Fertilizer Concentration Affects Growth and Foliar Elemental Concentration of *Strobilanthes dyerianus*

Erin E. Gamrod¹ and Holly L. Scoggins²

Department of Horticulture, Virginia Tech, Blacksburg, VA 24061-0327

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Abstract. Grown as an annual in most of the United States, *Strobilanthes dyerianus* Mast. has become increasingly popular in summer landscapes partially due to its superior performance in hot and humid conditions. At present, there is no published research on the nutritional requirements of *S. dyerianus*. Our study examined growth and foliar elemental response to different levels of fertilizer. Rooted cuttings were transplanted and grown with 0, 100, 200, 300, and 400 mg·L⁻¹ N from 5N–2.2 P–12.4 K fertilizer as constant liquid feed. Plants were irrigated whenever the volumetric water content of the substrate was <20% as determined with a Theta Probe moisture meter. Weekly pH and electrical conductivity (EC) were monitored using the pour through method. Eight weeks after initiation of treatment, dry weight and leaf area was measured. Recently mature leaf tissue was analyzed for total N, P, K, Ca, Mg, S, Fe, Mn, B, Cu, Zn, and Mo. There were no significant differences in plant quality under the 100, 200, 300, or 400 mg·L⁻¹ N treatments. The largest plants, based on leaf area and shoot dry weight, were produced with 200 mg·L⁻¹ N. Compared to recommended EC levels for bedding plants, the treatments receiving 300 and 400 mg·L⁻¹ N had excessively high levels of substrate soluble salts though overall plant quality was not reduced. The increase in fertilizer concentration yielded a linear increase in tissue concentration of N, P, and K and a linear decrease in tissue concentration of Ca and Mg.

Strobilanthes dyerianus (persian shield) has become a relatively popular bedding and landscape plant. A tropical perennial native to Burma in Southeast Asia, *S. dyerianus* is grown for its foliage: large, sessile leaves marked with purple, green and silver. It is a member of the Athens Select program (Athens, Ga.), which is made up of plants demonstrating exceptional performance under hot and humid conditions (Armitage and Green, 2001).

To produce high quality, marketable plants, nutritional requirements must be established. Without proper nutrition, a plant cannot achieve optimal growth and may become more susceptible to stressors (Jones, 1998). Minimizing fertilizer runoff is an environmental concern for greenhouse and nursery operations. As such, growers are trying to produce plants using the least amount of fertilizer that produces the quality plants the consumer demands. There has been no published research regarding the nutritional requirements for *S. dyerianus*. The optimal concentration of fertilizer varies depending on the plant. Plants that require higher rates of nutrients, such as *Euphorbia pulcherrima* Willd. ex. Klotzsch (poinsettia) may be grown at a higher electrical conductivity or substrate soluble salt range (Whipker et al., 2001).

Foliar sufficiency ranges and averages for essential nutrients have been established for many species of commercially produced ornamental plants. These elemental values provide an approximate range by which potential nutrient deficiencies or toxicities can be assessed and nutrition programs adjusted accordingly (Mills and Jones, 1996). The objectives of this experiment were to 1) determine the least amount of fertilizer necessary for producing the highest quality *S. dyerianus* and associated substrate solution EC and pH values for the pour-through, and 2) present tissue elemental content which could be used as a reference by growers, as no sufficiency averages or ranges are currently available.

Materials and Methods

Single-node cuttings (7 to 9 cm long) were taken from stock plants of *S. dyerianus* on 24 May 2002 and rooted in a mist propagation bed (50% peat : 50% perlite rooting substrate) using a talc-based rooting hormone (1-naphthaleneacetamide 0.20%, thiram 4.04%; Rootone, Dragon Corp., Roanoke, Va.). Cuttings rooted in 4 weeks, at which time 45 cuttings were transplanted into 1480-cm³ pots (10.8 × 10.8 × 12.7 cm) using a mix consisting of 45% peatmoss, 25% processed pine bark, 15% perlite and 15% vermiculite (Fafard 3B soilless potting mix, Fafard, Inc., Anderson, S.C.). Plants were grown for one week using tap water to irrigate, at which point 30 plants were selected for uniformity of height and approximate leaf area. The experiment took place in a glass greenhouse on the Virginia Tech campus in Blacksburg, Va. The average day temperature in the greenhouse was 30 ±

1.5 °C and the average night temperature was 21 ± 2.2 °C. Day length ranged from 14 h 43 min at the start of treatments to 13 h 16 min by the end of the experiment. No supplemental lights were used. Noon light levels over the course of the experiment averaged 1163 μmol·m⁻²·s⁻¹.

