HORTSCIENCE 26(11):1389-1391. 1991.

Effect of Manganese Source on Manganese Uptake by Pygmy Date Palms

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Additional index work. *Phoenix roebelenii,* micronutrient fertilizers

Abstract. **Pygmy date palms *(Phoenix roebelenii* 'O'Brien') growing in a pine bark-Canadian peat-sand container medium and in a sandy field soil were fertilized with one of five commercially available Mn sources. Fertilization with Mn sulfate plus ammonium sulfate consistently increased Mn uptake above that of control palms. Four soluble Mn sources were applied to the foliage of container-grown palms, but only Mu sulfate consistently increased Mn concentrations in the leaves. Addition of urea, calcium hydroxide, or dimethylsulfozide did not improve Mn uptake from foliar sprays, and foliar sprays and soil applications were equally rapid in their effects on leaf Mn concentration.**

Manganese deficiency is a serious and widespread problem on many species of palms (Eroschat, 1991). Recommended treatments for correction or prevention of the problem usually include soil or foliar applications of manganese sulfate (Dickey, 1977), but Broschat and Donselman (1985a) found that in a peat-based potting medium, other Mn sources provided equivalent levels of ammonium acetate-extractable Mn.

Addition of urea to foliar Mn sprays increased foliar absorption of Mn in some plants (Labanauskas and Puffer, 1964; Yamada et al., 1965), but, to our knowledge, this has never been shown for palms. A foliar spray of Mn sulfate plus calcium hydroxide is recommended by Dickey (1977) for treatment of Mn deficiency, but the value of the added Ca in palm treatment is not known. Dimethylsulfoxide (DMSO) is a widely used penetrant-solvent that could potentially enhance foliar absorption of Mn from foliar sprays, but, to our knowledge, has never been tested. Several Mn fertilizer sources have been evaluated on field crops (Fiskel and Mourkides, 1955; Randall et al., 1975; Shuman et al., 1979; Wilcox and Cantliffe, 1969), but none of these studies evaluated Mn fertilizers in a container medium or tested foliar fertilization effectiveness on palms. Similarly, soil acidification has been suggested as a means of alleviating deficiencies of micronutrients, such as Mn, Fe, and Zn (Kidder et al., 1990; Messenger and Hruby, 1990), but this has not been tested on palms. The purpose of this study was to determine which of the commercially available soil and foliar-applied Mn fertilizer materials are effective in supplying Mn to palms in a pine bark-peat-sand medium and if the addition of calcium hydroxide, urea, or DMSO enhanced the foliar absorption of Mn from foliar sprays.

Pygmy date palms, 25 to 30 cm tall, were planted in lo-liter plastic containers using a 4 pine bark : 2 Canadian peat : 1 sand (by volume) medium amended with dolomite at 6 $kg \cdot m^{-3}$. Eight replicate pots were each treated on 14 Oct. 1987 (first year) with single applications of the materials to the surface of the medium (Table 1) at rates equivalent to 3.2 g Mn/container. Seven replicate plants were also sprayed to runoff with single foliar sprays of the materials (Table 1) at concentrations equivalent to 1.3 g Mn/liter. The experiment was repeated starting 4 Jan. 1989 using 10 replicate palms per treatment (2nd year). All plants were grown under 63% shadecloth (1800 $\mu mol \cdot m^{-2} \cdot s^{-1}$ maximum photosynthetically active radiation) and received ≈10 mm of water daily from overhead irrigation. All pots received surface applications of Osmocote 17N-3P-15K (Grace-Sierra, Milpitas, Calif.) at 56 g/pot and a single micronutrient drench containing 0.6 mg Fe, 0.2 mg B, 0.06 mg Zn, 0.06 mg Cu, and 0.01 mg Mo and were arranged in a completely randomized design. Samples of central leaflets of recently matured leaves were collected from each plant 1, 2, 4, and 6 months after fertilization the first year and 2, 4, and 6 months after fertilization for the 2nd year. All leaves sampled for analysis had emerged subsequent to any foliar spray treatment and, therefore, were not washed before analysis. Dried and ground leaf samples were digested in sulfuric acid and hydrogen peroxide (Allen, 1974) and analyzed for total Mn content by atomic absorption spectrophotometry. Data were tested by analysis of variance with mean separations by the Wailer-Duncan k-ratio method.

