Calcium and Nitrogen Fertilization of *Alstroemeria* for Cut Flower Production

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Abstract. The effects of Ca and N on cut flower production of *Alstroemeria* were determined in separate greenhouse experiments. Calcium was supplied as $\text{Ca}(\text{NO}_3)_2$ and CaCl_2 at 0, 1, 2, 4, 8, and 12 $\text{mmol}\cdot\text{L}^{-1}$ added to tap water containing Ca at $\approx 0.2\text{ mmol}\cdot\text{L}^{-1}$. Nitrogen was supplied as KNO_3 and $\text{Ca}(\text{NO}_3)_2$ providing total N at 0, 3.5, 7, 14, 28.5, and 57 $\text{mmol}\cdot\text{L}^{-1}$ in tap water containing N $< 0.2\text{ mmol}\cdot\text{L}^{-1}$. Nutrient solutions were applied at 7- or 10-day intervals to plants growing in a soilless medium in 2.6- or 5.5-L containers. Flowering stems were harvested when the primary florets opened. Total N concentration was measured in leaf tissue from the upper portion of flowering stems. Flower production was not affected by Ca supply, but increased with N supply to a maximum of about four stems per plant on a weekly basis at 28.5 $\text{mmol}\cdot\text{L}^{-1}$, then decreased to less than three stems per plant at 57 $\text{mmol}\cdot\text{L}^{-1}$. Nitrogen concentration in leaf tissue on a dry mass basis was maintained at $45 \pm 3\text{ g}\cdot\text{kg}^{-1}$ in plants supplied with N at 28.5 $\text{mmol}\cdot\text{L}^{-1}$, $52 \pm 5\text{ g}\cdot\text{kg}^{-1}$ at 57 $\text{mmol}\cdot\text{L}^{-1}$, but $< 40\text{ g}\cdot\text{kg}^{-1}$ with N supply of 14 $\text{mmol}\cdot\text{L}^{-1}$ or lower. Nitrogen fertilization of *Alstroemeria* should be managed to maintain leaf tissue N close to 45 $\text{g}\cdot\text{kg}^{-1}$.

The genus *Alstroemeria* contains several species of herbaceous perennial monocots, and complex interspecific hybrids have been developed. *Alstroemeria* hybrids are grown as greenhouse cut flowers, garden flowers, or potted plants (Bridgen, 1997). The plant spreads by underground rhizomes, and has fleshy storage roots. Flowers arise in a terminal bracted umbel of cymes. Breeding programs have developed a number of cultivars offering a variety of bright colors. Cut stems have a relatively long postharvest life. Cut flower production is the major economic use of *Alstroemeria*, although efforts are being made to develop more cultivars with shorter stems suitable for potted plant production.

The effects of environmental factors such as temperature and light on *Alstroemeria* flowering have been extensively examined (Bridgen and Bartok, 1990; Healy and Wilkins, 1982, 1986a, 1986b; Keil, 1986; Lin, 1985; Lin and Molnar, 1983). Cultural practices to improve flowering, such as watering, shoot thinning, and fertilization have also been studied, but on

a more limited basis (Bik et al., 1980; Bik and Van den Berg, 1981; Bridgen et al., 1987; Healy and Lang, 1984; Whealy and Bridgen, 1988; Wilkins and Heins, 1976). Recommendations for N fertilization are inconsistent. Bik and van der Berg (1981) obtained maximum flower production with *Alstroemeria* 'Orchid' and 'Carmen' with N applied weekly at 220 mg per 12.5-L pot. They reported that this level was considerably higher than that used by Blomme and Dambre (1979), which was not specified. Wilkins and Heins (1976) suggested application of N on a biweekly basis at 600 $\text{mg}\cdot\text{L}^{-1}$ for *Alstroemeria* in general. Healy and Wilkins (1991) report applying KNO_3 up to twice weekly with N at 600 $\text{mg}\cdot\text{L}^{-1}$. Neither of these references specify the container volume or volume of fertilizer applied, so quantitative comparison is not possible. The $\text{NH}_4^+:\text{NO}_3^-$ ratio of N fertilizer does not affect flower production in *Alstroemeria* (Bridgen et al.,

1987), although Healy and Wilkins (1991) caution against use of ammoniacal fertilizers at low soil temperatures.