The experiment was arranged in a randomized complete block design with six replications. Within a block, plants were treated with five rates of fertilizer (mg·L⁻¹ based on nitrogen): 0 mg·L⁻¹ (tap water), 100, 200, 300, 400 mg·L⁻¹ N from 15N–2.2P–12.4K (Miracle-Gro Excel 15–5–15, The Scotts Co., Marysville, Ohio) as constant liquid feed. This complete (includes micronutrients) fertilizer contains 78.3% (w/w) NO₃⁻-N and 8.0% ammoniacal-N, with a slight potential basicity (141 lb CaCO₃ equivalent neutralized by one ton of fertilizer). Tap water pH ranged from 7.0 to 7.2 with alkalinity of 1 meq·L⁻¹ HCO₃⁻. Plants were irrigated with 450 mL of solution to achieve a 0.20 to 0.30 leaching fraction when the volumetric substrate moisture content (VMC) was 20% or less, measured with a ThetaProbe (ThetaProbe soil moisture sensor; Delta-T Devices, Ltd, Cambridge, U.K.; TH20 meter; Dynamax, Inc., Houston, Texas). When the VMC of at least three of the six replications of a treatment dropped to ≤20%, all pots in that treatment were watered. To measure substrate pH and EC, the pour-through extraction method (Wright, 1986) was utilized once weekly (every 6 to 7 d) for that particular treatment within one hour of an irrigation event. At the termination of the study, eight weeks after initiating treatments, plant quality was assessed, shoots were harvested, and leaf area determined. Plant quality was rated on a scale of 0 to 4 with 0 being dead, 1 having severe chlorosis and/or necrosis (or other deficiency symptom), 2 having moderate chlorosis and/or necrosis, 3 having mild chlorosis and/or necrosis and 4 with no chlorosis and/or necrosis.

Eight weeks after initiation of treatments, plants in all of the treatments except 0 mg·L⁻¹ N were deemed of marketable size, and leaf area measured using a portable area meter (LI-3000) with transparent belt conveyer accessory (LI-3050A) (LI-COR, Inc., Lincoln, Nebr.). The aerial portions were washed then dried at 65.5 °C for 7 d, and dry weight was recorded. Leaf tissue from recently mature leaves was then ground, combining two random plants from each treatment into one sample, for fifteen samples. Total nitrogen was determined using the Dumas method (Mills and Jones, 1996) with a C–N–S analyzer (model 2000; LECO Corp., St. Joseph, Mich.) which also was used to determine sulfur concentration. Phosphorous, potassium, calcium, magnesium, boron, copper, iron, manganese, molybdenum, and zinc were determined by dry ashing (Jones and Case, 1990) and inductively coupled plasma spectrophotometry (Jarrell-Ash ICAP 9000; Thermo Jarrell Ash Corp., Franklin, Mass.). All plant analysis was done at Micro-Macro Laboratories (Athens, Ga.). Data were analyzed by GLM and regressions using SAS Version 8 (SAS Institute, Inc., Cary, N.C.).

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¹Graduate research assistant.

²Associate professor.

Table 1. Analysis of variance of fertilizer rate on dry weight, leaf area, and overall plant quality for *Strobilanthes dyerianus*.

Parameter	Source	df	Mean square	P
Shoot dry weight (g)	Model	9	432	<0.0001*
	Error	20	14.3	
Leaf area (cm ²)	Model	9	8828693	<0.0001*
	Error	20	139777	
Quality ^a	Model	9	2.13	<0.0001*
	Error	20	0	

^aPlant quality ratings were determined on a scale of 0 to 4, with 0 = dead and 4 = excellent.

*Significant at $P \leq 0.05$.

Results and Discussion

Plant quality and growth. The rate of fertilizer applied affected overall plant quality, shoot dry weight and leaf area of *S. dyerianus* (Table 1). However, there was little visible difference among plants receiving some amount of fertilizer, and all plants treated with 100, 200, 300, or 400 mg·L⁻¹ N were given overall quality ratings of 4 (excellent) (data not presented). Fertilizer concentrations from 200 to 400 mg·L⁻¹ resulted in plants with the largest shoot dry weight and leaf area (Figs. 1 and 2). Despite similar quality, plants fertilized with 100 mg·L⁻¹ N had lower shoot dry weights and less leaf area than higher levels of N. Regression indicates maximum dry weight at 300 mg·L⁻¹ N, however the data points are very close to each other for the 200, 300, and 400 mg·L⁻¹ N treatments. Kuehny et al. (2000) noted no significant differences in shoot dry weight or quality of five poinsettia cultivars grown under different rates of fertilizer. Kovacic and Holcomb (1981) found *Kalanchoe blossfeldiana* v. Poelln 'Pixie' (kalanchoe) grown with 7–17.5–5 controlled-release fertilizer had no difference in quality when grown with 11.8

kg·m⁻³, two, or four times that rate. Whipker et al. (1999) recommended an N rate of 150 or 200 mg·L⁻¹, depending on cultivar, for *Impatiens walleriana* Hook. (Double impatiens). Other fertilizer recommendations include 200 mg·L⁻¹ N for *Petunia ×hybrida* Hort. ex. Vilm. 'Coral Sea,' for the greatest dry weight, branch length and flowering (Frett et al., 1985). Campos and Reed (1993) observed greatest leaf area with rates of 100 to 200 mg·L⁻¹ N for the tropical plant *Spathiphyllum* Schott. and 200 to 400 mg·L⁻¹ N for the tropical plant *Dieffenbachia* Schott.

