Hibiscus Leaf Tissue Nutrient Sufficiency Ranges by Chronological Age

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Abstract. Perennial hibiscus (Hibiscus sp.) are popular summer-flowering plants that are grown in greenhouses or nurseries, where growers must optimize production inputs such as fertility to maximize plant growth and produce high-quality flowering crops. The objective of this study was to determine the optimum fertilizer concentrations, identify leaf tissue nutrient sufficiency ranges by chronological age, and to expand leaf tissue nutrient standards of Hibiscus hybrid L. (hibiscus) grown in soilless substrates during container production. Two cultivars of hibiscus (H. hybrid L. ‘Mocha Moon’ and ‘Starry Starry Night’) were grown under six constant liquid fertilizer concentrations [50, 100, 200, 300, or 400 mg L−1 N] after an 8-week crop cycle. Recently, mature leaf tissue samples were collected and analyzed for elemental content of 12 nutrients at 2, 4, 6, and 8 weeks after transplant (WAT) from plants fertilized with 100–300 mg L−1 N. An overall trend of increasing sufficient tissue concentration over time was observed for total N, phosphorus (P), calcium (Ca), sulfur (S), zinc (Zn), copper (Cu), and boron (B), whereas a decreasing trend was observed for potassium (K), iron (Fe), manganese (Mn), and aluminum (Al). For instance, at 2 WAT, total N ranged from 3.1% to 5.1% N and a decreasing trend was observed for potassium (K), iron (Fe), manganese (Mn), and phosphorus (P), calcium (Ca), sulfur (S), zinc (Zn), copper (Cu), and boron (B), whereas a decreasing trend was observed for potassium (K), iron (Fe), manganese (Mn), and aluminum (Al). For instance, at 2 WAT, total N ranged from 3.1% to 5.1% N and a decreasing trend was observed for potassium (K), iron (Fe), manganese (Mn), and phosphorus (P), calcium (Ca), sulfur (S), zinc (Zn), copper (Cu), and boron (B), whereas a decreasing trend was observed for potassium (K), iron (Fe), manganese (Mn), and aluminum (Al). For instance, at 2 WAT, total N ranged from 3.1% to 5.1% N and a decreasing trend was observed for potassium (K), iron (Fe), manganese (Mn), and aluminum (Al).
leaves nutritional standards are limited to only 73 herbaceous perennial genera grown in containers (Bryson and Mills, 2014), and to date, herbaceous perennial leaf tissue nutritional sufficiency ranges by chronological age have not been reported. Therefore, the objectives of this study were to determine the optimum fertilizer concentrations, identify leaf tissue nutrient sufficiency ranges by chronological age, and to expand leaf tissue nutrient standards of H. hybrid L. (hibiscus) grown in soilless substrates during container production. Hibiscus served as a model crop because to date, no leaf tissue concentration limits are published for H. hybrid, but only survey measurements taken from greenhouse- and nursery-grown hibiscus species are reported by Bryson and Mills (2014).

Materials and Methods

Plant material and culture. On 8 Apr. 2017, rooted 72-cell plug trays (30.7-mL individual cell volume) of two cultivars of hibiscus (H. hybrid L. ‘Mocha Moon’ and ‘Starry Starry Night’) were received from a commercial supplier (Walters Gardens, Inc., Zeeland, MI). Young plants of each cultivar with similar heights, stem calipers, and node numbers were selected and transplanted one plant per 15.6-cm (1.9-L) diameter container (Landmark Plastic Corp., Akron, OH). Containers were filled with premoistened commercial soilless peat-based substrate, comprised (by volume) 65% peat, 20% perlite, and 15% vermiculite, amended with dolomitic limestone, wetting agent, and a starter nutrient and 15% vermiculite, amended with dolomitic lime and wetting agent, and a starter nutrient charge with gypsum (Fafard 2; Sun Gro Horticulture, Agawam, MA). Plants were irrigated to container capacity with water supplemented with 35% sulfuric acid (Auto-Irrig). Irrigation lines were extracted 1 h after irrigation using the pour-through method (Wright, 1986) and analyzed for pH and electrical conductivity (EC) using a HI 9813-6 portable meter (Hanna Instruments, Woonsocket, RI) mounted every 15 min by a data logger (WatchDog Model 2475 Plant Growth Station; Spectrum Technologies, Inc., Aurora, IL). Line quantum sensors (SQ-316-SS; Apogee Instruments, Inc., Logan, UT) mounted 60 cm above the benchtop measured PPFD every 30 s and the average of each sensor was determined as the lower optimal fertilizer concentration per replicate. Within each block, no significant differences occurred among replicates per cultivar; therefore, data were pooled. The effects of fertilizer concentrations per cultivar were analyzed using SAS (version 9.2; SAS Institute, Cary, NC) general linear model procedure (PROC GLM) for analysis of variance, and means were separated between fertilizer concentrations using Tukey’s honestly significant differences. For each cultivar, regression analyses of foliar nutrient concentrations within WAT with fertilizer concentration as the independent variable were performed using SAS regression procedure (PROC REG). Regression models, equations, and adjusted-R² are provided in Table 1. For all analyses, a P ≤ 0.05 was used to determine significant effects.

