2020

Fertilizer Rate and Substrate Water Content Effect on Growth and Flowering of Beardtongue

Amanda Bayer

horticulturae

MDPI

Article

Fertilizer Rate and Substrate Water Content Effect on Growth and Flowering of Beardtongue

Amanda Bayer

Stockbridge School of Agriculture, University of Massachusetts, 210 Bowditch Hall, Amherst, MA 01003, USA; abayer10@umass.edu

Received: 27 August 2020; Accepted: 14 September 2020; Published: 16 September 2020

Abstract: Research has shown that reduced irrigation and fertilizer rates can still produce good plant growth when irrigation is applied efficiently to reduce leaching. The impact of reduced irrigation and fertilizer rate on flowering and plant growth would provide additional information on the potential for reduced production inputs. The objective of this research was to quantify the impact of reduced irrigation and fertilizer rate on growth and flowering of Ruby Candle beardtongue (*Penstemon* × 'Ruby Candle'). A soil moisture sensor automated irrigation system was used to maintain plants at 40% volumetric water content [VWC; well-watered (WW)] or 18% VWC (reduced irrigation, RI). A controlled release fertilizer was applied at 100%, 50%, and 25% of the bag rate (12 g/plant). There was not a significant treatment effect on any flower parameter. Average plant height was greatest for plants receiving the 50% fertilizer rate (75.9 cm) and was lowest for the 100% fertilizer rate (64.5 cm). Internode length was greater for WW plants (36.9 mm) than RI plants (32.4 mm). Well-watered plants had greater fresh weight (99.1 g) than RI plants (79.2 g) and 100% fertilizer rate (97.1 g) was greater than the 25% fertilizer rate (82.7 g).

Keywords: *Penstemon*; sensor irrigation; reduced irrigation; container production; volumetric water content

1. Introduction

Improving irrigation and fertilization practices is important in the nursery and greenhouse industries to reduce leaching and runoff and to reduce the inputs needed during production. Irrigation and fertilizer applications in container plant production are generally frequent in order to maximize growth [1,2]. Over-irrigation frequently results in the need for additional fertilizer applications during the production cycle because nutrients are leached out of the container. Best management practices (BMPs) suggest a leaching fraction of 10-15% to avoid fertilizer salt buildup in containers [3]. However, it is also possible to reduce fertilizer applications and minimize leaching through more efficient irrigation practices [4].

Plant appearance is important to consumers, with consumers associating appearance with overall plant health [5] and poor plant form or uniformity resulting in reduced sales [6]. Uneven plant growth can be the result of irrigation practices, pruning, or plant growth regulation applications. Over-irrigation, under-irrigation, and poor irrigation uniformity can impact plant growth. Irrigation practices can impact overall plant size, internode length, flower number and size, and leaf size [6,7]. Species-specific information is needed to apply irrigation efficiently and with the most beneficial impact on growth.

Fertilizer BMPs include the use of controlled-release fertilizer which can last the duration of the production cycle along with monitoring substrate nutrient levels by measuring electrical conductivity (EC) during production [8]. Studies have shown that fertilizer applications above an optimum rate can reduce plant quality and growth [9,10].

Previous research has looked at the impact of fertilizer rate or irrigation rate on plant growth [11,12]; however, the effect of reduced irrigation based on plant water use and fertilizer rate on growth and flowering of herbaceous perennial species has not been adequately studied. Research has shown that controlled release fertilizer application rates and irrigation rates have different impacts on various aspects of plant growth and different responses amongst species necessitating species-specific information [4,9,11–13].

Flower development is not just important to consumer ornamental appeal of the plant but also to the attractiveness and benefit of pollinators. Abiotic stress from irrigation applications can impact flower trait development and may affect pollinator visitation to those plants [14]. To best support pollinators, it is important to ensure that production practices do not alter flower development to the extent that pollinator visitation decreases. To better understand this the impact of reduced irrigation and fertilizer on flower size and floral features is necessary.