Calcium is an essential macronutrient and is frequently supplied as a cation accompanying NO_3^- in liquid fertilizers. We are not aware of any published information regarding Ca nutrition of *Alstroemeria*, or of any specific factors (e.g., pH sensitivity) that might be relevant to its Ca requirements. The following studies were undertaken to determine how Ca and N fertilization affect growth and flowering of *Alstroemeria*.

Materials and Methods

Experiment 1. Calcium fertilization. Divisions comprising storage roots and rhizomes of *Alstroemeria* 'Parigo Pink' were potted on 21 Mar. 1989 in 2.6-L black plastic pots containing Fafard No. 2 growing mix (Conrad Fafard, Agawam, Mass.) with no additional amendments. Exact composition of the medium is proprietary information, but product labeling indicates that it is composed of sphagnum peat, vermiculite, and perlite and is amended with limestone and a soluble nutrient charge (Table 1). The pots were arranged in a randomized complete-block design with four pots of each treatment in a glass-covered greenhouse under natural daylength, heating setpoint temperature 10 °C night/15.5 °C day, and cooling setpoint 21 °C.

Fertilizer treatments were initiated on 9 Apr. 1989, when shoots from the plants were between 5 and 10 cm tall. Fertilizer solutions were based on that of Hoagland's #2 solution (Hoagland and Arnon, 1950), with six concentrations of Ca (Table 2), made up in tap water containing Ca at 0.20 to 0.22 $\text{mmol}\cdot\text{L}^{-1}$. Fertilizer was applied twice at 10-d intervals, and then weekly until the termination of the experiment. For the first 48 d after the initial fertilization, fertilizer solution was applied at 500 mL/pot. Thereafter, the volume was increased to 1 L/pot. Leaching was not measured, but little leachate was observed. Plants were watered as needed (based on visual observations of the medium) with tap water between fertilizer applications (zero to two times, depending on weather and plant size). Flower

Table 1. Initial electrical conductivity (EC) and pH in aqueous slurries (1:2 by volume), and nutrient concentrations in Spurway extracts of potting media prior to planting.

Medium	EC		Concn (mg·L ⁻¹)					
	(dS·m ⁻¹)	pH	Ca	Mg	K	P	$\text{NO}_3^-:\text{N}$	$\text{NH}_4^+:\text{N}$
Fafard #2	0.6	5.9	68	25	8	3	20	2
Fafard #2S	0.5	5.9	56	23	5	3	25	4

Table 2. Nutrient solutions used to provide different concentrations of Ca. All solutions contained micronutrients as follows, in $\mu\text{mol}\cdot\text{L}^{-1}$: NaFeEDTA, 90; H_3BO_3 , 46.3; MnCl_2 , 9.2; ZnSO_4 , 0.77; CuSO_4 , 0.32; Na_2MoO_4 , 0.09.

Ca concn (mmol·L ⁻¹)	Salt (mmol·L ⁻¹)						
	$\text{NH}_4\text{H}_2\text{PO}_4$	KNO_3	$\text{Ca}(\text{NO}_3)_2$	$\text{Mg}(\text{NO}_3)_2$	NH_4NO_3	NaNO_3	MgSO_4
0	1	6	---	1	1	4	1
1	1	6	---	1	1	4	1
2	1	6	---	1	1	4	1
4	1	6	4	---	---	---	2
8	1	6	4	---	---	---	2
12	1	6	4	---	---	---	2

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harvesting commenced on 17 May 1989. Stems were harvested when the primary floral buds opened. The date of harvest, the number of florets and buds, and the length of the stem from the level of the medium to the base of the flower cymes were recorded. Flowering stems were weighed after drying for at least 4 d at 60 to 70 °C.

Flower production ceased 8 Aug. 1989. At that time, the number of vegetative stems per pot was recorded. Stems were removed at the surface of the growing medium, dried and weighed. Electrical conductivity (EC) was measured in aqueous extracts (1:2 by volume) of media shaken loose from the roots from each pot after stems were harvested.

Data were analyzed for statistical significance using the GLM procedures in the SAS statistical software package (SAS Institute, 1988).

