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Phytotoxicity of Several Iron Fertilizers and Their Effects on Fe, Mn, Zn, Cu, and P content of African Marigolds and Zonal Geraniums

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***Abstract*. Zonal geraniums (*Pelargonium ×hortorum)* from seed and african marigolds (*Tagetes erecta*), which are known to be highly susceptible to Fe toxicity problems, were grown with I, 2, 4, or 6 mM Fe from ferrous sulfate, ferric citrate, FeEDTA, FeDTPA, FeEDDHA, ferric glucoheptonate, or ferrous ammonium sulfate in the subirrigation solution. FeEDTA and FeDTPA were highly toxic to both species, even at the 1 mM rate. Ferrous sulfate and ferrous ammonium sulfate caused no visible toxicity symptoms on marigolds, but did reduce dry weights with increasing Fe concentrations. Both materials were slightly to moderately toxic on zonal geraniums. FeEDDHA was only mildly toxic at the 1 mM concentration on both species, but was moderately toxic at the 2 and 4 mM concentrations. Substrate pH was generally negatively correlated with geranium dry weight and visible phytotoxicity ratings, with the least toxic materials, ferrous sulfate and ferrous ammonium sulfate, resulting in the lowest substrate pHs and the chelates FeEDTA, FeDTPA, and FeEDDHA the highest pH. The ionic Fe sources, ferrous sulfate and ferrous ammonium sulfate, suppressed P uptake in both species, whereas the Fe chelates did not. Fe EDDHA should be considered as an effective and less toxic alternative for the widely used FeEDTA and FeDTPA in the production of these crops.**

Iron deficiency chlorosis is a common problem on container-grown plants due to poor soil aeration, low soil temperatures, high bicarbonate irrigation water, etc. (Korcak, 1987; Wallace and Lunt, 1960). However, applications of inorganic Fe fertilizers such as ferrous sulfate are often ineffective in correcting Fe chlorosis (Martens and Westermann, 1991). Several synthetic chelating agents with high affinities for Fe have been shown to be much more effective in correcting Fe chlorosis in a wide range of plants (Martens and Westermann, 1991). However, some of these products can be phytotoxic to plants, and marigolds and zonal geraniums are reported to be especially sensitive to Fe toxicity (Albano et al., 1996; Bachman and Miller, 1995). The purpose of this study was to determine the relative phytotoxicity of several commercially-available Fe fertilizers and their effects on the uptake of Mn, Zn, Cu, and P in seedling marigolds and zonal geraniums.

Materials and Methods

Seeds of 'Atlantis Yellow' african marigold and 'Cardinal Orbit' zonal geranium were germinated in Jiffy Germination Mix #901 (Jiffy Products of America, Batavia, Ill.) in seedling plug trays having cells 2 × 2 × 4 cm deep. The plug trays were cut into blocks containing 10 seedlings each at the time when the first true leaf began to emerge for most seedlings. The blocks of plugs were set into plastic subirrigation trays and were irrigated as necessary by allowing the blocks to sit in a 1-cm-deep solution containing 100 mg N, 20 mg P, 100 mg K, 0.55 mg Mn, 0.56 mg Fe, 0.26 mg Zn, 0.06 mg Cu, 0.22 mg B, and 0.05 mg Mo/L from diammonium phosphate, potassium nitrate, ammonium sulfate, ferrous sulfate, manganese sulfate, zinc sulfate, copper sulfate, boric acid, and molybdic acid. In addition, the solutions applied to each plug block contained 0, 56, 112, 224, or 336 mg Fe/L (0, 1, 2, 4, or 6 mM Fe) from ferrous sulfate, ferric EDTA (Sigma Chemical, St. Louis, Mo.), ferric DTPA (Sequestrene 330, Becker-Underwood, Ames, Iowa), ferric EDDHA (Lidoquest, LidoChem Inc., Hazlet, N.J.)], ferric glucoheptonate (Florikan, Sarasota, Fla.), or ferrous ammonium sulfate (Sigma Chemical). Ferric glucoheptonate was not included in Expt. 2.