The genus *Penstemon* has around 250 species with numerous hybrids that are popular in European and North American gardens [15]. Most species and hybrids prefer sunny, dry locations. Winter survival is a challenge in northern areas and the need for well-drained soil is the greatest challenges to *Penstemon* survival in gardens in the United States and Europe. *Penstemon* is valued as a landscape plant for its showy flowers. The objective of this research was to quantify the effect of reduced fertilizer rate and irrigation on plant growth and flowering of Ruby Candle beardtongue (*Penstemon* 'Ruby Candle').

2. Materials and Methods

Research was conducted in a glass greenhouse at the University of Massachusetts in Amherst, MA, USA from 29 May 2019 to 9 August 2019. Greenhouse air temperature setpoints were 21 °C during the day and 18 °C at night during the experimental period. The greenhouse was set for a 16 h daylength.

2.1. Plant Material

Rooted cuttings of Ruby Candle beardtongue were obtained from Pioneer Gardens, Inc. (Deerfield, MA, USA) and potted on 29 May 2019. Cuttings were planted in 3 qt black plastic containers filled with a commercial substrate containing pine bark (55%) peat moss (30%), perlite, limestone, and a wetting agent (Pro-Mix BK55; Premier Tech Horticulture, QC, Canada). Controlled-release fertilizer (Nutricote Total 18-6-8, 180 d; 18 N- 2.6P- 6.6K; Chisso-Ashai Fertilizer Co., Tokyo, Japan) was applied to each container at planting. Plants were hand-watered for three weeks to allow for root establishment before irrigation treatments began on 19 June 2019.

2.2. Treatments and Data Collection

Treatment combinations included three fertilizer rates (subplots) of 100% (12 g/plant), 50% (6 g/plant), and 25% of medium bag rate (3 g/plant) and two VWC setpoints (whole plots) 18% or 40% for a total of six treatment combinations. There were two irrigation lines per block to maintain each of the substrate water content setpoints. Two plants receiving each fertilizer rate were on each irrigation line for a total of 6 plants per line and 12 plants per block. Irrigation was controlled using a soil moisture sensor automated irrigation system similar to that described by Nemali and van Iersel [16]. Soil moisture sensors (10HS; Decagon Devices (METER); Pullman, WA, USA) were inserted into the two pots receiving the 100% fertilizer rate for irrigation line for a total of 24 sensors. The sensors were connected to a multiplexer (AM16/32B; Campbell Scientific, Logan, UT, USA) which was connected to a datalogger (CR1000; Campbell Scientific). The datalogger measured sensor voltage output every 60 min. The voltage readings from the sensors were converted to VWC (θ) using our own calibration [$\theta = -\ 0.4207 + 0.0009 \times \text{output (V)}$] using the method described by Nemali et al. [17]. When both sensors were below the VWC threshold (40% or 18%), the datalogger signaled a relay driver (SDM16AC/DC controller; Campbell Scientific) to open the proper solenoid valve (Rainbird, Azusa, CA, USA). The solenoid valve was open for 1 min and applied 35 mL of water via drip tubing connected to pressure-compensated drip emitters (Netafim USA, Fresno, CA, USA). Readings from each sensor were averaged and recorded every 60 min and number of irrigation events per line was recorded daily. Daily and total irrigation volume for a line was calculated from the number of irrigation events and the volume of water applied per irrigation events.

Height and width were measured weekly. Internode length was measured for the longest stem on each plant. Leaf size of ten fully expanded leaves was measured at the conclusion of the experiment using a leaf area meter (LI-3100C; LI-COR, Lincoln, NE, USA). Shoots were cut off at the substrate surface and fresh weight was determined. Relative chlorophyll content was measured using a chlorophyll meter (SPAD 502DL Plus; Konica Minolta, Osaka, Japan). Canopy temperature was measured using an infrared temperature meter (IR Temp Meter, Spectrum Technologies, Inc.; Aurora, IL, USA) at the conclusion of the experiment. Water use efficiency (WUE) was calculated as grams shoot fresh weight/irrigation volume [18]. Inflorescence measurements were taken starting with flower development in July. Inflorescence length and width, number of florets, and weight were measured for individual peduncles along with number of peduncles per plant. A visual rating was made weekly for the final four weeks of the experiment.