Experiment 2. Nitrogen fertilization. Divisions of *Alstroemeria* 'Parigo Pink' were potted on 28 Oct. 1989, in 5.5-L black plastic pots containing Fafard No. 2-S (Conrad Fafard) growing medium, which is composed of sphagnum moss peat, polystyrene beads, and vermiculite, amended with lime and a soluble nutrient charge (Table 1). The pots were arranged in a randomized complete block design with four pots of each treatment in the same greenhouse with temperature setpoints as previously described. Metal halide high intensity discharge lamps (General Electric, #E-040M) were used to provide supplemental illumination for a 16-h photoperiod (intensity not measured) until 15 Jan. 1990, at which time the photoperiod was increased to 24 h. Lighting was discontinued on 2 Mar. 1990.

Fertilizer treatments were initiated on 26 Dec. 1989. Nitrogen was added at concentrations of 0, 3.5, 7, 14, 28.5, and 57 mmol·L⁻¹ (Table 3), in tap water containing N at <0.2 mmol·L⁻¹. Fertilizer solutions were applied initially every 10 d at 500 mL/pot. The volume was increased to 1 L/pot on 26 Mar. 1990, and the frequency was increased to once a week on 12 Apr. 1990. Leaching was not measured, but little leachate was observed. Plants were watered as needed (based on visual observations of the medium) with tap water between fertilizer applications (zero to two times, depending on weather and plant size).

Approximately one-third of the vegetative stems were removed from each plant on 20 Mar., 20 Apr., 22 May, and 23 June 1990, in order to stimulate flower production (Healy and Wilkins, 1991). Flower harvesting commenced on 29 Mar. 1990. Stems were harvested when the primary floral buds opened. The date of harvest, the number of cymes, florets and buds, and the length of the stem from the level of the medium to the base of the umbel were recorded. These data were used to grade stems using the system of Wilkins and Heins (1976), in which grade 1 stems have five or more cymes and are longer than 91 cm, grade 2 stems have three or four cymes and are between 61 and 91 cm long, and grade 3 stems either have fewer than three cymes or are shorter than 61 cm. A foliar tissue sample consisting of the eight leaves immediately

Table 3. Nutrient solutions used to provide different concentrations of N. All solutions contained micronutrients as follows, in $\mu\text{mol}\cdot\text{L}^{-1}$: NaFeEDTA, 90; H₃BO₃, 46.3; MnCl₂, 9.2; ZnSO₄, 0.77; CuSO₄, 0.32; Na₂MoO₄, 0.09.

N concn (mmol·L ⁻¹)	Salt (mmol·L ⁻¹)					
	KH ₂ PO ₄	MgSO ₄	KNO ₃	Ca(NO ₃) ₂	CaCl ₂	KCl
0	1	1	---	---	2	5
3.5	1	1	3.5	---	2	1.5
7	1	1	5	1	---	---
14	1	1	5	4.5	---	---
28.5	1	1	5	11.75	---	---
57	1	1	5	26	---	---

Table 4. Effect of Ca fertilization on flowering stem length and dry mass of the top growth of *Alstroemeria* 'Parigo Pink', and electrical conductivity (EC) in aqueous slurries (1:2 by volume) of the root medium at final harvest.

Ca concn (mmol·L ⁻¹)	Stem length (cm)	Dry mass (g/plant)	EC (dS·m ⁻¹)
0	77.4	97.8	0.57
1	78.8	91.2	0.54
2	74.1	90.9	0.62
4	75.8	105.0	0.73
8	68.2	82.9	1.39
12	70.7	60.7	1.84
Significance	**	**	**

**Significant linear effect at $P \leq 0.01$.

below the bracts at the base of the umbel was collected from each stem and dried at least 4 d. In commercial practice, leaves are stripped from the stem prior to sale. The remainder of the flower stem was dried and weighed.

The experiment was terminated on 29 July 1990. After harvesting the flowering stems, final height of each plant was measured. The remaining stems were then separated into vegetative stems and immature floral stems, which had obvious, but unopened, floral buds. The number of vegetative stems with necrotic, limp, and brittle terminal growth was recorded. Stems in each category were counted, dried, and weighed. A sample of medium was obtained from each pot, air-dried, and extracted in 0.017 mol·L⁻¹ acetic acid (1:5 by volume) for nutrient analysis (Spurway, 1943). The rhizomes and storage roots from each pot were cleaned and dried for dry mass measurement.

