Reduced End-of-production Fertilization Rate Increased Postproduction Shelf Life of Containerized Vegetative Annuals

Shannon E. Beach[1,4], Terri W. Starman[1,5,8], Kristen L. Eixmann[1,6], H. Brent Pemberton[2,7], and Kevin M. Heinz[3,7]

Additional index words. argyranthemum, bracteantha, calibrachoa, nemesia, petunia, sutera

Summary. Twenty-one cultivars of vegetative annuals were treated with 0%, 50%, or 100% of the production fertilization rate of 300 mg·L^{-1} N starting 2 weeks before and continuing until harvest. At harvest, plant width, flower number, and quality rating were measured. The plants were then placed in a simulated interior environment where flower number was counted and quality rating was assigned to each plant weekly for 3 weeks. Overall, 14% of the cultivars maintained a marketable quality (i.e., quality rating of ≥3.0 of 5) for 3 weeks, 43% for 2 weeks, 38% for 1 week, and one cultivar did not maintain quality during the postharvest evaluation. Reduced end-of-production fertilization rate (EPFR) resulted in higher quality ratings for at least one additional week of simulated shelf life for three cultivars, including 'Dreamtime Copper' bracteantha (*Bracteantha bracteata*), 'Vanilla Sachet' nemesia (*Nemesia ×hybrida*), and 'Bridal Showers' sutera (*Sutera hybrida*). 'Comet White' and 'Sunlight' argyranthemum (*Argyranthemum frutescens*) retained flowers an additional 2 weeks and 'Caritas Lavender' angelonia (*Angelonia angustifolia*), 'Dreamtime Copper' bracteantha, 'Liricashowers Deep Blue Imp.' and 'Starlette Trailing Purple' calibrachoa (*Calibrachoa* hybrid), 'Vanilla Sachet' nemesia, 'Cascadias Pink' petunia (*Petunia ×hybrida*), and 'Bridal Showers' sutera retained flowers an additional 1 week when treated with 0% compared with 50% or 100% EPFR. Four cultivars had decreased plant width at harvest with 0% EPFR. These results indicate that reducing fertilization 2 weeks before harvest can prolong shelf life of some vegetative annuals. Differences in the length of shelf life and responses to reduced EPFR occurred among cultivars of all the affected species. Reduced EPFR did not increase the shelf life of two species, including diascia (*Diascia ×hybrida*) and lantana (*Lantana camara*).

Preparing containerized garden plants for postproduction stress and reducing stress during transport and retail is important to reducing financial losses for the grower and retailer. Pay-by-scan marketing dictates that growers are paid when the consumer buys their product. Therefore, reduced shrinkage during shelf life increases revenue. Improved quality in products purchased by the consumer leads to greater consumer satisfaction and encourages repeat purchasing.

Factors influencing shelf life of a crop begin during production (Jones, 2002). Fertility "hardening off" or "toning" is a production practice that has been shown to increase shelf life of a variety of flowering potted plants and foliage plants (Jones, 2002; Roude and Barrett, 1991). For greenhouse production of bedding plants, toning recommendations include reducing night temperature to 50 to 55 °F, reducing irrigation frequency, and reducing fertilization by at least one half at the time of visible bud (McCann, 1991).

Terminating fertilizer has not been widely used for bedding plants because in the past they had such small growing media volumes and little nutrient reserves to sustain them (Jones, 2002). Today, however, with the use of larger containers for marketing bedding plants, this practice needs to be reexamined. Many garden plants are being produced as vegetative cuttings, which require production in larger pots (i.e., ≥4-inch-diameter). The increased root substrate volume allowable in pots versus plugs and cell packs is conducive to increased postproduction longevity because more water can be held for a longer time so that plants do not dry out as quickly. Using larger pot sizes and different media choices are two ways growers can influence how plants will survive postproduction water stress (Jones, 2002).

Fertilizer toning by reducing production fertilizer rate throughout production or by decreasing or ceasing end-of-production fertilization rate for 3 weeks or more increased postproduction longevity of flowering potted plants and foliage plants. Higher-quality schefflera (*Schefflera arboricola* and *Brassaia actinophylla*) were maintained for 3 months in an interior environment (Brasswell et al., 1982), the shelf life of chrysanthemum (*Dendranthemum grandiflorum*)

This research was funded in part by the Texas AgriLife Research and Floriculture Industry Research and Scholarship Trust (FIRST).

We thank Ball Horticulture, EuroAmerican Propagators, and Paul Ecke Ranch for donation of plant materials.

Mention of a trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the author, Texas A&M University, or Texas AgriLife Research, and does not imply its approval to the exclusion of other products or vendors that also may be suitable.

[1]Department of Horticultural Sciences, 2133 TAMU, Texas A&M University, College Station, TX 77843

[2]Department of Horticultural Sciences, Texas AgriLife Research and Extension Center at Overton, Overton, TX 75684

[3]Department of Entomology, 2475 TAMU, Texas A&M University, College Station, TX 77843

[4]Former Graduate Student.

[5]Associate Professor of Floriculture.

[6]Research Assistant.

[7]Professor.

[8]Corresponding author. E-mail: tstarman@tamu.edu.

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
10.7639	fc	lx	0.0929
29.5735	fl oz	mL	0.0338
0.3048	ft	m	3.2808
2.54	inch(es)	cm	0.3937
16.3871	inch^3	mL	0.0610
28.3495	oz	g	0.0353
0.001	ppm	g·L^{-1}	1000
1	ppm	mg·L^{-1}	1
(°F – 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

was increased by up to 7 d (Nell et al., 1989), and less bract necrosis occurred on poinsettia (*Euphorbia pulcherrima*) (Nell and Barrett, 1986). Decreased flower senescence occurred on campanula (*Campanula carpatica*) (Serek, 1990) and wax begonia (*Begonia* × *semperflorens-cultorum*) (Conover et al., 1993), extending their shelf life.

Higher carbohydrate reserves improve a plant's chance of survival when it leaves the greenhouse and is moved to less-than-ideal postproduction environments (Jones, 2002). Excessive N supply during cultivation causes secondary salt stress, leading to decreased carbohydrate levels, coinciding with low photosynthetic capacity, and leading to postproduction carbohydrate deficiency (Druege, 2001). Nitrogen influences C allocation, and the concentration of sugar and starch is decreased with increased N supply. In addition, salt-stressed roots have higher carbohydrate requirement for maintenance of respiration (Druege, 2001).

Reducing production fertilization rate at the end of production has not been applied to vegetative annual garden plants grown in larger pots versus seed-propagated bedding plants grown in bedding plant flats. The objective of this study was to determine the effects of reduced end-of-production fertilization rate on plant width at harvest, flower abscission during shelf life, and postproduction quality of 21 cultivars of vegetative annuals.

Materials and methods

Cool-season vegetative annuals. Twenty-milliliter–rooted liners (105 rooted liners/tray) from Flower Fields (Paul Ecke Ranch, Encinitas, CA) were received on 7 Jan. 2003 and were planted on 10 and 13 Jan. Twenty-seven-milliliter–rooted liners (34 rooted liners/strip, three strips/tray) from Simply Beautiful (Ball FloraPlant, Ball Horticulture, Chicago) were received on 14 Jan. and were planted on 15 and 16 Jan. Plant cultivars included Comet White and Sunlight argyranthemum or marguerite daisy; Liricashowers Deep Blue Imp., Starlette Trailing Purple, and Superbells Trailing Blue calibrachoa; Sun Chimes Coral diascia; Aromatica White and Vanilla Sachet nemesia; and Bridal Showers and Candy Floss Blue sutera or bacopa.

