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# Visual Nutrient Deficiency Symptoms in *Caladium* ×*hortulanum* Birdsey

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*Abstract.* **Visual symptoms of N, P, K, Ca, Mg, Mn, Fe and B deficiencies were induced in *Caladium* ×*hortulanum* Birdsey 'Candidum'. Characteristic symptoms were photographed and described and a key summarizing these symptoms follows:**

**a. Chlorosis or necrosis not expressed;**
**b. Petioles brittle and/or leaves orbicular ..... B**
**bb. Plants grow slowly, but have no other symptoms. ..... P**
**bbb. Rust colored spots on underside of leaf near petiole, spots may become "windows" (only the cuticle and epidermal layer remain) ..... Ca**
**aa. Chlorosis and/or necrosis expressed;**
**b. Chlorosis primary symptom.**
**c. Interveinal and veinal chlorosis**
**d. Chlorosis evident as leaves unfurl ..... Mn**
**dd. Chlorosis not evident as leaves unfurl, older leaf blades and veins may turn bright yellow as they abscise ..... N**
**cc. Interveinal chlorosis ..... Fe**
**bb. Both chlorosis and necrosis expressed.**
**c. Interveinal chlorosis developing into necrotic spots, leaves turn bright yellow (except basal veins remain green) as they abscise ..... Mg**
**cc. Necrotic specks (@ 1 mm) near veins, general chlorosis ..... Mn**
**bbb. Necrosis primary symptom.**
**c. Necrotic lesions (2–5 cm) on leaf apex and distal margin ..... K**
**cc. Marginal necrosis.**
**d. Necrosis spreads toward the center of the leaf, margins dry but the leaf blade around petiole remains intact ..... K**
**dd. Interveinal rust colored, blotchy areas. ..... Ca**

Caladium is an important and valuable crop in the ornamental industry as a landscape plant, bedding plant, a florist pot crop and for the retail sale and wholesale production of tubers. Even though caladiums are widely used in the various ornamental industries, little information is available on their nutritional requirements. General fertilization recommendations for tuber production (4) and pot-plant production (1, 5) have been reported, but these have been concerned primarily with rates of N, P, and K.

Nutrient deficiency symptoms have been described for a number of ornamentals (3) and other crops (9), but not for a caladiums. Visual expression of deficiency symptoms vary and are often unique for different species. For example, *Philodendron scandens* subsp. *oxycardium* and *Epipremnum aureum*, also Aroids, express Ca deficiency symptoms on basal (most mature) leaves rather than on new growth as is common in most other crops (2). Characterization of caladium deficiency symptoms could aid in diagnosing nutrient disorders and distinguishing nutrient imbalances from other disorders caused by pathogens, chemical damage, or other stresses. Objectives of this study were to induce and describe visual deficiency symptoms of N, P, K, Ca, Mg, Fe, Mg, and B in caladiums.

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## Materials and Methods

Tissue culture explants at the 2 leaf stage were established in 10-cm plastic pots with bottom drainage holes. 'Candidum' was used because it is most commonly produced (10) and used in all segments of the industry. Sand washed in a 10% HCl and rinsed in distilled water was used as the medium. A nylon capillary mat disk (0.6 cm thick and 8 cm diameter) was placed in the bottom of each pot to prevent loss of sand from drainage holes. Pots were placed on 1 ml plastic (10 × 10 cm) to eliminate the potential for roots to obtain nutrients from the bench. Nutrient solutions were formulated to eliminate one of the test nutrients, without changing the concentration of other test nutrients, by altering only Na and Cl within safe limits (Table 1). Zn (6.7 mg/l $ZnSO_4 \cdot 7H_2O$), Cu (3.6 mg/l $CuSO_4 \cdot 5H_2O$), and Mo (0.2 mg $Na_2MoO_4 \cdot 2H_2O$) were also added to each solution. Nutrient solutions were applied in 50 ml aliquots once a week for 6 weeks and then twice a week for the remainder of the test. Once a week the pots were leached with 100 ml of distilled water to prevent imbalances in the medium solution from concentration of carrier or test nutrients, or from total soluble salts. Plants were watered with distilled water as needed to saturate the sand with little or no leaching.