Plugs were transplanted into 10-cm plastic pots using Pro Mix BX (Premier Horticulture, Red Hill, Pa.) 1 week after plants started receiving nutrient solutions. All plants were grown in an open sided greenhouse with ambient air temperatures averaging 30/21 °C (day/night) and provided a maximum photosynthetic photon flux of 1350 $\mu mol \cdot m^{-2} \cdot s^{-1}$ in Fort Lauderdale, Fla. Plants were subirrigated every other day using the nutrient solutions described above. Subirrigation trays were filled to a depth of ≈2 cm and the plants were allowed to absorb the solution for ½ h before the excess was poured off. A split plot design using 10 replicate pots per treatment was used. Plot treatments were randomized on the greenhouse bench and the experiment was repeated once for each plant species.

Plants were rated subjectively by both authors (by consensus) for phytotoxicity severity on a 0 to 5 scale (0 = dead, 3 = moderate injury, 5 = no injury) and stems were cut off at the soil line for shoot dry weight determination. Leaf samples consisting of the youngest fully expanded leaves on each plant were collected for nutrient analysis. Leaf samples were digested using a modified Kjeldahl procedure (Hach et al., 1987). Samples were analyzed for Fe, Mn, Zn, and Cu using atomic absorption spectroscopy and for P using the ascorbic acid method (Greenberg et al., 1985). Plants were rated, sampled, and harvested when they reached a marketable size for a 10-cm pot.

Marigolds were transplanted on 1 Aug. 2001 and harvested on 16 Aug. 2001 for Expt. 1 and were transplanted on 27 Aug. 2001 and harvested on 11 Sept. 2001 for Expt. 2. Zonal geraniums were transplanted on 28 Nov. 2001 and harvested on 26 Dec. 2001 for Expt. 1 and transplanted on 22 Jan. 2002 and harvested on 4 Mar. 2002 for Expt. 2.

At harvest, the surface 2 to 3 cm of the 11.6 cm deep substrate column in each pot was removed to ensure that substrate samples were taken from the active root zone. Substrate samples were extracted with deonized water using the saturated media extraction method (Warncke, 1986). Substrate pH was determined on the extracted solution using a pH/conductivity meter at a standard 25 °C. Substrate samples were pooled by treatment into three replicate samples. Substrate pH was assumed to be similar for marigolds grown with the same treatments. Data were analyzed by regression analysis, analysis of variance, or analysis of covariance, with mean separations by the Waller-Duncan k ratio method (SAS, SAS Inst., Cary, N.C.)

Results and discussion

For zonal geraniums, phytotoxicity severity increased with increasing Fe concentrations in the irrigation solution for all Fe sources (Table 1). Toxicity symptoms appeared as marginal necrosis, necrotic spotting, cupping of the leaves, or occasionally chlorotic stippling on leaves of all ages. Although there were differences in the levels of phytotoxicity for all sources between Expts. 1 and 2, FeEDTA and FeDTPA were highly phytotoxic in both experiments. Plants receiving 1 mM Fe from these sources were extremely stunted and necrotic, and no plants survived with 4 or 6 mM Fe from either source. Plants receiving ferrous sulfate, ferrous ammonium sulfate, or ferric glucoheptonate showed very little to moderate toxicity in both experiments. Plants receiving FeEDDHA showed moderate toxicity in Expt. 1, but very little toxicity in Expt. 2 for

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Table 1. Substrate pH, phytotoxicity ratings, and dry weights for zonal geraniums treated with various iron sources. A rating scale of 0 to 5 was used, with 5 = excellent quality, no toxicity symptoms, 3 = moderate toxicity, and 0 = dead.