All were planted in soilless media (Pro Mix BX; Premier Brands, Quakertown, PA) in 4.5-inch-diameter (415-mL) geranium pots (Dillon Products, Middlefield, OH). Plants were hand watered with reverse osmosis water and were fertilized each time they were irrigated. From planting to 28 Jan., 15N–5.4P–14.1K (Peter's Professional; Scotts-Sierra Horticultural Products, Marysville, OH) water-soluble fertilizer was used at 200 mg·L^{-1} N. From 29 Jan. to 11 Feb., the fertilizer rate was increased to 300 mg·L^{-1} N. From 12 Feb. until harvest, 20N–3.4P–16.6K (Peter's Professional) fertilizer was applied at 300 mg·L^{-1} N. On 31 Jan. and at 4-week intervals from this date, 3 g·L^{-1} Soluble Trace Element Mixture (STEM; Peter's Professional) was applied to the plants during irrigation. On 11 Mar., calibrachoa and petunia cultivars received a 20% iron sulfate drench at 1.75 g per pot (to lower substrate pH and prevent iron deficiency symptoms; i.e., chlorosis of new foliage).

Plants were grown in a glass and polycarbonate greenhouse at 18/13 °C day/night temperature set points. The measured day/night temperatures were 18.0 ± 6.2 °C/13.3 ± 6.1 °C. Actual greenhouse temperatures were measured using data loggers (HOBO H8; Onset Computer, Bourne, MA). Average noontime light levels were measured at 145.44 µmol·m^{-2}·s^{-1} photosynthetic photon flux (*PPF*) using an Integrated Spectrum Datalogger (Apogee Instruments, Logan, UT).

Petunia cultivars had been sporadically pinched by the grower; any petunia plants not pinched previously were pinched on 31 Jan. 'Bridal Showers' and 'Candy Floss Blue' sutera were pinched on 7 Feb. For height control, a tank mix of paclobutrazole (40 mg·L^{-1}, Bonzi; Uniroyal Chemical, Middlebury, CT) and daminozide (2500 mg·L^{-1}, B-Nine; Uniroyal Chemical) was applied as a foliar spray to runoff (≈10 mL/pot) to 'Sunlight' argyranthemum on 31 Jan. and 'Comet White' argyranthemum on 5 Feb.

Warm-season vegetative annuals. Twenty-seven-milliliter–rooted liners from Simply Beautiful and 20-mL–rooted liners (84 rooted liners/tray) from Flower Fields and from Proven Winners (EuroAmerican Propagators, Bonsall, CA) were received on 26 and 27 Feb. and were planted on 12 March. Plant cultivars included Caritas Lavender angelonia; Dreamtime Copper, Dreamtime Cream, Florabella White, Florabella Gold, Sundaze Bronze, and Sundaze Golden Yellow bracteantha or strawflower; Lucky Lemon Cream and Lucky Peach Sunrise lantana; and Cascadias Pink and Suncatcher Pink petunia.

All were planted in soilless media (Sunshine Mix #1; SunGro Horticulture, Bellevue, WA) because of the lack of availability of the media used previously. Pot size depended on growth habit of the cultivar and included 4.5-inch-diameter (415-mL) geranium pots, 5.0-inch-diameter (535-mL) azalea pots (Dillon Products), or 4.5-inch-diameter (430-mL) azalea pots (ITML Horticultural Products, Brantford, ON, Canada). The plants were grown at 24/18 °C day/night temperature set points with actual temperatures of 24.0 ± 3.6 °C/20.0 ± 4.7 °C day/night. The average noontime light levels measured were 216.59 µmol·m^{-2}·s^{-1} *PPF*. A 50% interior shadecloth was applied on 2 Apr. for the remainder of the experiment. Plants were hand watered with reverse osmosis water and were fertilized at each irrigation with 20N–3.4P–16.6K at 300 mg·L^{-1} N. STEM was applied every 4 weeks. On 28 Mar., calibrachoa cultivars received a 20% iron sulfate drench at 1.75 g per pot. A paclobutrazol (40 mg·L^{-1}) and daminozide (2500 mg·L^{-1}) tank mix was applied as a foliar spray to runoff (10 mL/pot) to bracteantha cultivars for height control. These cultivars were Florabella White bracteantha treated on 24 Jan. and Florabella Gold bracteantha treated on 31 Jan.

Cool and warm-season vegetative annuals. Two weeks before and until harvest, plants were treated with one of three EPFR with 20N–3.4P–16.6K: 1) continuation of fertilization at 300 mg·L^{-1} N (100% EPFR), 2) reduction in fertilization to 150 mg·L^{-1} N (50% EPFR), and 3) termination of fertilization to 0 mg·L^{-1} N (0% EPFR). Each of the 21 cultivars was arranged separately in a completely randomized design because comparisons were not made among cultivars. This arrangement facilitated watering, by hand, all plants of the same cultivar with the same frequency as needed (i.e., when the medium surface was dry and light in color) with 120 mL of fertilizer solution. A single plant represented an experimental unit and each treatment was replicated six times for a total of 18 plants per cultivar.

Plants were harvested when they were judged marketable (i.e., had enough foliage that the root substrate in the container was not visible and the plants looked full and were flowering). Cultivars of the same species were harvested at the same time or when they reached a comparable, stipulated stage of development. Data taken at harvest included plant width, number of flowers, and plant quality. Plant width was the mean of two plant width measurements taken perpendicular to each other across the plant canopy.

After harvest, plants were moved to a controlled-environment room to simulate shelf life for postharvest evaluation. The room was 30 ft long × 8 ft 10 inches wide × 8 ft high and was equipped with 3-ft-wide two-tiered benches against each wall running the length of the room with a center aisle for accessing the plants. All plants were completely randomized on the bottom bench tier and spaced so that leaves were not touching. Black, polypropylene shadecloth (45%) was placed on the top bench tier to reduce and evenly diffuse the light level from 400-W metal halide lamps located in the ceiling of the room. The light intensity was measured 20 times across the bottom shelf of each bench at plant canopy level with a digital light meter (model FCM-10M+; Phytotronics, St. Louis) and averaged 30.05 ± 4.79 fc. Lights were turned on from 0800 to 1700 HR for a 9-h photoperiod. The temperature in the room was 21.1 ± 1.3 °C. The growing medium was maintained moist by hand watering with plain reverse osmosis water during the 3 weeks the plants remained in the growth room. No additional fertilizer was applied during the interior holding phase. Flower number and quality rating were recorded weekly for each postharvest time of measurement (weeks 1–3).

