Effects of Photoperiod Treatments on Stock Plants and Cutting Rooting of Three Cultivars of Ornamental Perennials

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KEYWORDS. *Diascia integerrima*, propagation, sage, *Salvia greggii*, twinspur

ABSTRACT. Many species of herbaceous perennials now have numerous cultivars, with growth habits and flower colors unique to each cultivar. Vegetative propagation is required so that resulting plants are genetically identical to the parent plant. Although many cultivars are selected for precocious and vigorous flowering, it is often difficult to collect adequate vegetative cuttings from such cultivars for commercial production because juvenile (vegetative) growth is preferred for high-quality cuttings. Cuttings that are reproductive (with flower buds or flowers) can have reduced or delayed rooting and increased occurrences of fungal pathogens (especially *Botrytis* species), resulting in lack of crop uniformity. We sought to answer the question, can growing stock plants of herbaceous perennials under defined photoperiods extend the length of the vegetative period and enhance the rooting of cuttings harvested from these stock plants? In this study, stock plants of 'P009S' twinspur (*Diascia integerrima*), 'Furman's Red' sage (*Salvia greggii*), and 'Wild Thing' sage (*Salvia greggii*) were grown under ambient, 12-hour light, 10-hour light, and 8-hour light to determine if a particular photoperiod could be used to suppress reproductive growth by promoting vegetative growth, thereby enhancing cutting rooting success. Effects of photoperiod treatments varied among the plant cultivars studied. Plants grown under 8-hour photoperiod had longer duration of vegetative growth, smaller growth rates, and lower dry weights when compared with plants grown under 12-hour or 10-hour photoperiod. Plants grown under 12-hour photoperiod had shorter duration of vegetative growth, larger growth rates, and higher dry weights when compared with plants grown under 10-hour and 8-hour photoperiods. The probability of rooting of cuttings harvested from stock plants of 'P009S' twinspur, 'Furman's Red' sage, and 'Wild Thing' sage grown under 12-hour and 10-hour photoperiods was greater when compared with cuttings harvested from stock plants grown under 8 h photoperiod.

Asexual vegetative propagation is commonly used in the production of ornamental horticultural crops. Methods of asexual vegetative propagation include budding, cuttings (root or shoot), division, grafting, layering, separation, and tissue culture/micropropagation (Hartmann et al. 2017). Although large quantities of young plants can be obtained from micropropagation, this technique requires a sterile environment and specialized growing media and supplies. Cutting propagation can be done in most greenhouses and does not require specialized growing media and supplies. Hartmann et al. (2017) noted that cutting propagation is the most important means for clonal regeneration of many horticultural crops, and adventitious root formation is a prerequisite to successful cutting propagation. Samarakoon and Faust (2022) noted that poor rooting is a common phenomenon for many perennial species, and attributed poor rooting to juvenility, seasonality, bud dormancy, and/or cultivar. The juvenile phase of a plant can be as short as a few days (in some herbaceous species) or can extend to several years (in some woody species). In many plants, the juvenile-to-adult phase change is associated with phenotypical changes, such as alterations in leaf shape and leaf arrangement on the stem, as well as the ability to produce flowers. Studies have shown that the presence of reproductive tissue in cuttings of herbaceous perennials can inhibit root development, resulting in failure of cuttings to root. DeVier and Geneve (1997) found that root formation in cuttings of 10 cultivars of chrysanthemum (*Dendranthemum grandiflora*) was reduced as flowers developed on stock plants. The initiation of reproductive growth is often triggered by a particular photoperiod or number of hours of light to which a particular plant cultivar is exposed. Some of the most prominent responses in plants influenced by photoperiod include regulation of flowering time, tuberization, bud setting, scent emission from flowers, growth cessation and dormancy of woody perennials, and senescence of herbaceous annuals (Roeber et al. 2022). Photoperiod, light integral, temperature, and plant hormones have all been shown to affect the length of the juvenile phase (Adams and Langton 2005; Jackson 2009). When grown under natural daylength, some plant cultivars initiate reproductive growth when the hours of light are less than 12 h, and other plant cultivars will initiate reproductive growth when the hours of light are more than 12 h. Pallez and Dole (2001) investigated the effects of photoperiod on the growth and quality of purple velvet plant (*Gynura aurantiaca*). Guo et al. (2019), reported that photoperiod affects root formation and flavonoid biosynthesis in cherry radish (*Raphanus sativus*). The sensitivity of species or cultivar to photoperiod can influence whether cuttings harvested from the plant will successfully develop roots. In a study involving three willow species (*Salix* spp.), Moshkov and Kocherzhenko (1939) found that stock plants of southern species grown under northern light conditions failed to reach the physiological state necessary for optimum rooting of cuttings unless they are grown with short-day photoperiod. The authors determined that the photoperiodic conditions experienced by a parent plant controls the rooting ability of cuttings harvested from that plant. In an investigation of the effects of photoperiod on the rooting of cuttings harvested from two cultivars of Tatarian dogwood (*Cornus alba*), Whalley and Cockshull (1976) found that rooting increased when cuttings were propagated under long-day photoperiod. Plant Select® (Fort Collins, CO, USA) is a nonprofit organization

