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Scientia Horticulturae 86 (2000) 223–233

SCIENTIA HORTICULTURÆ

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Effects of mineral nutrient deficiencies on leaf development, visual symptoms and shoot–root ratio of *Spathiphyllum*

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Accepted 12 February 2000

Abstract

Effects of deficiencies in N, P, K, Ca, Mg, B and Fe on leaf development, visual symptoms and shoot–root dry weight ratio were studied in *Spathiphyllum* 'Sensation' grown hydroponically. Leaf nutrient contents of treated plants were analyzed to confirm suspected deficiencies. Leaf number, leaf area and chlorophyll content were all significantly reduced in the nitrogen-deficient plants similar to plants grown in distilled water. The phosphorus-deficient plants grew slowly but no deficiency symptoms were visible on leaves. Many small yellow specks, usually 2 mm or less in diameter, developed on the adaxial surface of lower leaves in the potassium-deficient plants. Leaf area, but not leaf number, was significantly suppressed by the calcium-deficient treatment and the young leaves developed necrotic margins on the middle and basal leaf blade. Fully expanded leaves in the magnesium-deficient plants were distorted and had lower chlorophyll contents than the controls. The iron-deficient plants showed interveinal chlorosis on younger leaves. The boron-deficient plants showed two types of deficiency symptoms: a marginal necrosis at the leaf apex and distorted and crinkled petioles break at the leaf blade. Shoot–root dry weight ratio was decreased under N, P and Fe deficiencies but was increased under deficiencies of Ca and B. A key was developed for the identification of mineral nutrient deficiencies.

Keywords: *Spathiphyllum*; Nutrient deficiency; Leaf development; Shoot–root ratio; Leaf nutrient content

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0304-4238/00/$ – see front matter
PII: S0304-4238(00)00152-7

1. Introduction

Spathiphyllum (peace lily) is one of the most popular tropical foliage plants grown commercially. Interest in peace lily is steadily increasing as it is a shade-tolerant indoor plant, which has showy white spathes. Although it is produced worldwide, little information is available on its nutritional requirements. General fertilization recommendations have been reported for constant-feed (Campos and Reed, 1993) and for a subirrigation system (Kent and Reed, 1996) but these studies have been concerned primarily with the level of nitrogen fertilization.

Well-developed dark green leaves of *Spathiphyllum* are considered to be a measure of good plant quality. Some *Spathiphyllum* cultivars however are often seen to produce necrotic, chlorotic leaves and/or yellow spots that severely reduce plant quality (Chase, 1997). These symptoms have been associated with low fertilizer rates (Henny et al., 1991), suggesting a mineral nutrient deficiency. Nutrient deficiency symptoms have been described for a number of ornamentals (Joiner et al., 1983). In *Spathiphyllum*, however, apart from manganese deficiency symptoms reported by Broschet and Donselman (1986), there appear to be no published reports on other mineral nutrient-deficiency symptoms. In other aroids, visual mineral deficiency symptoms vary and are often unique for different species (Harbaugh, 1986; Hershey and Merritt, 1987). Characterization of leaf development and nutrient deficiency symptoms could aid in diagnosing nutrient disorders and distinguishing nutrient imbalances from other disorders caused by pathogens, chemical damage, or other stresses. A first objective of the present study was to explore this possibility and to describe leaf development and deficiency symptoms of N, P, K, Ca, Mg, Fe and B in *Spathiphyllum.*

A second objective was to investigate nutrient deficiency effects on shoot–root ratios, which are an important aspect of commercial pot–plant quality for *Spathiphyllum.* In other plants, nutrient deficiency not only reduced the provision of photosynthates by decreasing leaf number, size and area, but also by altering shoot–root partitioning of photoassimilates (Wilson, 1988; Marschner et al., 1996).

2. Material and methods

Tissue cultured *Spathiphyllum* ‘Sensation’ grown prior to treatment in a peat based compost were used in this study. Explants were selected for uniformity at the 4–5 macroscopic leaf stage, rinsed several times with deionized water to remove the root medium, with the least possible injury to the roots. The plants were then transferred for 2 days to plastic beakers, each containing 500 ml of aerated 0.1 mM $CaCl_2$. The plants were then placed into the various nutrient treatments provided in continuously aerated solutions in 2-liter plastic containers

Table 1
Nutrient formulations and rates used to induce mineral nutrient deficiencies in *Spathiphyllum* 'Sensation'

