Research Reports

Effectiveness of Various Iron Sources for Correcting Iron Chlorosis in Dwarf *Ixora*

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Summary. 'Petite Yellow' dwarf ixoras (*Ixora* spp.) were grown in an alkaline substrate (3 limestone gravel: 2 coir dust) or a poorly aerated composted seaweed substrate to induce iron (Fe) chlorosis. Chlorotic plants were fertilized every 2 months with soil applications of 0.1 g (0.0035 oz) Fe per 2.4-L (0.63-gal) pot using ferrous sulfate, ferric diethylenetriaminepentaacetic acid (FeDTPA), ferric ethylenediaminedi-o-hydroxyphenylacetic acid (FeEDDHA), Hampshire Iron (FeHEDTA plus FeEDTA), ferric citrate, iron glucoheptonate, or DisperSul Iron (sulfur plus ferrous sulfate). Additional chlorotic ixoras growing in a substrate of 3 sedge peat : 2 cypress sawdust : 1 sand were treated every 2 months with foliar sprays of Fe at 0.8 g·L^{-1} (0.11 oz/gal) from ferrous sulfate, FeDTPA, FeEDDHA, ferric citrate, or iron glucoheptonate. Only chelated Fe sources significantly improved ixora chlorosis when applied to the soil, regardless of whether the chlorosis was induced by an alkaline substrate or a poorly aerated one. As a foliar spray, only FeDTPA was effective in improving chlorosis in dwarf ixora. Leaf Fe content either showed no relationship to plant color or was negatively correlated with plant chlorosis ratings.

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Iron chlorosis is one of the most persistent and difficult to correct nutritional disorders in horticulture (Korcak, 1987; Wallace and Lunt, 1960). Although it is often associated with alkaline soils, it is also a common problem in container production if poorly aerated substrates are used. Iron chelates such as FeEDDHA have been shown to be highly effective in correcting Fe chlorosis on alkaline soils (Martens and Westermann, 1991), but little has been published on the relative effectiveness of commercially available Fe fertilizers on poorly aerated container substrates. Foliar applications of Fe fertilizers have been used to circumvent soil conditions that are unfavorable for Fe uptake by plants (Murphy and Walsh, 1972; Swietlik and Faust, 1984), but there have been few published comparisons of these treatments on container-grown plants (Fisher et al., 2003).

The purpose of this study was to evaluate the effectiveness of various commercially available Fe sources for correcting Fe chlorosis caused by alkaline soils or by poorly aerated soils in dwarf ixora, a species highly prone to Fe chlorosis.

Materials and methods

Liners [5.10 cm in diameter × 6.10 cm deep (2 × 2.4 inches)] of 'Petite Yellow' ixora were transplanted into 2.4-L (#1) plastic containers on 14 Feb. 2000 using an alkaline 3 limestone gravel [0.51–1.52 cm (0.2–0.6 inches)] : 2 coir dust substrate, or a poorly aerated composted mixture of 1 seaweed : 11 yard trimmings (Terranova Industries, Miami, Fla.) to induce Fe chlorosis. Plants were fertilized at the time of transplant and every 6 months thereafter with Osmocote 17–7–12 (13N–5.6P–10.8K) [12-14 months at 21.1 °C (70 °F) Scotts Co., Marysville, Ohio] at a rate of 17 g (0.6 oz) per 2.4-L pot. They were grown in a fabric-covered shadehouse having a maximum photosynthetic photon flux of 900 μmol·m^{-2}·s^{-1} and received about 1.905 cm (¾ inch) of water daily from overhead irrigation plus natural rainfall of about 149.9 cm (59 inches) annually. After one year of growth, chlorotic plants were selected from each substrate for treatment. Ten replicate chlorotic plants growing in each substrate received soil applications of Fe at 0.1 g/pot every 2 months for 6 months. Treatments used on the alkaline substrate were 1) control (no Fe fertilizer) 2) Hampshire Iron (FeHEDTA + FeEDTA on vermiculite) (Hampshire Chemical Co., Nashua, N.H.), 3) ferric citrate (Fisher Chemical Co., Fair Lawn, N.J.), 4) FeEDDHA (Becker-Underwood, Ames, Iowa.), 5) FeDTPA (Becker-Underwood), 6) ferrous sulfate (QC Corp., Cape Girardeau, Mo.), 7) iron glucoheptonate (Florikan, Sarasota, Fla.), and 8) DisperSul Iron (elemental sulfur + ferrous sulfate, Martin Resources, Kilgore, Texas.). Plants growing in the poorly aerated substrate received the same treatments except for the DisperSul Iron.

