Effect of Applied Iron Concentration on Growth and Phylloclade Marginal Chlorosis of Holiday Cactus (*Schlumbergera* sp.)

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ABSTRACT. Two studies were conducted to determine the effect of applied Fe concentration on the occurrence of phylloclade marginal chlorosis in holiday cactus. *Schlumbergera* sp. 'White Christmas', 'Twilight Tangerine', 'Christmas Charm', and 'Lavender Doll' were grown in either solution culture or a peat-based medium and supplied with a nutrient solution containing Fe-EDTA at either 0, 0.18, 0.36, 0.54, or 0.72 mM. Growth decreased while marginal chlorosis increased on all cultivars as Fe-EDTA treatment levels increased. Phylloclade marginal chlorosis developed more severely and consistently in plants grown in peat-based media versus solution culture. Marginal chlorosis and accumulation of Fe in the potting medium occurred very slowly, and first symptoms were not observed until after about 2 months of treatment. Symptomatic phylloclade tissue had a greater Fe concentration than corresponding asymptomatic phylloclade tissue. Cultivars varied in tissue Fe concentration and symptom severity across Fe-EDTA treatments. There were no significant correlations in other tissue micronutrient concentrations with either Fe treatment or symptom development. The pH of either the culture solution or peat-based medium leachate did not change significantly throughout either study, and there were no significant amounts of Fe²⁺ detected in solution. Chemical name used: ferric ethylenediaminetetraacetic acid, monosodium salt (Fe-EDTA).

Schlumbergera species of holiday cactus have become very popular ornamental plants for their beautiful flowers, wide flower-color range, and unusual plant form (Lang and Cushman, 1993). Their short-day photoperiodic flowering response and easy care make them a favorite plant with consumers during the Christmas season. The holiday cactus group generally consists of those plants derived from the two species: *Schlumbergera truncata* (Thanks-giving cactus) and *Schlumbergera bridgesii* (Christmas cactus). Breeding between the two species has produced a group of plants that are generally referred to as holiday cactus.

Production of holiday cactus has been limited by the common occurrence of marginal chlorosis of the phylloclade (a stem modified for photosynthesis), which can lead to poor plant quality and losses in sales (Fig. 1). To date, there have been no documented studies on the cause of this chlorosis. Previous scientific studies with holiday cactus have focused more on flowering requirements (Heins et al., 1981; Ho et al., 1985; Yonemura, 1979) and less on the requirements for healthy, vegetative growth. There have been some reports in the field that the disorder occurs more frequently under higher light and temperature regimes and that it may be related to cultivar susceptibility. However, there are no data published in the scientific literature to corroborate these reports and to suggest recommendations for control.

Tissue analyses of healthy and symptomatic plants have shown that the symptoms of marginal chlorosis and poor growth appear to be correlated with elevated levels of Fe in the plant tissue (R. Heins and H. Lang, unpublished data). However, these symptoms are atypical of symptoms of Fe or Mn toxicity (older leaf chlorosis,

bronze speckling, and necrosis) that are commonly observed in other susceptible floricultural crops, such as African marigold and geranium (Albano et al., 1996; Biernbaum et al., 1988; Vetanovetz and Knauss, 1989). Thus, the objective of this study was to determine if the problem of poor growth and phylloclade marginal chlorosis in holiday cactus is due to a toxic level of Fe in the plant and to compare cultivar susceptibility in culture solution and peat-based media.

