b | 9.8 a | 16 a | 9.0 a | 47 a | 9.5 a | 106 a | 9.5 a |
| $Ca(NO_3)_2$ | – | 27 c | 5.8 c | 45 bc | 6.3 d | 33 c | 5.1 d | 9 e | 5.1 b | 3 d | 4.8 d | 14 d | 4.8 d | 47 c | 5.1 c |
| $Ca(NO_3)_2$ | $MnSO_4$ | 39 b | 9.0 b | 53 a | 9.2 bc | 46 ab | 6.9 c | 26 bc | 9.3 a | 10 b | 8.0 b | 34 b | 8.1 b | 83 a | 7.3 b |
| $Ca(NO_3)_2$ | Chelate | 40 ab | 9.1 b | 49 ab | 9.1 c | 44 ab | 7.2 c | 21 cd | 9.3 a | 8 bc | 8.0 b | 23 cd | 8.1 b | 56 bc | 7.1 b |
| $Ca(NO_3)_2$ | Frits | 30 c | 6.3 c | 43 c | 6.4 d | 36 bc | 5.0 d | 14 de | 6.0 b | 4 cd | 7.0 c | 21 cd | 6.1 c | 54 bc | 5.5 c |
| $Ca(NO_3)_2$† | $MnSO_4$ | 46 a | 9.7 a | 54 a | 9.7 a | 50 a | 10.0 a | 32 ab | 9.5 a | 15 a | 7.1 c | 26 bc | 8.7 b | 85 ab | 9.4 a |

* Value within a column followed by the same letter are not significantly different at 0.05 level. † + Weekly fungicidal drenches.

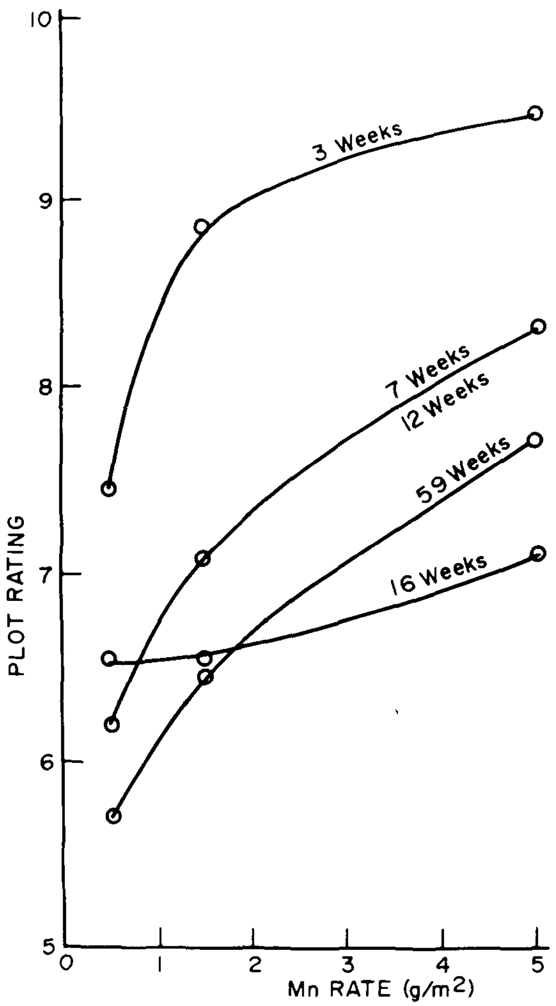


Fig. 4. 'Tifgreen' bermudagrass turf ratings resulting from Mn fertilization ($MnSO_4$) of $Ca(NO_3)_2$ fertilized plots on 9 Mar. 1977.

Application of Mn from the fritted source never resulted in tissue Mn significantly greater than in the corresponding check. Tissue Mn was significantly increased following application from the sulfate or chelate sources, relative to the corresponding check, but it never was as great as in AS plots that received no Mn during the experiment. Seven months after the Mn was applied, there were no significant differences in tissue Mn between the sulfate and chelate source treatments and the corresponding check. Tissue Mn in the CaN plots receiving the weekly fungicidal drenches was generally significantly greater than that in the corresponding CaN plots which did not receive fungicides.