The flower production period was divided into nine consecutive 2-week intervals. For each interval from the second through the eighth, all the leaf samples collected from a single plant were combined. The pooled samples were ground to pass a 20 mesh screen (≈ 1 -mm openings) for N analysis using a Leco FP-428 N analyzer (Leco Corp., St. Joseph, Mich.). The first and last 2-week periods were not included because some of the treatments did not produce flower stems during these periods.

Linear regression was used to estimate the rate of flower production for each treatment during the peak production period (day 166 through day 250). Data were analyzed for statistical significance using GLM and REG procedures with the SAS statistical software package (SAS Institute, 1988).

Results

Experiment 1. Calcium fertilization. The concentration of Ca in the fertilizer solution

had no significant effect on the number of flower stems produced per plant (16.3 to 21.5), the number of florets and flower buds on each stem (5.7 to 7.3), or the total number of stems produced (41.5 to 58.5). The average length of the floral stems and dry mass of the top growth decreased with increasing Ca concentration at 8 and 12 mm Ca with the two highest Ca treatments (Table 4). Electrical conductivity of the medium increased with increasing Ca fertilization. Conspicuous root injury was observed on plants fertilized with Ca at 12 mmol·L⁻¹. Negative correlations were obtained between plant dry mass and EC of the medium ($r = -0.59$, $P = 0.002$), and between flower stem length and EC ($r = 0.84$, $P = 0.021$).

Experiment 2. Nitrogen fertilization. The number of vegetative stems produced, the length of the flower stems, the total number of florets and flower buds produced per stem, and the total dry mass of the top growth tended to increase with N concentration in the fertilizer solution up to 28.5 mmol·L⁻¹ (Table 5). Dry mass of the rhizomes and storage roots (20.3 to 48.4 g) was not affected. Cumulative flower production increased with N supply to 27.5 mmol·L⁻¹, then decreased at 57 mmol·L⁻¹ (Fig. 1). Linear and quadratic effects were significant ($P \leq 0.05$) for the effect of N supply on total flower production. Flower production on a weekly basis during the main period of production with N supplied at 28.5 mmol·L⁻¹ amounted about 4 flowers per plant (Table 6). Both slope and intercept coefficients differed significantly ($P \leq 0.05$) among treatments.

Plants supplied with no N or N at 3.5 mmol·L⁻¹ produced no grade 1 stems, and far fewer grade 2 stems than grade 3 stems, while plants supplied with N at higher concentrations produced some grade 1 stems and a higher proportion of grade 2 stems (Fig. 2). With N supplied at 28.5 mmol·L⁻¹, the sum of grade 1 and 2 stems (95) nearly equalled the number of grade 3 stems (96). The proportion

Table 5. Effect of N supply on the number of vegetative stems (veg), number of florets and buds per inflorescence (florets), flower stem length, dry mass of the top growth, and plant height of *Alstroemeria* 'Parigo Pink'.

N concn (mmol·L ⁻¹)	No. veg. stems/plant	No. florets/plant	Flower stem length (cm)	Plant height (cm)	Dry mass (g)
0	14.3	4.5	48.0	24.0	12.0
3.5	45.5	5.5	50.3	50.5	47.2
7	37.5	7.0	61.8	66.3	89.3
14	68.8	7.2	62.5	64.0	152.3
28.5	75.5	7.7	64.0	54.0	185.5
57	50.8	8.5	59.3	34.0	119.9
Significance	*	**	**	**	**

*,** Significant linear effect at $P \leq 0.05$ and 0.01 , respectively.

Fig. 1. Cumulative flower production by *Alstroemeria* fertilized with N at concentrations indicated. Regression coefficients for the linear phase of flower production (days 166 through 250) are given in Table 6.

Table 6. Regression equations relating the number of *Alstroemeria* 'Parigo Pink' flowers produced per plant per day during the period day 166 to day 250 from planting (Fig. 1) with different N fertilizer treatments. Regression parameter estimates are significant at least at the 0.05 level.