The plant quality rating was assessed on a point scale of 5 to 0 with 5 being the highest quality. Postharvest quality ratings were defined as 5 = plant is healthy with no visible decline symptoms, 4 = <50% flower abscission and/or visible change in flower color or <10% chlorotic lower leaves, 3 = 100% flower abscission or <50% chlorotic lower leaves or <10% senesced lower leaves, 2 = >50% senesced lower leaves and 100% flower abscission or <10% dead stems, 1 = >10% dead stems, 100% flowers abscised or 100% lower leaves senesced, and 0 = total plant senescence. A plant was no longer considered marketable when the quality rating was lower than a rating of 3.

Postharvest flower data were square root transformed to satisfy the homogeneity of variance assumption. The covariance structure chosen to capture the repeated measures aspect follows the methods given in Littell et al. (2006). All data were analyzed using the Mixed Model procedure of SAS (version 9.1.3; SAS Institute, Cary, NC). Because many (likely correlated) statistical tests were conducted, an alpha level of 0.005 was chosen to help control the experiment-wise error rate. Mean separation was determined using the Tukey-Kramer adjustment at $P \leq 0.005$.

Results

At harvest, i.e., plants moved from production greenhouse to postharvest chamber, there were no statistical differences in number of flowers or plant quality due to EPFR treatments for all 21 cultivars. However, 0% EPFR decreased plant width from 4 to 9 cm for four of the cultivars (data not shown). These cultivars included Comet White argyranthemum, Florabella Gold bracteantha, Liricashowers Deep Blue Imp. calibrachoa, and Cascadias Pink petunia. Although this was not the primary reason for using reduced EPFR, it was a positive side effect of the treatments because reduced width is accommodating in packing and shipping practices. Advantageously, reduced EPFR treatments did not decrease flower number of any cultivar at harvest.

The results of the postharvest evaluation were consistent for the 21 cultivars in that whenever the EPFR × time (postharvest time of measurement) interaction was nonsignificant, the main effect of EPFR treatment was also nonsignificant. The main effect of postharvest time of measurement was always significant for flower number and plant quality with one exception, flower number of 'Sundaze Golden Yellow' bracteantha.

ANGELONIA. The EPFR × time interaction was nonsignificant for quality rating for 'Caritas Lavender' angelonia. Quality ratings declined over the postharvest evaluation time regardless of EPFR from 5 at harvest to below marketable quality week 2 (Table 1). The EPFR × time interaction was significant for number of flowers for 'Caritas Lavender' angelonia tested on the square root scale (Fig. 1A). The number of flowers in week 1 (average of 20 flowers) did not differ among EPFR treatments. By week 2, only 0% EPFR retained flowers (eight flowers), and by week 3, all treatments had abscised all flowers. In addition to flower senescence, chlorosis of lower leaves and internode elongation contributed to the demise of angelonia during shelf life. This was the only cultivar of angelonia available at the time that our experiment was conducted; hence, another cultivar may have fared differently.

ARGYRANTHEMUM. The EPFR × time interaction was nonsignificant for quality rating for 'Comet White' argyranthemum. 'Comet White' argyranthemum quality ratings declined from 5 to below marketable quality week 2 (Table 1). The EPFR × time interaction was significant for the number of flowers for 'Comet White' argyranthemum tested on the square root scale (Fig. 1B). Although all 'Comet White' plants opened flowers from harvest (average of three flowers) to week 1 (average of six flowers), the 50% and 100% EPFR-treated plants abscised all but one flower week 2, while 0% EPFR retained seven flowers through week 3 (Fig. 1B). Decreases in quality ratings for 'Comet White' argyranthemum were due not only to flower abscission, but also to chlorosis of lower leaves.

The EPFR × time interaction was significant for quality and number of flowers for 'Sunlight' argyranthemum. All plants remained at a quality rating of 5 through week 1 (Table 2). The 0% EPFR-treated plants had the highest quality rating week 3, although not significantly different from 100% EPFR, resulting in a lower percentage of change in quality compared with the other treatments.

Table 1. Common and cultivar name and the effect of postharvest time of measurement regardless of end-of-production fertilization rate (EPFR) on plant quality ratings. Times of postharvest measurement were at the end of greenhouse production (harvest) and subsequently at three 1-week intervals.

		Time of postharvest measurement								Change from harvest to 3 wks (%)
		Harvest		1 wk		2 wk		3 wk		
Common name	Cultivar	Quality rating on 0–5 scale [mean (SE)][z]								
Angelonia	Caritas Lavender	5.00 a[y]	(0.00)	3.44 b	(0.12)	2.00 c	(0.14)	1.61 c	(0.16)	68
Argyranthemum	Comet White	5.00 a	(0.00)	4.50 a	(0.17)	2.78 b	(0.19)	1.17 c	(0.23)	77
Bracteantha	Florabella Gold	5.00 a	(0.00)	2.89 c	(0.14)	3.39 b	(0.12)	2.89 c	(0.11)	42
	Florabella White	5.00 a	(0.00)	4.00 b	(0.00)	3.94 b	(0.06)	2.11 c	(0.33)	59
	Sundaze Bronze	5.00 a	(0.00)	2.33 b	(0.42)	0.39 c	(0.18)	0.00 c	(0.00)	100
	Sundaze Golden Yellow	5.00 a	(0.00)	3.33 b	(0.26)	1.00 c	(0.36)	0.17 c	(0.12)	97
Calibrachoa	Liricashowers DBI[x]	5.00 a	(0.00)	4.06 b	(0.06)	2.78 c	(0.10)	1.50 d	(0.15)	70
	Starlette Trailing Purple	5.00 a	(0.00)	5.00 a	(0.00)	2.89 b	(0.18)	1.83 c	(0.22)	63
	Superbells Trailing Blue	5.00 a	(0.00)	3.94 b	(0.13)	0.94 c	(0.40)	0.50 c	(0.27)	90
Diascia	Sun Chimes Coral	5.00 a	(0.00)	3.22 b	(0.21)	1.89 c	(0.34)	1.00 d	(0.27)	80
Lantana	Lucky Lemon Cream	5.00 a	(0.00)	4.00 b	(0.11)	1.94 c	(0.41)	1.11 c	(0.38)	78
	Lucky Peach Sunrise	5.00 a	(0.00)	4.83 a	(0.09)	4.06 b	(0.06)	3.83 b	(0.12)	23
Petunia	Suncatcher Pink	5.00 a	(0.00)	4.30 b	(0.16)	3.10 c	(0.13)	1.70 d	(0.11)	66

[z]5 = best, <3 = not marketable, 0 = dead.
[y]Mean separation in rows by Tukey-Kramer at $P \leq 0.005$.
[x]DBI = Deep Blue Improved.

'Sunlight' argyranthemum number of flowers did not differ due to EPFR treatment until after week 1, when only 0% EPFR-treated plants had two flowers week 2 and one flower week 3 (Fig. 1C).

Argyranthemum cultivars responded similarly to reduced EPFR in regard to flower senescence. However, 'Sunlight' had not developed as many flowers at the time of harvest as 'Comet White' and may have not had enough stored carbohydrates to open new flowers because bud abortion was observed on this cultivar during shelf life. Both of the cultivars suffered from chlorosis of lower leaves during postharvest.

Bracteantha. Two cultivars of each of three series of bracteantha were used in this study. Compared with the other species, bracteantha was slow to develop during greenhouse production and, at harvest, had three to eight flower buds depending on cultivar. Bracteantha flowers open and close throughout the day according to light intensity, making it difficult to distinguish between the stages of flower development, therefore, the flower buds were added to open flowers to calculate flower number for these cultivars.