Results and Discussion

Sufficiency range. At 8 WAT, increasing fertilizer concentrations significantly influenced plant height, diameter, GI, PSC, and TDM of both H. hybrid cultivars (Table 2; Figs. 1 and 2). Plant growth was analyzed to determine lowest and upper optimal nutritional limits. The Hibiscus plants fertilized with 50 and 75 mg L⁻¹ N resulted in similar and significantly smaller plant height, diameter, GI, PSC, and TDM than those fertilized with 100–400 mg L⁻¹ N. Therefore, 100 mg L⁻¹ N was determined as the lower
nutritional limit, and the plants fertilized with 50 and 75 mg L\(^{-1}\) N were excluded from further statistical analyses.

Plant growth of both Hibiscus cultivars was statistically similar among ascending fertilizer concentrations from 100 to 400 mg L\(^{-1}\) N (Table 2). However, TDM of ‘Mocha Moon’ and ‘Starry Starry Night’ at increasing fertilizer concentrations of 300–400 mg L\(^{-1}\) N decreased by 12.5% (4.6 g) and 11.8% (4.2 g), respectively. Smaller TDM is most likely attributed to sensitivity of an elevated substrate EC (Scoggins, 2005). For instance, average substrate EC extracted from ‘Mocha Moon’ and ‘Starry Starry Night’ grown at 400 mg L\(^{-1}\) N were 4.22 and 4.50 mS cm\(^{-1}\), respectively, and they were 30% to 929% (0.97–3.81 mS cm\(^{-1}\)) and 32% to 1084% (1.08–4.12 mS cm\(^{-1}\)) higher than the average substrate EC values determined for plants fertilized at 50–300 mg L\(^{-1}\) N, respectively. Furthermore, drawing from experience of common grower practices, fertilizer costs, and possible environmental impacts of excessive fertilization, it was concluded that plants fertilized with ≥300 mg L\(^{-1}\) N would be entering a situation of luxury nutrient consumption and the additional fertilizer was not beneficial to plant quality (Jeong et al., 2009; Krug et al., 2010; Papineau and Krug, 2014). When TDM and substrate EC data are taken together, 300 mg L\(^{-1}\) N was determined as the upper nutritional range limit, and plants fertilized with 400 mg L\(^{-1}\) N were excluded from further statistical analyses. Thus, the optimal sufficiency range for both Hibiscus cultivars in this study is 100–300 mg L\(^{-1}\) N.