The growing environment was a fan-and-pad cooled glasshouse with temperatures normally ranging from 20°C night to 30°C day. Shade was provided by exterior paint and ranged from 50% winter to 80% summer (22–54 klx light within the glasshouse). Preliminary studies to determine adequate nutrient levels for growth of check plants revealed that plants in the −N, −P, −K, −Mg, and −Mn treatments would require the

Table 1. Nutrient formulations and rates used to induce visible deficiency symptoms in *Caladium* × *hortulanum* 'Candidum'.

| Nutrient formulation | Rate mg/l | Treatment[z] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Check | −N | −P | −K | −Ca | −Mg | −Fe | −Mn | −B |
| $NH_4NO_3$ | 840 | + | − | + | + | + | + | + | + | + |
| $NaNO_3$ | 710 | − | − | − | + | − | − | − | − | − |
| $KNO_3$ | 840 | + | − | + | − | + | + | + | + | + |
| KCl | 310 | − | + | − | − | − | − | − | − | − |
| $K_2SO_4$ | 360 | − | + | − | − | − | − | − | − | − |
| $NaH_2PO_4$ | 260 | + | + | − | + | + | + | + | + | + |
| $CaCl_2 \cdot 2H_2O$ | 480 | + | + | + | + | − | + | + | + | + |
| $MgSO_4 \cdot 7H_2O$ | 370 | + | + | + | + | + | − | + | + | + |
| Fe 330[y] | 38 | + | + | + | + | + | + | − | + | + |
| $MnSO_4 \cdot H_2O$ | 6 | + | + | + | + | + | + | + | − | + |
| $H_3BO_3$ | 5 | + | + | + | + | + | + | + | + | − |

[z]Nutrient included (+) or nutrient omitted (−) in treatment solution.
[y]Sequestrine 330 iron chelate.

complete nutrient solution be applied for the first 6 weeks after establishment (Feb.–15 Mar.). Symptoms were expressed so quickly in these plants that growth was inhibited before enough leaves were produced to sample for tissue analyses. Plants in the other treatments were fertilized with −Ca, −Fe, or −B solutions from February until termination of the experiment in August.

Preliminary studies also served to determine when samples could be taken because these plants were allowed to deteriorate until little growth or death occurred. The full range of symptoms was thus discerned, and photographs and tissue samples were taken in the present test when these symptoms were expressed, but before the plants deteriorated to an extent that too few leaves would be available for sampling. Tissue samples included all above ground petioles and leaf blades of unfurled leaves on the plant. N was determined by a modified Kjeldahl procedure (8); P colorimetrically (7); B by the carmine-colorimetric method (6); Mg by thiazole yellow-colorimetric method (11); Ca and K by flame spectrophotometry; and Fe, Mn, Zn, and Cu by atomic absorption spectrophotometry.

Tissue analyses helped ascertain that the symptoms expressed were due to imbalances or deficiencies of the nutrient in question, and were not to establish critical minimum levels for these elements. Treatments were replicated 5 times in a completely randomized design, and 2 plants comprised the experimental unit. Means of foliar nutrient content were separated by Dunnett's test (0.05 level) for comparison of means with a check.

## Results

Leaf blades on check plants ranged in color from entirely dark green to white with dark green veins. Young plants always had green leaves until week 10–12, when white patterns began to develop on new leaves. Plants with greater than 15 leaves and established for more than 12 weeks had leaves of degrees of green and white (check plant, Fig. 1b). Some deficiency symptoms were more readily discernable on entirely green leaves, whereas other deficiency symptoms were clearly displayed on variegated (predominantly white) leaves. The following photographs and discussion of nutrient deficiency symptoms characterize expression on both dark green (DG) and predominantly white (PW) leaves.

*Nitrogen*. DG leaves became uniformly chlorotic, including veins, while PW leaves developed chlorotic margins and veins. Leaves were constantly dropping and chlorotic areas rapidly turned yellow as leaves abscised (Fig. 1a). New leaves were similar to check plants as they unfurled and then became chlorotic. These leaves were always smaller than previous ones, resulting in rapid deterioration in plant size and quality. Foliar N content from samples taken when the first chlorotic leaves abscised (4–5 weeks −N) was 2.0%.