The EPFR treatments interacted with postharvest time of measurement for quality rating of 'Dreamtime Copper' and 'Dreamtime Cream' bracteantha. 'Dreamtime Copper' bracteantha 100% EPFR plants had a lower quality rating than 0% or 50% EPFR by week 2 and plants in that treatment group were totally senesced by week 3 (Table 2). 'Dreamtime Cream' 0% EPFR plants were higher quality than 50% and 100% at week 3, although below marketable (>3.0) quality, resulting in a lower percentage of change in quality compared with the other treatments. There was not an EPFR × time interaction for quality for the other four bracteantha cultivars. Regardless of EPFR treatment, the last marketable quality ratings were at week 2 for 'Florabella Gold' and 'Florabella White', at harvest for 'Sundaze Bronze' and week 1 for 'Sundaze Golden Yellow' (Table 1). Bracteantha quality was compromised during postharvest shelf life by chlorosis of lower leaves and internode elongation in addition to bud abortion and flower senescence.

The EPFR × time interaction was significant for number of flowers for 'Dreamtime Copper' bracteantha. The 0% EPFR treatment extended flower retention 1 week compared with 50% and 100% EPFR for 'Dreamtime Copper' bracteantha (Fig. 2A). The number of flowers week 2 was greater for 0% (average of seven flowers) than 50% (average of three flowers) and 100% (average of one flower), which were not different. Week 3, 0% and 50% EPFR had two flowers and 100% had zero flowers, although none of the treatments were different statistically. There was not an EPFR × time interaction for the other five bracteantha cultivars, but the main effect of postharvest time of measurement affected number of flowers for these cultivars, with the exception of 'Sundaze Golden Yellow' (data not shown). 'Dreamtime Cream' bracteantha flower number at harvest (average of eight flowers) did not decrease until week 3 (Table 3). For the Florabella cultivars, flower number increased or remained the same throughout the postharvest evaluation, regardless of EPFR (Table 3). 'Sundaze Bronze' decreased flower number from at harvest (average eight flowers) to week 1 (average five flowers) to week 2 (average zero flowers), and by week 3, all plants were dead (Table 3).

Calibrachoa. There was not an EPFR × time interaction on quality for the three calibrachoa cultivars, but postharvest time of measurement did affect their quality. From harvest time, the 5-point quality rating for 'Liricashowers Deep Blue Imp.', 'Starlette Trailing Purple' and 'Superbells Trailing Blue' calibrachoa

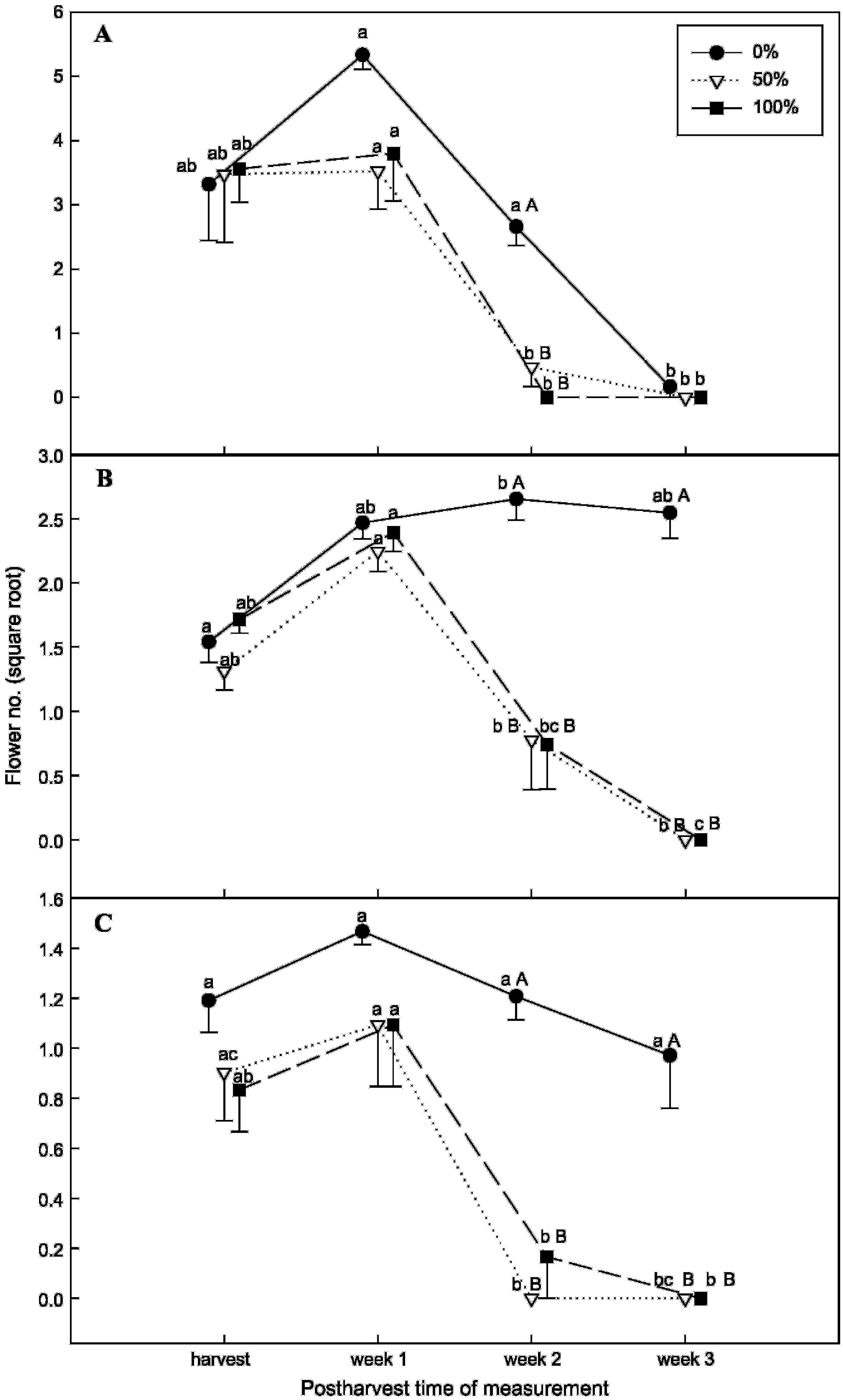

Fig. 1. Effect of 0% [termination of fertilization to 0 mg·L^{-1} nitrogen (1 mg·L^{-1} = 1 ppm)], 50% (reduction in fertilization to 150 mg·L^{-1} nitrogen), or 100% (continuation of fertilization at 300 mg·L^{-1} nitrogen) end-of-production fertilization rate (EPFR) 2 weeks before and until harvest and postharvest time of measurement on number of flowers for (A) 'Caritas Lavender' angelonia, (B) 'Comet White' argyranthemum, and (C) 'Sunlight' argyranthemum. Times of postharvest measurement were at the end of greenhouse production (harvest) and subsequently at three 1-week intervals. Mean separation within EPFR treatments (lowercase letters) and among EPFR treatments (uppercase letters) by Tukey-Kramer at $P \leq 0.005$. SE were based on the data and were symmetrical about the mean but only the bottom half of the bars are shown. Data points without an error bar had no (or very little) variability.

decreased below 3 week 2, regardless of EPFR treatment (Table 1). The reduced quality rating over time for calibrachoa cultivars was provoked by flower color fading, flower size decrease, chlorosis of lower leaves, and internode elongation.