Nutrient formulation	Rate (mg/l)	Treatment[a]							
		Control	−N	−P	−K	−Ca	−Mg	−Fe	−B
$Ca(NO_3)_2{\cdot}4H_2O$	295.2	+	−	+	+	−	+	+	+
KNO_3	126.4	+	−	+	−	+	+	+	+
$MgSO_4{\cdot}7H_2O$	123.3	+	+	+	+	+	−	+	+
KH_2PO_4	34.0	+	+	−	−	+	+	+	+
Fe-EDTA	8.2	+	+	+	+	+	+	−	+
Na_2SO_4	71.0	−	−	−	−	−	+	−	−
$NaH_2PO_4{\cdot}2H_2O$	39.0	−	−	−	+	−	−	−	−
$CaCl_2{\cdot}2H_2O$	183.8	−	+	−	−	−	−	−	−
$NaNO_3$	106.3	−	−	−	+	−	−	−	−
$NaNO_3$	212.5	−	−	−	−	+	−	−	−
KCl	93.2	−	+	−	−	−	−	−	−
KCl	186.4	−	−	+	−	−	−	−	−
H_3BO_3	0.72	+	+	+	+	+	+	+	−

[a] Nutrient included (+) or nutrient omitted (−) in treatment solution. All treatments contained, per liter, 0.45 mg $MnCl_2{\cdot}4H_2O$, 0.03 mg $ZnCl_2$, 0.01 mg $CuCl_2{\cdot}2H_2O$ and 0.006 mg $Na_2MoO_4{\cdot}2H_2O$.

fitted with lids with holes to support the plants. Containers were spaced 10 cm apart on benches. The nutrient treatments were arranged in a completely randomized design with 5 plants per treatment.

Apart from the distilled water treatment, nutrient deficient treatments comprised −N, −P, −K, −Ca, −Mg, −Fe and −B in $\frac{1}{4}$ strength of modified Hoagland solution (Hoagland and Arnon, 1950). Nutrient solutions were formulated to eliminate particular specified nutrients, without changing the concentration of other test nutrients. This was achieved by replacing the associated missing anions or cations using an appropriate Na or Cl compound. Unavoidably this leads to a slight increase in either Na or Cl in particular treatments (Table 1). To prevent salt accumulation and nutrient depletion, nutrient solutions were changed every week and distilled water was added periodically to maintain solution volume. The pH levels of all nutrient solutions were measured using an EC10 pH meter with a model 50200 electrode (Hach, Loveland, CO) and adjusted to pH 5.6±0.1 following the methods described by Kirkby and Mengel (1967). The pH range is within 5.5–6.5 recommended for *Spathiphyllum* (Joiner et al., 1983). Electroconductivity (EC) of all nutrient solutions in this study averaged 0.8 mS/cm as measured at 25°C by a model 44600 conductivity/TDS meter (Hach, Loveland, CO). This EC level was expected to avoid salt injury as *Spathiphyllum* has been shown to be sensitive to soluble salts (Campos and Reed, 1993).

Plants were grown under 50% natural greenhouse irradiance conditions (2–6 MJ/m^2 per day) from August to December 1997 for 110 days. The temperature ranges during the experimental period were 20–32°C (mean 25°C). Daily radiation receipts and air temperatures were measured at the top of plant canopy and recorded every 30 min by using LI-200SZ pyranometer sensors (LI-COR, Lincoln) and screened thermocouples, respectively, attached to a 'Squirrel' datalogger (Grant Instrument Cambridge, Cambridge, UK). The temperatures of the nutrient solutions ranged from 25 to 30°C. Plants' growth and nutrient uptake were expected to be conducive under the irradiance, air and root temperatures constructed in this experiment as recommended for *Spathiphyllum* production (Vogelezang, 1992).

The number of visible leaves, length and width of recently fully developed leaves were measured at the end of experiment. Leaf area was measured with an LI-COR 3000 area meter (LI-COR, Lincoln). Two 0.65 cm discs from each of the two youngest fully expanded leaves of five plants were used for *N*,*N*-dimethylformamide (DMF) extraction of chlorophyll (Moran, 1982). Chlorophyll contents were measured using a spectrophotometer (U-2001, Hitachi) and calculated following the methods described by Inskeep and Bloom (1985). Leaves and roots were oven-dried at 65°C for 48 h to determine dry weights. Recently expanded leaves were harvested from 5 plants in each treatment and combined for a composite sample, weighed and analyzed. Total N was determined by the Kjeldahl procedure and other elements were measured with inductively coupled plasma emission spectroscopy. Tissue analysis would help to ascertain that the symptoms expressed were due to deficiencies or imbalances of the nutrient, and were not to establish critical minimum levels for these elements. Means of development parameters and leaf nutrient contents measured were separated by *t*-test (0.05 level) for comparison of means with the complete nutrient treatment.