*Phosphorus*. Plants grew slowly but no other visible deficiency symptoms were observed on either DG or PW leaves. Thus plants were smaller than check plants, but unless a plant of similar age was present, foliar deficiency symptoms could not be discerned. Foliar P content from samples taken 9 weeks after P was withheld (Fig. 1b) was 0.10%.

*Potassium*. DG leaves developed a marginal chlorosis followed by interveinal chlorosis with marginal necrotic lesions (often 2–5 cm wedge or semicircular shape), usually on the leaf apex or distal margin. Margins on PW leaves became light brown or tan along the entire leaf margin and eventually the tissue dried to a papery condition. The final appearance was that of leaf scorch with shriveled margins and only the area close to the petiole was intact (Fig. 1c). Foliar K content from samples taken when plants had several leaves expressing severe symptoms (7–8 weeks −K) was 1.18%.

*Calcium*. Two distinct types of symptoms were expressed on Ca deficient plants. Reddish brown spots occurred on lower leaf surfaces near the attached petioles. These developed into necrotic spots on DG leaves. On PW leaves, these areas became transparent and gave a window-like appearance (Fig. 1f) leaving only the cuticle and epidermis before further deterioration caused holes in the leaf. The other type of symptom was a marginal necrosis and blotchy interveinal rust coloration (Fig. 1e). Foliar Ca content from plants taken with both types of symptoms (20–22 weeks −Ca) was 0.29%.

*Magnesium*. Initial symptoms of interveinal chlorosis were most easily observed on DG leaves. However, necrotic spots developed in interveinal and some marginal areas in both DG and PW leaves that often left holes in the leaf as the dead tissue deteriorated (Fig. 2h). Leaves turned bright yellow, usually over a 2-day period, leaving only the lower or basal midrib green as the leaf abscised (Fig. 2g). New leaves showed no visible signs of deficiency and characteristically emerged as older leaves turned yellow. Foliar Mg content from samples taken when at least one leaf was yellow (6–8 weeks −Mg) was 0.08%.