2.3. Experimental Design and Data Analysis

The experiment was designed as a split-plot design with six replications with main plots being VWC setpoints and fertilizer rates as split plots. Each experimental unit consisted of two plants and data were averaged for the two plants. Data were analyzed using the PROC ANOVA procedure of SAS (version 9.4; SAS Institute, Cary, NC) with $p = 0.05$ considered statistically significant. Data are presented as mean ± standard error. Treatment means were separated using Tukey's honestly significant difference.

3. Results and Discussion

3.1. Vegetative Growth

There was a significant fertilizer rate effect on peduncle length with the 50% fertilizer rate having longer peduncles (75.9 cm) than the 100% fertilizer rate (64.5 cm) and similar to the 25% fertilizer rate (71.5 cm) (Table 1). Peduncle length was not affected by irrigation rate. Li et al. [19] reported irrigation and fertilizer rate had no significant impact in plant height of *Helianthus annuus* L. 'Choco Sun' at the flowering stage (55 days after transplanting); however, there was a significant interactive effect at 25 and 45 days after transplanting. At 25 and 45 days after transplanting, there was no fertilizer rate effect for WW plants but there was a fertilizer rate effect under drier conditions. Bayer et al. [4] reported that there was no fertilizer or irrigation treatment effect on plant height of *Gardenia Jasminoides* 'MADGA 1'. Plant height of *Viburnum Odoratissimum* was unaffected by irrigation volume but was 15% greater for plants receiving 30 g/plant CRF than plants receiving 15 g/plant [11]. Final height of *Begonia* × *semperflorens-cultorum* 'Ambassador Scarlet' was greatest for plants grown with fertilizer with an EC of 1.4 dS m^{-1}. Final height of *Petunia* × *hybrida* 'Dreams Mix' was greatest for plants grown with an EC of 1.8 dS m^{-1} [10]. These results indicate that fertilizer rate has a greater impact on plant height than irrigation volume. However, other studies looking at the impact of VWC have shown that plant height generally increases with increasing VWC [4,13,20–23]. These studies did report good growth at moderate VWC, with higher VWC sometimes resulting in excessive growth [20]. The variability in plant height response to irrigation treatments may be due to water-stress tolerance of some species and lower irrigation treatments, although being reduced, being adequate to support growth.

Table 1. Growth measurements for 'Ruby Candle' beardtongue in response to irrigation and fertilizer rate treatments at the conclusion of the 73 d experiment.

Treatment		**Peduncle Length (cm)**	**Internode Length (mm)**	**Leaf Size (cm^2)** [X]	**Fresh Weight (g)**
		Treatment significance			
Irrigation [Z]		0.25	0.003	0.67	<0.001
Fertilizer [Y]		0.001	0.38	0.44	0.04
Irrigation by fertilizer		0.82	0.82	0.53	0.66
		Least squares means for main effects			
Irrigation	Fertilizer				
	100%	64.5b [W]			97.1a
	50%	75.9a			87.7ab
	25%	71.5ab			82.7b
Well-watered			36.9a		
Reduced irrigation			32.4b		
		Least squares means grouped by treatment combination			
Irrigation	Fertilizer				
Well-watered	100%	65.5	35.0	11.29	108.4
	50%	76.6	38.5	10.27	94.8
	25%	73.8	37.2	9.32	94.1
Reduced irrigation	100%	63.4	31.7	9.64	85.7
	50%	75.2	33.1	9.53	80.7
	25%	69.1	32.2	9.14	71.2

[Z] Well-watered irrigation treatments were maintained at a volumetric water content (VWC) of 40% and reduced irrigation treatments were maintained at a VWC of 18%. [Y] Fertilizer treatments are 100% (12 g/plant), 50% (6 g/plant), and 25% (3 g/plant) of the medium bag rate of (Nutricote Total 18-6-8, 180 d; 18 N- 2.6P- 6.6K; Chisso-Ashai Fertilizer Co., Tokyo, Japan). [X] Leaf size is the average of 10 fully expanded leaves. [W] Means within a column with different letters are different (α = 0.05) according to the Tukey's honestly significant difference tests. Each value is the mean of three replications with each replication consisting of two pseudoreplicate plants.