Materials and Methods

SOLUTION CULTURE STUDY—EXPT. 1. Cuttings with three to four phylloclades of *Schlumbergera* sp. 'White Christmas', 'Twilight Tangerine', 'Christmas Charm', and 'Lavender Doll' were rooted under intermittent mist in medium-texture vermiculite. After 5 weeks, roots were washed thoroughly with deionized water and plants were transplanted to individual 1.3-L opaque plastic containers holding a nutrient solution (Lang, 1986) with varying amounts of Fe supplied as Fe-EDTA. Treatments consisted of 0, 0.18, 0.36, 0.54, and 0.72 mM Fe. The base nutrient solution, prepared in deionized water, was composed of the following macronutrients—(in mM) 5 Ca(NO₃)₂, 2 MgSO₄, 5 KNO₃, and 1 KH₂PO₄—and micronutrients—(in μ M) 12 MnSO₄, 0.76 ZnSO₄, 0.32 CuSO₄, 0.16 (NH₄)₆Mo₇O₂₄, and 0.046 H₃BO₃. All plants were grown in a controlled-environment chamber at 22/18 °C (day/night) under a 16-h photoperiod from 6:00 AM to 10:00 PM with a photosynthetic photon flux density (PPFD) of 220 μ mol·m⁻²·s⁻¹ supplied from a combination of fluorescent and incandescent lamps. Plants were arranged as a 4 × 5 factorial (four varieties × five Fe treatments) in a completely randomized design with four plants (one plant per container) per treatment combination. Solution samples were collected every 2 weeks beginning after first treatment application and analyzed for pH and electrical conductivity (EC) using a combination pH and conductivity meter (Accumet model 20; Fisher Scientific, Pittsburgh) and Fe concentration (total Fe and Fe²⁺) using the colorimetric method described by Pierson and Clark (1984). Iron absorption into plants was calculated by depletion of Fe from solution. After sampling, old solutions were replaced

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Fig. 1. Chlorosis of phylloclade margins is a commonly observed disorder in the production of holiday cactus. (A) Overall view of plant and (B) close-up of phylloclades. The arrows indicate several phylloclade segments showing marginal chlorosis.

with fresh nutrient solutions to maintain uniform volume and treatment levels. After 120 d, plants were harvested and visual evaluations, total fresh mass, shoot height, and phylloclade number were recorded. After harvesting, phylloclades were washed in 0.1 N HCl, double rinsed with deionized water, and dried at 60 °C for 72 h. After drying, samples were ground in a stainless-steel Wiley mill to pass a 20-mesh screen and were taken as an individual sample from one replication (plant) of each cultivar and Fe treatment. Samples were sent to a commercial research analytic laboratory (Ohio State Univ., Worster), where P, K, Ca, Mg, Mn, Cu, Zn, B, and Fe were determined using inductively coupled plasma (ICP) spectrometry. Data were analyzed to determine the main effect of variety and Fe treatment and determine the presence of interaction between these

factors using ANOVA. Where there was no interaction, the effect of Fe treatment over all varieties was analyzed using simple linear and quadratic regression. Calculations were performed using GLM and REG procedures of SAS (SAS Institute, Cary, N.C.).

PEAT-BASED MEDIUM STUDY—EXPT. 2. The same four varieties of holiday cactus used in Expt. 1 were propagated similarly under mist and grown in individual 600-cm³ (13-cm-wide × 10-cm-tall) plastic azalea pots containing a 1 peat : 1 perlite (v/v) medium amended with 14 kg-m⁻³ dolomitic limestone to reach a beginning pH of 6.0 to 6.2 using a saturated media extract (SME) technique (Warncke and Krauskopf, 1983). Plants were grown in a polyethylene greenhouse with a peak PPFD of 350 μmol-m⁻²·s⁻¹ and day/night setpoints of 25/18 °C. The actual temperature range was 24–28/16–20 °C (day/night) throughout the experiment. Plants were maintained under long-day conditions using a 4-h night interruption (10 PM to 2 AM) with incandescent lamps and fertilized at every watering with a similar nutrient solution as in Expt. 1 containing Fe-EDTA at 0, 0.18, 0.36, 0.54, or 0.72 mM. Plants were placed in a completely randomized design with five plants (one plant per container) per treatment. Treatment solutions were first applied to plants 1 week after transplanting from rooted cuttings and were reapplied at regular intervals throughout the experiment as needed to maintain constant moisture. Three hundred milliliters of solution was applied by hand to each pot to produce a leaching fraction of 10% to 20%. Growth parameters and observations of visual symptoms were taken periodically as in Expt. 1. The medium leachate was collected on a weekly basis beginning 1 week after the first treatment application using a modified pour-through procedure (Wright, 1986). In the procedure, the plants were fertigated 4 h before beginning the extraction. After 4 h, 50 mL of

