Nitrogen Source Affects Growth and Quality of *Bougainvillea*

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SUMMARY. Container-grown *Bougainvillea* Comm. Ex Juss. 'Brasilensis' were fertilized with ammonium sulfate, sodium nitrate, or ammonium sulfate plus sodium nitrate as N sources. Plants fertilized with sodium nitrate were stunted, extremely chlorotic, and produced few flowers compared to those receiving ammonium sulfate. In a second experiment bougainvilleas were fertilized with 12 different controlled-release or soluble ammonium, urea, or nitrate fertilizers as N sources. Plants grown with only nitrate N were chlorotic, stunted, and produced fewer flowers compared to those receiving N from urea or ammonium salts. High substrate pH, associated with nitrate fertilization, was believed to be a cause of the chlorosis, but possible toxicity symptoms (small necrotic lesions and premature leafdrop) were also observed on nitrate-treated plants. Plants receiving controlled-release urea or potassium nitrate were of higher quality than those receiving similar uncoated fertilizers.

Bougainvillea is a popular flowering landscape and container plant in mild climates, but can be difficult to grow in containers. Iron deficiency chlorosis is a common disorder in container-grown plants and may have multiple causes. High soil pH, root rots, soluble salt injury, or poor soil aeration are usually associated with Fe deficiency symptoms in bougainvilleas (T.K. Broschat, unpublished data). Fertilizer N form can also affect

Fe deficiency in some plants (Colgrave and Roberts, 1956; Conover and Poole, 1982; Nelson and Selby, 1974; Sideris and Young, 1956). The purpose of this study was to determine the effects of N source on the growth, quality, and flowering of container-grown bougainvilleas.

Materials and methods

EXPERIMENT 1. Liners of *Bougainvillea* 'Brasilensis' were planted into 3-L plastic pots containing a 5 pine bark : 4 sedge peat : 1 sand substrate (by volume) amended with 4.9 kg dolomite and 880 g·m⁻³ of Micromax micronutrient blend (Scotts Co., Marysville, Ohio). Plants were fertilized every 2 weeks with 30, 60, or 90 mL/container of a solution containing P at 0.38 mg·mL⁻¹, K at 1.66 mg·mL⁻¹, and Mg at 0.55 mg·mL⁻¹ from monosodium phosphate, potassium sulfate, and magnesium sulfate, plus N at 1.70 mg·mL⁻¹ from either ammonium sulfate, sodium nitrate, or half ammonium sulfate and half sodium nitrate. This resulted in N application rates of 50, 100, and 150 mg N/pot. This experiment was set up on 28 June 1995. Twenty replicate plants were assigned to each fertilizer rate × N-source treatment and were arranged in a completely randomized design in an open-sided greenhouse (maximum photosynthetic photon flux = 1890 μmol·m⁻²·s⁻¹). Plants were irrigated daily with ≈1.5 cm of water from overhead irrigation. Temperature in this greenhouse ranged from a minimum of 15 °C to a maximum of 37 °C.

Plants were rated subjectively for chlorosis severity on 4 Jan. 1996. A rating scale of 0 to 5 was used (0 = dark green, no chlorosis, 3 = moderate chlorosis, 5 = dead from severe chlorosis). Plant dry mass, number of flowers, and substrate pH were also determined on that date. Fertilizer source effects were determined by analysis of variance. Fertilizer rate effects were determined by regression analysis.

EXPERIMENT 2. Liners of *Bougainvillea* 'Brasilensis' were potted on 13 Nov. 1996 using the same substrate and containers as in Expt. 1. Phosphorus and potassium were provided by 3.9 g of superphosphate (0N-8.7P-0K) and 6.9 g of sulfur-coated potassium sulfate (Lescro, Rocky River, Ohio) per container every 3 months. Fertilizer treatments consisted of biweekly per-pot applications of 50 mL of a solution containing N at 6.3 mg·mL⁻¹ from urea, ammonium sulfate, diammonium phos-

phate, ammonium chloride, ammonium nitrate, sodium nitrate, potassium nitrate, or calcium nitrate. Four other materials—sulfur-coated urea (Lescro), two resin-coated ureas (Osmocote 38N-0P-0K, Scotts Co., and Polycoated urea, Lescro), and resin-coated potassium nitrate (Haifa Chemicals, Haifa, Israel)—were applied once at rates of 3.8 g N/pot. The total amounts of N applied over a 6-month period by liquid and controlled-release fertilizer were equivalent. Ten replicate containers per treatment were arranged in a completely randomized design as in Expt. 1.