		Expt. 1			Expt. 2		
Source	Rate (mM)	pH	Dry wt (g)	Rating	pH	Dry wt (g)	Rating
None	0	4.84 hi[z]	1.35 a	5.0 a	4.52 i	2.15 bc	5.0 a
Ferrous sulfate	1	4.52 mn	1.20 ab	5.0 a	4.43 ij	1.85 d	4.8 ab
	2	4.77 ij	1.17 b	4.3 b	3.99 l	1.32 fg	3.7 de
	4	4.59 lmn	1.04 bcd	3.9 c	4.10 kl	1.11 gh	3.7 de
	6	4.62 klm	0.75 hi	3.5 de	3.63 m	0.65 ij	3.4 efg
Ferric EDTA	1	4.96 gh	0.18 kl	0.3 i	4.74 gh	0.02 k	0.2 i
	2	5.02 fg	0.11 l	0.2 ij	4.74 gh	0.0 k	0.0 j
	4	5.39 b	0.0 l	0.0 j	5.54 c	0.0 k	0.0 j
	6	5.61 b	0.0 l	0.0 j	5.78 b	0.0 k	0.0 j
Ferric DTPA	1	5.06 fg	0.43 j	1.4 h	5.18 ef	0.19 k	1.3 h
	2	5.31 bc	0.29 k	0.4 i	5.38 cd	0.0 k	0.1 i
	4	5.69 ab	0.0 m	0.0 j	5.80 b	0.0 k	0.0 j
	6	5.81 a	0.0 m	0.0 j	6.08 a	0.0 k	0.0 j
Ferric EDDHA	1	5.08 efg	0.88 d-h	3.8 cd	5.13 ef	2.43 a	5.0 a
	2	5.41 b	0.87 e-h	3.7 d	5.27 de	2.33 ab	5.0 a
	4	5.83 a	0.43 j	2.9 ef	5.32 de	2.17 bc	5.0 a
	6	5.34 bc	0.25 kl	1.8 g	5.56 c	0.63 j	4.1 c
Ferric glucoheptonate	1	5.23 cd	0.95 c-g	4.1bc	5.00 f	1.98 cd	4.9 ab
	2	5.21 cde	0.96 c-f	3.9 c	5.01 f	1.82 d	4.6 b
	4	5.14 def	0.78 ghi	3.5 de	4.76 g	1.32 fg	3.3 fg
	6	5.08 efg	0.69 i	3.1 e	4.54 hi	0.96 h	3.2 g
Ferrous ammonium sulfate							
	1	4.75 ijk	1.12 bc	4.3 b	4.28 jk	1.74 de	5.0 a
	2	4.68 jkl	1.15 b	4.4 b	4.28 jk	1.51 ef	3.9 cd
	4	4.46 n	1.04 b-e	4.1 bc	3.96 c	0.90 hi	3.6 def
	6	4.80 ij	0.81 f-i	3.6 d	3.39 n	0.92 h	3.1 g

[z]Mean separation within columns by the Waller-Duncan k ratio method, k = 100.

all but the highest (6 mM) rate. Zonal geraniums receiving FeEDDHA typically had a reddish tinge to the foliage color when young due to the presence of this intensely colored compound in the leaf tissue. This foliar reddening has also been observed on bush beans (*Phaseolus vulgaris*) when using high levels of this material (Wallace and Wallace, 1983).

When african marigolds were treated with high levels of Fe compounds, visible toxicity symptoms were most severe for FeEDTA and FeDTPA at all rates, and FeEDDHA at 4 and 6 mM rates (Table 2). Typical toxicity symptoms on this species consisted of leaflet tip necrosis, cupping of the leaflets, and necrotic spotting on the leaves. These symptoms were most prominent on the oldest leaves. Besides being stunted, marigolds receiving high levels of Fe fertilizers also had weak stems that had a strong tendency to fall over. As with zonal geraniums, african marigolds treated with FeEDDHA also had a reddish tinge to their leaf color. Very few marigolds survived when FeEDTA or FeDTPA were supplied at 4 or 6 mM, and those receiving FeEDTA were quite stunted and necrotic, even at the 1 mM rate. Application of ferrous sulfate, ferric citrate, ferric glucoheptonate, and ferrous ammonium sulfate generally resulted in little visible injury, but dry weights decreased with increasing Fe concentrations for all of these sources.

Iron source significantly affected substrate pH for zonal geraniums. Substrate pH generally increased with increasing concentrations of chelates such as FeEDTA, FeDTPA, and FeEDDHA, but decreased with increasing concentrations of Fe glucoheptonate or ferrous ammonium sulfate (Table 1). Substrate pH showed no consistent trends with increasing concentrations of ferrous sulfate applied. When dry weights and phytotoxicity rating were regressed against substrate pH across all treatments, a significant ($P < 0.0001$) negative correlation was obtained for toxicity ratings in both experiments and for dry weight in Expt. 1. Dry weight was not significantly correlated with substrate pH in Expt. 2. The least phytotoxic Fe sources (ferrous sulfate and ferrous ammonium sulfate) had the lowest substrate pH's and the most toxic sources (FeEDTA and FeDTPA) had significantly higher pH's. This suggests that low substrate pH is not a significant factor in Fe toxicity of geraniums as suggested by Biernbaum et al. (1988) and Fisher et al.(2001).