### Table 1. Regression models, equation, and adjusted-\(R^2\) for sufficiency ranges of macronutrients [nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S)] and micronutrients [iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), and aluminum (Al)] over an 8-week crop cycle in two hibiscus (Hibiscus hybrid L. ‘Mocha Moon’ and ‘Starry Starry Night’) cultivars grown at six fertilizer concentrations, harvested at 8 weeks after transplant.

| Elemental nutrients | Unit of measure | N concn (mg L\(^{-1}\) N) | Figure | Model\(^a\) | Equation\(^b\) | Adjusted-\(R^2\) |
|---------------------|-----------------|--------------------------|--------|------------|----------------|----------------|
| **Macronutrients**  |                 |                          |        |            |                |                |
| Total N             | %               | 100                      | 3 A    | Q**        | \(y = 0.8251 + 1.2213x - 0.0971x^2\) | 0.5447 |
|                     |                 | 300                      | 3 B    | Q***       | \(y = 4.3654 + 0.4386x - 0.0489x^2\) | 0.5008 |
| P                   |                 | 100                      | 3 C    | Q***       | \(y = 2.4944 + 0.4467x - 0.0544x^2\) | 0.5077 |
| K                   |                 | 300                      | L***   | Q***       | \(y = 4.6408 - 0.1730x\) | 0.6661 |
| Ca                  |                 | 100                      | 3 D    | Q***       | \(y = 0.3975 + 0.7573x - 0.0738x^2\) | 0.9414 |
| Mg                  |                 | 300                      | 3 E    | Q***       | \(y = 0.9925 + 0.6698x - 0.0702x^2\) | 0.7254 |
| S                   |                 | 300                      | 3 F    | Q***       | \(y = 0.0050 - 0.2151x - 0.0209x^2\) | 0.9669 |
| **Micronutrients**  | mg L\(^{-1}\)   | 100                      | 4 A    | Q**        | \(y = 38.2796 + 22.9996x - 2.0971x^2\) | 0.2338 |
| Fe                  |                 | 300                      | 4 B    | Q***       | \(y = 54.0208 + 31.3700x - 3.4600x^2\) | 0.9726 |
| Mn                  |                 | 300                      | 4 C    | Q***       | \(y = 131.0333 - 32.5691x - 3.6194x^2\) | 0.3238 |
| Zn                  |                 | 300                      | 4 D    | L*         | \(y = 3.0059 - 0.1243x\) | 0.7607 |
| Cu                  |                 | 300                      | 4 E    | Q**        | \(y = 22.5538 + 2.6050x - 0.2305x^2\) | 0.4968 |
| Al                  |                 | 300                      | 4 F    | Q***       | \(y = 72.9437 - 19.0650x + 1.0687x^2\) | 0.8166 |

\(^a\)Linear (L) or quadratic (Q) response for N concentration.

\(^b\)\(L = (v = ax + b)\) or \(Q = (v = ax^2 + bx + c)\) equations for concentration.

\(^c\)\(*\), **, ***Nonsignificant or significant at \(P \leq 0.05, 0.01, \) or 0.001.

### Table 2. Average plant height, diameter, growth indices (GI), primary shoot caliper (PSC), and total plant dry mass (TDM) of two hibiscus (Hibiscus hybrid L. ‘Mocha Moon’ and ‘Starry Starry Night’) cultivars grown at six fertilizer concentrations, harvested at 8 weeks after transplant.

| Nitrogen (N) concn (mg L\(^{-1}\) N) | Hr\(^a\) (cm) | Diam\(^a\) (cm) | GI\(^a\) (cm) | PSC\(^a\) (mm) | TDM\(^a\) (g) |
|----------------------------------|--------------|----------------|-------------|----------------|-------------|
| **Mocha Moon**                  |              |                |            |                |             |
| 50                              | 41.9 b\(^d\) | 43.0 b         | 74.3 c      | 13.0 c         | 22.1 c      |
| 75                              | 54.6 ab      | 45.9 ab        | 88.9 bc     | 15.4 bc        | 27.8 bc     |
| 100                             | 61.0 a       | 47.1 a         | 96.9 ab     | 18.3 ab        | 31.5 ab     |
| 200                             | 67.3 a       | 52.6 a         | 106.6 a     | 18.9 a         | 34.6 a      |
| 300                             | 71.1 a       | 51.3 a         | 109.6 a     | 18.2 ab        | 36.8 a      |
| 400                             | 70.4 a       | 51.9 a         | 108.9 a     | 18.1 ab        | 32.2 b      |
| Significance                     | ***          | **             | ***         | ***            | ***         |
| **Starry Starry Night**          |              |                |            |                |             |
| 50                              | 29.9 d       | 33.1 c         | 54.6 c      | 10.5 d         | 16.4 c      |
| 75                              | 43.6 d       | 39.0 abc       | 72.8 b      | 14.8 c         | 22.5 b      |
| 100                             | 59.5 a       | 45.7 a         | 85.7 a      | 18.9 a         | 26.8 ab     |
| 200                             | 61.8 a       | 46.1 a         | 97.4 a      | 19.3 a         | 32.3 a      |
| 300                             | 63.8 a       | 42.7 abc       | 96.1 a      | 17.3 b         | 35.6 a      |
| 400                             | 63.4 a       | 36.2 c         | 90.4 a      | 17.5 b         | 31.4 b      |
| Significance                     | ***          | **             | ***         | ***            | ***         |