A comparison of yields (Tables 2 and 3) and tissue Mn (Table 4) reveals that tissue Mn was always 26 ppm or greater in the highest yielding plots, and 35 ppm or less (usually less than 20 ppm) in the lowest yielding plots. Approximately similar tissue-Mn values were associated with the best and poorest visual ratings. From these data it appears that Mn is likely to be limiting Tifgreen bermudagrass growth and appearance when tissue contains less than 20 to 25 ppm Mn, and is not likely to be limiting when values of 30 to 35 ppm or greater are observed. However, trying to determine a "critical level" of tissue Mn was complicated by the method of taking the sample. Samples taken by hand with stainless steel or Ni-plated scissors were often found to contain considerably less Mn than corresponding samples taken with the greens mower. This was most noticeable in samples containing the least Mn, i.e., in the CaN plots which received no Mn. In a comparison involving five harvests of these plots, tissue sampled with the mower averaged 18 ppm Mn whereas tissue sampled by hand averaged 11 ppm. The reason for this difference could not be readily determined. Perhaps it was due to Mn contamination from the mower blades, for Mn is a necessary component of finished steel (11).

A comparison of soil Mn extracted by various reagents (Table 5) with turf ratings on corresponding observation dates (Tables 2 and 3) indicates that none of the reagents consistently reflect Mn availability in this study. For example, in the 11 May 1976 sampling, significantly less Mn was extracted by $NH_4OAc$ (pH 7 or 4.8) and $H_3PO_4$ from AS plots which received no Mn than from AS plots that were Mn fertilized. Yet there was no significant difference in rating between these treatments; both rated very high. There was no significant difference in the amount of Mn extracted from AS and CaN plots which did not receive Mn. Yet the latter rated significantly lower than the former. Similar inconsistencies are encountered for the other reagents and for other observation dates.

It is clear from the above that when the soil pH was less than about 7, Mn was sufficiently available for normal turf appearance and growth. Thus, Mn deficiencies observed were pH-induced rather than attributable to insufficient total Mn in the soil. At soil pH levels only slightly greater than 7, Mn deficiency

Table 4. 'Tifgreen' bermudagrass leaf blade tissue Mn following Mn application (5.0 g/m²) on 19 May 1977.

| N source | Mn source | 1977: 19 May | 1977: 7 June | 1977: 5 July | 1977: 3 Aug. | 1977: 14 Dec. | 10 May 1978 |
|---|---|---|---|---|---|---|---|
| | | ppm | | | | | |
| $(NH_4)_2SO_4$ | – | 146 a* | 146 b | 151 a | 139 a | 82 a | 70 a |
| $(NH_4)_2SO_4$ | $MnSO_4$ | 141 a | 224 a | 169 a | 130 a | 77 a | 56 ab |
| $Ca(NO_3)_2$ | – | 11 b | 24 d | 16 d | 16 d | 10 c | 13 d |
| $Ca(NO_3)_2$ | $MnSO_4$ | 13 b | 109 c | 51 c | 35 c | 23 bc | 16 d |
| $Ca(NO_3)_2$ | Chelate | 15 b | 88 c | 52 bc | 34 c | 22 bc | 19 cd |
| $Ca(NO_3)_2$ | Frits | 11 b | 35 d | 32 cd | 17 d | 13 c | 14 d |
| $Ca(NO_3)_2$† | $MnSO_4$ | 26 b | 142 b | 81 b | 72 b | 36 b | 40 bc |

* Values within a column followed by the same letter are not significantly different at 0.05. † + Weekly fungicidal drenches.