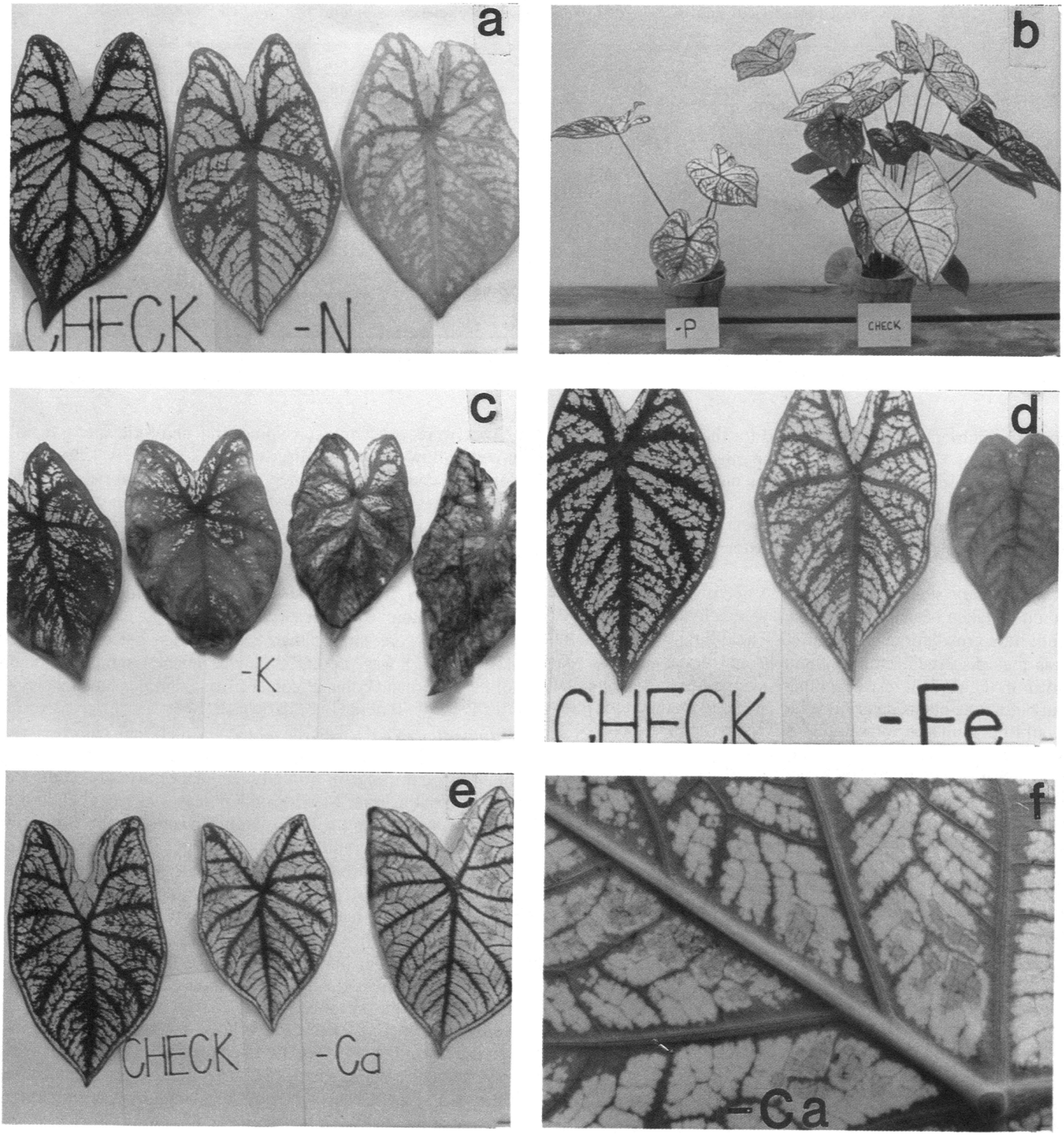


Fig. 1. Characteristic symptoms of 8 induced nutrient deficiencies of *Caladium* ×*hortulanum* 'Candidum': a) −N; b) −P; c) −K; d) −Fe; e–f) −Ca.

*Iron*. Veins remained dark green during initial stages while interveinal areas became chlorotic (Fig. 1d). Early diagnosis on PW leaves was difficult, since only the margins and small veins turned a light green. Even the main larger veins became light green with further development of symptoms, and comparison with check leaves revealed significant loss of green pigment. Foliar Fe content (20 weeks −Fe) was 53.6 ppm.

*Manganese*. Initial symptoms were expressed as a general chlorosis but with a more yellow-green appearance (a pale olive green) than in N deficient plants. Once symptoms were expressed on old leaves, new leaves were observed to be smaller and light green as they unfurled (Fig. 2i). Small necrotic specks (usually 1 mm or less in diameter) developed over the entire leaf blade but were primarily located along main veins (Fig. 2j). The necrotic specks became more prevalent as the plants grew and soon were observed on leaves as they unfurled. Foliar Mn content from samples taken when necrotic specks were prevalent on several leaves (9–10 weeks −Mn) was 5.8 ppm.

*Boron*. Plants appeared to grow normally with no symptoms for 14–16 weeks. Petioles then were observed to break just from