3. Results

Plants grew normally and without any deficiency symptoms in the complete nutrient treatment indicating that the EC and pH range adopted was appropriate. The maximum growth response for *Spathiphyllum* was recorded in the complete nutrient treatment as measured by leaf number, size of fully expanded leaf, total leaf area and chlorophyll content (Table 2). The number of visible leaves of plants in complete nutrients increased by 5–6 during the experimental period for 110 days. The youngest fully expanded leaves were bigger than older ones. Dry weights of shoot and root were 4.9 and 1.4 g per plant, respectively, and the shoot–root dry weight ratio was 3.50 (Table 3). Leaf nutrient contents from samples were N, 2.09%; P, 0.28%; K, 4.39%; Ca, 1.45%; Mg, 0.31%; B, 47.8 ppm; Fe, 131.2 ppm (Table 4).

Table 2
Effects of N, P, K, Ca, Mg, B and Fe deficiencies on leaf number, size and chlorophyll content in *Spathiphyllum* 'Sensation' grown hydroponically for 110 days

Treatment	Leaf number	Fully developed leaf		Leaf area (cm^2)	Chlorophyll (mg/g)
		Length (cm)	Width (cm)		
Control	10.2	21.6	8.9	706.8	3.85
H_2O	4.8[a]	11.8[a]	3.9[a]	128.1[a]	1.12[a]
−N	5.2[a]	11.3[a]	3.6[a]	144.8[a]	0.53[a]
−P	8.6[a]	17.6[a]	7.3[a]	436.8[a]	2.50[a]
−K	11.0	19.0	8.3	672.9	3.63
−Ca	9.2	6.3[a]	2.5[a]	336.9[a]	4.31[a]
−Mg	10.8	19.7	8.2	614.6	3.40[a]
−Fe	10.6	21.4	8.6	678.3	1.46[a]
−B	11.8[a]	19.7	8.0	693.8	4.29[a]

[a] Values in columns significantly different from the check (complete nutrients) by *t*-test, 5% level.

Leaf development, visual deficiency symptoms, shoot and root dry weights, and leaf nutrient content in the experimental treatments were as follows:

Nitrogen deficiency. Leaves were constantly dropping and leaf initiation appeared to have stopped. Size of the fully developed leaves and total leaf area were significantly reduced. Chlorophyll content in the −N treated plants was significantly smaller than that in the plants grown in complete nutrients (Table 2). Young and recently developed leaves became uniformly chlorotic, while the lower leaves were yellow, particularly on the veins. Small and chlorotic leaves

Table 3
Effects of N, P, K, Ca, Mg, B and Fe deficiencies on shoot and root dry weights and shoot–root dry weight ratio in *Spathiphyllum* 'Sensation' grown hydroponically for 110 days

Treatment	Shoot dry weight (g/plant)	Root dry weight (g/plant)	Shoot–root dry weight ratio
Control	4.9	1.4	3.50
H_2O	1.3[a]	1.0[a]	1.30[a]
−N	1.4[a]	0.9[a]	1.56[a]
−P	3.3[a]	1.3	2.54[a]
−K	4.6	1.4	3.29
−Ca	3.8[a]	0.6[a]	6.33[a]
−Mg	4.4	1.3	3.38
−Fe	4.3[a]	1.6[a]	2.69[a]
−B	6.7[a]	1.2	5.58[a]

[a] Values in columns significantly different from the check (complete nutrients) by *t*-test, 5% level.