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that promotes an array of plant species and cultivars that have demonstrated resilience when grown in various locations throughout the Rocky Mountain region. Species and cultivars promoted by Plant Select® have been in high demand over the years because of their desirable growth habits, vibrant flower/inflorescence colors, and relatively low water use requirements. The unique characteristics of many of the plants promoted by Plant Select® can only be perpetuated through asexual vegetative propagation methods (Plant Select® 2009 and 2017). Based on comments from some growers, some of these species and cultivars can be challenging to propagate. To learn more about the effects of photoperiod in some of the more challenging to propagate herbaceous perennials promoted by Plant Select®, a study was conducted at Colorado State University (CSU) Horticulture Center (Fort Collins, CO, USA; lat. 40.5703° N, long. 105.0903° W) that began in Jan 2022. The purpose of this study was to determine if photoperiod regulation can be used to suppress reproductive growth by promoting vegetative growth in stock plants of selected herbaceous ornamental species, thereby enhancing rooting of cuttings harvested from those stock plants.

Materials and methods

Three experiments were conducted. Expt. 1 was started 9 Feb 2022, Expt. 2 was started 11 Apr 2022, and Expt. 3 was started 10 Nov 2022.

Photoperiod treatment areas. The study was conducted in a greenhouse at CSU Horticulture Center. The ambient photoperiod treatment was conducted on a greenhouse bench, and the three programmed photoperiod treatments [12-h light (12 h), 10-h light (10 h), and 8-h light (8 h)] were conducted in 4-ft × 8-ft × 8-ft grow tents (Gorilla Grow Tent, Santa Rosa, CA, USA) set up in the same greenhouse with the ambient light treatment. Each photoperiod treatment area was equipped with a digital thermometer (AcuRite, Lake Geneva, WI, USA) that provided minimum, maximum, and current temperatures, which were recorded daily or at least several times each week. Each grow tent was also equipped with two light-emitting diode (LED) lights (Philips Toplighting Linear GPL DR/W MB 200 400V, Signify Netherlands, Eindhoven, North Brabant, Netherlands), two 4-inch 165-ft^3/min inline fans (Active Air, Hydrofarm, Shoemakersville, PA, USA), and one 3-speed floor fan (Home Depot, Atlanta, GA, USA). The linear LED lights were used because they were available at the Horticulture Center. LED lights were positioned ~52 inches above the bench on which the plants were grown. The inline fans helped to remove hot air from within the grow tents. The floor fan helped to circulate air within the grow tents. The 12-h, 10-h, and 8-h photoperiod treatments were each assigned to one of the three grow tents. Within each grow tent, the linear LED lights were programmed with a mechanical timer (Apollo® 10–240v 10A; Titan Controls®, Angleton, TX, USA). Each photoperiod treatment was assigned to its grow tent for the duration of the study. The plant cultivars chosen for this study were P009S twinspur, Furman's Red sage, and Wild Thing sage. Between Feb 2022 and Nov 2022, 72-cell trays of rooted cuttings were obtained from a local greenhouse (Gulley Greenhouse, Fort Collins, CO, USA). Rooted plugs of each cultivar were transplanted into square black plastic containers (4-inches × 4-inches × 5-inches) filled with growing medium composed of coarse grade peatmoss, coarse grade perlite, dolomitic and calcitic limestone, and nonionic wetting agent (Berger BM6 HD, Berger, Saint-Modeste, QC, Canada). After plugs were transplanted into the containers, each container was labeled, and placed in a 15-cell square pot carry tray (one tray of each cultivar for each of the four photoperiod treatment areas). The height (H) and two widths (W1 and W2) were measured (in centimeters) for each plant; these measurements were then used to generate a beginning size index for each plant [(H + W1 + W2)/3]. The trays of labeled containers were then placed into their assigned photoperiod treatment area. Each plant was observed weekly for signs of reproductive growth. Onset of reproductive growth was affirmed when a flower bud first became visible in the terminal growth of a stem. The date that reproductive growth was first observed on a plant was recorded on a data sheet. Observations continued weekly for all plants in each photoperiod treatment area. An experiment was concluded when all (or most) of the plants in any one of the programmed photoperiod treatment areas (12 h, 10 h, or 8 h) exhibited reproductive growth. At the conclusion of each experiment, each replicate of each cultivar in each photoperiod treatment area was remeasured to obtain an ending size index [(H+W1 + W2)/3]. The experimental design used was completely randomized design. In Expts. 