There was an EPFR × time interaction for number of flowers for 'Liricashowers Deep Blue Imp.' and 'Starlette Trailing Purple' calibrachoas. 'Liricashowers Deep Blue Imp.' 0% EPFR plants opened flowers from harvest (average of 15 flowers) to week 1 (average of 26 flowers) (Fig. 2B). Flower number declined to zero by week 2 for 50% and 100% EPFR-treated plants, while 0% EPFR-treated plants still had an average of 14 flowers. 'Starlette Trailing Purple' calibrachoa 0% EPFR plants had an average of 11 flowers week 2, while the other EPFR treatments had 100% abscission by that time (Fig. 2C). There was no EPFR × time interaction on 'Superbells Trailing Blue' calibrachoa number of flowers, although there was an effect of postharvest time of measurement. Plants averaged eight flowers at harvest and abscised all flowers by week 1, regardless of EPFR treatment (Table 3). 'Superbells Trailing Blue' calibrachoa was not as floriferous at harvest as the other two cultivars.

DIASCIA. The EPFR × time interaction was nonsignificant for quality for 'Sun Chimes Coral' diascia. All plants were rated 5 at harvest, but after week 1, none of the treatments were marketable (Table 1). The EPFR × time interaction was significant for number of flowers for 'Sun Chimes Coral' diascia. The 50% EPFR plants had fewer flowers (average of six flowers) compared with 0% (average of 19 flowers) and 100% (average of 22 flowers) at week 1 (data not shown). By week 2, there was 100% flower abscission in all treatments. In addition to flower abscission, chlorosis of lower leaves, flower color fading and stem dieback were observed on diascia.

LANTANA. The EPFR × time interaction was nonsignificant for quality or number of flowers for the two lantana cultivars. 'Lucky Lemon Cream' plants decreased in quality from 5 at harvest to below marketable quality at week 2, regardless of EPFR (Table 1). 'Lucky Peach Sunrise' quality was marketable the entire

Table 2. Common and cultivar name and the effect of end-of-production fertilization rate (EPFR) and postharvest time of measurement on plant quality ratings. Times of postharvest measurement were at the end of greenhouse production (harvest) and subsequently at three 1-week intervals.

			Time of postharvest measurement								
			Harvest		1 wk		2 wk		3 wk		Change from harvest to 3 wks (%)
Common name	Cultivar	End-of-production fertilization rate (%)	Quality rating on 0–5 scale [mean (SE)][z]								
Argyranthemum	Sunlight	0	5.00 A a[y]	(0.00)	5.00 A a	(0.00)	3.17 A b	(0.17)	2.67 A b	(0.21)	47
		50	5.00 A a	(0.00)	5.00 A a	(0.00)	2.67 A b	(0.21)	1.17 B c	(0.40)	77
		100	5.00 A a	(0.00)	5.00 A a	(0.00)	3.50 A b	(0.22)	2.00 AB c	(0.52)	60
Bracteantha	Dreamtime Copper	0	5.00 A a	(0.00)	4.33 A a	(0.33)	3.67 A a	(0.42)	0.83 A b	(0.54)	83
		50	5.00 A a	(0.00)	4.33 A a	(0.21)	2.50 A b	(0.72)	1.00 A b	(0.63)	80
		100	5.00 A a	(0.00)	3.50 A a	(0.34)	0.50 B b	(0.50)	0.00 A b	(0.00)	100
	Dreamtime Cream	0	5.00 A a	(0.00)	4.83 A ab	(0.17)	4.33 A ab	(0.21)	2.83 A b	(0.17)	43
		50	5.00 A a	(0.00)	4.67 A a	(0.21)	4.50 A a	(0.22)	1.00 B b	(0.45)	80
		100	5.00 A a	(0.00)	4.83 A a	(0.91)	2.83 A b	(0.91)	0.83 B c	(0.54)	83
Nemesia	Aromatica White	0	5.00 A a	(0.00)	4.17 A a	(0.17)	3.00 A b	(0.00)	2.00 AB b	(0.37)	60
		50	5.00 A a	(0.00)	4.00 A a	(0.00)	1.67 B b	(0.42)	0.83 B b	(0.54)	83
		100	5.00 A a	(0.00)	4.00 A a	(0.00)	2.83 A b	(0.17)	2.33 A b	(0.21)	53
Nemesia	Vanilla Sachet	0	5.00 A a	(0.00)	5.00 A a	(0.00)	3.50 A b	(0.22)	3.00 A b	(0.00)	40
		50	5.00 A a	(0.00)	4.00 B b	(0.00)	3.00 B c	(0.00)	3.00 A c	(0.00)	40
		100	5.00 A a	(0.00)	4.00 B b	(0.00)	2.83 B c	(0.17)	1.17 B d	(0.48)	77
Petunia	Cascadias Pink	0	5.00 A a	(0.00)	5.00 A a	(0.00)	3.67 A b	(0.21)	2.83 A b	(0.17)	43
		50	5.00 A a	(0.00)	5.00 A a	(0.00)	2.17 B b	(0.31)	0.33 B c	(0.21)	93
		100	5.00 A a	(0.00)	5.00 A a	(0.00)	2.67 A b	(0.21)	2.00 A b	(0.45)	60
Sutera	Bridal Showers	0	5.00 A a	(0.00)	4.00 A b	(0.21)	3.33 A ab	(0.00)	4.00 A b	(0.00)	20
		50	5.00 A a	(0.00)	4.00 A bc	(0.26)	3.00 A ab	(0.00)	2.50 B c	(0.34)	50
		100	5.00 A a	(0.00)	4.00 A b	(0.34)	2.50 A a	(0.00)	2.00 B b	(0.52)	60
Sutera	Candy Floss Blue	0	5.00 A a	(0.00)	3.00 A b	(0.00)	3.00 A ab	(0.00)	2.83 A ab	(0.40)	43
		50	5.00 A a	(0.00)	2.50 A b	(0.34)	1.00 A c	(0.68)	0.00 B c	(0.00)	100
		100	5.00 A a	(0.00)	3.00 A b	(0.26)	2.17 A bc	(0.75)	0.50 B c	(0.50)	90

[z] 5 = best, <3 = not marketable, 0 = dead.
[y] Mean separation within cultivars and EPFR treatments in rows (lowercase letters) and within cultivars among EPFR treatments in columns (uppercase letters) by Tukey-Kramer at $P \leq 0.005$.