Chlorosis ratings, plant dry mass, and number of flowers were recorded after 3 months, as in Expt. 1. Leaf samples consisting of the youngest fully expanded leaves were collected from all plants and analyzed for total Fe and N content. Pour-through substrate solution samples were collected 5 d after a liquid fertilizer application during the final week of the experiment. These leachate samples were analyzed for ammonium N, nitrate N, Fe, electrical conductivity (EC), and pH. Since small (1- to 2-mm) necrotic lesions appeared on the older leaves of some plants shortly after the initial treatment, the number of leaves with lesions per plant were counted on 6 Dec. 1996. Data were analyzed by regression analysis or by analysis of variance, with mean separations by the Waller-Duncan k ratio method.

Results and discussion

In the first experiment, *Bougainvillea* 'Brasilensis' fertilized with only sodium nitrate as a N source exhibited more severe chlorosis symptoms than those receiving only ammonium sulfate (Table 1). Plants receiving ammonium sulfate plus sodium nitrate had intermediate chlorosis ratings. Bougainvilleas fertilized with ammonium sulfate had an average of 47.9 flowers vs. 4.4 flowers per plant for those receiving sodium nitrate (Table 1). Plant dry mass was also much larger for bougainvilleas fertilized only with ammonium sulfate.

The fertilizer source by rate interaction was highly significant for plant dry mass, but was not significant for chlorosis severity and number of flowers (Table 1). When fertilization rate effects were analyzed within each N source treatment, the following trends were evident. 1) Increasing fertilization rate within the ammonium sulfate treatments had no effect on chlorosis severity, but

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increased the number of flowers and plant dry mass (Table 1). 2) Increasing fertilization rate within the sodium nitrate treatments increased chlorosis severity, but had no effect on number of flowers or dry mass. 3) Increasing the overall fertilization rate (data from both fertilizer sources combined) slightly increased plant chlorosis severity, but also significantly increased flower number and plant dry mass (data not shown).

The first experiment suggests that bougainvilleas respond positively in terms of growth (as measured by dry mass) and flowering to increasing amounts of ammonium sulfate, but ammonium sulfate had little or no effect on chlorosis severity. On the other hand, chlorosis increased with increasing amounts of sodium nitrate, but increasing sodium nitrate had no effect on flowering or growth. Although flower production was much greater for plants fertilized with ammonium sulfate than with sodium nitrate, the number of flowers appeared to be related to plant size and vigor. Still, ammonium sulfate-fertilized plants averaged about five flowers, ammonium sulfate plus sodium nitrate about four flowers, and sodium nitrate about three flowers per gram of dry mass. Plant size and vigor were greatly reduced in chlorotic plants.

Fertilization with only nitrate N fertilizer has been associated with Fe

deficiency and reduced growth in *Calathea* (Conover and Poole, 1982), conifers (Nelson and Selby, 1974), azaleas (Colgrave and Roberts, 1956), and pineapple (Sideris and Young, 1956). Nitrate fertilizers are known to increase soil and plant tissue pH, whereas ammonium fertilizers have the opposite effect (Kirkby and Mengel, 1967). Container substrate pH for plants in the first experiment averaged 6.43 with ammonium sulfate, 6.46 with ammonium sulfate plus sodium nitrate, and 6.82 with sodium nitrate. Although flower number and plant dry mass had significant negative correlations with substrate pH ($r = 0.60$, $P = 0.019$ and $r = 0.58$, $P = 0.022$, respectively), the negative correlation of chlorosis rating with substrate pH was only marginally significant ($r = 0.47$, $P = 0.076$).