1 and 2, 60 containers of each of the three cultivars were prepared and then divided equally among four photoperiod treatment areas. Only the two sage cultivars were used in Expt. 3, and only 32 plants of each cultivar were prepared, and then divided equally among the four photoperiod treatment areas. A third experiment was not conducted with 'P009S' twinspur. While in their photoperiod treatment areas, plants were watered with a solution of 20N–4.4P–16.6K diluted to a concentration of 100 parts per million N (Greencare Fertilizers, Inc., Kankakee, IL, USA). At each irrigation event, 250 mL of fertilizer solution were applied to each container. To better understand when containers needed to be watered, a soil moisture sensor (Theta Probe; Delta-T Devices Ltd, Burwell, Cambridgeshire, England) was used in Expts. 2 and 3. Soil moisture measurements were taken two to three times each week to assess moisture content in the growing medium, and to determine when a container needed to be watered. When soil moisture percentage was 10% or less, that container was given 250 mL of fertilizer solution. Plants were in assigned photoperiod treatment areas for 6 to 7 weeks for Expt. 1 (9 Feb 2022–5 Apr 2022), for 6 to 7 weeks for Expt. 2 (11 Apr 2022–27 May 2022), and for 9 to 11 weeks for Expt. 3 (10 Nov 2022–22 Jan 2023). At the conclusion of each experiment, ending heights and widths were measured and recorded for each replicate of each plant cultivar in each photoperiod treatment area. Growth rates, calculated as centimeters per week, were calculated as the difference between ending and starting size indices divided by the number of weeks separating measurements. Subsequently, 10 of 15 plants (for Expts. 1 and 2) and five of eight plants (for Expt. 3) were severed at stem bases, placed in labeled paper bags, and weighed (in grams), using an analytical balance (Ohaus Corporation, Parsippany, NJ, USA), then oven dried in a drying oven (Despatch, Minneapolis, MN, USA) at 70 °C for 72 h. Dried plants (in their paper bags) were reweighed after removal from drying oven. Vegetative cuttings were clipped from the unharvested plants in each photoperiod treatment, and 24 cuttings from plants in each photoperiod treatment area were dipped into a 1:19 solution of a rooting hormone composed of 1% indole-3-butyric acid and 0.5% 1-napthaleneacetic acid (Dip'N Grow, Inc., Clackamas, OR, USA) for 15 s before being stuck into moistened 72-cell rooting tray (Jiffy Preforma, Jiffy Products of America, Inc., Lorain, OH, USA). The trays of cuttings were then placed on a bench equipped with heat mats set at 72 °F and misting system initially programmed to deliver 8 s of mist every 30 min. After 2 weeks, the misting time was adjusted to 8 s every 60 min. The plants from which the cuttings were obtained were then cut back to a height of 4 to 6 cm, allowed to regrow in their assigned photoperiod treatment area, and again observed for production of reproductive growth. The stuck cuttings were observed weekly for rooting for 4 weeks.

Statistical analysis. Linear mixed models were fit to observations of the duration of vegetative growth, growth rate, and final dry weight. Photoperiod treatments, cultivars, and their interaction were modeled as fixed effects, and experimental repeats were modeled as random effects. For significant fixed effects, means separation was performed using Tukey's honestly significant difference test. For harvested cuttings, a logistic model was fit to binary observations of the absence (0) or presence (1) of roots over time with similar fixed and random effects, but the model contained an additional continuous variable indicating the elapsed time (in days) after sticking cuttings. Means comparison was performed by computing the probability of rooting for a given fixed effect after 14 d. The data were analyzed using R (R Core Team 2021).