Iron source had a significant effect on the nutrient content of zonal geraniums (Table 3). Leaf Fe content increased sharply with increasing application rates for all sources except FeEDDHA (data not shown). All Fe sources tended to increase leaf Fe content over that of the untreated control plants, but leaf Fe content was highly variable, both within a treatment and between experiments, and differences were often not statistically significant. Although Fisher et al. (2001) have attributed the Fe toxicity in these species to the accumulation of Fe in the foliage, our data do not support that hypothesis. Leaf Fe content often bears little relationship to plant Fe chlorosis or toxicity symptom severity (Chaney, 1984; Wallace and Lunt, 1960)

Iron sources differed in their effects on Mn uptake by zonal geraniums (Table 3). Chelates such as FeDTPA and FeEDDHA suppressed Mn uptake in Expt. 2, but differences in Expt. 1 were not statistically significant. Ferrous sulfate, ferric glucoheptonate, and ferrous ammonium sulfate generally did not influence leaf Mn content. Iron source effects on Zn and Cu uptake by geraniums were inconsistent between experiments.

Iron applications had a strong effect on leaf P content of zonal geraniums (Table 3). In preliminary experiments where only Nutricote 18N–2.6P–6.7K (Type 70) controlled release fertilizer was used as a P source, severe stunting and reddening of the plants was widespread among geraniums receiving high levels of ferrous sulfate. Ferrous sulfate, ferric glucoheptonate, and ferrous ammonium sulfate consistently decreased leaf P with increasing application rates (data not shown), presumably due to the formation of insoluble iron phosphates. FeEDDHA did not significantly reduce P content when its application rates were increased, perhaps due to the stability of the FeEDDHA complex (Norvell, 1972). Although FeEDTA appears to have increased P content of geranium leaves in Expt. 1, this was thought to be due to the lack of growth and therefore little or no dilution of existing P in these extremely stunted plants.

In african marigolds, FeEDDHA was the only Fe source that consistently resulted in greater leaf Fe concentrations than the untreated control plants (Table 4). FeEDDHA was also the only source that showed increasing leaf Fe content with increasing application rates (data not shown). All other Fe sources had inconsistent or nonsignificant effects on leaf Fe concentrations in this species, and there was no relationship between foliar Fe content and phytotoxicity severity.

Both ferrous sulfate and ferrous ammonium sulfate significantly increased Mn uptake in african marigolds over that of the untreated control plants in both experiments (Table 4), although increasing application rates of these materials did not affect Mn content of the foliage (data not shown). Similar effects on foliar Mn concentrations were observed for ferric glucoheptonate in Expt. 1 and ferric citrate in Expt. 2. Ferrous ammonium sulfate also consistently increased Zn uptake over that of the untreated control plants (Table 4). The chelates FeEDDHA and FeEDTA consistently increased leaf Cu content, but other sources had no consistent effects on leaf Cu content.

Fertilization with ferrous sulfate, ferric citrate, ferric glucoheptonate, or ferrous ammonium sulfate consistently resulted in decreased marigold leaf P content (Table 4), with leaf P decreasing with increasing Fe application rates for each of these sources (data not shown). As with geraniums, the EDTA and EDDHA chelates had relatively little effect on leaf P content of marigolds.

Iron sources differ greatly in their phytotoxicity to zonal geraniums and african marigolds. Ferrous sulfate, ferrous ammonium sulfate, ferric glucoheptonate, and ferric citrate were relatively nontoxic to african marigolds at all rates tested, but were mildly to moderately toxic to zonal geraniums, especially at higher application rates. All of these products, however, had a tendency to precipitate out of solution if not used immediately, and their effectiveness in correcting Fe chlorosis problems has generally