To determine if results from the container experiments would be valid for field-grown palms, a 2-year-old field planting of 50- to 60-cm-tall pygmy date palms was treated on 4 Jan. 1989 with single soil applications of the same materials used in the first container experiment. These palms were growing in a Margate fine sand soil and planted 3 m apart in rows of 4 m apart. Treatments were assigned on a completely randomized basis with nine replicate palms per treatment. Rates were 32 g of Mn and 550 g of Osmocote 17N-3P-15K per plant. Sampling and analysis were carried out as in the first container experiment.

Application to medium-firs year. Only Mn sulfate plus ammonium sulfate had significantly increased leaf Mn 1 month after its application to the medium, but both Mn sulfate plus ammonium sulfate and Mn citrate-treated palms had higher leaf Mn concentrations than control palms at 2, 4, and 6 months after treatment (Table 2). Manganese sulfate plus ammonium sulfate also in-

Table 1. Manganese fertilizer materials used for soil applications on pygmy date palms.

Material	Trade name	Manufacturer	% Mn
Soil application			
Mn oxide	Granusol	American Minerals	40
Mn sulfate[z]		Mallinckrodt	33
Mn sulfate + ammonium sulfate	Tecmangam	Eastman Chemical	27
Mn EDTA	Sequestrene Mn	CIBA-GEIGY	12
Sulfur + Mn sulfate	Disper-Sul + Mn	Chemical Enterprises	5
Mn citrate	Micro-Green	Liquid Ag Systems	5
Foliar application			
Mn sulfate		Mallinckrodt	32
+ urea[y]		Mallinckrodt	32
+ urea[y] + calcium hydroxide[x]		Mallinckrodt	32
+ calcium hydroxide[x]		Mallinckrodt	32
+ DMSO[w]		Mallinckrodt	32
Mn citrate		Mallinckrodt	30
+ urea[y]		Mallinckrodt	30
Mn EDTA	Sequestrene Mn	CIBA-GEIGY	12
+ urea[y]	Sequestrene Mn	CIBA-GEIGY	12
Mn glucoheptanate	Keyplex 250	Morse Enterprises	1.1
+ urea[y]	Keyplex 250	Morse Enterprises	1.1

[z]Used only in 2nd year when applied to container medium.
[y]Rate = 6 $g \cdot liter^{-1}$.
[x]Rate = 0.22 $g \cdot liter^{-1}$.
[w]Rate = 1 $ml \cdot liter^{-1}$; used only in 2nd-year experiment.

Received for publication 25 Feb. 1991. Florida Agricultural Experiment Station Journal Series no. R-01264. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked advertisement solely to indicate this fact.

Table 2. Foliar Mn concentrations of container-grown pygmy date palms treated with various Mn fertilizers applied to the growing medium.

	Mn concn (μg·g⁻¹)						
	First year				2nd year		
	Months after treatment						
Material	1	2	4	6	2	4	6
Control	46	54	81	71	51	62	38
Mn oxide	30	43	53	60	43	63	59
Mn sulfate + ammonium sulfate	148	149	177	122	1308	1308	505
Sulfur + Mn sulfate	27	39	55	74	131	225	498
Mn citrate	70	110	134	143	830	1069	717
Mn EDTA	61	85	70	73	136	151	127
Mn sulfate	---	---	---	---	1095	1800	838
$MSD_{0.05}$	43	36	42	43	66	58	31

Table 3. Foliar Mn concentrations of field-grown pygmy date palms treated with various soil-applied Mn fertilizers.

	Mn concn (μg·g⁻¹)			
	Months after treatment			
Material	1	2	4	6
Control	28	39	50	62
Mn oxide	83	68	85	81
Mn sulfate + ammonium sulfate	83	233	436	356
Sulfur + Mn sulfate	50	46	88	95
Mn citrate	38	52	81	98
Mn EDTA	86	94	105	93
$MSD_{0.05}$	NS	112	194	138

Table 4. Foliar Mn concentrations of container-grown pygmy date palms treated with various foliar-applied Mn fertilizers.

	Mn concn (μg·g⁻¹)						
	First year				2nd year		
	Months after treatment						
Material	1	2	4	6	2	4	6
Control	46	54	81	71	45	59	38
Mn glucoheptanate	61	73	92	91	53	76	48
+ urea	43	43	51	46	44	58	48
Mn EDTA	35	50	51	67	35	56	54
+ urea	36	51	64	78	45	75	51
Mn citrate	82	95	103	101	39	68	60
+ urea	65	70	81	83	41	57	47
Mn sulfate	222	116	118	100	42	78	63
+ urea	102	81	83	90	42	73	50
+ calcium hydroxide	149	90	59	50	42	75	48
+ urea + calcium hydroxide	156	135	119	103	55	74	55
+ DMSO	---	---	---	---	45	80	56
$MSD_{0.05}$	39	39	32	41	11	4	4

creased leaf Mn concentrations significantly more than Mn citrate after 2 and 4 months, but the differences were nonsignificant 6 months after treatment.