Results

Can growing stock plants of selected cultivars of herbaceous perennials under defined photoperiods extend the length of the vegetative period and enhance rooting success of cuttings harvested from these stock plants? The key findings indicate that although stock plants grown under an 8-h photoperiod remain vegetative for a longer time, they have lower growth rates and lower ending dry weights, when compared with stock plants grown under 12-h photoperiod. Based on analysis of variance calculations, the interactions between photoperiod and plant cultivars were significant for duration of vegetative growth ($P < 0.001$), size indices ($P = 0.001$), and ending dry weights ($P = 0.010$). Although the length of the programmed photoperiod treatments (12 h, 10 h, and 8 h) remained constant, the conditions in the ambient light treatment area varied with each experiment. Not only did the length of photoperiod and the quality of light vary with the time of year that each experiment was conducted, but because that bay of the greenhouse was used by several other people, it was impossible to regulate overhead lights and shade curtains. Because of the variability associated with the ambient light treatment area, we focused primarily on the results from the three programmed photoperiod treatments.

Temperatures within photoperiod treatment areas

Although the study was conducted in a greenhouse, and the three programmed photoperiod treatments were conducted in grow tents set up inside the greenhouse, temperatures within photoperiod treatment areas varied depending on the time of year the experiments were conducted (Table 1). Mean maximum temperatures for experiment 2 (conducted 11 Apr 2022–27 May 2022) ranged from 81.4 to 83.3 °F for all photoperiod treatment areas; higher than mean maximum temperatures for Expts. 1 and 3. Mean maximum temperatures for Expt. 1 (conducted 9 Feb 2022–5 Apr 2022) ranged from 76.1 to 79.0 °F, and those for Expt. 3 (conducted 10 Nov 2022–22 Jan 2023) ranged from 71.1 to 74.4 °F (Table 1). Inside temperatures appeared to have been affected by outside temperatures. Based on local temperature data (Colorado Climate Center, Fort Collins, CO, USA) outside mean maximum temperature during Expts. 1, 2, and 3 was 52.5 °F, 69.7 °F, and 43.1 °F, respectively, and maximum temperature ranges during Expts. 1, 2, and 3 were 10 to 80 °F, 44 to 90 °F, and 0 to 61 °F, respectively.

Duration of vegetative growth

The interactions between photoperiods and cultivars for duration of vegetative growth were significant for all three cultivars (Table 2). When grown under 8-h photoperiod, plants of all three cultivars remained vegetative for significantly longer when compared with plants grown under 12-h photoperiod (Table 3).

Growth rates

Growth rate for each plant was calculated as the difference between ending size index and beginning size index divided by the elapsed time between the measurement of the ending size index and the measurement of the beginning size index {[size

Table 1. Mean temperature and range of temperatures for each experiment within each photoperiod treatment area.

	Photoperiod treatment															
	Ambient				12 h light				10 h light				8 h light			
	Min °F[i]		Max °F		Min °F		Max °F		Min °F		Max °F		Min °F		Max °F	
Expt.	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
1[ii]	65.2	62–69	76.1	66–83	73.1	59–81	77.5	68–86	68.4	62–73	79.0	63–87	64.7	61–85	77.4	69–86
2[iii]	66.4	52–72	83.3	73–97	77.4	69–88	81.4	72–91	75.0	68–79	83.3	72–92	67.0	64–78	81.8	72–91
3[iv]	64.6	62–67	71.1	67–77	61.8	56–70	73.1	67–79	61.7	56–71	74.4	68–81	62.8	60–65	73.2	66–80

[i] °F – 32*1.8 = °C
[ii] Expt. 1 (9 Feb 2022–5 Apr 2022).
[iii] Expt. 2 (11 Apr 2022–27 May 2022).
[iv] Expt. 3 (10 Nov 2022–22 Jan 2023).

Table 2. Analysis of variance of duration of vegetative growth for 'P009S' twinspur, 'Furman's Red' sage, and 'Wild Thing' sage plants grown under different photoperiods.

Effect	*df*	*F*	*P*
Photoperiod	3, 410	38.59	<0.001
Cultivar	2, 411	63.63	<0.001
Photoperiod × Cultivar	6, 410	6.90	<0.001
Photoperiod: 'P009S' twinspur	3, 410	9.07	<0.001
Photoperiod: 'Furman's Red' sage	3, 410	40.34	<0.001
Photoperiod: 'Wild Thing' sage	3, 410	4.93	0.002

Table 3. Comparison of duration of vegetative growth for 'P009S' twinspur, 'Furman's Red' sage, and 'Wild Thing' sage when grown under different photoperiods.

