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Astilbe and Coneflower Growth as Affected by Fertilizer Rate and Substrate Volumetric Water Content

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Abstract: Improved irrigation and fertilization practices, such as reduced applications, are needed to improve the sustainability of container plant production. The objective of this study was to assess growth of Visions astilbe (*Astilbe chinensis* 'Visions') and Mellow Yellow coneflower (*Echinacea purpurea* 'Mellow Yellow') grown at two controlled-release fertilizer (CRF) rates (100% or 50% of the medium bag rate) and two volumetric water contents (VWC; 40% and 18%). For coneflower, there were no significant treatment effects for height, growth index, shoot dry weight, or leaf size. There was a significant VWC effect on number of flowers with the 40% treatment having more flowers (5.6) per plant than the 18% treatment (2.7). Shoot dry weight, growth index, and leaf size of astilbe were greater for the 40% VWC treatment than the 18% VWC treatment with no fertilizer rate effect. Astilbe height and number of flowers was not significant. These results indicate that there is a species-specific effect of VWC on growth whereas reduced fertilizer applications are possible for both species without impacting growth. Although a substrate VWC of 18% is likely too low to produce salable plants, a VWC below 40% can potentially be used to support adequate growth.

Keywords: sensor irrigation; water stress; reduced irrigation; *Echinacea*; greenhouse production; container production

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1. Introduction

Container plant production is input intensive with frequent irrigation and fertilization. Actual plant water and nutrient needs are not well known, and growers prefer to err on the side of applying too much water and fertilizer than risk negative impacts on plant growth [1,2]. Over-irrigation is a common problem in container plant production which can result in fertilizer leaching from production areas. Nutrient laden runoff can enter local ecosystems having a negative environmental impact [3]. Excessive water and fertilizer applications can also have a negative impact on plant growth with uneven growth and stretching resulting in poor appearance. Over-irrigation, under-irrigation, and lack of uniformity can all impact plant development and overall crop quality. This demonstrates the need to understand plant water requirements in order to improve irrigation applications.

Best management practices (BMPs) have been developed to improve efficiency of irrigation and fertilization in container plant production. Irrigation best management practices include cyclic irrigation, grouping plants by water requirements, and assessing irrigation system uniformity [4]. More recently, technologies such as soil moisture sensors have been used to monitor and control irrigation in greenhouse and nursery settings [5]. Soil moisture sensors have provided the ability to easily grow plants at different substrate volumetric water contents (VWC). This information provides insight to plant responses to reduced irrigation volumes that can be utilized by growers, even if they are not using sensor-controlled irrigation. Fertilizer and nutrient leaching BMPs include the use of controlled-release fertilizers and substrate nutrient monitoring [6]. One of the concerns with reduced irrigation applications along with reduced leaching is the buildup of fertilizer salts in the substrate which can damage plant roots [7].

Astilbe and coneflower are both popular herbaceous perennials considered to have moderate irrigation and fertilizer requirement during production. Astilbe however is sensitive to drying, especially during plume maturation while coneflower does not perform well in wet conditions with over-watering resulting in slowed growth. Coneflower is also sensitive to over fertilization [8]. The objective of this research was to quantify the effect of reduced fertilizer rate and high and low substate water contents on growth of Visions astilbe and Mellow Yellow coneflower.

2. Materials and Methods

Two separate experiments were conducted in a glass greenhouse at the University of Massachusetts in Amherst, MA from 13 June 2018 to 3 October 2018. Irrigation and fertilization treatments along with data collection were the same for both experiments. Greenhouse lighting was set for a 16 h daylength and air temperature setpoints were 70 °F during the day and 65 °F at night during the experimental period.

Plant material. Expt 1. Rooted cuttings of astilbe (Pioneer Gardens Inc., Deerfield, MA, USA) were potted up on 13 June 2018. Cuttings were planted in 3 qt black plastic containers filled with a commercial substrate mix containing peat moss, bark, perlite, dolomitic lime, and a wetting agent (Metro Mix 865; Sun Gro Horticulture, Agawam, MA, USA). Controlled-release fertilizer (Nutricote 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 one week before irrigation treatment began on 20 June 2018. The experiment was concluded on 2 August 2018.