Application to medium-2nd year. All materials except Mn oxide had increased leaf Mn concentrations at 2, 4, and 6 months, but Mn sulfate, Mn sulfate plus ammonium sulfate, and Mn citrate-treated palms had much higher Mn concentrations (Table 2). Manganese concentrations of palms in medium treated with most materials began decreasing at 6 months, but continued to increase in sulfur plus Mn sulfate-treated palms. All of the materials except Mn oxide are water soluble and some decrease in availability is expected over time due to microbial binding or precipitation. Elemental sulfur constitutes 80% of the sulfur plus Mn sulfate material and thus would be expected to gradually decrease medium pH and increase Mn solubility (Ridder et al., 1990). The large differences in Mn uptake between years for similar materials can only be accounted for by the lower average ambient temperatures during the first year 6 = 22.4 vs. 24.2C). Manganese uptake in palms is strongly temperature dependent (Broschat and Donselman, 1985b).

Soil application-field-grown palms. No significant differences were observed among treatments after 1 month (Table 3). However, Mn concentrations in palms treated with Mn sulfate plus ammonium sulfate were significantly higher than those of all other treatments 2 to 6 months following application. Thus, results under field conditions confirm the superior effectiveness of Mn sulfate in providing Mn to palms compared to other commercially available Mn sources. Similar results were obtained for field crops on other soil types (Fiskel and Mourkides, 1955; Randall et al., 1975; Shuman et al., 1979; Wilcox and Cantliffe, 1969). The pH of the field soil was higher than that of the container medium (7.25 vs. 6.45), and this likely decreased Mn availability (Lindsay, 1972). However, acidifying materials, such as sulfur plus Mn sulfate, did not improve palm Mn uptake under alkaline field soil conditions as predicted from Messenger and Hruby's (1990) work on Mn deficiency in red maple (*Acer rubrum* L.).

Foliar application-first year. Only Mn sulfate significantly increased leaf Mn concentrations over that of control plants after 1 month, but Mn citrate also did 2 months after application (Table 4). Foliar Mn concentrations in palms sprayed with Mn sulfate gradually decreased or stayed the same during the period between the first and 6th month, but no significant differences existed among treatments after 6 months. Plant uptake from foliar sprays was not enhanced by addition of calcium hydroxide or urea for any Mn source throughout the experiment.

Foliar application-2nd year. Leaf Mn concentration after 2 months was not significantly increased by foliar application of any Mn source, but palms in all treatments, except those sprayed with Mn glucoheptanate plus urea, Mn EDTA, and Mn citrate plus urea, had higher leaf Mn concentrations after 4 months than the control palms (Table 4). Palms in all treatments had higher foliar Mn concentrations than the controls after 6 months. The addition of urea enhanced Mn uptake only from Mn EDTA after 4 months and addition of both calcium hydroxide and urea or DMSO did not improve plant uptake of foliar-applied Mn sulfate at any time.

These results appear contrary to those reported by Yamada et al. (1965) and Labanauskas and Puffer (1964), but in those studies, urea increased Mn uptake in leaves that had been sprayed. However, the latter study also examined the effects of urea on Mn concentrations in leaves produced subsequent to spraying and reported no significant increases in Mn concentration of the new leaves due to urea application. This result is consistent with those from the current study in which only new leaves were sampled. Although foliar fertilization is generally considered to be a quicker, though short-term, method of getting micronutrients into plants, this study suggests that uptake from soil applications is just as fast, even under slightly alkaline field soil conditions.

In conclusion, of the various commercially available Mn fertilizer sources, Mn sulfate plus ammonium sulfate (Tecmangam) was the most effective material for soil or foliar fertilization of pygmy date palms, both in a container medium and in a slightly alkaline sandy field soil. Manganese citrate is moderately effective for both container medium and foliar applications, but all other materials tested were relatively ineffective as soil-applied fertilizers and produced inconsistent responses when applied to the foliage of palms. Also, there appears to be no advantage to adding calcium hydroxide, urea, or DMSO to Mn foliar sprays on palms.

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