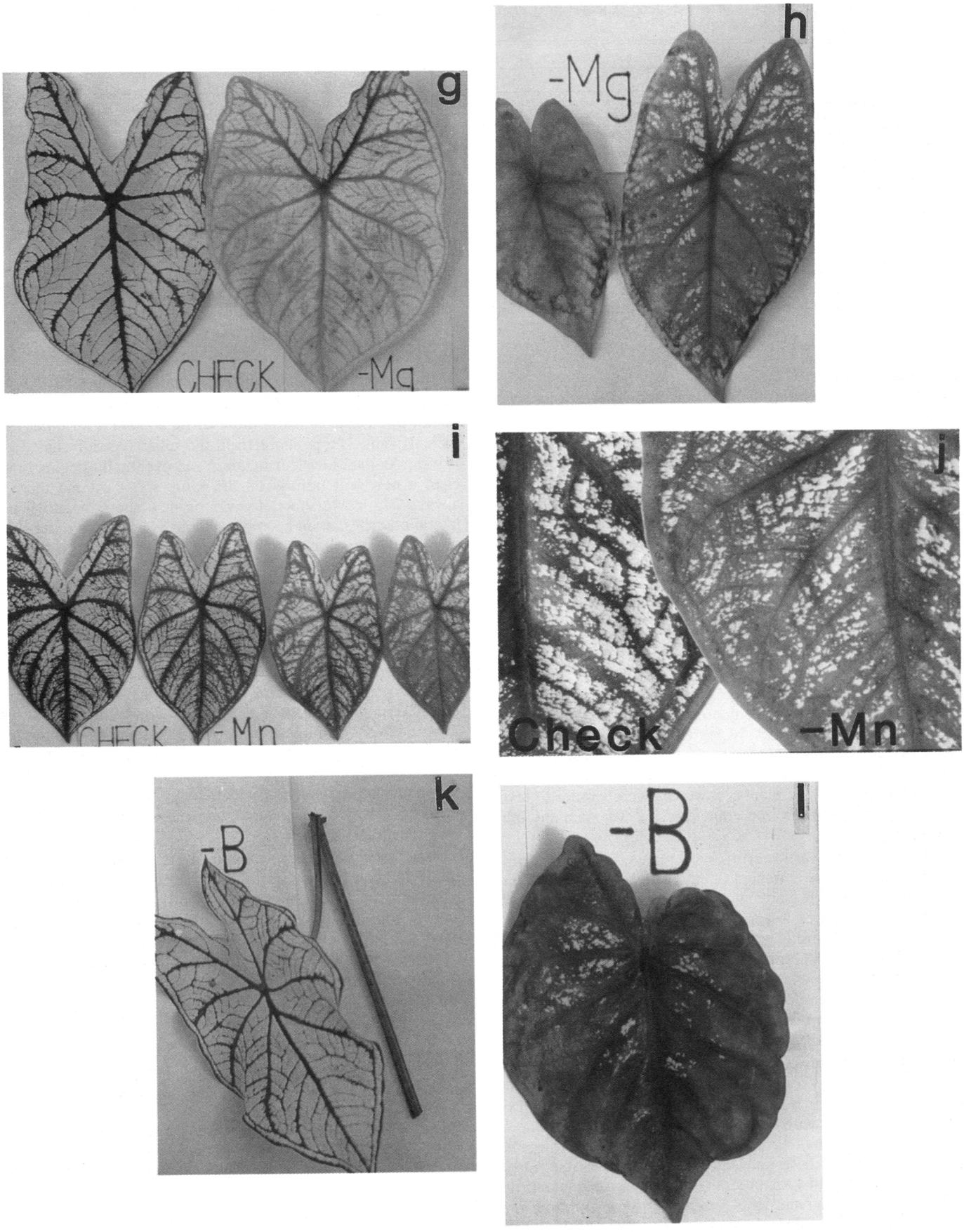


Fig. 2. Characteristic symptoms of 8 induced nutrient deficiencies of *Caladium* ×*hortulanum* 'Candidum': g–h) −Mg; i–j) −Mn; k–l) −B.

Table 2. Foliar nutrient content of leaves of *Caladium* ×*hortulanum* 'Candidum' sampled when visible nutrient deficiencies were expressed.

| Treatment | Foliar nutrient content | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | % | | | | | ppm | | | | |
| | N | P | K | Ca | Mg | Fe | Mn | Zn | Cu | B |
| Check | 2.40 | 0.21 | 2.64 | 0.55 | 0.16 | 69.0 | 20.1 | 38.4 | 4.0 | 38.7 |
| −N | 2.00* | 0.44* | 4.20* | 0.57* | 0.14 | 67.1 | 24.4 | 57.0 | 3.9 | 47.8* |
| −P | 2.48 | 0.10* | 2.92 | 0.93* | 0.14 | 64.0 | 15.2 | 41.0 | 4.1 | 42.8 |
| −K | 2.72* | 0.41* | 1.18* | 0.82* | 0.21* | 61.3 | 24.7 | 32.4 | 3.6 | 39.1 |
| −Ca | 2.38 | 0.27* | 2.92 | 0.29* | 0.14 | 58.8 | 20.7 | 48.9 | 2.8* | 42.5 |
| −Mg | 2.76* | 0.33* | 3.56* | 0.70* | 0.08* | 69.2 | 24.6 | 48.3 | 4.3 | 41.6 |
| −Fe | 2.52 | 0.31* | 3.30* | 0.77* | 0.13 | 53.6 | 79.1* | 35.1 | 4.5 | 41.5 |
| −Mn | 2.34 | 0.25 | 2.40 | 0.89* | 0.14 | 72.0 | 5.8* | 22.0 | 3.4 | 33.1 |
| −B | 2.28 | 0.27* | 3.16* | 0.59* | 0.17 | 63.5 | 21.9 | 44.5 | 3.7 | 22.9* |