Photoperiod treatment	Duration of vegetative growth [mean (*SE*) weeks]		
	'P009S' twinspur[i]	'Furman's Red' sage[ii]	'Wild Thing' sage[ii]
12 h light	4.90[iii] (0.4) a[iv]	3.46 (0.39) a	3.88 (0.39) a
10 h light	5.93 (0.4) b	3.94 (0.39) a	3.99 (0.39) a
8 h light	6.20 (0.4) b	5.75 (0.39) b	4.67 (0.39) b
Ambient	5.60 (0.4) b	5.12 (0.39) b	4.41 (0.39) ab

[i] N = 30 (Expts. 1 and 2 combined).
[ii] N = 38 (Expts. 1, 2, and 3 combined).
[iii] Within columns, values listed are expected marginal means, followed by standard error in ().
[iv] Within columns, expected marginal means followed by the same letter are not significantly different at α = 0.05.

index(time2) – size index(time1)]/elapsed time between time1 and time2}. The interactions between photoperiods and cultivars for mean growth rates were significant for all three cultivars. Mean growth rates, expressed as centimeters per week, varied significantly among the studied photoperiods and cultivars (Table 4). Plants of 'Furman's Red' sage and 'Wild Thing' sage grown under 8-h photoperiod had significantly lower mean growth rates when compared with plants grown under 12-h and 10-h photoperiods (Table 5).

Ending dry weights

The interactions between photoperiods and cultivars for ending dry weights were significant for all three cultivars (Table 6). Plants of all three cultivars grown under 8-h photoperiod had significantly lower mean ending dry weights when compared with plants grown under 12-h photoperiod (Table 7).

Rooting of cuttings

With regard to rooting of cuttings, the interactions between photoperiods and cultivars were not statistically significant (Table 8), thus no comparison of means is provided. Based on comparison of mean probability of rooting for cuttings, cuttings of 'Wild Thing' sage had significantly greater probability of rooting when compared with cuttings of either 'P009S' twinspur or 'Furman's Red' sage (Table 9). Based on comparison of mean probability of rooting for cuttings, cuttings harvested from plants grown under 12-h or 10-h photoperiods had significantly greater probability of rooting when compared with cuttings harvested from plants grown under 8-h photoperiod (Table 10). Although in the study reported here there were no significant effects of the interactions between photoperiods and cultivars on the rooting of cuttings, we did observe differences in cutting rooting success among the three experiments. When compared across the three experiments, mean percent rooting of cuttings was noticeably lower for Expt. 2 (Table 11). In an attempt to explain the lower rooting success observed for cuttings harvested in Expt. 2, we examined the temperature data. As previously noted, temperatures within the photoperiod treatment areas varied depending on the time of year the experiments were conducted. Mean maximum temperatures for all photoperiod treatment areas were higher during Expt. 2 than during Expts. 1 and 3 (Table 1). Although it is unclear as to how temperatures affected duration of vegetative growth, growth rate, and dry weight of stock plants grown under the different photoperiods, it does appear that the higher maximum temperatures that occurred in all of the photoperiod treatment areas during Expt. 2 had a negative impact on the rooting success of cuttings harvested from those stock plants (Table 11).

Results by plant cultivar

'P009S' TWINSPUR. Plants of 'P009S' twinspur grown under 10-h and 8-h photoperiods remained vegetative for 5.93 and 6.20 weeks, respectively, statistically significantly longer than 4.90 weeks for plants grown under 12-h photoperiod (Table 3). Mean ending dry weight was statistically significantly greater for plants grown under 12-h photoperiod (5.70 g), when compared with plants grown under 8-h photoperiod (3.75 g), but not for plants grown under 10-h photoperiods (4.88 g) (Table 7). With regards to rooting of cuttings, the interactions between photoperiod and cultivars were not significant (Table 8), thus no comparison of means is provided. Comparison of mean probability of rooting for cuttings harvested from 'P009S' twinspur was 0.58, statistically no different than for cuttings harvested from 'Furman's Red' sage (0.62), but statistically lower than for cuttings harvested from 'Wild Thing' sage (0.81) (Table 9). When cutting rooting data for all three cultivars were

Table 4. Analysis of variance of growth rates for 'P009S' twinspur, 'Furman's Red' sage, and 'Wild Thing' sage when grown under different photoperiods.