Internode length was greater for WW plants (36.9 mm) than RI plants (32.4 mm, Table 1). This is similar to the results of Bayer et al. [20] in which internode length of *Hibiscus acetosella* 'Panama Red' was reduced at lower VWCs than WW conditions. Elongation is reduced during drought stress as a result of reduced cell division and expansion [24]. This is further demonstrated by Bayer et al. [25] in which the number of internodes along with plant height was reduced under drought-stressed conditions compared to WW conditions.

Fresh weight was greater for the 100% fertilizer rate (97.1 g) than the 25% fertilizer rate (82.7 g) but not different than the 50% fertilizer rate (87.7 g) and no irrigation effect (Table 1). Bayer et al. [4] found that there was an interactive effect of irrigation and fertilizer rate on shoot dry weight of *Gardenia jasminoides* 'MAGDA I' with shoot dry weight for the 25% fertilizer treatment being less than the 50% and 100% rates. For the 100% fertilizer rate, increasing irrigation volume increased shoot dry weight. Petunia shoot dry weight increased with fertilizer rate from 1.0 to 1.67 g/plant but decreased with higher rates [9]. The fertilizer rate effect of growth was more pronounced at higher VWC [9].

Tyler et al. [12] reported that shoot dry weight of *Cotoneaster dammeri* 'Skogholm' was reduced by 26% when fertilizer rate was reduced by 50% and Million et al. [11] found that shoot dry weight of *V. odoratissimum* was reduced by 32% with a lower fertilizer rate (15 g/plant vs. 30 g/plant). Shoot dry weight of *Lantana camara* 'Sunny Side Up' increased with fertilizer rate from 14 g at 25% fertilizer rate to 35 g at 150% fertilizer rate [13]. Cabrera [26] found that shoot dry weight of *Ilex opaca* 'Hedgeholly' and *Lagerstroemia* × 'Tonto' was reduced with increasing N treatments over 60 mg L^{-1} indicating a threshold at which increased nutrients do not result in additional growth.

The effect of irrigation volume on shoot growth has been variable. Li et al. [19] found that irrigation had a significant effect on stem dry mass of *H. annuus*, whereas fertilizer rate had no effect.

Maintaining a low leaching fraction during production of *C. dammeri* 'Skogholm' reduced shoot dry weight by 8% [12]. Shoot dry weight of *V. odoratissimum* was reduced by 6% at a 2 cm irrigation application compared to a 1 cm application [11]. Bayer et al. [13] reported *L. camara* 'Sunny Side Up' was unaffected by irrigation volume. These results indicate species specific responses to irrigation volume and fertilizer rate which could be due to physiological and morphological adaptations and acclimation to water and nutrient stress. However, the potential for both reduced fertilizer and irrigation rates in container production was demonstrated.

Leaf size was not affected by fertilizer or irrigation treatments (Table 1). Other researchers have reported a reduction in leaf size with lower VWC [9,20]. Leaf area is an indicator of drought stress as cell elongation is reduced with low soil water potential [27]. This suggests that the RI treatment in this experiment did not result in water stress.

3.2. Flowering

Inflorescence measurements including days to flower, inflorescence length, inflorescence internode length, and number of florets were not significantly different (Table 2). Most plants were in flower by day 45. Inflorescence length ranged from 20.4–26.1 cm and inflorescence internode length ranged from 31.5 to 49.9 mm. Number of florets per inflorescence ranged from 9.5 to 13.5.

Table 2. Days to flower, inflorescence length, inflorescence internode length, and number of florets per inflorescence for beardtongue.