*Values in columns significantly different from the check treatment by Dunnett's test, 5% level.

the weight of the leaf blade, but the break was only partial and the leaf blade was still attached (Fig. 2k). The petioles would form callus tissue at the break and were apparently able to function even though partially broken, since the leaf blades remained without symptoms. Further examination revealed that the petioles were brittle and were easily broken with normal handling. Another symptom developed after the plants were sampled for foliar B content. New leaves that emerged were distorted, becoming orbicular, thickened, and without a white color pattern (Fig. 2l). This was the only time the lack of white color was not attributed to the age of the plant as regrowth of plants from other treatments was similar to presampling. Foliar B content (14–16 weeks −B) was 22.9 ppm.

## Discussion

Tissue analyses indicated significant decreases in foliar content of withheld nutrients compared to levels in check plants, except for −Fe treatments. Apparently, tissue samples were taken before the foliar content of Fe was reduced in enough leaves on the −Fe plants to show a significant plant decrease. Other nutrients in these plants, however, were similar to levels in check plants, and the iron content was lower than any other treatment.

Foliar B content was lower in −Mn plants, but was 1.4 times greater than in the −B treated plants. The B deficiency symptoms observed in −B plants were not observed in −Mn plants. Foliar Cu content was lower in −Ca treatments than in check plants. However, further studies (unpublished data) to induce Cu deficiencies have shown levels as low as 1.5 ppm Cu before any symptoms were observed.

Increased foliar content of nutrients when a test nutrient was withheld were common. Results indicated that rates of macroelements used were low, since plants in treatments which resulted in loss of leaves and reduced growth (and thus the same quality of nutrients was available for less plant mass) typically had increases in foliar N, P, and/or K. Furthermore, competitive elements increased with removal of antagonists (increases in foliar Mn content in −Fe treatments, for example). Increases in foliar content of these nutrients, however, were not considered undesirable or in a toxicity range for other ornamentals (3). The balance of foliar nutrients was also affected, which may actually have intensified deficiency symptoms in some instances. In light of all these factors, the tissue analyses appeared to verify that the visual symptoms expressed were due to deficiencies of the specific nutrient withheld.

Since caladiums are a tuberous crop and do not have aboveground stems, the use of leaf position or age to aid in diagnosis of nutrient deficiencies is more difficult than with other ornamental plants. Each shoot from the tuber typically has 2 or 3 leaves. As the older leaf matures and eventually begins to abscise, a new leaf unfurls on the same shoot so that there are always 2–3 leaves/shoot. Leaves on new shoots, equivalent to lateral branches, soon become as large as leaves on older shoots or, when tubers are planted, many shoots emerge at the same time with similar leaf size.

Observations of new leaves as they unfurl and of color changes in leaves as they abscise serve similar purposes as leaf position and age of plants with stems above ground. For example, initial deficiency symptoms of N and Mn were similar and expressed as a general chlorosis. Nitrogen deficiency could be distinguished by noting the color of leaves which had just unfurled. These were not chlorotic in −N plants while −Mn leaves were chlorotic as they unfurled. Initial −Mg symptoms of interveinal chlorosis were similar to those of −Fe leaves. −Fe plants had interveinal chlorosis on new leaves, especially on new leaves on small lateral shoots. Mg deficiency was expressed on the older of 2 leaves on a shoot and these leaves turned bright yellow as they abscised.