\(^d\)Plant height measured from the substrate surface to the apical meristem.

\(^a\)Plant diameter determined by measuring the widest dimension and the axis perpendicular to the widest dimension and averaged.

\(^b\)GI = (plant height + plant diameter)/2.

\(^c\)PSC determined by measuring below the lowest axillary shoot.

\(^d\)TDM = young plant dry mass + plant dry mass.

\(^e\)Within-column means (\(n = 3\)) followed by different lower-case letters are significantly different by Tukey’s honestly significant differences test at \(P \leq 0.05\).
Sufficiency ranges for both Hibiscus cultivars were used to determine recommend leaf tissue concentrations of 12 elements by chronological age. Similar to Papineau and Krug (2014), lower and upper limits of recommended leaf tissue concentration ranges were defined as the best fit regressions of the pooled data from all Hibiscus plants grown at 100–300 mg L⁻¹ N over an 8-week crop cycle. The nutrient concentrations differed between ‘Mocha Moon’ and ‘Starry Starry Night’, but the means were within the established range for each elemental nutrient. To date, no leaf tissue concentration limits are published for H. hybrid, but survey measurements taken from greenhouse- and nursery-grown Chinese hibiscus (Hibiscus rosa-sinensis L.) and rose of Sharon (Hibiscus syriacus L. ‘Aphrodite’, ‘Blue Bird’, ‘Blushing Bride’, ‘Collie Mullens’, ‘Diana’, ‘Helene’, and ‘Red Heart’) are reported by Bryson and Mills (2014). These tissue concentration ranges will be referred to as the genera Hibiscus.

Nitrogen. Total N (NO₃⁻ and NH₄⁺) concentration of Hibiscus cultivars in this study harvested at 2, 4, 6, and 8 WAT (Table 3; Fig. 3A) were within a narrower sufficiency range than those previously reported (2.50% to 4.56% N; Bryson and Mills, 2014). At all stages of growth, total N tissue concentration was higher in the plants fertilized with 300 mg L⁻¹ N than those fertilized with 100 mg L⁻¹ N (Fig. 3A). At 2 WAT, total N tissue concentration ranged from 3.1% to 5.1% and increased to 5.2% to 5.4% at 6 WAT. These results are consistent with Jeong et al. (2009) which reported increased leaf tissue N concentration of gerbera when fertilized with 100–200 mg L⁻¹ N from transplant until first open flower (2–8 WAT). Total N tissue concentration of Hibiscus decreased to 4.2% to 4.7% at 8 WAT when floral buds were visible. This is similar to Krug et al. (2010) which observed decreased leaf tissue N concentration of flowering zonal geranium ‘Tango Dark Red’ and ‘Rocky Mountain Dark Red’ plants fertilized with 100–300 mg L⁻¹ N at 12 WAT.

Phosphorus. The recommended range for leaf tissue P concentration for the genera Hibiscus is between 0.2% and 1.0% (Bryson and Mills, 2014). Leaf tissue P concentration of the Hibiscus cultivars in this study is consistent with those previously published. The overall lower and upper limit range increased in a quadratic fashion over time (Fig. 3B), and this trend was also observed in gerbera (Jeong et al., 2009). For plants fertilized with 100 mg L⁻¹ N, lower optimal P concentrations were 0.30% to 0.45% P at 2 (young growth) to 8 WAT (visible bud), respectively (Table 3; Fig. 3B). For plants fertilized with 300 mg L⁻¹ N, P concentrations increased from 0.53% to 0.73% P from 2 to 6 WAT, respectively, and then decreased to 0.57% P at visible bud (Table 3; Fig. 3B). At all stages of the crop cycle, P tissue concentration were higher in plants grown at 300 mg L⁻¹ N than 100 mg L⁻¹ N and within a narrower range than recommended published ranges by Bryson and Mills (2014).