Table 4
Effects of N, P, K, Ca, Mg, B and Fe deficiencies on leaf nutrient content of young fully expanded leaves of *Spathiphyllum* 'Sensation' grown hydroponically

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	B (ppm)	Fe (ppm)
Control	2.09	0.28	4.39	1.45	0.31	47.8	131.2
H_2O	0.60[a]	0.18[a]	1.79[a]	1.23[a]	0.30	27.5[a]	144.8
−N	0.48[a]	0.56[a]	3.41[a]	1.75[a]	0.37	33.8	161.3
−P	1.85	0.10[a]	4.41	1.71[a]	0.34	34.3	243.1[a]
−K	1.91	0.25	2.07[a]	2.42[a]	0.44[a]	31.1	157.3
−Ca	1.68[a]	0.19[a]	4.44	0.64[a]	0.46[a]	37.1	134.1
−Mg	2.15	0.29	4.56[a]	1.69[a]	0.38	34.7	190.6[a]
−Fe	1.85	0.31	4.61[a]	1.85[a]	0.45[a]	48.4	148.7
−B	1.74	0.23	4.45	1.48	0.42[a]	10.4[a]	142.9

[a] Values in columns significantly different from the check (complete nutrients) by *t*-test, 5% level.

fell prematurely and the chlorotic areas turned brown (Fig. 1a and b). Leaf development, shoot and root dry weights, and shoot–root dry weight ratio were all significantly reduced by the −N treatment, similar to the distilled water treatment (Table 3). The −N treatment decreased leaf N and K contents but increased P and Ca contents as compared with the complete nutrient treatment (Table 4). This imbalance of leaf nutrients may actually have intensified deficiency symptoms.

Phosphorus deficiency. The −P treated plants grew slowly with fewer leaves, smaller individual leaf size and total leaf area (Table 2). Although the −P leaves had a lower chlorophyll content, the leaf color appeared similar to the plants in complete nutrients. The −P treated plants were smaller but no visible deficiency symptoms on leaves were observed. Thus, leaf deficiency symptoms could not be discerned unless a plant in complete nutrients of similar age was present (Fig. 1c). The shoot–root dry weight ratio for the −P treated plants decreased as a result of a significant decrease in shoot dry weight (Table 3). The −P treatment decreased leaf P content but increased Ca and Fe contents as compared with the complete nutrient treatment (Table 4).

Potassium deficiency. No significant differences in leaf number, leaf area and chlorophyll content were recorded in plants treated by −K and complete nutrients (Table 2). However, many small specks (usually 2 mm or less in diameter) were developed on the adaxial surface of lower leaves (Fig. 1d). The specks became more prevalent as the plants grew. The shoot–root dry weight ratio for the −K plants was not significantly different from that for plants in complete nutrients (Table 3). The −K treatment decreased leaf K content but increased Ca and Mg contents (Table 4), indicating the competition between these cations.

Calcium deficiency. The −Ca treatment resulted in severe suppression of leaf expansion and total leaf area when compared with complete nutrient treatment