Some visual deficiency symptoms were similar at certain stages of development, but each of the nutrients studied caused unique symptoms that could be used to identify the nutritional disorders. A key was developed (see abstract) that can be used as a diagnostic aid in addition to the photographs (Fig. 1 and 2) depicting symptoms. Foliar nutrient content of plants with visual symptoms (Table 2) can be used to confirm suspected deficiencies.

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# Response Surface Analysis of Flowering in Chrysanthemum 'Bright Golden Anne'

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*Additional index words.* central composite design, day temperature, modeling, night temperature, photosynthetic photon flux, shoot length, *Chrysanthemum morifolium*

***Abstract.*** ***Chrysanthemum morifolium*** **Ramat. 'Bright Golden Anne' plants were grown under 15 combinations of photosynthetic photon flux (PPF), day temperature, and night temperature in a central composite design. Time to flower was a function of both irradiance and the interaction between day and night temperature. The surface response to temperature was bowl shaped with delayed development as temperatures were either increased or decreased from the optimum combinations. High temperature delay was compensated for in part by increased PPF. Shoot length increased linearly as day temperature increased; final shoot length first decreased, then increased with increasing night temperature. The response surface appeared as a rising valley with the longest shoot lengths at high day temperatures. Total flower area per plant increased as PPF increased or as night temperature decreased. For any PPF and night temperature, maximum flower area occurred near 20°C. At a constant PPF, the response surface appeared as a rising ridge with maximum flower area at low night temperature.**

Although the influence of environmental factors on growth and development in many greenhouse crops has been studied extensively, few experiments have addressed several environmental factors simultaneously (15). Simultaneous evaluation of several environmental factors is important when determining the functional relationship between the environment and plant response. Commercially available computer systems for controlling greenhouse climate allow environmental control to be interactive. For example, temperature and $CO_2$ concentration can be controlled based on photosynthetic photon flux (PPF) in the greenhouse (16). To use this type of computer control system, however, one must know the functional relationship between environmental factors and subsequent growth and development of a particular plant.

Both time to flower and plant quality are primary factors of concern in commercial production of chrysanthemums. Whereas an extensive body of literature exists on *Chrysanthemum morifolium* Ramat., we are unaware of any information describing the functional relationships between chrysanthemum growth and the environmental factors of day temperature (DT), night temperature (NT), and PPF. This paper addresses this problem by describing such functions.

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## Materials and Methods

Rooted cuttings of 'Bright Golden Anne' were planted individually in 10 cm pots and placed in growth chambers (Rheem/Sherer, Ashville, N.C.) under a PPF of 325 μmol $s^{-1}m^{-2}$ (16 hr $d^{-1}$) at a constant temperature of 20°C for 7 days. On the 7th day after potting, a short day (SD) photoperiod was initiated (10 hr light, 14 hr dark), and plants were pinched to 6 nodes and placed under appropriate treatment combinations (Table 1) with the DT and NT paralleling the photoperiod and nyctoperiod. Daminozide was applied as a foliar spray to run off 7 and 14 days after the start of SD at 2500 mg $l^{-1}$ (12). Ten days after the start of SD, the number of lateral shoots was reduced to 3/plant. Lateral flower buds were removed when they reached a stage where removal would not damage the apical flower bud.

Shelves were lowered as necessary to maintain the desired PPF at the canopy top; PPF was measured with a LI-COR LI-185B Meter and LI-190SB Quantum sensor. The PPF was provided by cool-white fluorescent lamps (GE, F48T12, CW 1500) and incandescent lamps (GE, 40 W, 120 V) with an input wattage of 80:20, respectively. Average daily temperature fluctuated ± 1°C from the setpoint and was monitered by recording water temperature in a closed beaker. PPF varied ± 10% over the canopy.

Plants were grown in a peat-lite medium (VSP, Michigan Peat Co.) and were automatically irrigated 1–3 times daily, depending on plant size and environmental conditions, using an individual emitter in each pot. The irrigation was controlled by time clocks; plants in all treatments were irrigated at the beginning of the light period with additional irrigations 4 and 7 hr later if required to prevent wilting. Nutrition consisted of 200 mg $l^{-1}$ N and K at every watering provided by ammonium nitrate, potassium nitrate and nitric acid (used to adjust water pH to