Additional chlorotic plants from another source that had been growing in 2.4-L containers filled with a 3 sedge peat : 2 cypress sawdust : 1 sand substrate were similarly fertilized with Osmocote 17-7-12, but foliar sprays that provided Fe at 0.8 g·L^{-1} plus 2 mL·L^{-1} (0.26 oz/gal) of a surfactant (Wet All, Sun Chemical Co., Arcadia, Fla.) were applied every 2 months for 6 months to 10 replicate plants per treatment. Foliar Fe treatments were 1) control (no Fe fertilizer), 2) ferrous sulfate (Fisher Chemical Co.), 3) ferric citrate (Fisher Chemical Co.), 4) FeDTPA (Becker-Underwood), 5) FeEDDHA (Becker-Underwood), and 6) iron glucoheptonate (Florikan). Foliar sprays were applied up to the

point of runoff. Sprays were applied in the mornings and plants did not receive any irrigation until the following morning. All plants were arranged in a randomized complete block design with two blocks and five plants per block for each treatment within each substrate type.

Plant chlorosis severity was determined for each plant at the initiation of the Fe treatments and every 2 months thereafter for 6 months. Since chlorosis was not uniform on these plants, a chlorosis index was calculated as the percentage of the foliage that was healthy (e.g., free of all chlorosis) times the average severity rating of the chlorosis (5 = darkest green, 3 = moderate chlorosis, 1 = severe chlorosis, completely white). The net change (positive or negative) in chlorosis index for each plant was calculated by subtracting the initial chlorosis index from that obtained at our 2, 4, and 6-month evaluations.

Leaf samples consisting of the youngest fully expanded leaf pairs on each shoot were collected prior to retreatment at 4 and 6 months for Fe analysis. Only leaves produced since the last foliar Fe fertilization were collected to eliminate the possibility of leaf contamination by foliar Fe applications. Samples were dried at 62.8 °C (145 °F), ground, and digested using a modified Kjeldahl procedure (Hach et al., 1987). Iron concentrations were determined by atomic absorption spectroscopy. Data were analyzed by analysis of variance, with mean separation by the Waller-Duncan k ratio method (SAS Inst., Cary, N.C.).

Results and discussion

Two months after the first soil Fe application to the alkaline substrate, the FeDTPA, FeEDDHA, and Hampshire Iron treatments resulted in a significant increase in chlorosis ratings (e.g., less chlorosis) over the untreated controls (Table 1). All other treatments were not significantly different from the untreated controls. At 4 months the iron glucoheptonate treatment, in addition to the FeDTPA, FeEDDHA, and Hampshire Iron treatments, resulted in significantly increased chlorosis ratings. The ferrous sulfate, ferric citrate, and DisperSul Iron treatments were not significantly different from the untreated controls. At six months only FeEDDHA, FeDTPA, Hampshire Iron, and DisperSul Iron were significantly different from the untreated controls. The three chelates (FeDTPA, FeEDDHA, and Hampshire Iron) provided rapid and lasting improvement in plant chlorosis ratings up to 6 months, while DisperSul Iron only slowly provided significant improvement in plant chlorosis ratings up to 4 months. Fisher et al. (2003) found that soil drenching with FeEDDHA was the most effective treatment for calibrachoa (*Calibrachoa ×hybrida*).

In the poorly aerated substrate, Hampshire Iron, FeEDDHA, and FeDTPA resulted in significant increases in plant chlorosis ratings at 2 months, but by 4 and 6 months, only Hampshire Fe was better than the unfertilized controls (Table 2).

When foliar sprays were applied, none of the Fe treatments provided significant improvement in plant chlorosis ratings at 2 months (Table 3). At 4 months, FeDTPA, and FeEDDHA,

Table 1. Net change (Δ) in chlorosis index [percentage of healthy foliage × chlorosis severity rating (5 = dark green, 3 = moderate chlorosis, 1 = severe chlorosis, completely white)] in 'Petite Yellow' dwarf ixora grown in a substrate of 3 crushed limestone : 2 coir substrate (by volume) and treated with soil applications of various iron (Fe) fertilizer sources at a rate of 0.1 g (0.0035 oz) Fe per 2.4-L (0.62-gal) pot every 2 months for 6 months.

Fe source	Product rate (g/pot)	Chlorosis index (Δ) 2 months	4 months	6 months	Fe concn [µg·g^{-1} (ppm)] 4 months	6 months
Control	0.00	–0.09 cd[z]	0.44 de	–1.41 d	146.2 f	99.3 cd
DispserSul Iron (ferrous sulfate + sulfur)	2.10	–0.01 cd	1.23 bcd	0.38 abc	135.2 ef	93.5 d
Ferric citrate	0.63	–0.40 d	0.11 e	–0.69 cd	205.0 c	121.7 a
FeDTPA	1.00	1.79 a	2.49 a	1.11 a	255.2 a	103.4 bc
FeEDDHA	1.67	1.63 a	2.46 a	1.44 a	198.3 c	110.0 b
Ferrous sulfate	0.49	0.35 cd	1.25 bcd	–0.02 bcd	165.8 e	103.4 bc
Hampshire Iron (FeEDTA + FeHEDTA)	2.00	1.40 ab	2.25 ab	0.89 ab	225.1 b	98.4 cd
Iron glucoheptonate	2.00	0.06 cd	1.60 abc	–0.26 bcd	126.7 f	100.9 cd

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

Table 2. Net change (Δ) in chlorosis index [percentage of healthy foliage × chlorosis severity rating (5 = dark green, 3 = moderate chlorosis, 1 = severe chlorosis, completely white)] in 'Petite Yellow' dwarf ixora grown in a poorly aerated composted seaweed substrate and treated with soil applications of various iron (Fe) fertilizer sources at a rate of 0.1 g (0.0035 oz) Fe per 2.4-L (0.62-gal) pot every 2 months for 6 months.