deionized water was poured evenly over the surface of the medium and leachate collected in a clean, dry container. Samples were held in the dark for about 20 min in air-tight 20-mL scintillation vials and were analyzed for pH, EC, total Fe, and Fe⁺² as in Expt. 1. After 150 d, plants were harvested, roots were washed thoroughly with deionized water, and visual evaluations, fresh mass, height, and phylloclade number were recorded. After harvesting, phylloclades were washed in 0.1 N HCl, double rinsed with deionized water, and dried at 60 °C for 72 h. After drying, samples were ground in a stainless-steel Wiley mill to pass a 20-mesh screen and were taken as an individual sample from one replication (plant) of each cultivar and Fe treatment. Tissue nutrient analysis and statistical analysis of data were handled similarly as in Expt. 1.

Results and Discussion

Experiment 1—solution culture

GROWTH AND SYMPTOM DEVELOPMENT. Across cultivars, all

plants responded similarly to the Fe treatment, with higher Fe concentrations in solution causing significant decreases in growth (Table 1). All cultivars grew best under 0 ppm Fe treatment, indicating that holiday cactus has a very low Fe requirement for growth. Because plastic containers were used and other precautions were taken to eliminate outside Fe sources, there was little, if any, Fe contamination of the solutions. There apparently was sufficient Fe in the tissue at the beginning of treatment to sustain the growth of the plants over the 120-d period. There was no interaction between cultivar and Fe treatment for any of the growth parameters; however, there were significant growth differences between the cultivars. 'Christmas Charm' generally grew better than the other cultivars, while 'Twilight Tangerine' had the poorest growth. Differences in growth between holiday cactus genotypes has been supported in previous studies illustrating the genetic variability inherent within cultivars (Wade et al., 1985).

Across all cultivars, phylloclade marginal chlorosis appeared only on those plants treated with Fe (Table 1). There was a significant linear and quadratic response to Fe concentration, with increased concentrations causing symptoms of marginal chlorosis. Of those plants that showed symptoms, there was only slight to moderate chlorosis of the phylloclades, with variability in symptom development occurring within each treatment. Most plants did not begin to show chlorosis until after about 7 weeks of treatment. 'Christmas Charm' was the only cultivar that did not show any marginal chlorosis in any of the treatments.

Symptoms of Fe toxicity disorder induced in holiday cactus with Fe-EDTA in this experiment were not consistent with those described for the disorder on other crops by Biernbaum et al. (1988) and Vetanovetz and Knauss (1989). It is well documented that symptoms of Fe toxicity vary among species. Leaf bronzing is characteristic on rice (*Oriza sativa* L.) growing under flooded soil conditions (Tanaka and Yoshida, 1970). Tobacco (*Nicotiana tabacum* L.) leaves develop a bronze cast and brown spotting or speckling (Arnold and Binns, 1987). Symptoms on older leaves of marigold (*Tagetes erecta* L.) consist of small bronze spots, which enlarge with age until the entire leaf becomes necrotic when leaf Fe concentrations are excessive (Albano et al., 1996). *Petunia ×hybrida*, on the other hand, is very resistant to Fe toxicity and does not show foliar damage except at very high concentrations of

applied Fe (>6 mM) (Lee et al., 1992).

The unique pattern of marginal chlorosis on holiday cactus phylloclades could indicate deposition of Fe in concentrated areas (along the margins). Lack of mobility would enhance this deposition; however, mobility studies have not been conducted to confirm this hypothesis. The unique pattern of symptom development that characterizes this disorder on holiday cactus begins with slight chlorosis of mature phylloclade margins and, in severe cases, progresses to new phylloclades. On very chlorotic phylloclades, the outer marginal edge may develop a purplish cast.