Treatment		**Days to Flower**	**Inflorescence Length (cm)**	**Inflorescence Internode Length (mm)**	**Number of Florets Per Inflorescence**
Irrigation [Z]		0.82	0.65	0.55	0.15
Fertilizer [Y]		0.29	0.07	0.06	0.13
Irrigation by fertilizer		0.40	0.85	0.71	0.94
Irrigation	Fertilizer				
Well-watered	100%		21.0	31.5	11.0
	50%		26.1	46.6	11.5
	25%		23.2	49.9	9.5
Reduced irrigation	100%		20.4	37.6	11.6
	50%		23.8	39.9	13.5
	25%		25.4	47.6	12.4

[Z] Well-watered irrigation treatments were maintained at a volumetric water content (VWC) of 40% and reduced irrigation treatments were maintained at a VWC of 18%. [Y] Fertilizer treatments are 100% (12 g/plant), 50% (6 g/plant), and 25% (3 g/plant) of the medium bag rate of (Nutricote Total 18-6-8, 180 d; 18 N- 2.6P- 6.6K; Chisso-Ashai Fertilizer Co., Tokyo, Japan).

Alem et al. [9] found that flowering of *Petunia × hybrida* 'Dreams White' was reduced by a combination of high fertilizer rates and high substrate VWC. Maximum flowering occurred at 0.21 to 0.63 g/plant fertilizer and 0.20 VWC threshold. Similarly, James and van Iersel [10] found that flowering of subirrigated petunia and wax begonia (*Begonia × semperflorens*) increased from a fertilizer EC of 0.15 to 1.8 dS m^{-1} after which flowering decreased. At seven weeks after transplant, the maximum number of inflorescences for begonia was with a fertilizer rate of 1.6 dS m^{-1}, with the number of inflorescences reduced by 10% or more for plants grown with an EC of less than 0.85 or greater than 2.3 dS m^{-1}. For petunia, the maximum number of flowers was at 2.1 dS m^{-1}, with a 10% of greater reduction in flowers at an EC less than 1.3 or greater than dS m^{-1}.

Number of cut racemes of big bend bluebonnet (*Lupinus havardii*) was reduced by 35% for plants at 12% and 15% volumetric moisture content (VMC) compared to plants at 20% and 35% VMC [28]. Cai et al. [29] found no difference in flower number for 30% and 40% SMC for *Rosa hybrida* 'Radrazz' and 'Belinda's Dream'. For Radrazz flower number was reduced by 27% and 85% for the 20% and 10% SMC and for Belinda's Dream flower number was reduced by 42% and 75% at 20% and 10% compared to the 30% SMC treatments. Number of flowers for *Helenium hybrida* 'Helbro' (sneezeweed) was greater for plants grown at 40% VWC compared to 20% VWC and there was no difference in flowering of *Echinacea purpurea* 'PAS702917' for plants grown at 25% or 40% VWC [30]. The variability in fertilizer and irrigation treatment on flowering suggests differences in plant water and nutrient requirements, adaptation features, and degree of water stress imposed by the reduced irrigation treatments.

3.3. Plant Stress and Irrigation

SPAD was greater for the 100% fertilizer rate than the 25% fertilizer rate and not different than the 50% fertilizer rate, with no irrigation effect (Table 3). Alem et al. [9] reported that SPAD readings increased with increasing fertilizer rate, but decreased over the course of the experiment. The effect of fertilizer rate was greatest at low VWC with no difference at the 40% VWC threshold. In contrast to this study, leaf greenness of *H. hybrida* was greater for plants receiving a RI treatment compared to WW plants but similarly there was no effect of irrigation treatment on SPAD readings of *E. purpurea* [30]. For *H. hybrida*, it may be possible that the excessive growth of plants at receiving the WW treatment resulted in depletion of available nutrients in the substrate and subsequently, resulted in lower SPAD readings. Similar to sneezeweed, leaf greenness of big bend bluebonnet was also reduced at lower water contents and the authors postulated that plants at the lower water contents had reached a critical growth stage and began to senesce [28]. Differences in leaf greenness may also be the result of leaf thickness or leaf chlorophyll content [31]. For this study, results may indicate that the 25% fertilizer rate may not have been sufficient to supply adequate nutrients.

Table 3. Leaf greenness [Special Products Analysis Division (SPAD)], IR temperature, visual rating, total irrigation volume, and water use efficiency of beardtongue at the conclusion of the 73 d experiment. Well-watered irrigation treatments were maintained at a volumetric water content (VWC) of 40% and reduced irrigation treatments were maintained at a VWC of 18%.