Potassium. The recommended range for leaf tissue K concentration for the genera Hibiscus is between 1.21% and 3.35% (Bryson and Mills, 2014). When plants were fertilized with 100 mg L⁻¹ N, a quadratic
Table 3. Sufficiency ranges of 12 elemental nutrients determined at 2 (young growth), 4 (active growth), 6 (mature growth), and 8 (visible bud) weeks after transplant (WAT) for two hibiscus (*Hibiscus hybrid* L. ‘Mocha Moon’ and ‘Starry Starry Night’) cultivars (n = 3) grown with 100–300 mg L⁻¹ nitrogen (N) and recommended leaf tissue for the genera *Hibiscus* as previously published by Bryson and Mills (2014).

| Elemental nutrients | Unit of measure | 2 (Young growth) | 4 (Active growth) | 6 (Mature growth) | 8 (Visible bud) | Bryson and Mills (2014)²
|--------------------|----------------|------------------|------------------|------------------|----------------|----------------------|
| **Macronutrients** |                |                  |                  |                  |                |                      |
| Total N           | %              | 3.08–5.11        | 3.59–5.15        | 5.25–5.42        | 4.20–4.68      | 2.50–4.56           |
| Phosphorus        |                | 0.30–0.53        | 0.44–0.70        | 0.69–0.73        | 0.45–0.57       | 0.20–1.00           |
| Potassium         |                | 3.17–4.08        | 3.43–4.15        | 3.20–3.86        | 3.02–2.59       | 1.21–3.35           |
| Calcium           |                | 1.60–2.01        | 2.30–2.67        | 2.23–2.36        | 1.76–1.90       | 1.00–1.18           |
| Magnesium         |                | 0.66–0.76        | 0.77–0.79        | 0.61–0.81        | 0.43–0.53       | 0.25–1.12           |
| Sulfur            |                | 0.34–0.45        | 0.53–0.65        | 0.52–0.61        | 0.46–0.38       | 0.20–0.50           |
| **Micronutrients**|                |                  |                  |                  |                |                      |
| Iron              | mg L⁻¹         | 79.2–103.5       | 82.9–122.1       | 107.6–119.7      | 75.6–82.9       | 50–200              |
| Manganese         |                | 66.3–82.8        | 21.1–51.4        | 16.2–73.1        | 18.1–99.7       | 40–289              |
| Zinc              |                | 29.0–43.3        | 41.1–67.0        | 61.1–69.5        | 44.7–69.7       | 20–200              |
| Copper            |                | 2.5–3.3          | 3.3–3.8          | 6.7–10.2         | 5.9–10.3        | 6–50                |
| Boron             |                | 27.5–29.8        | 27.5–29.1        | 31.7–34.4        | 28.0–35.6       | 25–114              |
| Aluminum          |                | 39.3–41.8        | 13.9–15.0        | 6.9–8.5          | 9.4–13.7        | 20–100              |

¹Recommended leaf tissue range for the genera *Hibiscus* previously published by Bryson and Mills (2014).
²No previously reported recommended leaf tissue range for the genera *Hibiscus* by Bryson and Mills (2014).

Response was observed where an increase in K concentration occurred between 2 and 4 WAT (young active growth), and decreased over time from 6 to 8 WAT (maturity to visible bud) (Table 3; Fig. 1C). At 300 mg L⁻¹ N, K concentration decreased linearly from 4.08% to 2.59% K at 2–8 WAT, respectively (Table 3; Fig. 3C). However, the upper range limit was 21.7%, 23.8%, and 15.2% higher at 2, 4, and 6 WAT than the limit reported by Bryson and Mills (2014), thus broadening the recommended range of leaf tissue K concentration.