TISSUE FE ANALYSIS AND FE UPTAKE. Tissue Fe concentration and total plant uptake of Fe increased with increasing Fe-EDTA concentration in solution (Fig. 2). There was a significant interaction between cultivar and Fe level, suggesting that all cultivars did not behave the same way to applied Fe. At low Fe levels in solution, 'White Christmas' and 'Twilight Tangerine' accumulated more Fe in phylloclade tissue, while, at higher Fe levels, 'Twilight Tangerine' and 'Lavender Doll' showed greater accumulation of Fe (Fig. 2A). Across all Fe treatments, 'Christmas Charm' accumulated less Fe in shoot tissue than the other cultivars.

Uptake of Fe followed a similar trend as with tissue Fe accumulation within shoots (Fig. 2B). As would be expected, plants absorbed more Fe from solution as Fe-EDTA level increased; however, uptake of Fe differed between cultivars. 'Twilight Tangerine' Fe absorption was more quadratic over treatment levels compared to the other cultivars. 'Christmas Charm', on the other hand, had a slower and more linear uptake rate. It should be noted that, since absorption of Fe was calculated by depletion from the nutrient solution, there is a possibility that precipitation of Fe may have occurred; however, observations indicated that there were no precipitates in the container. There is also the possibility that insoluble Fe precipitates may have been imbedded either on or inside the root system, since roots growing in Fe-treated solutions had a slightly darker tint relative to roots in the 0-Fe treatments.

It appears that cultivars of holiday cactus differ in the amount of Fe taken up by roots and the amount translocated from roots to shoots (Welch and LaRue, 1990). Differences in Fe accumulation between cultivars may be related to differences in efficient mechanisms of Fe uptake (Albano and Miller, 1996; Lang et al., 1990); however, these mechanisms have been shown to occur only under

Table 1. Total plant fresh mass, shoot height, phylloclade number, and symptom severity rating of holiday cactus after 120 d in solution culture (Expt. 1).

Fe treatment (mM)	Growth parameter ^a			
	Fresh mass (g)	Ht (cm)	Phylloclade number	Symptom severity ^b
0	30.8	8.1	23.1	1.0
0.18	28.9	8.0	19.2	1.7
0.36	24.7	7.8	15.8	1.7
0.54	17.6	6.8	12.1	1.9
0.72	13.4	5.6	8.3	2.0
Significance	L*Q*	L*Q*	L*Q*	L*Q*
Cultivar				
White Christmas	22.6 b*	8.4 a	15.2 ab	1.3 a
Twilight Tangerine	9.9 c	5.4 b	12.5 b	2.2 a
Christmas Charm	33.8 a	7.2 a	19.3 a	1.0 a
Lavender Doll	26.1 ab	8.0 a	15.7 ab	1.4 a
Significance	*	*	*	NS
Cultivar × Fe treatment	NS	NS	NS	NS

^aCalculated as final measurement minus initial measurement.

^b1 = green, healthy phylloclade, 2 = slight chlorosis of phylloclade margin, 3 = moderate to severe chlorosis of phylloclade margin.

*Mean separation within columns by Duncan's multiple range test at $P \leq 0.05$.

NS,*Nonsignificant or significant at $P \leq 0.05$, respectively, using ANOVA; L = linear, Q = quadratic.

low Fe stress. Under these conditions, many Fe-efficient plants activate an inducible Fe^{+3} reductase system, which is commonly associated with rhizosphere acidification via membrane bound ATPase proton extrusion (Bienfait, 1988). In this study, there were no significant differences in solution pH between either Fe treatments or cultivars, even under the 0-Fe treatment. Solution pH levels ranged from 6.0 to 6.3 throughout the entire experiment (data not shown). There was also insignificant Fe^{+2} concentration found in solutions, indicating that Fe^{+3} reduction and subsequent uptake probably occurred at the plasmalemma and not through the action of released reductants (Lang et al., 1990). A reductase system has been proposed that will operate continuously under Fe sufficient conditions and can be detected via ferricyanide reduction (Bienfait, 1987). There is little information, however, describing how the system operates in the presence of synthetic Fe^{+3} chelates, such as Fe-EDTA.