**Table 5. Manganese (ppm) extracted by various reagents from soil samples taken 11 May 1976, 19 May 1977, and 10 May 1978.**

| | | 1 *N* $NH_4OAc$, pH 7 | | | 1 *N* $NH_4OAc$, pH 4.8 | | | 0.1 *N* $H_3PO_4$, pH 1.5 | | | DTPA, pH 7.3 | | | 1 *N* $NH_4OAc$, pH 7 + 0.2% hydroquinone | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N source | Mn source | 1976 | 1977 | 1978 | 1976 | 1977 | 1978 | 1976 | 1977 | 1978 | 1976 | 1977 | 1978 | 1976 | 1977 | 1978 |
| $(NH_4)_2SO_4$ | – | 1.6 c* | 12.8 b | 4.8 a | 11 bc | 24 ab | 15 bcd | 11 d | 20 b | 19 b | 3.6 a | 24.4 a | 11.2 a | 17 ab | 21 b | 18 d |
| $(NH_4)_2SO_4$ | $MnSO_4$ | 3.4 ab | 16.4 a | 5.2 a | 18 a | 30 a | 21 abc | 14 bc | 23 a | 26 b | 3.8 a | 28.3 a | 12.6 a | 17 abc | 30 a | 44 a |
| $Ca(NO_3)_2$ | – | 1.4 c | 1.9 c | 1.0 b | 9 c | 11 d | 11 d | 11 cd | 4 c | 19 b | 1.2 c | 3.8 b | 1.6 b | 12 c | 16 b | 16 d |
| $Ca(NO_3)_2$ | $MnSO_4$ | 3.0 bc | 4.1 c | 1.8 b | 20 a | 19 bc | 20 abc | 15 ab | 4 c | 27 b | 2.4 b | 6.3 b | 3.0 b | 16 abc | 21 b | 33 ab |
| $Ca(NO_3)_2$ | Chelate | 3.0 bc | 3.8 c | 2.0 b | 18 a | 18 bcd | 24 ab | 14 ab | 4 c | 29 ab | 2.8 ab | 4.8 b | 2.8 b | 14 abc | 21 b | 32 bc |
| $Ca(NO_3)_2$ | Frits | 2.2 bc | 2.2 c | 1.0 b | 15 ab | 15 cd | 14 cd | 13 bcd | 3 c | 28 ab | 1.8 bc | 3.9 b | 1.4 b | 13 bc | 17 b | 22 cd |
| $Ca(NO_3)_2$† | $MnSO_4$ | 4.8 a | 4.5 c | 2.2 b | 18 a | 19 bc | 28 a | 17 a | 6 c | 38 a | 3.8 a | 7.8 b | 4.2 b | 19 a | 27 a | 42 ab |

* Values within a column followed by the same letter are not significantly different at 0.05. † + Weekly fungicide drenches.

often severely limited turf appearance and growth. Manganese applications at 2 $g/m^2$ markedly improved turf appearance but not yield, suggesting that Mn deficiency may be present even when not recognized visually. Applications of Mn at 5 $g/m^2$ from either $MnSO_4$ or from a chelate temporarily alleviated the Mn deficiency in high pH treatments. But turf appearance ratings decreased with time, relative to those of the low pH treatments, and were significantly lower after about 2 months. Sustained adequate Mn nutrition was achieved at high pH with Mn applied to plots in which fungal activity was suppressed by repeated fungicidal drenches. However, the best method of alleviating the deficiency appeared to be through reducing soil pH. This might be done by using S, but pH maintenance in a favorable range can probably be achieved most economically by choosing N sources with the proper degree of potential acidity, since high rates of N are used on bermudagrass. Naturally, some Mn will eventually have to be added to the soil as total Mn is depleted.

Manganese deficiency symptoms based upon leaf blade appearance have been described (3), but they are difficult to see on fine-textured bermudagrass turf. In this study, Mn deficiency was associated with chlorosis, limited growth, and poor response to N and Fe in plots with pH above 7. Tissue tests and soil tests may help identify a Mn deficiency and help distinguish between it and chlorosis produced by other causes, such as insufficient N or Fe. More positive identification can be obtained by treating a small area with Mn and observing color and growth responses. For diagnostic purposes we use a 1,000 ppm Mn (3 g $MnSO_4 \cdot H_2O$/liter)solution sprayed to the drip point. Visual response is observed in 1 to 2 weeks for Mn-deficient turf.


## ACKNOWLEDGMENT

The authors wish to express their appreciation to Mrs. Esther Figueiras and Mrs. C. V. Deaton for soil and plant tissue analyses, and to Miss Joan Bergin and Mr. Nimrod Relph for assisting with the field operations associated with this study.


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