The positive effects of ammonium sulfate fertilization are believed to be due to NH_4^+ rather than SO_4^{2-} , since all plants received adequate amounts of SO_4^{2-} in the form of K_2SO_4 . Although the increased chlorosis severity associated with sodium nitrate fertilization could be due to Na^+ , there is no support in the literature for such an interaction. The second experiment was set up to eliminate the possibility that Na^+ or SO_4^{2-} affected these results.

In the second experiment, where bougainvilleas were grown with a vari-

ety of ammonium or nitrate sources, the largest plants were those receiving controlled-release ureas (Table 2). Plant size was intermediate for the soluble urea and ammonium sources and smallest for nitrate-fertilized plants. Number of flowers was highest for plants receiving controlled-release ureas, but all soluble ammonium and nitrate salts produced equally low numbers of flowers. Chlorosis severity also was lowest for plants receiving controlled-release ureas, intermediate for most of the soluble urea and ammonium sources, and highest for nitrate-fertilized plants. The number of leaves with small necrotic lesions was highest for sodium, potassium, and calcium nitrate-fertilized plants and lowest for those receiving urea or ammonium salts or controlled-release potassium nitrate. Thus, plant quality, as measured by these four variables, was generally poorest for plants receiving nitrate N, best for those receiving controlled-release urea, and intermediate for those receiving soluble urea or ammonium fertilizers.

The physiological basis for this association of chlorosis and leafspotting with nitrate fertilization is less clear. The chlorosis symptoms observed appeared to be classical Fe deficiency symptoms, with sharply delimited green veins on otherwise yellow or whitish new leaves. New leaf size was also greatly reduced in

Table 1. Response of *Bougainvillea* 'Brasiliensis' to fertilizer source and rate (Expt. 1.).

N source	Biweekly N fertilizer rate (mg/pot)	Chlorosis rating ²	Flowers (no.)	Dry mass (g)
Ammonium sulfate	50	0.8	25.2	4.9
	100	0.8	63.6	10.8
	150	1.2	55.4	12.5
Mean		0.9	47.9	9.3
Fertilizer rate		NS	*	***
Ammonium nitrate + sodium nitrate	50	1.4	9.2	3.2
	100	1.8	20.9	5.8
	150	1.4	30.6	7.2
Mean		1.5	20.2	5.4
Fertilizer rate		NS	*	***
Sodium Nitrate	50	1.9	3.6	1.5
	100	2.1	6.3	1.9
	150	2.9	3.3	1.3
Mean		2.3	4.4	1.5
Fertilizer rate		*	NS	NS
Overall effects				
N source (L)		***	***	***
N rate (L)		*	**	***
N source × rate		NS	NS	***

²Rating: 0 = dark green, no chlorosis, 3 = moderate chlorosis, 5 = dead from severe chlorosis.

NS, *, **, *** Nonsignificant or significant at $P = 0.05$, 0.01 , or 0.001 , respectively; L = linear.

more severe cases. Leaf Fe concentrations were not correlated with fertilizer treatments, chlorosis severity, or with any of the other plant quality variables (data not shown). However, the role of Fe deficiency in this disorder cannot be completely ruled out since leaf Fe concentrations often are not correlated with plant quality or chlorosis severity (Mills and Jones, 1996).

Nitrate fertilizers increased substrate pH to a greater extent in Expt. 2 ($\bar{x}$ = 7.21 for nitrate vs. 6.28 for ammonium) than in Expt. 1. Although the lowest substrate pH values were those from ammonium chloride and diammonium phosphate treatments, these treatments did not result in the best-quality plants. Substrate nitrate concentrations were equivalent for containers fertilized with soluble ammonium and nitrate fertilizers, suggesting that nitrification of ammonium was occurring during this study. The very low substrate nitrate and ammonium levels for S-coated urea can be attributed to its having released most of its N during the 3-month study. On the other hand, Osmocote 38N-0P-0K is claimed to have a 12- to 14-month life at 21 °C. It apparently released N at a very slow rate due to its heavy coating.