Effect	*df*	*F*	*P*
Photoperiod	3, 408	34.50	<0.001
Cultivar	2, 408	209.85	<0.001
Photoperiod × Cultivar	6, 408	3.75	0.001
Photoperiod: 'P009S' twinspur	3, 408	6.31	<0.001
Photoperiod: 'Furman's Red' sage	3, 408	19.94	<0.001
Photoperiod: 'Wild Thing' sage	3, 408	18.56	<0.001

Table 5. Comparison of growth rates for 'P009S' twinspur, 'Furman's Red' sage, and 'Wild Thing' sage when grown under different photoperiods.

Photoperiod treatment	Growth rate [mean (*SE*) cm/week][i]		
	'P009S' twinspur[ii]	'Furman's Red' sage[iii]	'Wild Thing' sage[iii]
12 h light	6.34[iv] (0.59) b[v]	4.70 (0.58) c	4.48 (0.58) c
10 h light	6.25 (0.59) b	3.91 (0.58) b	3.62 (0.58) b
8 h light	5.95 (0.59) ab	2.98 (0.58) a	2.79 (0.58) a
Ambient	5.32 (0.59) a	3.41 (0.58) ab	3.35 (0.58) ab

[i] Mean growth rate = difference between ending growth indices [(height + width1 + width2)/3] and beginning growth indices [(height + width1 + width2)/3] divided by the elapsed time between the measurement of the ending growth indices and the measurement of the beginning growth indices {[size index(time2) – size index(time1)]/elapsed time between time1 and time2}; 1 cm = 0.3937 inch.
[ii] N = 30 (Expts. 1 and 2 combined).
[iii] N = 38 (Expts. 1, 2, and 3 combined).
[iv] Within columns, values listed are expected marginal means, followed by standard error in ().
[v] Within columns, expected marginal means followed by the same letter are not significantly different at $\alpha = 0.05$.

Table 6. Analysis of variance of ending dry weight for 'P009S' twinspur, 'Furman's Red' sage, and 'Wild Thing' sage when grown under different photoperiods.

Effect	*df*	*F*	*P*
Photoperiod	3, 264	43.87	<0.001
Cultivar	2, 264	8.27	<0.001
Photoperiod × Cultivar	6, 264	2.86	0.010
Photoperiod: 'P009S' twinspur	3, 264	4.89	0.003
Photoperiod: 'Furman's Red' sage	3, 264	34.24	<0.001
Photoperiod: 'Wild Thing' sage	3, 264	13.21	<0.001

combined, cuttings from plants grown under 10-h and 12-h photoperiods had statistically significantly greater probability of rooting when compared with cuttings from plants grown under 8-h photoperiod (Table 10). For the study reported here, percent rooting of cuttings from 'P009S' twinspur ranged from 75.0% to 91.7% for cuttings harvested from plants grown under 12-h photoperiod, from 79.2% to 95.8% for cuttings harvested from plants grown under 10-h photoperiod, and from 41.7% to 95.8% for cuttings harvested from plants grown under 8-h photoperiod (Table 11).

'Furman's Red' sage. Plants of 'Furman's Red' sage grown under 8-h photoperiod remained vegetative for 5.75 weeks, statistically significantly longer than for the plants grown under 12-h photoperiod (3.46 weeks) and 10-h photoperiod (3.94 weeks) (Table 3). Mean growth rate and mean ending dry weight were statistically significantly greater for plants grown under 12-h photoperiod (4.70 cm per week and 8.33 g, respectively), and least for plants grown under 8-h photoperiod (2.98 cm per week and 3.90 g, respectively) (Tables 5 and 7). With regard to rooting of cuttings, the interactions between photoperiod and cultivars were not significant (Table 8), thus no comparison of means is provided. Comparison of mean probability of rooting for cuttings harvested from 'Furman's Red' sage was 0.62, statistically no different than for cuttings harvested from 'P009S' twinspur (0.58), but statistically lower than for cuttings harvested from 'Wild Thing' sage (0.81) (Table 9). When cutting rooting data for all three cultivars were combined, cuttings from plants grown under 12-h and 10-h photoperiods had statistically significantly greater probability of rooting when compared with cuttings from plants grown under 8-h photoperiod (Table 10). For the study reported here, percent rooting of cuttings from 'Furman's Red' sage ranged from 66.7% to 100% for cuttings harvested from plants grown under 12-h photoperiod, from 91.7% to 95.8% for cuttings harvested from plants grown under 10-h photoperiod, and from 66.7% to 95.8% for cuttings harvested from plants grown under 8-h photoperiod (Table 11).