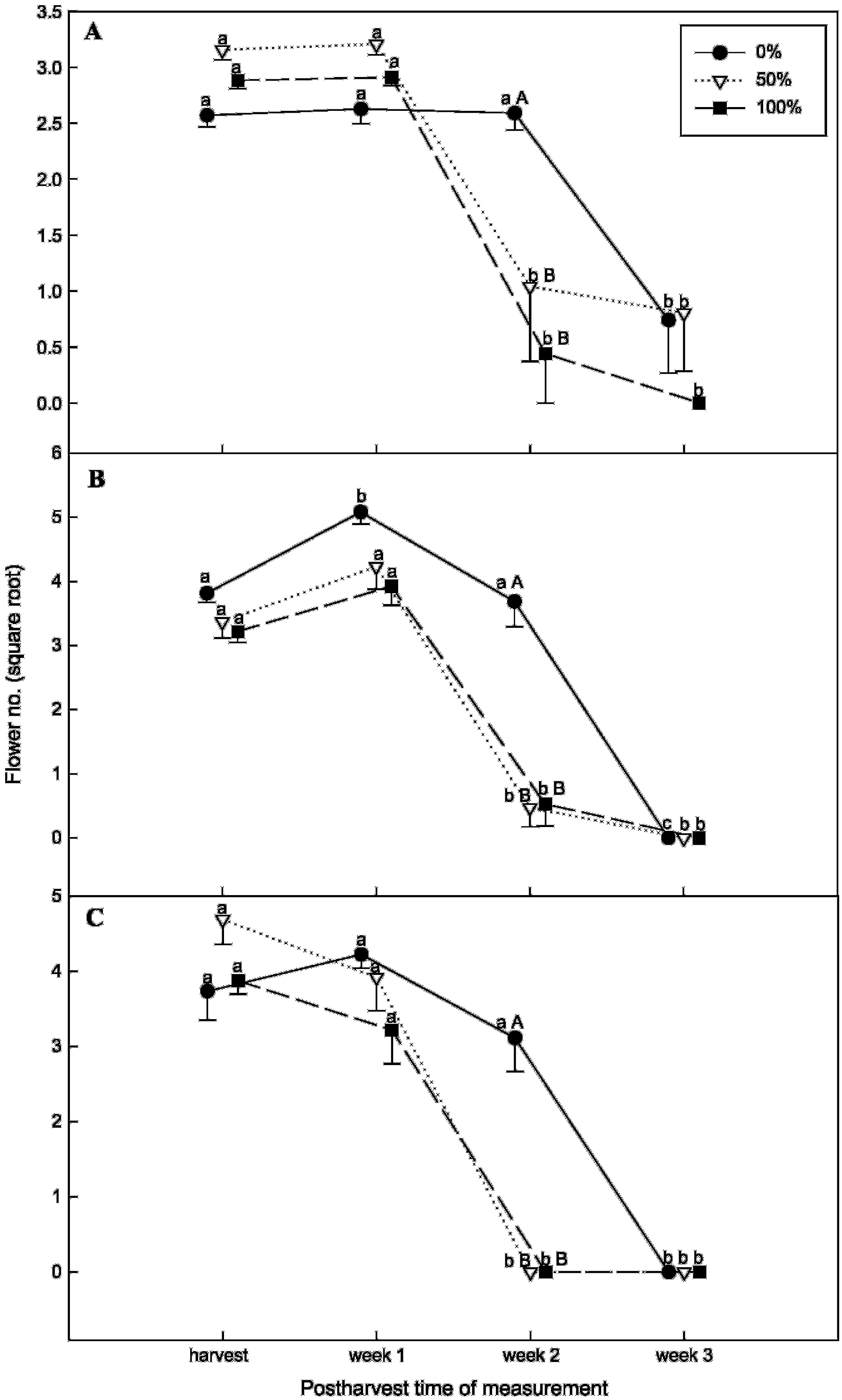

Fig. 2. Effect of 0% [termination of fertilization to 0 mg·L^{-1} nitrogen (1 mg·L^{-1} = 1 ppm)], 50% (reduction in fertilization to 150 mg·L^{-1} nitrogen), or 100% (continuation of fertilization at 300 mg·L^{-1} nitrogen) end-of-production fertilization rate (EPFR) 2 weeks before and until harvest and postharvest time of measurement on number of flowers for (A) 'Dreamtime Copper' bracteantha, (B) 'Liricashowers Deep Blue Imp.' calibrachoa, and (C) 'Starlette Trailing Purple' calibrachoa. Times of postharvest measurement were at the end of greenhouse production (harvest) and subsequently at three 1-week intervals. Mean separation within EPFR treatments (lowercase letters) and among EPFR treatments (uppercase letters) by Tukey-Kramer at $P \leq 0.005$. SE were based on the data and were symmetrical about the mean but only the bottom half of the bars are shown. Data points without an error bar had no (or very little) variability.

duration of the evaluation because the leaves remained dark green (Table 1). Time affected the number of flowers on the lantana cultivars. At harvest, the number of flowers averaged three and five for lantana 'Lucky Lemon Cream' and 'Lucky Peach Sunrise', respectively (Table 3). By week 2, both cultivars had 100% flower abscission.

NEMESIA. The EPFR × time interaction affected quality of both nemesia cultivars. The quality of 'Aromatica White' nemesia 0% EPFR plants were rated marketable 1 week longer than 50% EPFR, although none of the treatments were marketable week 3 (Table 2). The higher quality was due to less chlorosis of lower leaves and internode elongation in the 0% EPFR plants compared with the 50% EPFR plants. Quality rating of 'Vanilla Sachet' nemesia 0% EPFR plants was higher weeks 1 and 2 than 50% and 100% EPFR and were still marketable week 3 (Table 3). At harvest, 'Aromatica White' nemesia plants averaged 50 flowers and abscised all flowers by week 1 (Table 3). There was an EPFR × time interaction for number of flowers on 'Vanilla Sachet' nemesia. Plants treated with 0% EPFR opened flowers from harvest (average of 14 flowers) to week 1 (average of 26 flowers), while plants in the other treatments had zero flowers week 1 (Fig. 3A). The 0% EPFR plants decreased to an average of two flowers by week 2 and zero flowers by week 3.

PETUNIA. There was an EPFR × time interaction for 'Cascadias Pink' petunia quality. 'Cascadias Pink' petunia plants treated with 0% EPFR remained higher quality week 2 compared with 50% EPFR and was the only treatment rated marketable although not different from 100% EPFR (Table 2). The EPFR × time interaction was nonsignificant for 'Suncatcher Pink' petunia plants but postharvest time of measurement affected plant quality. Plants were rated 5 at harvest and then declined each week and were not marketable by week 3 regardless of EPFR (Table 1). There was an EPFR × time interaction for the number of flowers for both petunia cultivars. 'Cascadias Pink' 0% EPFR plants opened and retained a greater number of flowers (average of five flowers) through week 2 compared with the other

Table 3. Common and cultivar name and the effect of postharvest time of measurement regardless of end-of-production fertilization rate (EPFR) on number of flowers tested on square root scale. Times of postharvest measurement were at the end of greenhouse production (harvest) and subsequently at three 1-week intervals.