Expt. 2. Rooted cuttings of coneflower (Pioneer Gardens, Inc., Deerfield, MA, USA) were potted up on 27 July 2018. Cuttings were planted in 3 qt black plastic containers filled with a commercial substrate mix containing peat moss, bark, perlite, dolomitic lime, and a wetting agent (Metro Mix 865; Sun Gro Horticulture, Agawam, MA, USA). Controlled-release fertilizer (Nutricote 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 one week before irrigation treatment began on 3 August 2018. The experiment was concluded on 3 October 2018.

Treatments and Data Collection. Treatment combinations consisted of two substrate water content setpoints (18% or 40%) and two fertilizer rates for a total of four treatment combinations. Fertilizer rates were 100% (12 g/plant) or 50% (6 g/plant) of the medium bag rate. Substrate water content setpoints were chosen to supply reduced irrigation (18%) and well-watered (40%) conditions and were based on previous research. Fertilizer rates were chosen to represent an average industry application (100% of the bag rate) and a reduced fertilizer application (50%). There were four irrigation lines per block to maintain two lines at each of the substrate water content setpoints. Each of the two lines had five plants receiving either the 50% or 100% fertilizer treatments for a total of 20 plants per block.

Soil moisture sensors (10HS; Decagon Devices, Pullman, WA, USA) were used to automate irrigation using an irrigation system similar to that described by Nemali and van Iersel [9]. A sensor was interested into the center of the substrate of two pots in all 12 lines for a total of 24 sensors. Sensors were connected to a multiplexer (AM16/32B; Campbell Scientific, Logan, UT, USA) connected to a datalogger (CR1000; Campbell Scientific). Voltage output was measured by the datalogger every 60 min and was converted to VWC using a substrate specific calibration [VWC = $-0.4207 + 0.0009 \times$ output (V)] using the method described by Nemali et al. [10]. Volumetric water content was then converted to a percent from $L{\cdot}L^{-1}$. The datalogger signaled the relay driver (SDM16AC/DC controller; Campbell Scientific) to open the appropriate solenoid valve (Rainbird, Azusa, CA, USA) when both sensors in a line were below the VWC threshold (18% or 40%) for that line. Individual sensor readings were averaged and recorded every 60 min.

Plant height, width, and number of flowers and/or buds were measured weekly. 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 were dried at 50 °C for 1 week after which dry weight was determined. Relative chlorophyll content was measured using a chlorophyll meter (SPAD 502DL Plus; Konica Minolta, Osaka, Japan). Growth index (GI) was calculated as follows: (height + width 1 + width 2/3) [11].

Experimental design and data analysis. The experiment was designed as a randomized complete block with four treatments combinations and three replications for a total of twelve plots with five pseduoreplications plants each. Data for each species were analyzed separately. Data were subjected to analysis of variance using the PROC GLM procedure of SAS (version 9.4; SAS Institute, Cary, NC, USA) and when significant, means were separated using Tukey's honestly significance test with $p = 0.05$ considered statistically significant.

3. Results and Discussion

3.1. Vegetative Growth

Dry weight of astilbe was greater for the 40% VWC treatment (8.88 g) than the 18% VWC treatment (4.33 g) with no fertilizer rate effect (Table 1). Astilbe height was not significant. Growth index of astilbe was also greater for plants maintained at 40% VWC than at 18% VWC (Table 1). Dry weight, height, and GI were not significant for coneflower (Table 2). Other research has also been variable in response to reduced irrigation and fertilizer rates. Similar to this study, Li et al. [12] reported greater stem dry mass of *Helianthus annuus* L. 'Choco Sun' at higher irrigation levels but no fertilizer rate effect and no impact of irrigation or fertilizer rate on final height. Shoot dry weight of *Gardenia jasminoides* 'MAGDA I' was greater for the 50% and 100% fertilizer rates than the 25% rate [13]. At the 100% fertilizer rate shoot dry weight increased with increasing irrigation volume. There was no treatment effect on gardenia height. There was an interactive effect of fertilizer and irrigation rate on final growth index of *Gardenia jasmonoides* 'MAGDA 1' with a significant irrigation volume effect at the 50% and 100% fertilizer rates but not at the 25% fertilizer rate. This was likely due to the reduced growth at the 25% rate. In contrast to this study, 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 and was unaffected by irrigation volume [14].