Treatment		SPAD	IR	Visual Rating	Irrigation Volume (L/Plant)	Water Use Efficiency ($g \cdot L^{-1}$) ^{z}
Treatment significance						
Irrigation ^{Z}		0.08	0.46	0.02	0.0075	0.0013
Fertilizer ^{Y}		0.004	0.46	0.37		0.25
Irrigation by fertilizer		0.85	0.48	0.28		0.86
Irrigation	Fertilizer					
	100%	49.7a ^{X}				
	50%	44.3ab				
	25%	41.5b				
Well-watered				3.3b	40.8a	2.42b
Reduced irrigation				3.9a	26.7b	3.05a
Least squares means grouped by treatment combination						
Irrigation	Fertilizer					
Well-watered	100%	48.5	33.4	3.8		2.67
	50%	41.9	33.4	3.1		2.36
	25%	40.0	32.8	3.0		2.33

Table 3. *Cont.*

Treatment		**SPAD**	**IR**	**Visual Rating**	**Irrigation Volume (L/Plant)**	**Water Use Efficiency ($g{\cdot}L^{-1}$) ^{z}**
Reduced irrigation	100%	50.9	32.9	3.8		3.29
	50%	46.7	33.3	4.3		3.19
	25%	42.8	33.0	3.7		2.89

[Z] Well-watered irrigation treatments were maintained at a volumetric water content (VWC) of 40% and reduced irrigation treatments were maintained at a VWC of 18%. [Y] Fertilizer treatments are 100% (12 g/plant), 50% (6 g/plant), and 25% (3 g/plant) of the medium bag rate of (Nutricote Total 18-6-8, 180 d; 18 N- 2.6P- 6.6K; Chisso-Ashai Fertilizer Co., Tokyo, Japan). [X] Means within a column with different letters are different ($\alpha = 0.05$) according to the Tukey's honestly significant difference tests. Each value is the mean of three replications with each replication consisting of two pseudoreplicate plants.

As expected, irrigation volume was greater for the WW treatment (40.8 L/plant) than the RI (26.7 L/plant). Visual rating for RI plants (3.9; Figure 1) were greater than the WW plants (3.3; Figure 2), with no effect of fertilizer rate (Table 3). These results are similar to other studies that have reported production of salable plants at reduced irrigation volumes [4,13,20–23]. Water use efficiency was greater for plants receiving the RI treatment than the WW treatment. This result is similar to that of sneezeweed, which also had greater WUE at RI than WW, but differs from coneflower which was not affected by treatments [30]. These results indicate the RI treatments not only result in water savings, but are beneficial for production and salability of plants.

Figure 1. Representative 'Ruby Candle' beardtongue plants maintained at 18% VWC at the conclusion of the 73 day experiment. Plants received 25% (3 g/plant), 50% (6 /plant), or 100% (12 g/plant) of the medium bag rate of controlled release fertilizer (left to right).

Figure 2. Representative 'Ruby Candle' beardtongue plants maintained at 40% VWC content at the conclusion of the 73 day experiment. Plants received 25% (3 g/plant), 50% (6 /plant), or 100% (12 g/plant) of the medium bag rate of controlled release fertilizer (left to right).

4. Conclusions

The results of this research demonstrate the potential for reduced fertilizer applications and reduced irrigation in herbaceous perennial production. Reduced inputs had a significant effect on vegetative plant growth, with fertilizer rate and irrigation level having different impacts on growth. Although RI and reduced fertilizer rates did impact some aspects of vegetative growth, the overall appearance (visual rating) of plants was greater for RI plants with fertilizer rate not impacting the visual rating. Reduced inputs did not impact flowering, which is important for both plant appeal and attractiveness to pollinators. The visual appearance of plants is important for consumer appeal so the improved appearance with reduced inputs shows that not only can reducing inputs improve production but can also increase the appeal to consumers. These results show that, similar to in the landscape, *Penstemon* perform better in a well-drained substrate that does not remain too wet during production. Improvements in growth of *Penstemon* hybrids are possible with reduced irrigation practices and appropriate soil/substrate use in production and in the landscape. More research is needed to understand if changes in irrigation or fertilization practices impact other aspects of flower development such as nectar and pollen production. Additional research looking at other genus would provide further information on similarities and differences between genus.