		Time of postharvest measurement							
		Harvest		1 wk		2 wks		3 wks	
Common name	Cultivar	No. of flowers [mean (SE)]							
Bracteantha	Dreamtime Cream	2.6 a[z]	(0.1)	2.8 a	(0.1)	2.4 a	(0.2)	1.3 b	(0.3)
	Florabella Gold	1.5 a	(0.1)	2.0 b	(0.1)	1.8 c	(0.0)	1.9 bc	(0.1)
	Florabella White	0.6 a	(0.1)	0.9 a	(0.2)	1.2 b	(0.1)	0.8 a	(0.1)
	Sundaze Bronze	2.5 a	(0.2)	1.2 ab	(0.3)	0.1 b	(0.1)	—y	—
Calibrachoa	Superbells Tr. Blue	2.5 a	(0.2)	0.1 b	(0.1)	0.0 b	(0.0)	0.0 b	(0.0)
Lantana	Lucky Lemon Cream	1.2 a	(0.2)	0.2 b	(0.1)	0.0 b	(0.0)	0.1 b	(0.1)
	Lucky Peach Sunrise	2.1 a	(0.1)	1.1 b	(0.1)	0.1 c	(0.1)	0.0 c	(0.0)
Nemesia	Aromatica White	6.7 a	(0.2)	0.3 b	(0.3)	0.0 b	(0.0)	0.0 b	(0.0)

[z]Mean separation in rows by Tukey Kramer $P \leq 0.005$.
[y]Plants were dead.

treatments (Fig. 3B). Although all EPFR treatments for 'Suncatcher Pink' petunia opened flowers from harvest to week 1, the 50% and 100% EPFR plants opened twice as many flowers (average of 14 flowers for 50% and 13 flowers for 100%) compared with 0% (average of seven flowers). At week 2, there was no difference in number of flowers (average of 7 flowers) between EPFR treatments, and by week 3, none of the plants had flowers (data not shown).

Sutera. The sutera cultivars were of two species and differed morphologically in that 'Candy Floss Blue' had thinner leaves and stems than 'Bridal Showers'. The EPFR × time interaction was significant for quality of both cultivars. By week 3, only 0% EPFR 'Bridal Showers' sutera were marketable (Table 2). 'Candy Floss Blue' sutera 0% EPFR was the only treatment rated 3 week 2 and rated a higher quality week 3 compared with 50% or 100% EPFR (Table 2). A decline in the quality of 'Candy Floss Blue' was due to stem dieback in addition to flower abscission. The EPFR × time interaction was significant for the number of flowers for both sutera cultivars. The 0% EPFR treatment extended the amount of time flowers were retained on 'Bridal Showers' plants by 1 week compared with the other treatments (Fig. 3C). All flowers on 50% or 100% EPFR plants had abscised by week 1 whereas 0% EPFR plants still had an average of 17 flowers. Although the EPFR × time interaction was significant for 'Candy Floss Blue' number of flowers, this was due to an average of two new flowers opening on the 100% EPFR plants week 2, otherwise all treatments followed the same trend, which was to abscise all flowers from harvest (average of 70 flowers) to week 1 (data not shown).

Discussion

Reduced EPFR prolonged marketable postharvest quality (≥3.0) 1 week for 'Dreamtime Copper' bracteantha, 'Vanilla Sachet' nemesia, and 'Bridal Showers' sutera. Whether postharvest quality was prolonged for two additional cultivars, Dreamtime Cream bracteantha and Candy Floss Blue sutera, was questionable in that they had higher quality ratings, albeit below 3, with 0% EPFR treatment compared with 50% or 100% EPFR, during the final week of the evaluation. Nine cultivars had reduced flower abscission with 0% EPFR, including Caritas Lavender angelonia, Comet White and Sunlight argyranthemum, Dreamtime Copper bracteantha, Liricashower Deep Blue Imp. and Starlette Trailing Purple calibrachoa, Vanilla Sachet nemesia, Cascadias Pink petunia, and Bridal Showers sutera.

Only eight of the cultivars in this study were unaffected by reduced EPFR and included Florabella Gold, Florabella White, Sundaze Bronze and Sundaze Golden Yellow bracteantha, Superbells Trailing Blue calibrachoa, Sun Chimes Coral diascia, and Lucky Peach Sunrise and Lucky Lemon Cream lantana. While some plants will not respond to fertility toning with increased shelf life and resistance to stress, none to date have been reported to have a decrease in shelf life as a result of this practice (Jones, 2002). Although 38% of the cultivars we examined did not show any improved shelf life due to reduced EPFR, these treatments did not reduce shelf life. Moreover, McCann (1991) stated that one toning procedure is not applicable to every species.

Two species that did not respond with increased shelf life with reduced EPFR were diascia and lantana. Only one cultivar of diascia was tested due to availability at the time of the experiment. The shelf life of vegetative growth on lantana plants does not leave much room for improvement. The pubescent and scabrous leaves of this species help make it resistant to water deficit (Starman and Lombardini, 2006) and these morphological features may have contributed to the long shelf life observed despite EPFR treatment. In all other species in this study, there were differences in postharvest longevity between cultivars when multiple cultivars were tested. Genetics have been shown to exert a major influence on the interior performance of flowering potted plants (Nell and Hoyer, 1995).

Although factors influencing postproduction longevity begin during production, it is the combined effects of production, storage, and interior conditions that determine shelf life (Nell and Hoyer, 1995). The importance of carbohydrate reserves depends on postproduction