There is also the suggestion that the relatively high concentrations of Fe-EDTA in solution may have induced a deficiency of other nutrients. Complete tissue analysis, however, did not reveal any apparent induced deficiency of other macro- or micronutrients. Manganese concentration in tissue was not correlated with Fe accumulation and was well within the range of sufficiency (Dole and Wilkins, 1989) averaging $184 \mu\text{g}\cdot\text{g}^{-1}$ Mn in shoot tissue (data not shown).

Experiment 2—peat-based medium

GROWTH AND SYMPTOM DEVELOPMENT. Growth of holiday cactus was significantly affected by Fe-EDTA treatments (Table 2). Trends were very similar to the solution culture study, with plants growing more poorly at higher Fe concentrations. There was no interaction between cultivar and Fe treatment for any of the growth parameters. Across all Fe treatments, 'Christmas Charm' and 'White Christmas' generally grew better than the other cultivars, although there was significant marginal chlorosis on many plants of 'White Christmas'. While 'Twilight Tangerine' had the smallest plants among cultivars (in height and fresh mass accumulation), it had a significantly higher number of phylloclades; however, many of these phylloclades were relatively small and inconsistent with normal phylloclade expansion. Overall, all cultivars grew better in Expt. 2 (peat-based medium) than in Expt. 1 (solution culture) at all treatment levels. This may have been due to the higher temperatures that were reached in the greenhouse, the peat-based medium that allowed for more favorable root development, or the longer production time.

Occurrence and severity of marginal phylloclade chlorosis increased with increasing Fe-EDTA concentration for all cultivars (Table 2). Symptoms were more highly correlated with Fe-EDTA concentration in this experiment than in solution culture. There was also less variability in growth within each treatment and

symptoms of marginal chlorosis developed more uniformly across replicate plants when plants were grown in the peat-based medium. At higher Fe-EDTA concentrations, symptoms appeared earlier, progressed more rapidly, and were more severe at harvest. First signs of marginal chlorosis were observed in the 0.72 mM Fe treatment about 2 months after treatments began. Several plants at the 0.72 mM Fe level had margins that eventually became severely chlorotic, with some light purpling on the very outer edges. For all cultivars, the percentage of plants showing marginal chlorosis within each treatment generally increased as Fe-EDTA treatment level increased. There were also differences in symptom severity between the different cultivars. 'Twilight Tangerine' and 'White Christmas' had the most severely chlorotic plants, with a greater percentage of plants showing marginal chlorosis than the other two cultivars. 'Christmas Charm' developed phylloclade marginal chlorosis only at the 0.72 mM Fe treatment, with only 40% of the plants in this treatment showing symptoms.

TISSUE FE ANALYSIS AND FE ACCUMULATION IN MEDIA. Iron concentration in symptomatic and asymptomatic phylloclades increased with increasing Fe-EDTA concentrations for all cultivars. Plants under the 0.72 mM Fe treatment averaged $978 \mu\text{g}\cdot\text{g}^{-1}$ Fe, with some individual plants reaching Fe levels greater than $1300 \mu\text{g}\cdot\text{g}^{-1}$. As with the solution culture study, there were significant differences in Fe accumulation between the different cultivars. 'Twilight Tangerine' had the highest overall Fe tissue concentration ($735 \mu\text{g}\cdot\text{g}^{-1}$) and 'Christmas Charm' had the least ($413 \mu\text{g}\cdot\text{g}^{-1}$). There was significant interaction

Fig. 2. Effect of Fe-EDTA concentration on (A) tissue Fe level and (B) total Fe uptake of holiday cactus after 120 d of growth in culture solution. Each point represents the mean of four observations.

between cultivar and Fe treatment and interaction plots were similar to those for Expt. 1 (Fig. 2A), except that 'Christmas Charm' had a sharp increase in tissue Fe concentration at the 0.72-mm Fe treatment (data not shown).