N concn (mmol·L ⁻¹)	Predictive equation	R ²
0	$Y = 0.07 (\text{day}) - 10.9$	0.98
3.5	$Y = 0.11 (\text{day}) - 17.9$	0.99
7	$Y = 0.14 (\text{day}) - 23.4$	0.99
14	$Y = 0.26 (\text{day}) - 42.0$	0.98
28.5	$Y = 0.56 (\text{day}) - 92.1$	0.99
57	$Y = 0.39 (\text{day}) - 68.1$	0.98

of grade 3 stems increased during the latter half of the production period, and they comprised the majority of stems harvested beginning with the fourth interval for the 3.5 and 7 mmol·L⁻¹ treatments, and the fifth interval for the 14, 28.5, and 57 mmol·L⁻¹ treatments.

Nitrogen concentration of leaf tissue from flowering stems increased with N supply (Fig. 3A). Within treatments, the concentration of N did not change significantly ($P \leq 0.05$) during the production period when N was supplied at 0, 3.5, 28.5, or 57 mmol·L⁻¹, but tended to decrease with time at 7 or 14 mmol·L⁻¹ (Fig.

3B). Maximum flower production, with N at 28.5 mmol·L⁻¹, was associated with tissue N levels maintained close to 45 g·kg⁻¹ (Fig. 4).

Nitrate-N concentrations in Spurway extracts of root media were less than 5 mg·L⁻¹ with N supply up to 14 mmol·L⁻¹, increasing to 48 mg·L⁻¹ at 28.5 mmol·L⁻¹ and 60 mg·L⁻¹ at 57 mmol·L⁻¹. Phosphorus and K concentrations were lowest in extracts of media fertilized with N at 14 or 28.5 mmol·L⁻¹. Electrical conductivity ranged from 0.62 to 0.88 dS·m⁻¹ in media fertilized with N at 0 to 14 mmol·L⁻¹, increasing to 1.4 dS·m⁻¹ at 28.5 mmol·L⁻¹ and to 2.7 dS·m⁻¹ at 57 mmol·L⁻¹.

Discussion

Calcium fertilization. Plants receiving fertilizer solution with no added Ca evidently acquired enough Ca from the lime incorporated in the growing medium, as well as from Ca in irrigation water, to sustain levels of growth and flower production similar to those in plants supplied with Ca up to 4 mmol·L⁻¹. Calcium concentration in tap water was less than 0.25 mmol·L⁻¹ and the initial media Ca concentration (Table 1) was in the low range of recommended values for floricultural crops (Koths et al., 1980). Monocotyledonous plants generally have a low Ca requirement (Marschner, 1995). *Alstroemeria* evidently conforms to this general tendency, since supplemental Ca was not required to sustain growth and flowering. Therefore, little or no Ca fertilization should be necessary for *Alstroemeria* production.

Fertilizer treatments supplying Ca at less than 12 mmol·L⁻¹ had no negative effects on growth. Calcium is generally regarded as non-toxic to plants (Marschner 1995). The negative effects of high Ca fertilizer treatments might be attributed either to the effect of fertilizer solutions on the soluble salt concentration of the growing medium or the use of Cl⁻ as a counterion for Ca²⁺ at 8 and 12 mmol·L⁻¹. With Ca at 12 mmol·L⁻¹, the EC of media extracts was in the high range for established crops (Koths et al., 1980). The negative correlations obtained between EC and shoot dry mass, and EC and flowering stem length, support the contention that EC was the most likely factor restricting growth. Fenn et al. (1987) observed growth inhibition of *Phaseolus vulgaris* with CaSO₄ at 16 mmol·L⁻¹. They suggested that this was due to the increase in soluble salts at that concentration. In our experiment, Cl⁻ concentration was 16 mmol·L⁻¹ in the 12 mmol·L⁻¹ Ca fertilizer solution, so the possibility of Cl⁻ toxicity cannot be ruled out. Little information is available on Cl⁻ toxicity pertinent to this study, but Cl⁻ levels in excess of 4 mmol·L⁻¹ are considered excessive for water used for irrigation of greenhouse crops (Petersen, 1996).

Nitrogen fertilization. *Alstroemeria* plants fertilized with N at 28.5 mmol·L⁻¹ produced more flowers of higher quality with earlier onset of flowering than did plants fertilized with lower or higher concentrations. The maximum top dry mass at final harvest in plants that were provided N at 28.5 mmol·L⁻¹ can be accounted for by the number of vegetative stems, since the average dry mass per stem was relatively constant within N treatments from 7 to 57 mmol·L⁻¹.