There were no significant correlations of any plant quality variables with substrate EC. Leafspot severity was nega-

tively correlated only with substrate ammonium N levels (r = -0.25, P = 0.006). Substrate pH was strongly affected by N form (P < 0.0001) in Experiment 2, but was less strongly correlated with plant dry mass (r = -0.20, P = 0.025) and with chlorosis severity (r = 0.23, P = 0.011). Leafspot severity was significantly affected by N form (P < 0.0001) and was positively correlated with substrate pH (r = 0.39, P < 0.0001). Leafspot severity was only marginally related to substrate nitrate N concentrations (r = 0.16, P = 0.076). Although pH-induced Fe deficiency associated with nitrate fertilization appears to be the primary cause of the chlorosis in bougainvilleas, it is possible that factors other than substrate pH, nitrate N, ammonium N, or EC may also be involved in this problem. The leafspotting disorder appears to be a phytotoxic response associated more with a lack of ammonium N than the presence of nitrate N.

Conclusions

These studies showed that N source strongly affects the growth and quality of bougainvilleas. Although the physiological reasons are unclear, plants fertilized with controlled-release ureas were the largest, had the most flowers, and the least chlorosis and leafspotting. Those receiving only nitrate N were

severely stunted, extremely chlorotic, had a high incidence of leafspotting and leafdrop, and produced few flowers. Water-soluble urea and ammonium salts produced plants of intermediate quality. Thus, bougainvillea growers should use controlled-release urea fertilizers and avoid using nitrate fertilizers for optimum plant growth and quality.

Literature cited

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Table 2. Effects of N source on dry mass, number of flowers, chlorosis severity, and number of leaves with necrotic lesions in *Bougainvillea* 'Brasiliensis'.

N source	Dry mass (g)	Flowers (no.)	Chlorosis severity ²	Leaves with lesions (no.)	Leaf Fe ($\mu\text{m}\cdot\text{g}^{-1}$)	Substrate pH	Substrate $\text{NO}_3\text{-N}$ ($\mu\text{g}\cdot\text{mL}^{-1}$)	Substrate $\text{NH}_4\text{-N}$ ($\mu\text{g}\cdot\text{mL}^{-1}$)	EC ($\text{dS}\cdot\text{m}^{-1}$)
S-coated urea	12.1 ab ¹	41.9 b	0.8 c	1.4 c	217 b	6.89 cd	3.3 c	0.1 c	3.32
Resin-coated urea ^x	13.6 a	54.6 a	1.1 c	0.3 c	158 cd	6.70 de	7.8 c	0.3 c	2.40
Urea	8.0 cd	4.6 d	1.7 b	0.0 c	439 a	6.35 f	165.3 a	5.0 c	1.93
Resin-coated urea ^w	11.3 abc	22.8 c	1.9 b	0.2 c	160 cd	6.66 f	119.7 ab	5.9 c	2.56
Ammonium sulfate	8.8 bcd	3.7 d	1.9 b	0.1 c	165 cd	5.99 g	110.0 ab	27.5 b	2.32
Diammonium phosphate	5.6 def	1.2 d	2.5 a	0.2 c	129 d	5.59 h	117.3 ab	31.5 b	2.37
Ammonium chloride	7.0 de	0.9 d	2.1 b	0.3 c	144 cd	5.76 h	129.9	39.4 a	3.25
Ammonium nitrate	7.9 d	3.3 d	1.8 b	0.1 c	185 bc	6.25 f	158.8 a	6.6 c	2.18
Sodium nitrate	3.6 f	2.3 d	2.7 a	8.3 a	129 d	7.31 ab	154.1 a	0.0 c	2.80
Potassium nitrate	3.2 f	2.5 d	2.8 a	5.5 b	143 cd	7.20 b	190.9 a	0.1 c	2.87
Calcium nitrate	2.8 f	3.3 d	2.8 a	6.0 ab	133 d	6.93 c	138.6 a	0.1 c	2.67
Resin-coated potassium nitrate ^v	4.5 ef	8.8 d	2.7 a	1.4 c	165 cd	7.45 a	23.1 bc	0.1 c	2.55
N source	***	***	***	***	***	***	***	***	NS

¹Rating: 0 = dark green, no chlorosis, 3 = moderate chlorosis, 5 = dead from severe chlorosis.

²Osmocote 38N-0P-0K.

³Mean separation by the Waller-Duncan k ratio method, k = 100.

⁴Lesco polycoated urea.

⁵Haifa Multicote.

***Significant at P < 0.0001.