Electrical conductivity. The rate of fertilizer applied had a significant effect on substrate electrical conductivity (EC) over the course of the experiment as expected (Table 2). Plants receiving no fertilizer (0 rate) had the lowest EC levels and foliage was chlorotic and stunted, compared to the other treatments. A low EC is associated with a malnourished plant, which may be visually noted by stunted growth or leaf discoloration (varying depending on the deficient nutrient) (Whipker et al., 2001). On the contrary, a high EC may contribute to necrotic leaf margins, poor or erratic rooting of cuttings and increased vulnerability to dis-

eases affecting the root and crown (Dole and Wilkins, 1999). Morvant et al. (1997) found that lower concentrations of soluble salts in the substrate encouraged root growth, while higher concentrations of substrate soluble salts inhibited root growth.

Strobilanthes dyerianus, though a tropical perennial, is usually grown as an annual in temperate climates. Using information on recommended EC levels for bedding plants, the treatments receiving 300 and 400 mg·L⁻¹ N had excessively high levels of soluble salts (Table 2). Similar salt accumulations at higher rates of N were seen by Campos and Reed (1993) for *Spathiphyllum* and *Dieffenbachia* which ultimately led to plant death. For *S. dyerianus*, the 200 mg·L⁻¹ N treatment maintained the EC within the recommended range for bedding plants of 1.0 to 2.6 mS·cm⁻¹ (Whipker et al., 2001) throughout the experiment. The fact that there was no difference in overall plant quality suggests that *S. dyerianus* is tolerant of excess substrate soluble salts. Similar performance was noted in *Viola ×wittrockiana* Gam., which produced optimal leaf area and shoot dry weight at a leachate EC ranging from 1.5 to 4.0 dS·m⁻¹ (van Iersel, 1999).

pH. The substrate pH was also affected by the fertilizer treatment (Table 2). The recommended pH range for soilless substrate is between 5.4 and 6.0; however, this can vary depending on crop type (Dole and Wilkins, 1999). Only plants receiving 0 mg·L⁻¹ N had a substrate pH that fell within this range (Table 2). By termination of the experiment, pH for the 100, 200, 300, and 400 mg·L⁻¹ N treatments had dropped as low as 3.4, decreasing with increasing N concentrations. Though a supposedly basic fertilizer was used (15N–2.2P–12.4K),

Fig. 1. Leaf area of *Strobilanthes dyerianus* measured 8 weeks after initiation of treatments, regressed over concentration of nitrogen in the fertilizer.

Fig. 2. Shoot dry weight of *Strobilanthes dyerianus*, measured 8 weeks after initiation of treatments, and regressed over concentration of nitrogen in the fertilizer.

Table 2. Mean substrate electrical conductivity (EC) and pH for *Strobilanthes dyerianus*. Measured weekly by the pour-through extraction method from the beginning of fertilizer treatments until termination (Week 5 data excluded due to equipment malfunction) ($n = 6$).

Rate (mg·L ⁻¹ N)	Week						
	1	2	3	4	6	7	8
EC (dS·m ⁻¹)							
0	1.00	0.53	0.24	0.18	0.13	0.14	0.13
100	1.67	1.08	0.88	0.63	0.48	0.44	0.68
200	2.19	1.94	2.02	1.81	2.34	3.01	2.79
300	3.04	3.02	3.39	3.34	3.94	4.10	4.37
400	3.69	3.97	4.68	4.42	5.16	4.93	5.38
pH							
0	6.1	5.9	6.0	5.9	5.6	5.5	4.9
100	6.0	5.9	5.7	5.6	5.1	4.9	4.2
200	5.8	5.6	5.3	5.1	4.2	4.0	3.4
300	5.7	5.6	5.2	5.0	4.1	4.1	3.4
400	5.7	5.5	5.3	5.1	4.2	4.3	3.6

we saw a decrease in pH, both over time and with increasing rates. van Iersel (2003) reported decreases in substrate pH associated with increasing fertilizer concentrations and attributed this decrease to the actual pH of the fertilizer solution. Substrate pH can be affected by the breakdown of the components in the substrate, irrigation water alkalinity, and the acidity–basicity of the fertilizer being used. A pH that is too far outside of the optimal range can cause problems with nutrient availability, rendering certain nutrients, particularly micronutrients, unavailable for uptake by the plant (Whipker et al., 2001). However, the plants did not show any visible nutrient deficiency or toxicity symptoms, and the tissue elemental content was in agreement with two similar species from the *Acanthaceae* family (Table 3).