'Wild Thing' sage. Plants of 'Wild Thing' sage grown under 8-h photoperiod remained vegetative for 4.67 weeks, statistically significantly longer than plants grown under 12-h and 10-h photoperiods (3.88 weeks and 3.99 weeks, respectively) (Table 3). Mean growth rate and ending dry weight were statistically significantly greater for plants grown under 12-h photoperiod (4.48 cm per week and 6.42 g, respectively), and least for plants grown under 8-h photoperiod (2.79 cm per week and 3.55 g, respectively) (Tables 5 and 7). With regard to rooting of cuttings, the interactions between photoperiod and cultivars were not significant (Table 8), thus no comparison of means is provided. Comparison of mean probability of rooting for cuttings harvested from 'Wild Thing' sage was 0.81, significantly higher than for cuttings harvested from 'P009S' twinspur (0.58) and 'Furman's Red' sage (0.62) (Table 9). When cutting rooting data for all three cultivars were combined, cuttings from plants grown under 10-h and 12-h photoperiods had statistically significantly greater probability of rooting when compared with cuttings from plants grown under 8-h photoperiod (Table 10). For the study reported here, percent rooting of cuttings from 'Wild Thing' sage ranged from 91.7% to 100% for cuttings harvested

Table 7. Comparison of ending dry weights for 'P009S' twinspur, 'Furman's Red' sage, and 'Wild Thing' sage when grown under different photoperiods.

Photoperiod treatment	Ending dry wt [mean (*SE*) g][i]		
	'P009S' twinspur[ii]	'Furman's Red' sage[iii]	'Wild Thing' sage[iii]
12 h light	5.70[iv] (1.77) b[v]	8.33 (1.76) c	6.42 (1.76) b
10 h light	4.88 (1.77) ab	6.29 (1.76) b	5.37 (1.76) b
8 h light	3.75 (1.77) a	3.90 (1.76) a	3.55 (1.76) a
Ambient	4.00 (1.77) a	3.99 (1.76) a	4.05 (1.76) a

[i] 1 g = 0.0353 oz.
[ii] N = 30 (Expts. 1 and 2 combined).
[iii] N = 38 (Expts. 1, 2, and 3 combined).
[iv] Within columns, values listed are expected marginal means, followed by standard error in ().
[v] Within columns, expected marginal means followed by the same letter are not significantly different at $\alpha = 0.05$.

Table 8. Analysis of deviance of the probability of rooting of cuttings harvested from 'P009S' twinspur, 'Furman's Red' sage, and 'Wild Thing' sage grown under different photoperiods.

Effect	*df*	D	*P*
Days	1, 3,058	1,141.07	<0.001
Photoperiod	3, 3,055	19.42	<0.001
Cultivar	2, 3,053	112.54	<0.001
Photoperiod × Cultivar[i]	6, 3,047	12.05	0.061

[i] Mean separation was not performed because analysis of deviance for the probability of rooting showed no interaction between photoperiod and cultivar.

Table 9. Comparison of probability of rooting of cuttings harvested from 'P009S' twinspur, 'Furman's Red' sage, and 'Wild Thing' sage.

Cultivar	Probability of rooting [mean (*SE*)]
'P009S' twinspur	0.58[i] (0.02) a[ii]
'Furman's Red' sage	0.62 (0.02) a
'Wild Thing' sage	0.81 (0.01) b

[i] Values listed are expected marginal means, followed by standard error in ().
[ii] Expected marginal means followed by the same letter are not significantly different at $\alpha = 0.05$ level.

from plants grown under 12-h photoperiod, from 91.7% to 100% for cuttings harvested from plants grown under 10-h photoperiod, and from 83.3% to 100% for cuttings harvested from plants grown under 8-h photoperiod (Table 11).