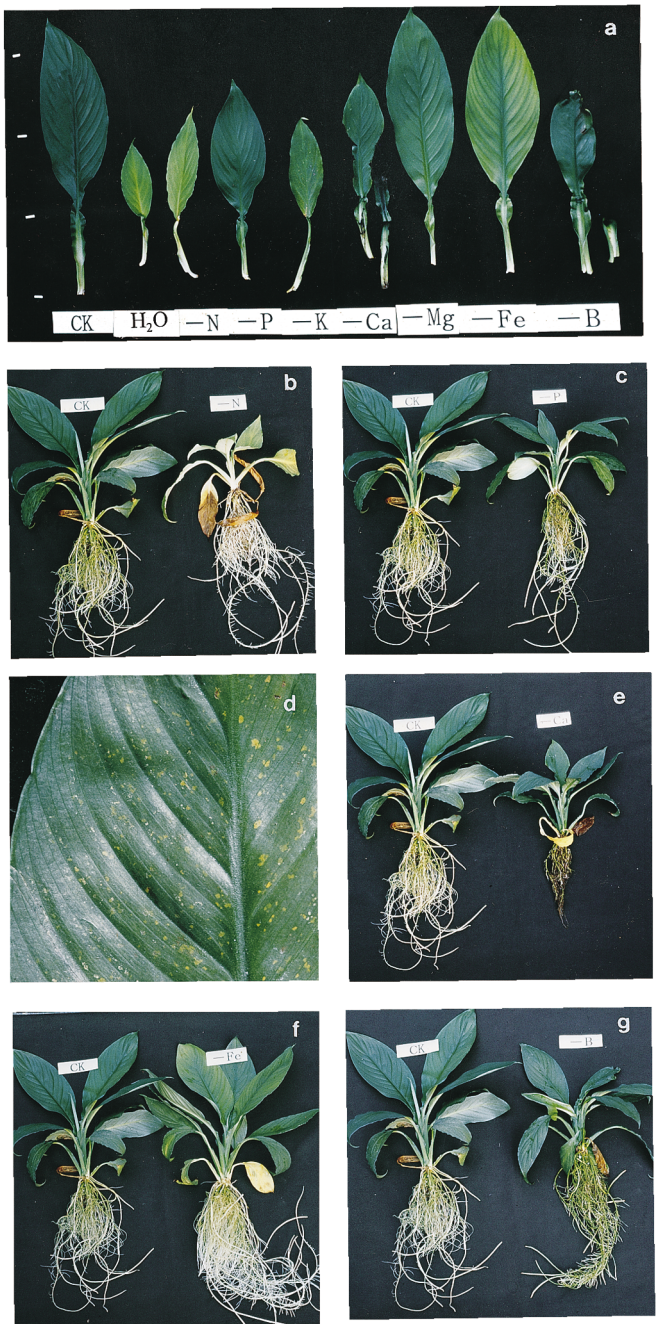

Fig. 1. Visual symptoms and growth of *Spathiphyllum* 'Sensation' under mineral nutrient deficiencies: (a) characteristic symptoms expressed on leaves in the specified nutrients; (b) −N, (c) −P, (d) −K, (e) −Ca, (f) −Fe, and (g) −B.

(Table 2). Leaf numbers were unchanged. Leaf thickness of the −Ca treated plants was 0.37 mm, thicker than the 0.27 mm of those grown with complete nutrients. Chlorophyll content was increased and the leaves appeared dark green. Young leaves developed necrotic margins, usually on the middle and basal leaf blade. Severe symptoms were expressed as brown and necrotic lesions (2–3 cm) developing near the attached petioles, leaving only partial leaf blade and petiole intact (Fig. 1a). Root growth was poor and roots were short, brown and thickened (Fig. 1e). Root dry weight was significantly reduced by the −Ca treatment, which resulted in an increase in the shoot–root dry weight ratio (Table 3). The −Ca treatment decreased leaf N, P and Ca contents but increased Mg contents (Table 4).

Magnesium deficiency. Leaf chlorophyll content was decreased in the –Mg treated plants; however, other parameters of leaf development were shown not to differ significantly from the plants in complete nutrients (Table 2). Symptoms of slight interveinal chlorosis were observed only on lower leaves (Fig. 1a). The fully developed leaves appeared puckered and light green. Lateral roots were long with few branches. The shoot–root dry weight ratio for the −Mg treated plants was not significantly different from that for plants in complete nutrients (Table 3). Although leaf Mg content was not significantly different from the control, leaf K and Ca contents were increased by the −Mg treatment (Table 4). This again indicated the antagonism between K, Ca and Mg.

Iron deficiency. The −Fe plants showed a decrease in chlorophyll content (Table 2). Interveinal chlorosis was found only on younger leaves. Roots of *Spathiphyllum* grown without Fe appeared white and showed increased root hair formation on the young lateral roots (Fig. 1a and f). Root dry weight of the −Fe treated plants was significantly enhanced and thus the shoot–root dry weight ratio was decreased (Table 3). Leaf Fe content was not significantly different from the control (Table 4).

Boron deficiency. The −B plants showed increases in leaf number and chlorophyll content (Table 2). Fully developed leaves were thick and dark green. Two distinct types of symptoms were expressed on the young leaves of −B treated plants (Fig. 1a). One was a marginal necrosis on leaf apex. The other type was observed as distorted and crinkled petioles, liable to break at the leaf blade. The leaf blade failed to fully expand if the break was only partial. Longer main roots and many short and brown lateral roots were observed (Fig. 1g). Shoot dry weight was significantly increased in the −B treated plants and the shoot–root dry weight ratio was therefore increased (Table 3). Leaf B content from samples was significantly reduced to 10.4 ppm (Table 4).

4. Discussion

Apart form the −Mg and −Fe treatments, tissue analyses showed significant decreases in leaf content of the withheld nutrient. In the −Mg treatment, where

only a few lower leaves showed slight interveinal chlorosis, it is probable that sampling occurred before the leaf content of Mg was reduced in sufficient leaves to show a significant effect. Although deficiency symptoms of interveinal chlorosis were expressed on most leaves in the −Fe treatment, *Spathiphyllum* 'Sensation' showed no significant difference in leaf Fe concentration on a dry weight basis. However, significant decreases in total Fe per shoot or plant would be expected as the −Fe plants showed reduced shoot and plant dry weights. Similar examples of chlorotic leaves caused by −Fe have also been reported in other plants, which possess similar or higher tissue Fe concentrations on a dry weight basis but lower Fe contents on a whole plant level (Lang et al., 1990).