Petunia x *hybrida* 'Dreams Mix' shoot dry weight increased with fertilizer rate from 1.0 to 1.67 g/plant but decreased with higher rates [15]. The fertilizer rate effect on shoot dry weight was more pronounced at higher VWC. Tyler et al. [2] found that shoot dry weight of *Cotoneaster dammeri* 'Skogholm' was reduced by 26% when fertilizer rate was reduced by 50% and maintenance of a low leaching fraction reduced shoot dry weight by 8% compared to a higher leaching fraction with the interactive effect of fertilizer by leaching fraction not significant. Million et al. [16] also found that shoot dry weight of *Viburnum odoratissimum* was reduced by 6% at a 2 cm irrigation application compared to a 1 cm application and was reduced by 32% with a lower fertilizer rate (15 g/plant vs. 30 g/plant). *Viburnum odoratissimum* height was also unaffected by irrigation volume but was greater for plants receiving 30 g/plant CRF than plants receiving 15 g/plant [16].

Shoot dry weight, height and GI of *Hydrangea macrophylla*, *Buxus* x 'Green Velvet', *Spiraea japonica* 'Magic Carpet', *Heuchera micrantha* 'Palace Purple', and *Hibiscus* syricaus was generally greater for higher CFR rates than low rates [17]. However, the response was also species specific with maximum dry weight, height, and GI achieved at different CRF rates by species. For example, *Heuchera micrantha* 'Palace Purple' was not different for the 0.45–1.65 kg/m^{-3} N fertilizer rates. Scoggins [18] also reported fertilizer rate impact on shoot dry weight to be variable by species. Allbritton et al. [19] found that shoot dry mass of *Eupatorium fistulosum* increased with increasing fertilizer rate but low CRF rates still produced commercially acceptable growth. Shoot dry weight and height of *Hibiscus* acetosella 'Panama Red', *Rosmarinus officinalis*, *Dianthus gratianopolitanus* 'Bath's Pink', and *Gaura lindheimeri* has been reported to generally increase with increasing substrate VWC [20–22]. However, moderate VWC were adequate to produce salable plants.

Table 1. Shoot dry weight, height, and growth index of 'Visions' astilbe in response to substrate volumetric water content (VWC) and fertilizer rate treatments at the conclusion of the 61d experiment. The 40% VWC treatment was considered well-watered while the 18% treatment supplied a reduced irrigation treatment. Shoots were cut off at the substrate surface and were dried at 50 °C for 1 week after which dry weight was determined. Growth index (GI) was calculated as follows: (height + width 1 + width 2/3).

Treatment		Shoot Dry Weight (g)	Height (cm)	Final GI (cm)
		Treatment significance		
Irrigation		0.003	0.06	0.001
Fertilizer [Z]		0.87	0.43	0.88
Irrigation by fertilizer		0.76	0.77	0.94
		Least squares means for main effects		
40% VWC		8.88a [Y]		28.8a
18% VWC		4.33b		23.5b
		Least squares means grouped by treatment combination		
Irrigation by fertilizer				
40%	100%	8.94	24.1	28.7
40%	50%	8.79	22.6	28.8
18%	100%	4.05	20.9	24.0
18%	50%	4.61	20.2	23.0

[Z] Fertilizer treatments are 100% (12 g/plant) and 50% (6 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). [Y] 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 five pseudoreplicate plants.