Funding: This research was supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, the Center for Agriculture, Food and the Environment and the Stockbridge School of Agriculture at University of Massachusetts Amherst, under project number MAS00487. The contents are solely the responsibility of the authors and do not necessarily represent the official views of the USDA or NIFA. It was also supported by the University of Massachusetts Center for Agriculture, Food, and the Environment Summer Scholar Program.

Acknowledgments: The author wishes to thank Ryan MacMullan for assistance with data collection and project maintenance.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Beeson, R.C., Jr. Relationship of plant growth and actual evapotranspiration to irrigation frequency based on management allowed deficits for container nursery stock. *J. Am. Soc. Hort Sci.* **2006**, *131*, 140–148. [CrossRef]
2. Owen, J.S., Jr.; Warren, S.L.; Bilderback, T.E.; Albano, J.P. Phosphorus rate, leaching fraction, and substrate influence on influent quantity, effluent nutrient content, and response of a containerized woody ornamental crop. *HortScience* **2008**, *43*, 906–912. [CrossRef]
3. Chappell, M.; Owen, J.; White, S.; Lea-Cox, J. Irrigation management practices. In *Best Management Practices: Guide for Producing Nursery Crops*, 3rd ed.; Yeager, T., Bilderback, T., Fare, D., Giliam, C., Lea-Cox, J., Niemiera, A., Ruter, J., Tilt, K., Warren, S., Whitwell, T., et al., Eds.; Southern Nursery Association: Acworth, GA, USA, 2013.
4. Bayer, A.; Ruter, J.; van Iersel, M.W. Optimizing irrigation and fertilization of Gardenia jasminoides for good growth and minimal leaching. *Hortscience* **2015**, *50*, 994–1001. [CrossRef]
5. Brand, M.H.; Leonard, R.L. Consumer product and service preference related to landscape retailing. *HortScience* **2001**, *36*, 1111–1116. [CrossRef]
6. Koniarski, M.; Matysiak, B. Growth and development of potted *Rhododendron* cultivars 'Catawbiense Boursault' and 'Old Port' in response to regulated deficit irrigation. *J. Hort. Res.* **2013**, *21*, 29–37. [CrossRef]
7. Sánchez-Blanco, M.J.; Álvarez, S.; Navarro, A.; Bañon, S. Comparative growth and water relation of *Cistus albidus* and *Cistus monspeliensis* plants during water deficit conditions and recovery. *Plant Sci.* **2002**, *162*, 107–113. [CrossRef]
8. Yeager, T.; Million, J.; Larsen, C.; Stamps, B. Florida nursery best management practices: Past, present, and future. *HortTechnology* **2010**, *20*, 82–88. [CrossRef]
9. Alem, P.; Thomas, P.A.; van Iersel, M.W. Substrate water content and fertilizer rate affect growth and flowering of potted petunia. *HortScience* **2015**, *50*, 582–589. [CrossRef]
10. James, E.C.; van Iersel, M.W. Fertilizer concentration affects growth and flowering of subirrigated petunias and begonias. *HortSceince* **2001**, *36*, 40–44. [CrossRef]