Symptomatic phylloclade tissue had consistently higher Fe concentrations than asymptomatic tissue (Fig. 3). For some cultivars, symptomatic phylloclades had levels nearly four times greater than green, healthy phylloclades. In addition, there appear to be differences in tolerance to Fe toxicity between cultivars. For plants growing in peat-based media after 150 d, 'Twilight Tangerine', 'White Christmas', and 'Lavender Doll' began to show consistent symptoms of phylloclade marginal chlorosis at tissue Fe concentrations ranging from 500 to 700 $\mu\text{g}\cdot\text{g}^{-1}$. This is consistent with critical toxic concentrations and symptom development in geranium and marigold (Bierbaum et al., 1988). 'Christmas Charm' marginal chlorosis appeared only in tissue having Fe concentrations above 900 $\mu\text{g}\cdot\text{g}^{-1}$. There were also no significant correlations between other micronutrients and Fe concentration in the phylloclades. Tissue concentrations of Mn, Zn, B, Cu were generally consistent across all Fe treatments, averaging 76, 41, 45, and 2 $\mu\text{g}\cdot\text{g}^{-1}$, respectively.

There are several factors that are involved in the uptake of Fe and accumulation within the plant. These may include Fe-efficient uptake mechanisms characteristic of the plant itself (Bienfait, 1988; Romheld and Marschner, 1983), environmental factors such as light and temperature (Brown et al., 1979), or the inhibition or promotion by other plant nutrients (Pandey and Kannan, 1979). Higher average daily temperatures and light intensity in the greenhouse probably led to improved growth and uptake of nutrients across all cultivars in Expt. 2. Peat-based media have also been shown to increase the level of leachable nutrients to abnormally high concentrations, leading to unregulated uptake and accumulation within the plant (Albano et al., 1996). In this experiment, leachate Fe concentrations generally increased over time for all cultivars and were significantly higher at 5 months versus 1 month of cropping (Table 3). Except for the 0.18-mm Fe treatment, Fe concentrations in the medium reached levels higher than those of actual applied Fe-EDTA concentrations. Chelating agents have been shown to be excellent extractants for Fe and other micronu-

trients (Berghage et al., 1987; Handreck, 1989) and will keep the nutrient in a more soluble and plant available form. It appears that frequent irrigations with Fe-EDTA under long cropping durations can lead to critically high concentrations of soluble Fe within the potting medium. Previous research has shown that the chelating agent itself is only absorbed in very small quantities, or only negligibly, relative to Fe uptake in the tissue and is generally accepted as being the supplier of Fe to roots rather than a toxic agent itself (Romheld and Marschner, 1983).

There was not a significant decrease in leachate pH over time for any of the treatments; therefore, there was no opportunity for pH effect on plant availability of Fe from Fe-EDTA. Equilibria studies of metal chelates in soil solution have determined that EDTA chelates Fe^{+3} almost exclusively below pH 6.5 and that Fe-EDTA remains very stable from pH 4 to 6.5 (Lindsay, 1974; Lindsay and Norvell, 1969). This supports other preliminary studies in our laboratory where we have found that Fe toxicity could not be induced by low to moderate concentrations of Fe-EDTA (0.08 to 0.09 mm Fe) after adjusting the medium pH to 5.0 (Ramirez, 1996). The pH levels in this experiment ranged from 6.1 to 6.3 throughout the entire cropping period. This would be expected from a medium irrigated with a nutrient solution from purified water containing little $\text{NH}_4^+\text{-N}$ as in this study (Lang and Elliott, 1991). It is common for growers to acidify irrigation water or fertilizer solution to reduce water alkalinity and maintain moderately acidic conditions within the potting medium. However, additional studies are needed to determine the effect of medium pH on the accumulation of Fe within the plant tissue from a medium irrigated with a solution containing Fe-EDTA.