been poor (Martens and Westermann, 1991). The chelates FeEDTA, FeDTPA, and FeEDDHA are much more stable in solution, do not seem to precipitate out phosphates as readily, and are known to be effective treatments for Fe chlorosis in a wide range of plants (Martens and Westermann, 1991). However, this study clearly demonstrates that FeEDTA and FeDTPA are highly toxic to zonal geraniums and african marigold. Bachman and Miller (1995) found that FeDTPA was toxic to zonal geraniums at concentrations as low as 0.56 mM, a lower level than any of our rates. FeEDDHA, on the other hand, is a highly effective Fe source and was much less toxic to these species than the EDTA and DTPA chelates. Wallace et al. (1977) and Wallace and Wallace (1983) also found that FeEDDHA was significantly less phytotoxic on bush beans (*Phaseolus* vulgaris) than FeEDTA or ferrous sulfate. Unfortunately, FeEDTA and FeDTPA are the most commonly used Fe chelates in liquid fertilization programs (Jones, 1983), and research on Fe toxicity using only these sources may have led to the conclusion that Fe itself is highly toxic to zonal geraniums and marigolds (Biernbaum et al., 1988; Fisher et al., 2001). Lee et al (1996) and Choi et al (1996) documented that Fe itself is not particularly toxic to these species. They reported few or no visible toxicity symptoms on either zonal geraniums or French marigolds when grown with ferrous sulfate at concentrations up to 6 mM. As in the present study, they found that plants were stunted at the highest rates.

Similarly, low substrate pH has been implicated as a cause of Fe toxicity in these plants (Biernbaum et al., 1988; Fisher et al., 2001). Our data do not support this hypothesis. However, increasing substrate pH with liming

Table 2. Phytotoxicity ratings and dry weights for african marigolds treated with various iron sources. A rating scale of 0 to 5 was used, with 5 = excellent quality, no toxicity symptoms, 3 = moderate toxicity, 0 = dead.

		Expt. 1		Expt. 2	
Source	Rate (mM)	Dry wt (g)	Rating	Dry wt (g)	Rating
None	0	2.15 ab[z]	5.0 a	1.09 a	5.0 a
Ferrous sulfate	1	2.13 ab	5.0 a	0.78 fg	5.0 a
	2	2.15 ab	5.0 a	0.91 b–f	5.0 a
	4	1.80 def	5.0 a	0.82 def	5.0 a
	6	1.73 d–g	5.0 a	1.04 ab	5.0 a
Fe rric citrate	1	2.29 a	5.0 a	0.88 cef	5.0 a
	2	1.89 cde	5.0 a	0.92 b–e	5.0 a
	4	1.52 g–j	4.6 b	0.82 d–f	4.9 ab
	6	1.65 e–h	5.0 a	0.96 abc	4.8 ab
Ferric EDTA	1	0.78 no	2.7 e	0.58 hi	3.0 d
	2	0.14 p	1.1 f	0.52 ij	2.3 f
	4	0.00 p	0.0 g	0.00 m	0.0 h
	6	0.00 p	0.0 g	0.00 m	0.0 h
Ferric DTPA	1	1.95 bcd	3.0 de	0.67 gh	4.0 c
	2	1.04 lm	3.0 de	0.42 jk	2.6 e
	4	0.00 p	0.0 g	0.42 kl	0.1 h
	6	0.00 p	0.0 g	0.0 m	0.0 h
Ferric EDDHA	1	1.81 def	5.0 a	0.95 bc	5.0 a
	2	1.42 h–k	5.0 a	0.55 hij	4.7 b
	4	0.82 mn	3.7 c	0.50 ijk	3.9 c
	6	0.55 o	3.2 d	0.27 l	1.9 g
Ferric glucoheptonate	1	1.87 de	5.0 a	---	---
	2	1.89 cde	5.0 a	---	---
	4	1.39 ijk	5.0 a	---	---
	6	1.28 jkl	5.0 a	---	---
Ferrous ammonium sulfate	1	1.60 f–i	5.0 a	0.93 bcd	5.0 a
	2	1.47 h–k	5.0 a	0.80 efg	5.0 a
	4	1.54 ghi	5.0 a	0.54 hij	5.0 a
	6	1.24 kl	4.8 ab	0.37 kl	5.0 a

[z]Mean separation within columns by the Waller-Duncan k ratio method, k = 100.

Table 3. Leaf nutrient concentrations of zonal geraniums treated with various iron sources. Data represent means for each Fe source over all levels tested.