Discussion

Another common name associated with *Salvia greggii* is autumn sage. In their work with three species of *Salvia*, Zanin and Erwin (2006) classified autumn sage as a facultative short-day plant, indicating that plants are more likely to produce flowers when grown under 12 h or less of light per day, but will eventually flower when grown under more than 12 h of light per day. In our study, plants of both cultivars of sage produced reproductive growth when grown under 12-h, 10-h, and 8-h photoperiods; however, plants grown under 12-h and 10-h photoperiod produced reproductive growth sooner than plants grown under 8-h photoperiod. Although no reference could be located that indicated the photoperiodic group for twinspur, based on our duration of vegetative growth data for 'P009S' twinspur, it too could be a facultative short-day plant because plants grown under 12-h photoperiod produced reproductive growth sooner than plants grown under 10-h and 8-h photoperiods. Torres and Lopez (2011) found that yellow trumpet bush (*Tecoma stans*) grown under short-day photoperiod (less than 12 h of light) produced few flower buds when compared with plants grown under long-day photoperiod (12 h or more of light). According to Adams and Langton (2005), there have been numerous reports that when plants are grown under long-day photoperiod (12 h or more of light), the dry weight of above-ground parts of the plant increases. We found that when stock plants of 'P009S' twinspur, 'Furman's Red' sage, and 'Wild Thing' sage were grown under photoperiods of 12 h, 10 h, and 8 h, the plants grown under 12-h photoperiod had shorter duration of vegetative growth, greater mean growth rates, and greater ending dry weights, when compared with plants grown under 8-h photoperiod (Tables 3, 5, and 7). Roll and Newman (1997) showed that the photoperiod under which stock plants of poinsettia (*Euphorbia pulcherrima*) were grown influenced the rooting of cuttings harvested from those stock plants. They also found that for this short-day plant, interrupting the dark period with a brief period of light (referred to as a night break) prevented flower initiation, prolonged vegetative growth, and increased yield of high-quality cuttings that had high rooting success. We found that when stock plants of 'P009S' twinspur, 'Furman's Red' sage, and 'Wild Thing' sage were grown under photoperiods of 12 h, 10 h, and 8 h, the mean probability of rooting of cuttings harvested from those stock plants was significantly greater for cuttings harvested from stock plants grown under 12-h or 10-h photoperiods than for cuttings harvested from plants grown under 8-h photoperiod, and there was no significant difference in the mean probability of rooting of cuttings between 12-h or 10-h photoperiods (Table 10). Therefore, if a grower can get the same rooting success for cuttings harvested from stock plants grown under 12-h photoperiod as they can for cuttings harvested from stock plants grown under 10-h photoperiod, the 10-h photoperiod would be preferred because each day it would require 2 hours less of electricity than the 12-h photoperiod. In addition to limiting the hours of light to control reproductive growth in short-day or facultative short-day plants, disrupting/interrupting the dark period with light (a night break) could be used to prevent flowering in short-day plants because that light exposure interrupts the critical dark period required flower initiation. Although not the focus of our study, providing a night break during the production of stock plants of short-day plants might prove more profitable to growers, and could prevent the side effect of lower growth rates associated with shorter photoperiods. However, providing additional light to long-day plants would most likely promote reproductive growth, thus providing a night break to stock plants of long-day plants would not improve cutting production. There may, however, be other light-related techniques that will promote vegetative growth of stock plants, thus additional light-regulated research is needed to determine the most efficient and

Table 10. Comparison of probability of rooting of cuttings harvested from stock plants grown under different photoperiods.

Photoperiod	Probability of rooting (mean %)
12 h light	0.72[i] (0.02) b[ii]
10 h light	0.72 (0.02) b
8 h light	0.61 (0.02) a
Ambient	0.65 (0.02) ab

[i] Values listed are expected marginal mean followed by standard error in ().
[ii] Expected marginal means followed by the same letter are not significantly different at $\alpha = 0.05$ level.

Table 11. Percent rooting 4 weeks after sticking cuttings from stock plants of 'P009S' twinspur, 'Furman's Red' sage, and 'Wild Thing' sage grown under different photoperiods and dates.

Cultivar	Expt.	Date cuttings stuck	Cuttings rooted (mean %)[i]		
			12 h light	10 h light	8 h light
'P009S' twinspur	1[ii]	5 Apr 2022	91.7[ii]	95.8	95.8
	2[ii]	27 May 2022	75.0	79.2	41.7
'Furman's Red' sage	1	6 Apr 2022	83.3	95.8	95.8
	2	27 May 2022	66.7	91.7	66.7
	3[ii]	10 Jan 2023	100.0	91.7	87.5
'Wild Thing' sage	1	4 Apr 2022	100.0	100.0	100.0
	2	27 May 2022	91.7	91.7	83.3
	3	22 Jan 2023	100.0	100.0	100.0

[i] Values listed are mean percent of cuttings rooted.
[ii] N = 24.

profitable lighting practices for management of stock plants of attractive, resilient, and water-efficient ornamental plants.

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