According to general interpretive guidelines for Spurway extraction (Koths et al., 1980), NO₃-N concentrations were low in all treatments with N < 28.5 mmol·L⁻¹, high at 28.5 mmol·L⁻¹, and excessive at 57 mmol·L⁻¹. Phosphorus and K were in the low range in media with N at 14 or 28.5 mmol·L⁻¹, but were in the medium range with other N concentrations. These observations suggest that P or K might have become limiting factors in plant nutrition with N at 28.5 mmol·L⁻¹. Further

Fig. 2. Percent of *Alstroemeria* flower stems produced in each grade at N fertilizer concentrations ($\text{mmol}\cdot\text{L}^{-1}$) indicated, during successive 2-week intervals beginning with the first flower harvest.

Fig. 3. Effect of N supply on N concentration (dry mass basis) of standard leaf tissue (eight leaves immediately below the bracts subtending the umbel) of *Alstroemeria* during the flower production period. Each point is the mean of 28 samples, each sample comprising standard leaf tissue pooled from all flowering stems harvested from an individual plant during an interval of 2 weeks. Error bars show range of observations. Inset: N concentration over time for varying fertilizer N treatments. Each point is the mean of four samples.

research will be required to determine optimal rates of P and K fertilization for *Alstroemeria*. When N was supplied at $57 \text{ mmol}\cdot\text{L}^{-1}$, plants were evidently unable to completely utilize the NO_3^- and other ions provided, thus increasing electrical conductivity in the medium.

Reduction in stem quality over time was not related to N supply, as it occurred at approximately the same time in all of the treatments, and was attributable for the most part to decreased flower stem length. Healy and Lang (1984) observed that *Alstroemeria*

tends to produce progressively shorter shoots as stems are removed from the rhizome.

Previous reports have not provided consistent recommendations for N fertilization of *Alstroemeria*. For example, Healy and Wilkins (1991) report fertilizing twice weekly with KNO_3 providing N at $600 \text{ mg}\cdot\text{L}^{-1}$, without any adverse effects. Volume was not specified, so the quantity cannot be calculated. In this experiment, fertilizing once weekly with N at $57 \text{ mmol}\cdot\text{L}^{-1}$ ($798 \text{ mg}\cdot\text{L}^{-1}$) inhibited flower production. On the other hand, Bik and van der

Berg (1981) obtained maximum flower production with N applied weekly at $220 \text{ mg}/12.5 \text{ L}$ pot, which is considerably less than that applied in the $28.5 \text{ mmol}\cdot\text{L}^{-1}$ treatment in this experiment ($400 \text{ mg}/5.5 \text{ L}$ pot on a weekly basis). These discrepancies are most likely due to differences in crop growth potential as the result of differences in the growing environment, or the use of different cultivars.

Low Ca requirement coupled with tolerance of Ca up to $8 \text{ mmol}\cdot\text{L}^{-1}$ and relative indifference to $\text{NH}_4^+:\text{NO}_3^-$ ratio makes preparation of liquid fertilizer for *Alstroemeria* relatively simple. The N requirement can be fulfilled with combinations of NH_4^+ and NO_3^- salts, using Ca^{2+} as a variable cation depending on requirements for other nutrients and for $\text{NH}_4^+:\text{NO}_3^-$ ratio to maintain desired pH.

Optimal fertilization of a crop must be related to growth potential. The use of tissue analysis may be the most accurate method of determining the appropriate rate of N fertilization for a given set of growing conditions. We found the optimum concentration of N in *Alstroemeria* leaf tissue to be $45 \pm 3 \text{ g}\cdot\text{kg}^{-1}$, in agreement with Bik et al. (1980), who reported N concentrations from 40 to $45 \text{ g}\cdot\text{kg}^{-1}$ in productive plantings of *Alstroemeria*. Nitrogen fertilization of *Alstroemeria* should be adjusted to maintain leaf tissue N close to $45 \text{ g}\cdot\text{kg}^{-1}$. Tracking tissue N would be fully justified in *Alstroemeria* as it is a relatively long-term crop that is most productive when tissue N is relatively constant throughout its reproductive life.

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Fig. 4. Association between *Alstroemeria* flower production and mean N concentration (dry mass basis) of standard leaf tissue. Data for flower production are the cumulative means of 4 plants, while N concentration data represent averages for four pooled samples for each of seven sampling intervals. Error bars show standard deviations.

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