Plant growth response and deficiency symptoms were similar in the −N and distilled water treatments. These results indicated that nitrogen deficiency could be a limiting factor affecting normal growth. However, only a small increase in nitrogen concentration was needed to greatly enhance growth and nutrient utilization as shown by the 56 ppm N in complete nutrients in this study. This is consistent with a report by Campos and Reed (1993). The −P treated *Spathiphyllums* grew slowly but showed no other symptoms, this is similar to the symptoms described on *Caladium* under P deficiency by Harbaugh (1986). Deficiency of K was expressed as specks throughout the old leaves but was not associated with necrosis. This differs from symptoms commonly expressed as both necrotic and chlorotic flecks in other foliage plants (Joiner et al., 1983) and in other *Spathiphyllum* cultivars suggested by commercial growers (Griffith, 1998). The Ca deficiency symptoms in *Spathiphyllum* were expressed on new leaves as is common in most other ornamental crops. This is contrast to Ca deficiency symptoms that are found on mainly mature leaves in other aroids, for example *Philodendron scandens* subsp. *oxycardium* and *Epipremnum aureum* (Dickey and Joiner, 1966). Some visual deficiency symptoms for *Spathiphyllum* were similar at certain stages of development but each of the nutrients caused unique symptoms that would identify the nutritional disorders. For example, it was difficult to distinguish between −Ca and −B treatments as both produced thick and dark-green mature leaves. However, initial necrotic areas occurred notably in the middle to basal blade in −Ca plants compared to tip burn in the −B plants. These visual differences in response to mineral deficiencies have been used to create a key (Table 5) which should be a valuable diagnostic tool to identify the nutritional deficiencies of *Spathiphyllum.*

Shoot–root dry weight ratio was decreased in the −N or −P treated *Spathiphyllums*. Similar examples for preferential partitioning of photosynthetic carbon to the roots and decrease in this ratio are well documented for other plants under nitrogen or phosphorus deficiency (Fredeen et al., 1989; Peuke et al., 1994). Shoot–root dry weight ratio was also decreased in *Spathiphyllum* grown without Fe, with plants showing increased root hair formation on the young lateral roots. These results suggest that *Spathiphyllums* were iron-efficient,

Table 5
A diagnostic key to N, P, K, Ca, Mg, B and Fe deficiencies in *Spathiphyllum* 'Sensation'

(a) Chlorosis or necrosis not expressed:	
(b) Plants grow slowly. No visible deficiency symptoms	P
(bb) Yellow specks (at 2 mm) on the interveinals of lower leaves	K
(aa) Chlorosis and/or necrosis expressed:	
(b) The dominant symptom is chlorotic leaf	
(c) Entire leaf blades are chlorotic	
(d) Leaves on all parts of plant are chlorotic. Small leaves prematurely defoliated. Plant growth is strongly affected	N
(dd) Only recently fully developed or lower leaves are slightly chlorotic. Some old leaves are interveinal chlorotic	Mg
(cc) Interveinal chlorosis on young leaves. Plants has increased root hairs on young lateral roots	Fe
(bb) The dominant symptom is necrotic leaf	
(c) Marginal necrosis on middle and basal blade of young leaves. Roots are short, brown, thickened and fail to elongate	Ca
(cc) Marginal necrosis on distal blade of young leaves, sometimes leaving a blunt end. Crinkled petioles. Main roots elongate, with many short lateral roots	B

similar to *Ficus benjamina* (Lang et al., 1990) and other plants which increase root hair number when placed under Fe deficiency stress (Brown, 1972; Lang and Reed, 1987). This growth response facilitates Fe uptake through increased root surface area and transfer cell formation, which is associated with the increased capacity to reduce Fe^{3+} in the epidermis (Romheld and Marschner, 1981).

In contrast, the ratio of shoot–root dry weight for *Spathiphyllum* was increased by deficiencies in nutrients of low mobility in the phloem, e.g. −Ca or −B plants, which had thicker leaves. This increase in accumulation of carbohydrate in leaves has also been reported for other plants (Gossett et al., 1977; van de Venter and Currier, 1977). Our results are consistent with the physiological mechanisms proposed by Marschner et al. (1996) whereby photosynthate partitioning is markedly dependent on cycling of mineral nutrients through source leaves and deficiencies of these mineral nutrients disrupts the export of photosynthates.

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