Tissue elemental content. Most foliar elements increased linearly with increasing fertilizer rates (Table 3). Exceptions were S, Fe,

and Mo, which exhibited quadratic increases, and Mn, Ca, and Mg, which exhibited a quadratic decrease. There was a sharp decrease (or increase, depending on the nutrient) in the tissue elemental concentrations of these six elements when the fertilizer concentration increased from 0 to 100 ppm, then little effect on nutrient concentrations with a further increase in fertilizer concentration. The decrease in Ca and Mg can most likely be attributed to the dilution effect, that is, more dry matter at higher fertilizer concentrations. While Ca and Mg are often present in higher concentrations than K in soils, K is taken up quickly and at higher rates (Mengel and Kirkby, 2001). Calcium can only be taken up by young root tips, while the uptake mechanism of Mg is not fully understood (Mengel and Kirkby, 2001). Similar decreases in Ca due to increased K have been noted in double impatiens (Whipker et al., 1999) and in poinsettia (Whipker and Hammer, 1997).

The elemental concentration averages of three samples per treatment are reported in Table 3. The tissue elemental content of *S. dyerianus* was comparable to the sufficiency data from two other species in the *Acanthaceae* family, *Aphelandra squarrosa* Nees. (zebra plant) and *Fittonia versaffeltii* var. *argyroneura* Coem. (silver nerve plant) as presented in Mills and Jones (1996).

In conclusion, there was no visible difference in the quality of plants produced with 100, 200, 300, or 400 mg·L⁻¹ N, and the largest plants (quantified by shoot dry weight and leaf area) were produced by 200 and 300 mg·L⁻¹ N. However, EC values indicated relatively high soluble salts in the substrate at 300 mg·L⁻¹ N. Only the 200 mg·L⁻¹ N treatment maintained a substrate EC level within the range recommended for the production of most bedding plants (1.0 to 2.6 dS·m⁻¹).

Though substrate pH was low towards the end of the study, tissue analysis results suggest that the pH differences had little effect on growth as there was no indication of micronutrient toxicity. That in turn suggests that growth effects were probably due to substrate EC. With mounting environmental concerns such as N (nitrate) and P runoff along with potential total maximum daily load (TMDL) restrictions imposed by local or state governments, growers should take every opportunity to reduce fertilizer inputs, especially if they can be reduced without compromising quality. A nutrition regime consisting of 200 mg·L⁻¹ N from a complete fertilizer is appropriate for producing high quality *S. dyerianus* plants. Elemental tissue concentration from these foliar analyses may be helpful in evaluations of nutrient sufficiency.

Table 3. Foliar elemental content of *Strobilanthes dyerianus* harvested 8 weeks after treatment with five fertilizer rates ($n=3$). Also interpretive values for two other herbaceous Acanthaceae taxa.

Rate (mg·L ⁻¹ N)	Elemental content (g·kg ⁻¹)						Element content (μg·g ⁻¹)					
	N	P	K	Ca	Mg	S	Fe	Mn	B	Cu	Zn	Mo
0	11.8 ^z	2.66	17.9	24.0	19.1	0.93	30.9	242.0	34.1	2.10	40.5	0.12
100	31.0	4.73	29.3	15.1	10.8	1.70	61.4	127.0	42.4	3.79	36.0	5.19
200	39.0	5.87	39.4	14.1	9.9	1.60	70.6	141.0	67.7	5.02	52.5	3.86
300	43.0	5.77	48.3	14.0	9.6	1.53	68.4	144.0	89.4	5.54	54.1	3.91
400	46.5	6.12	52.2	12.7	8.9	1.67	66.8	133.0	103.0	6.46	53.9	3.42
Significance ^z	L	L	L	L	L	Q	Q	Q	L	L	L	Q
<i>Fittonia</i> ^y	41.6	7.6	56.9	22.4	13.4	6.3	114.0	80.0	41.0	9.00	61.0	3.0
<i>Aphelandra</i>	20–30	2–4	10–20	4–20	5–10	2–3	50–300	50–300	35–50	10–50	20–200	0.12–0.5

^zSignificant linear (L) or quadratic (Q) effects at $P \leq 0.05$.

^yInterpretive values: survey average for *Fittonia verschaaffeltii* var. *argyroneura* and sufficiency range for *Aphelandra squarrosa*. From Mills and Jones, 1996.

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