Table 2. Shoot dry weight, height, and growth index of 'Mellow Yellow' coneflower in response to substrate volumetric water content (VWC) and fertilizer rate treatments at the conclusion of the 69 d experiment, the 40% VWC treatment was considered well-watered while the 18% treatment supplied a reduced irrigation treatment. Shoots were cut off at the substrate surface and were dried at 50 °C for 1 week after which dry weight was determined. Growth index (GI) was calculated as follows: (height + width 1 + width 2/3).

Treatment		Shoot Dry Weight (g)	Height (cm)	Final GI (cm)
		Treatment significance		
Irrigation		0.07	0.88	0.31
Fertilizer [Z]		0.55	0.22	0.61
Irrigation by fertilizer		0.33	0.68	0.96
		Least squares means grouped by treatment combination		
Irrigation by fertilizer				
40%	100%	13.68	25.2	27.5
40%	50%	16.05	32.0	32.5
18%	100%	12.20	19.4	25.2
18%	50%	11.59	22.9	26.5

[Z] Fertilizer treatments are 100% (12 g/plant) and 50% (6 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). Each value is the mean of three replications with each replication consisting of five pseudoreplicate plants.

These results indicate that there is a species-specific response to both fertilizer rate and irrigation rate. Variability in growth responses could be due to differences in growth rate, water and nutrient requirements, drought-stress tolerance, or nutrient deficiency and toxicity responses. Fertilizer rate response shows that the threshold after which increased nutrients do not result in additional growth varies by species. For some species excessive fertilizer enters the toxicity range, negatively impacting growth. In general, high fertilizer rates and irrigation volumes are not needed to produce high quality, salable plants. Although growth is generally reduced at moderate irrigation and fertilizer rates, plant appearance and size are commercially acceptable allowing for the reduction in inputs. The results of this study suggests that substrate volumetric water content has a greater effect on growth of astilbe (Figure 1) than coneflower (Figure 2).

Figure 1. Representative plants of 'Visions' astilbe at the conclusion of the 61 day experiment. Plants were maintained at either 40% VWC or 18% VWC and received either 100% (12 g/plant) or 50% (6 g/plant) of the medium bag rate of controlled release fertilizer. Treatments were 18% VWC 50% (6 g/plant) CRF, 40% VWC 50% CRF, 18% VWC 100% CRF, and 40% VWC 100% CRF (left to right).

Leaf size of astilbe was greater for the 40% VWC treatment (81.6 cm^2) than the 18% VWC treatment (36.2 cm^2, Table 3). There was no significant VWC or fertilizer rate effect on leaf size of coneflower (Table 4). Leaf size of *Penstemon* 'Ruby Candle' was also not affected by fertilizer or irrigation treatment [23]. Conversely, leaf size of *Hibiscus acetosella* 'Panama Red' [20] and *Petunia* x *hybrida* 'Dreams White' were reduced with lower irrigation rates [15]. Cell elongation is reduced with water stress and is an indicator of drought stress in plants [24]. This suggests that the reduced irrigation treatment caused water stress induced reduced growth for astilbe but not coneflower.

Figure 2. Representative plants of 'Mellow Yellow' coneflower at the conclusion of the 69-day experiment. Plants were maintained at either 40% VWC or 18% VWC and received either 100% (12 g/plant) or 50% (6 g/plant) of the medium bag rate of controlled release fertilizer. Treatments were 18% VWC 50% (6 g/plant) CRF, 40% VWC 50% CRF, 18% VWC 100% CRF, and 40% VWC 100% CRF (left to right).

3.2. Flowering

There was a significant VWC level effect on number of flowers for coneflower with average number of flowers greater for plants at 40$%VWC (5.6) than plants at 18% VWC (2.7) with no fertilizer rate effect (Table 4). There was no VWC or fertilizer rate effect on number of flowers for astilbe (Table 3). Conversely Bayer et al. [25] found that flowering of

Echinacea purpurea 'PAS702917' was not different when grown at 25% or 40% VWC. This indicates that 18% VWC in this study caused significant enough water stress to reduce flowering whereas 25% in the 2020 study did not. Similar to this study, number of flowers of *Helenium hybrida* 'Helbro' was greater at 40% VWC than 20% VWC [25]. Maximum flowering of *Petunia* x *hybrida* 'Dreams White' occurred at 0.21 to 0.63 g/plant fertilizer and 20% VWC threshold with higher fertilizer rates and substrate VWC reducing flowering [15]. *Lupinus havardii* racemes was greater for plants at high Volumetric moisture contents (VMC) than low VMC [26]. Similar to vegetative growth, the variability in flowering response to VWC and fertilizer rate indicates differences in plant water and nutrient requirements for flowering. It also demonstrates species differences in response to water stress.