	Expt. 1					Expt. 2				
	Element (mg·kg^{-1})									
Source	Fe	Mn	Zn	Cu	P	Fe	Mn	Zn	Cu	P
None	93 b[z]	225 ab	59 abc	4.5 a	8820 bc	557 c	781 a	72 b	4.7 ab	5490 a
Ferrous sulfate	232 ab	142 ab	58 abc	4.4 a	6630 d	1436 a	793 a	95 a	3.7 b	4510 b
Ferric EDTA	517 a	156 ab	77 a	2.5 b	10,000 a	---	---	---	---	---
Ferric DTPA	350 ab	106 b	44 c	2.5 b	9160 b	990 abc	357 c	49 c	3.8 b	6360 a
Ferric EDDHA	812 a	133 ab	53 bc	4.0 ab	7570 cd	756 bc	122 d	46 c	4.5 ab	5530 a
Ferric glucoheptonate	382 ab	168 ab	63 abc	3.2 ab	6870 d	1313 ab	770 a	89 a	5.8 a	4100 b
Ferrous ammonium sulfate	729 a	402 a	68 ab	2.5 b	6370 d	1177 ab	656 b	75 b	3.5 b	4250 b
Significant effects										
Source	0.002	0.0001	0.008	0.03	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Rate	0.03	0.0003	NS	0.008	0.0001	0.0001	0.0002	0.0001	0.02	0.0001
Source × rate	0.0001	0.0001	0.002	0.008	0.0001	0.002	0.0001	0.0007	0.0002	0.0001

[z]Mean separation within columns by the Waller-Duncan k ratio method, k = 100.

Table 4. Leaf nutrient concentrations of African marigolds treated with various iron sources. Data represent means for each Fe source over all levels tested.

	Expt. 1					Expt. 2				
	Element (mg·kg^{-1})									
Source	Fe	Mn	Zn	Cu	P	Fe	Mn	Zn	Cu	P
None	167 c[z]	165 c	93 bc	6.4 d	2670 a	182 b	208 cd	113 bc	7.8 c	2690 a
Ferrous sulfate	594 c	280 b	104 b	7.0 d	2270 c	361 ab	384 b	152 abc	8.0 c	2410 c
Ferric EDTA	645 c	203 c	101 b	12.9 b	2630 ab	607 ab	268 c	162 ab	15.4 a	2620 ab
Ferric DTPA	1157 b	176 c	95 b	11.7 b	2550 b	818 ab	212 cd	105 b	9.7 bc	2520 bc
FerricEDDHA	1846 a	155 c	90 bc	14.7 a	2570 b	950 a	147 d	97 c	11.7 b	2580 ab
Ferric glucoheptonate	563 c	291 b	108 b	9.2 c	2250 c	---	---	---	---	---
Ferrous ammonium sulfate	1380 ab	746 a	248 a	6.8 d	2320 c	661 ab	600 a	190 a	8.1 c	2430 c
Ferric citrate	300 c	193 c	75 c	7.3 d	2300 c	570 ab	399 b	176 a	8.9 bc	2430 c
Significant effects										
Source	0.0001	0.0001	0.0001	0.03	0.0001	0.0001	0.0001	0.004	0.003	0.0001
Rate	0.0001	NS	0.0001	0.008	NS	0.0001	0.013	NS	NS	0.0001
Source × rate	0.0001	0.0001	0.05	0.008	NS	0.0001	NS	NS	NS	NS

[z]Mean separation within columns by the Waller-Duncan k ratio method, k = 100.
[NS]Nonsignificant.

materials should alleviate toxicity symptoms caused by FeEDTA and FeDTPA due to the substitution of Ca for Fe in the EDTA or DPTA complexes at higher pH's (Norvell, 1972). The Fe^{3+} ions thus released from these chelates are much less toxic to plants and are also susceptible to precipitation as bicarbonates, oxides, and phosphates.

In conclusion, the toxicity observed on zonal geraniums and marigolds appears to be due to the specific toxicity of the FeEDTA and FeDTPA chelate complexes and not to the ferrous or ferric ions themselves. Lee et al. (1996) and Choi et al. (1996) showed that the Fe^{2+} ion was much less toxic to zonal geraniums and marigolds than other micronutrient elements such as Zn, Cu, Mn, B, or Mo. This toxicity also is not related to Fe content of the foliage or the pH of the growing substrate. Since FeEDDHA is only slightly more toxic than ferrous sulfate, is highly stable in solution, and is a highly effective Fe source, it should be used instead of FeEDTA or FeDTPA in liquid fertilization programs. From a practical standpoint, quality control has been identified as a problem with FeEDDHA (Korcak, 1987). It is important that finely ground FeEDDHA products (e.g., Lidoquest Fe) be used, since we found that coarser textured products such as Sequestrene 138 (Becker-Underwood) dissolve very poorly in water and are unsuitable for use in liquid fertilization programs.

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