In conclusion, there is good correlation between applied Fe concentration and the occurrence of phylloclade marginal chlorosis, a common disorder in holiday cactus. As Fe increased in phylloclade tissue, symptom severity increased and overall growth decreased. There appears to be differential sensitivity to the Fe toxicity among cultivars, with some varieties being very susceptible. In greenhouse studies, consistent symptom development did not occur on any of the cultivars until Fe tissue concentrations reached about 500 $\mu\text{g}\cdot\text{g}^{-1}$. The occurrence of the disorder and its severity in commercial production would depend on the Fe con-

Table 2. Total plant fresh mass, shoot height, phylloclade number, and symptom severity rating of holiday cactus after 150 d in a peat-based medium (Expt. 2).

Fe treatment (mM)	Growth parameter ²			
	Fresh mass (g)	Ht (cm)	Phylloclade number	Symptom severity ³
0	69.9	10.1	38.6	1.0
0.18	64.4	9.6	37.4	1.8
0.36	59.9	9.4	35.1	1.8
0.54	50.7	8.7	31.8	2.0
0.72	48.7	6.3	31.2	2.7
Significance	L*Q*	L*Q*	L*Q*	L*Q*
Cultivar				
White Christmas	64.5 a ⁴	11.8 a	33.6 b	2.0 ab
Twilight Tangerine	46.5 c	6.4 c	42.0 a	2.2 a
Christmas Charm	62.2 a	11.7 a	35.8 b	1.2 b
Lavender Doll	59.3 ab	9.6 b	27.8 c	1.8 ab
Significance	*	*	*	*
Cultivar $\times$ Fe treatment	NS	NS	NS	NS

²Calculated as final measurement minus initial measurement.

³1 = green, healthy phylloclade, 2 = slight chlorosis of phylloclade margin, 3 = moderate to severe chlorosis of phylloclade margin.

⁴Mean separation within columns by Duncan's multiple range test at $P \leq 0.05$.

NS,*Nonsignificant or significant at $P \leq 0.05$, respectively, using ANOVA; L = linear, Q = quadratic.

Fig. 3. Tissue Fe concentration of symptomatic (showing marginal chlorosis) and asymptomatic phylloclades for various holiday cactus cultivars. Plants were grown in a peat-based medium for 150 d. Error bars indicate the SE of the mean of five observations.

centration in the liquid fertilizer program or incorporated fertilizer formulations. Although in these studies the Fe concentrations applied were well in excess of those that would be applied in a continuous liquid fertilizer program (0.02 to 0.04 mM), the accumulation of Fe in tissue and development of marginal chlorosis appears to be a consequence of long-term exposure to relatively high levels of Fe in the potting medium solution. For holiday cactus, which has a long production time (up to 10 months), medium Fe concentrations in peat-based medium will increase over time with repeated applications of Fe-EDTA or perhaps other Fe chelates, even when periodically leached, as was done in this study. However, because the plants would probably not be irrigated with such high concentrations of Fe in typical commercial production, one can not rule out other factors, such as phytotoxic levels of Mn (Birnbaum et al., 1988), which may be involved in the disorder as well. Environmental factors that enhance Mn and Fe uptake, such as warm temperatures (Lang, 1986), or accumulation within the medium may hasten and exacerbate the disorder. In commercial settings, plant tissue should be periodically tested and cultivars monitored closely for early symptoms.

Table 3. Leachate Fe concentration across all cultivars in a peat-based medium (Expt. 2).

Fe-EDTA (mM)	Month ²	
	1	5
	Fe (mM)	
0.18	0.081	0.088 ^{NS}
0.36	0.16	0.41*
0.54	0.34	0.68*
0.72	0.45	1.10*

²Months of cropping after the start of the experiment.

^{NS}, *Nonsignificant or significant difference between months at $P \leq 0.05$ using pairwise t test.

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