**Calcium.** The recommended range for leaf tissue Ca concentration for the genera *Hibiscus* is between 1.0% and 5.18% (Bryson and Mills, 2014). The previously published Ca concentration range for *Hibiscus* is broader than observed for the cultivars in this study (Table 3). In general, a quadratic response was observed (Fig. 2E). For the lower range limit, tissue Mg concentration increased by 17% from 2 to 4 WAT (young to active growth) and then decreased as the plants matured from 6 to 8 WAT (maturity to visible bud). However, the observed decrease in Ca concentration occurred between 2 and 4 WAT (young growth), and ranged from 79.2 to 103.6, 82.9 to 122.1, and 107.6 to 119.7, respectively, which were greater than the published ranges (Table 3). In general, upper and lower limits followed a quadratic response (Fig. 3D). The measured Ca tissue concentrations were significantly lower at 8 WAT and may be attributed to the antagonist effect of K from the fertilizer source, reduced residual effect of the dolomitic limestone used to adjust substrate pH, or a dilution effect of dry mass and a consistent volume of MgSO₄ applied.

**Sulfur.** The recommended range for leaf tissue S concentration for the genera *Hibiscus* is between 0.2% and 0.5% (Bryson and Mills, 2014). Lower and upper limits for the *Hibiscus* cultivars in this study followed a quadratic response over time (Fig. 3F), and were similar to gerbera (Jeong et al., 2009). The upper limit increased steadily from 0.76% to 0.81% Mg from 2 to 6 WAT (young to maturity) and then decreased at 8 WAT (0.53% Mg). Krug et al. (2010) reported a similar trend for the upper range limit of geranium ‘Rocky Mountain Dark Red’ from 2 to 12 WAT. Although within the recommended range, Mg concentrations were significantly lower at 8 WAT and may be attributed to the antagonist effect of K from the fertilizer source, reduced residual effect of the dolomitic limestone used to adjust substrate pH, or a dilution effect of dry mass and a consistent volume of MgSO₄ applied.

**Iron.** The recommended range for leaf tissue Fe concentration for the genera *Hibiscus* is between 20 and 200 mg L⁻¹ Fe at 2, 4, 6, and 8 WAT, respectively. The observed lower range may likely be attributed to the constant rate of micronutrients supplied at each fertilizer concentration and not related to Fe deficiency which is associated with substrate pH > 6.5 because no deficiency symptoms were observed. Manganese. The recommended range for Mn concentration for the genera *Hibiscus* is between 40 and 289 mg L⁻¹ Mn (Bryson and Mills, 2014). In the present study, Mn concentration decreased quadratically when plants were fertilized with 100 and 300 mg L⁻¹ N, but was higher for plants fertilized with 300 than 100 mg L⁻¹ N (Fig. 4B). Manganese concentrations for plants grown with 100 mg L⁻¹ N declined from 66.3 to 18.1 mg L⁻¹ Mn beginning at 2–8 WAT, respectively (Table 3). These values are lower than those previously published (Bryson and Mills, 2014) and plant tissue would be considered Mn deficient. Although Mn concentrations were narrower than previously published ranges, visual symptomology was not observed in either *Hibiscus* cultivars. Increased substrate pH may attribute to the suppression of Mn uptake on plant Mn uptake and content or the antagonist effect of Fe competing for absorption (Bryson and Mills, 2014). The upper optimal ranges for plants grown with 300 mg L⁻¹ N increased by 20% (16.9 mg L⁻¹ Mn) at 2–8 WAT. Although the Mn concentration were within a narrower range than previously published ranges, the range became broader as the plants matured (Fig. 4B). This is consistent with trends reported for geranium ‘Tango Dark Red’ (Krug et al. 2010), gerbera (Jeong et al., 2009), and osteospermum cultivars (Papineau and Krug, 2014). Zinc. The recommended range for Zn concentration for the genera *Hibiscus* is between 20 and 200 mg L⁻¹ Zn (Bryson and Mills, 2014). Zinc tissue concentrations in the present study were lower and within a narrower range that those previously published for the genera *Hibiscus*. Lower and upper limits followed a quadratic response over time (Fig. 4C), similar to gerbera (Jeong.
et al., 2009) and osteospermum cultivars (Papineau and Krug, 2014). The lower and upper range limits for Zn tissue concentration increased from 29.0 to 61.1 and 43.3 to 69.5 mg·L⁻¹ Zn from 2 and 6 WAT (young to maturity), respectively, and then decreased at 8 WAT (Table 3). Although within the recommended range, lower Zn tissue concentrations observed at 8 WAT may be the result of limited diffusion of available Zn for uptake because of extensive root growth and development. However, uptake earlier in the crop cycle (at 4–6 WAT) was not limited. Furthermore, Bryson and Mills (2014) indicated that high levels of available P and Fe in soils also adversely affects plant uptake of Zn, which may attribute to lower concentrations observed at 8 WAT.