11. Million, J.; Yeager, T.; Larsen, C. Water use and fertilizer response of azalea using several no-leach irrigation methods. *HortTechnology* **2007**, *17*, 21–25. [CrossRef]
12. Tyler, H.H.; Warren, S.L.; Bilderback, T.E. Reduced leaching fractions improve irrigation use efficiency and nutrient efficacy. *J. Environ. Hort.* **1996**, *14*, 199–204.
13. Bayer, A.; Whitaker, K.; Chappell, M.; Ruter, J.; van Iersel, M.W. Effect of irrigation duration and fertilizer rate on plant growth, substrate EC, and leaching volume. *Acta Hort.* **2014**, *1034*, 477–484. [CrossRef]
14. Carroll, A.B.; Pallardy, S.G.; Galen, C. Drought stress, plant water status, and floral trait expression in fireweed, *Epilobium angustifolium* (Onagraceae). *Am. J. Bot.* **2001**, *88*, 438–446. [CrossRef] [PubMed]
15. Armitage, A. *Herbaceous Perennial Plants: A Treatise on their Identification, Culture, and Garden Attributes*, 3rd ed.; Stipes: Champaign, IL, USA, 2008; pp. 768–774.
16. Nemali, K.S.; van Iersel, M.W. An automated system for controlling drought stress and irrigation in potted plants. *Sci. Hort.* **2006**, *110*, 292–297. [CrossRef]
17. Nemali, K.S.; Montesano, F.; Dove, S.K.; van Iersel, M.W. Calibration and performance of moisture sensors in soilless substrates: ECH_2O and Theta probes. *Sci. Hort.* **2007**, *112*, 227–234. [CrossRef]
18. Kong, Y.; Zheng, Y. Potential of producing *Salicornia bigelovii* hydroponically as a vegetable at moderate NaCl salinity. *HortScience* **2014**, *49*, 1154–1157. [CrossRef]
19. Li, Z.; Fontanier, C.; Dunn, B.L. Physiological response of potted sunflower (*Helianthus annuus* L.) to precision irrigation and fertilizer. *Sci. Hort.* **2020**, *270*, 109417. [CrossRef]
20. Bayer, A.; Ruter, J.; van Iersel, M.W. Water use and growth of *Hibiscus acetosella* 'Panama Red' grown with a soil moisture sensor-controlled irrigation system. *Hortscience* **2013**, *48*, 980–987. [CrossRef]
21. Burnett, S.E.; van Iersel, M.W. Morphology and irrigation efficiency of *Gaura lindheimeri* grown with capacitance sensor-controlled irrigation. *HortScience* **2008**, *43*, 1555–1560. [CrossRef]
22. Van Iersel, M.W.; Seymour, R.M.; Chappell, M.; Watson, F.; Dove, S. Soil moisture sensor-based irrigation reduced water use and nutrient leaching in a commercial nursery. *Proc. South Nurs. Assn.* **2009**, *54*, 17–21.
23. Zhen, S.; Burnett, S.E.; Day, M.E.; van Iersel, M.W. Effects of substrate water content on morphology and physiology of rosemary, canadian columbine, and cheddar pink. *HortScience* **2014**, *49*, 486–492. [CrossRef]
24. Hsiao, T.C.; Xu, L.K. Sensitivity of growth of roots vs. leaves to water stress: Biophysical analysis and relation to water transport. *J. Exp. Bot.* **2000**, *51*, 1595–1616. [CrossRef]
25. Bayer, A.; Ruter, J.; van Iersel, M.W. Elongation of Hibiscus acetosella under well-watered and drought-stressed conditions. *HortScience* **2016**, *51*, 1384–1388. [CrossRef]
26. Cabrera, R.I. Nitrogen balance for two container-grown woody ornamental plants. *Sci. Hort.* **2003**, *97*, 297–308. [CrossRef]
27. Lambers, H.; Pons, T.L.; Chapin, S. *Plant Physiological Ecology*, 2nd ed.; Springer: New York, NY, USA, 2008.
28. Niu, G.; Rodriguez, D.S.; Rodriguez, L.; Mackay, W. Effect of water stress on growth and flower yield of big bend bluebonnet. *HortTechnology* **2007**, *17*, 557–560.
29. Cai, X.; Starman, T.; Niu, G.; Hall, C. The effect of substrate moisture content of growth and physiological responses of two landscape roses (*Rosa hybrida* L.). *HortScience* **2014**, *49*, 741–745. [CrossRef]
30. Bayer, A. Effect of reduced irrigation on growth and flowering of coneflower and sneezeweed. *HortTechnology* **2020**, *30*, 315–321. [CrossRef]
31. Martínez, D.; Guiamet, J. Distortion of the SPAD 502 chlorophyll meter readings by changes in irradiance and leaf water status. *Agronomie* **2004**, *24*, 41–46. [CrossRef]