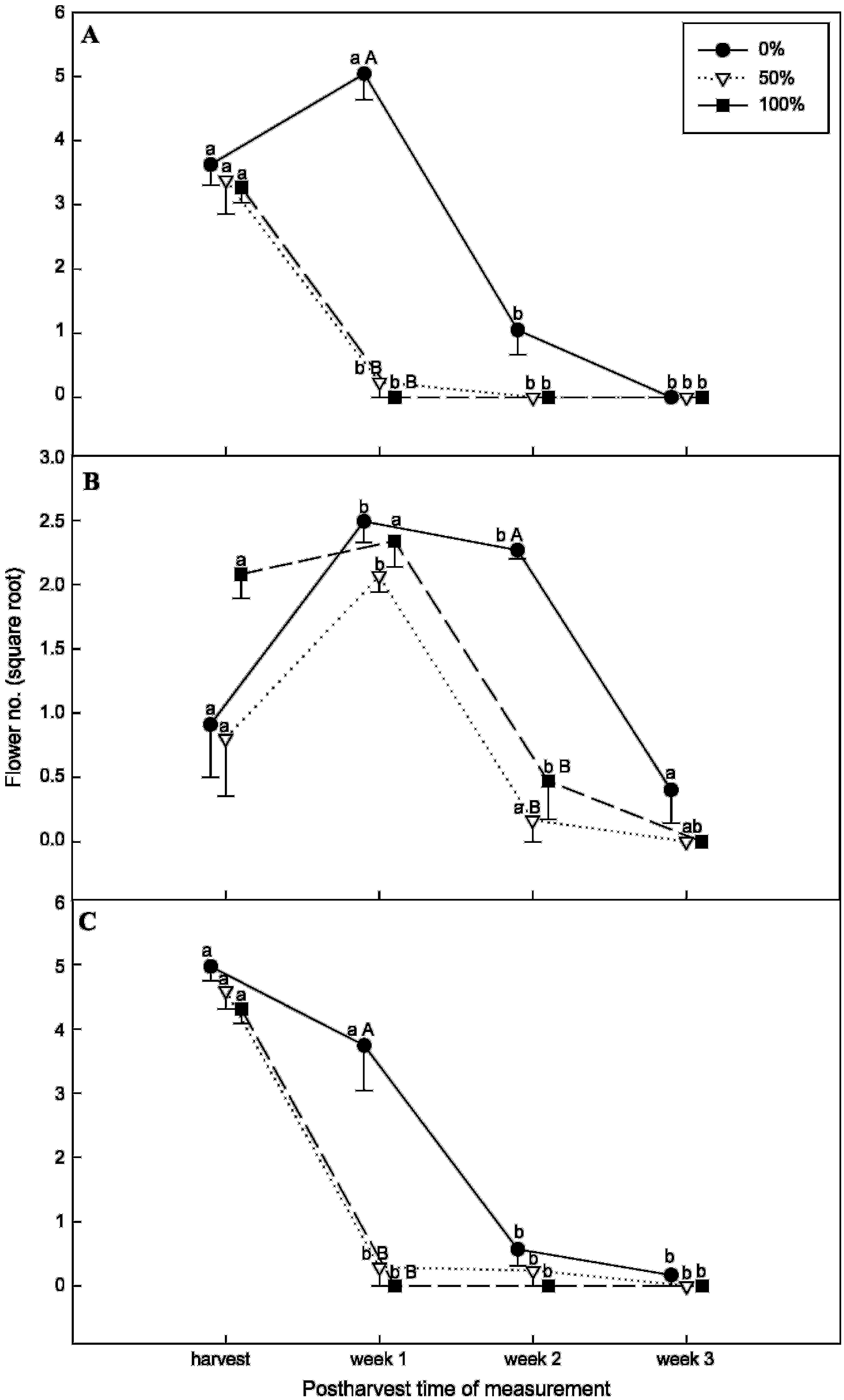

Fig. 3. Effect of 0% [termination of fertilization to 0 mg·L^{-1} nitrogen (1 mg·L^{-1} = 1 ppm)], 50% (reduction in fertilization to 150 mg·L^{-1} nitrogen) or 100% (continuation of fertilization at 300 mg·L^{-1} N) end-of-production fertilization rate (EPFR) 2 weeks before and until harvest and postharvest time of measurement on number of flowers for (A) 'Vanilla Sachet' nemesia, (B) 'Cascadias Pink' petunia, and (C) 'Bridal Showers' sutera. Times of postharvest measurement were at the end of greenhouse production (harvest) and subsequently at three 1-week intervals. Mean separation within EPFR treatments (lowercase letters) and among EPFR treatments (uppercase letters) by Tukey-Kramer at $P \leq 0.005$. SE were based on the data and were symmetrical about the mean but only the bottom half of the bars are shown. Data points without an error bar had no (or very little) variability.

light conditions (Druege, 2001). With flowering potted plants versus foliage plants, it is more important to continue the higher light intensities during production to build up carbohydrates so that these plants can survive better in postproduction environments with low light conditions (Jones, 2002). This may also be the case with the vegetative annual garden plants used in this study. Although the majority of cultivars lasted an average of 1 to 2 weeks, they may have lasted longer with higher light. Plant quality and number of flowers postharvest was higher as light intensity increased for wax begonia (*Begonia ×semperflorens-cultorum*) (Conover et al., 1993).

In this study, three cultivars (14%) had a shelf life of 3 weeks, nine cultivars (43%) had a shelf life of 2 weeks, and eight cultivars (38%) had a shelf life of 1 week. One cultivar did not last through the first week postharvest. Nell and Hoyer (1995) stated plants should survive a minimum of 2 weeks in an interior environment. In general for the vegetative annuals in this study, the number of flowers decreased and their quality decreased to unmarketable after 1 or 2 weeks of postharvest evaluation. The keeping quality of plants in this study was comparable to flowering potted plants, possibly due to the water holding capacity of the larger containers they were grown in. Larger containers that hold more water have been recommended for production so that garden plants do not dry out so fast (McCann, 1991).

In most crops, storage effects will not be evident at the termination of shipping, but will become obvious over a 4- to 10-d period under interior conditions (Nell and Hoyer, 1995). With the advent of pay-by-scan marketing, it has become more important for growers to be aware of how long their plants keep their quality in the market channel.

Reducing EPFR to 0% delayed flower abscission for 'Caritas Lavender' angelonia, 'Comet White' and 'Sunlight' argyranthemum, 'Dreamtime Copper' bracteantha, 'Lirica-shower Deep Blue Imp.' and 'Starlette Trailing Purple' calibrachoa, 'Vanilla Sachet' nemesia, 'Cascadias Pink' petunia, and 'Bridal Showers' sutera. The vegetative annual cultivars that had prolonged marketable quality with 0% or 50% EPFR compared with 100% EPFR were 'Dreamtime Copper' bracteantha, 'Vanilla Sachet' nemesia, and 'Bridal Showers' sutera. In addition, 'Dreamtime Cream' bracteantha, and 'Candy Floss Blue' sutera had higher quality ratings (albeit <3) with 0% EPFR compared with 50% or 100% EPFR. Therefore, we recommend that growers stop fertilizing these cultivars 2 weeks before harvest. This practice would improve shelf life while reducing fertilizer inputs, which would save on costs and environmental impact due to greenhouse runoff.

Literature cited

Brasswell, J.H., T.M. Blessington, and J.A. Price. 1982. Influence of cultural practices on postharvest interior performance of two species of schefflera. HortScience 17:345–347.

Conover, C.A., L.N. Satterthwaite, and K.G. Steinkamp. 1993. Production fertilizer and postharvest light intensity effects on begonias. Proc. Florida State Hort. Soc. 106:299–302.

Druege, U. 2001. Postharvest responses of different ornamental products to preharvest nitrogen supply: Role of carbohydrates, photosynthesis and plant hormones. Acta Hort. 543:97–105.

Jones, M.L. 2002. Postproduction care and handling. Ohio Florists' Assn. Bul. 872:15–16.

Littell, R.C., G.A. Milliken, W.W. Stroup, R.D. Wolfinger, and O. Schabenberger. 2006. SAS for mixed models. 2nd ed. SAS Institute, Cary, NC.

McCann, K.R. 1991. Toning techniques. Greenhouse Grower 9(3):42–46.

Nell, T.A. and J.E. Barrett. 1986. Growth and incidence of bract necrosis in 'Gutbier V-14 Glory' poinsettias. J. Amer. Soc. Hort. Sci. 111:266–269.

Nell, T.A. and L. Hoyer. 1995. Terminology and conditions for evaluation of flowering potted plant longevity. Acta Hort. 405:28–32.

Nell, T.A., J.E. Barrett, and R.T. Leonard. 1989. Fertilization termination influences postharvest performance of pot chrysanthemum. HortScience 24:996–998.

Roude, N.T.A.N. and J.E. Barrett. 1991. Nitrogen source and concentration, growing medium, and cultivar affect longevity of potted chrysanthemums. HortScience 26:49–52.

Serek, M. 1990. Effects of pre-harvest fertilization on the flower longevity of potted *Campanula carpatica* 'Karl Foerster'. Scientia Hort. 44:119–126.

Starman, T.W. and L. Lombardini. 2006. Growth, gas exchange, and chlorophyll fluorescence of four ornamental herbaceous perennials during water deficit conditions. J. Amer. Soc. Hort. Sci. 131(4): 469–475.