**Copper.** The recommended range for Cu concentration for the genera *Hibiscus* is between 6 and 50 mg·L⁻¹ Cu (Bryson and Mills, 2014). Over time, Cu tissue concentration increased linearly (Fig. 4D). Copper concentrations of plants fertilized with 100–300 mg·L⁻¹ N were 2.5–3.3 and 3.3–3.8 mg·L⁻¹ Cu at 2–4 WAT (Table 3), respectively, and were lower than those previously published for the genera *Hibiscus*. However, Cu deficiency is uncommon in greenhouse production (Jeong et al., 2009) and no deficiency symptoms were observed. Copper deficient plant tissue may be attributed to the dilution effect caused by plant growth following N fertilization (Bryson and Mills, 2014), although average GI of plants fertilized with 100–300 mg·L⁻¹ N at 2 and 4 WAT were 15.7–16.9 and 24.4–29.4 cm, respectively, and not statistically different (data not shown).

**Boron.** The recommended range for B concentration for the genera *Hibiscus* is between 25 and 114 mg·L⁻¹ B (Bryson and Mills, 2014). When plants were fertilized with 100 mg·L⁻¹ N, a quadratic response was observed where a slight increase in B concentration occurred from 2 to 6 WAT (young to maturity), and decreased at 8 WAT (visible bud) (Table 3; Fig. 4E). At 300 mg·L⁻¹ N, B concentration increased linearly from 29.8% to 35.6% mg·L⁻¹ B at 2–8 WAT, respectively (Table 3; Fig. 4E). Boron tissue concentrations in this study provide a narrower range limit than values reported by Bryson and Mills (2014).

**Aluminum.** To date, no recommended range for Al concentration for the genera *Hibiscus* exists over time. The present study establishes an optimal concentration range over time where tissue concentration decreased in a quadratic fashion (Fig. 4F). Aluminum concentrations of plants fertilized with 100–300 mg·L⁻¹ N were 39.3–41.8 mg·L⁻¹ at 2 WAT and decreased to 9.4–13.7 mg·L⁻¹ at 8 WAT (Table 3). Although not an essential element (Bryson and Mills, 2014), Morgan (2000) describes Al as a new beneficial element for plants which may influence root activity for P uptake. Based on these findings and the statement by Morgan (2000), it is postulated that the observed decreasing Al concentrations from 2 to 8 WAT may contribute to increased root activity and thus, increased concentration of P in leaves from 2 to 8 WAT.

**Conclusion**

Collectively, the results from this study establish an optimum fertilizer concentration of 100–300 mg·L⁻¹ N and more precise leaf
Campbell, C.R. 2000. Reference sufficiency ranges for *H. hybrid*. This study expands the general understanding of leaf tissue nutrient sufficiency ranges by chronological age. An overall trend of increasing tissue concentration over time was observed for N, P, Ca, S, Zn, Cu, and B, although a decreasing trend was observed for K, Fe, Mn, and Al. The leaf tissue concentration sufficiency ranges determined in this study are narrower than those reported by Bryson and Mills (2014) and likely because of investigating only two cultivars. Therefore, further experiments including more than two cultivars of *Hibiscus* and other fertilizer sources is warranted. Furthermore, continued research to establish nutrient sufficiency ranges by chronological age of other popular herbaceous perennial species grown in soilless substrates during container production is needed.

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