Fe source	Product rate (g/pot)	Chlorosis index (Δ) 2 months	4 months	6 months	Fe concn [µg·g^{-1} (ppm)] 4 months	6 months
Control	0.00	–0.25 b[z]	0.18 bcd	–1.49 bc	506.5 a	140.6 c
Ferric citrate	0.63	–0.46 b	–0.50 d	–1.86 bc	599.2 a	263.2 a
FeDTPA	1.00	1.26 a	1.13 ab	–0.46 ab	251.6 c	126.6 de
FeEDDHA	1.67	1.08 a	0.73 abc	-0.42 ab	224.8 c	118.4 ef
Ferrous sulfate	0.49	–0.20 b	0.33 bc	–1.39 bc	358.9 b	163.7 b
Hampshire Iron (FeEDTA + FeHEDTA)	2.00	1.16 a	1.43 a	0.97 a	199.7 c	113.3 f
Iron glucoheptonate	2.00	–0.46 b	–0.12 cd	–1.15 bc	218.8 c	140.6 c

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

Table 3. Net change (Δ) in chlorosis index [=percentage of healthy foliage × chlorosis severity rating (5 = dark green, 3 = moderate chlorosis, 1 = severe chlorosis, completely white)] in 'Petite Yellow' dwarf ixora grown in a substrate of 3 sphagnum peat : 2 cypress sawdust : 1 perlite substrate (by volume) and treated with foliar applications of various iron (Fe) fertilizer sources at a rate of 0.8 g Fe/L (0.11 oz Fe/gal) of solution every 2 months for 6 months.

Fe source	Product rate ($g \cdot L^{-1}$)	Chlorosis index (Δ)			Fe concn [$\mu g \cdot g^{-1}$ (ppm)]	
		2 months	4 months	6 months	4 months	6 months
Control	0.00	–0.17 a[z]	–0.08 c	–2.23 d	692.2 abc	298.8 c
FeDTPA	8.00	0.53 a	2.56 a	1.52 a	321.8 d	130.1 fg
FeEDDHA	13.3	0.14 a	1.03 b	–0.16 b	620.7 bc	122.4 g
Ferric citrate	5.00	0.04 a	0.27 c	–1.68 c	703.4 abc	275.4 d
Ferrous sulfate	4.00	0.34 a	–0.11 c	–2.20 d	881.4 a	319.3 b
Iron glucoheptonate	16.0	0.11 a	0.28 c	–1.48 c	822.3 abc	378.9 a

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

were significantly better than the controls, but at 6 months FeDTPA was the only treatment that significantly improved plant chlorosis ratings. Chlorosis became more severe over time for all but the FeDTPA treatment. Fisher et al. (2003) also found that FeDTPA was the most effective foliar spray on calibrachoa. Iron chlorosis is believed to be due to poor distribution of Fe within a leaf and FeDTPA has been shown to be the most mobile of the Fe chelates (Rutland, 1971; Rutland and Chung, 1971). However, partial regreening of chlorotic foliage by other treatments was not observed.

Leaf Fe content decreased between 4 and 6 months for all treatments in the alkaline substrate (Table 1). Leaf Fe content was not significantly correlated with chlorosis ratings at either 4 or 6 months. Foliar Fe concentrations also decreased for all treatments for plants grown in the poorly aerated substrate (Table 2). Although the treatments that provided the best improvement in chlorosis ratings appeared to have the lowest leaf Fe concentrations, correlations between chlorosis ratings and leaf Fe content were not significant. The leaf Fe content of chlorotic ixoras sprayed with various Fe sources also decreased sharply between 4 and 6 months (Table 3), with the most effective treatments (FeDTPA and FeEDDHA) having the lowest leaf Fe concentrations at both 4 ($r = 0.47$, $P < 0.0001$) and 6 ($r = 0.46$, $P < 0.0001$) months. Other studies have also found either no correlation between leaf Fe content and chlorosis severity, or a higher Fe content in the most chlorotic leaves (Chaney, 1984; Wallace, 1971). This may be due to a dilution effect, since severely chlorotic plants were stunted and produced smaller leaves.

In summary, the only effective soil-applied treatments for Fe chlorosis in dwarf ixora were Fe chelates, regardless of whether the chlorosis was caused by an alkaline or poorly aerated substrate. Ferric citrate, ferrous sulfate, and iron glucoheptonate were generally no better than the untreated controls for correcting Fe chlorosis in this species. The only effective foliar-applied Fe source was FeDTPA, and it was highly effective in greening up severely chlorotic dwarf ixoras. Leaf analysis was not found to be a good indicator of ixora Fe status in this study.

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