Table 3. Leaf size, number of flowers, and leaf greenness [Special Products Analysis Division (SPAD)] of 'Visions' astilbe at the conclusion of the 61 d experiment. The 40% VWC treatment was considered well-watered while the 18% treatment supplied a reduced irrigation treatment. Leaf size of ten fully expanded leaves was measured at the conclusion of the experiment using a leaf area meter.

Treatment		Leaf Size (cm^2) [X]	Number of Flowers	SPAD
			Treatment significance	
Irrigation [Z]		0.005	0.69	0.90
Fertilizer [Y]		0.63	0.26	0.78
Irrigation by fertilizer		0.60	0.44	0.22
			Least squares means for main effects	
40% VWC		81.6a [W]		
18% VWC		36.2b		
			Least squares means grouped by treatment combination	
Irrigation by fertilizer				
40%	100%	81.8	1.3	53.5
40%	50%	81.2	1.3	55.1
18%	100%	30.1	1.1	54.7
18%	50%	42.2	1.4	53.6

[Z] Substrate volumetric water content (VWC) treatments were 40% and 18%. [Y] Fertilizer treatments are 100% (12 g/plant) and 50% (6 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 five pseudoreplicate plants.

3.3. Plant Stress

Leaf greenness, as represented by SPAD measurements, was not significant for astilbe or coneflower (Tables 3 and 4). Similar to this study there was no irrigation or fertilizer rate effect on SPAD measurements for *Echinacea purpurea* 'PAS702917'; however, there was a significant effect of irrigation treatment on *Helenium hybrida* 'Helbro' with the reduced irrigation treatments have greater SPAD readings than the well-watered plants [25]. This was potentially due to the exuberant growth of plants in the well-watered treatment depleting nutrients from the substrate. For *Penstemon* 'Ruby Candle', SPAD was greater for the 100% fertilizer rate than the 25% rate but not different than the 50% rate with no irrigation rate effect [23]. *Petunia* x *hybrida* 'Dreams White' SPAD readings increased with increasing fertilizer rate, with the fertilizer rate effect greater at low VWC than high VWC [15]. SPAD readings of *Lupinus havardii* were reduced at lower water contents compared to high water contents, potentially due to senescence from water stress [26]. Differences could also be the result of plant features such as leaf thickness or chlorophyll content levels [27]. For this study, results indicate that the 50% fertilizer rate supplied adequate nutrients.

Table 4. Leaf size, number of flowers, and leaf greenness [Special Products Analysis Division (SPAD] of 'Mellow Yellow' coneflower at the conclusion of the 61 d experiment. The 40% VWC treatment was considered well-watered while the 18% treatment supplied a reduced irrigation treatment. Leaf size of ten fully expanded leaves was measured at the conclusion of the experiment using a leaf area meter.

Treatment		Leaf Size (cm^2) X	Number of Flowers	SPAD
			Treatment significance	
Irrigation Z		0.56	0.03	0.37
Fertilizer Y		0.72	0.93	0.13
Irrigation by fertilizer		0.73	0.84	0.96
			Least squares means for main effects	
40% VWC			5.6a W	
18% VWC			2.7b	
			Least squares means grouped by treatment combination	
Irrigation by fertilizer				
40%	100%	28.3	5.8	50.6
40%	50%	31.2	5.5	52.7
18%	100%	27.2	2.7	51.6
18%	50%	27.3	2.8	49.4

Z Substrate volumetric water content (VWC) treatments were 40% and 18%. Y Fertilizer treatments are 100% (12 g/plant) and 50% (6 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 five pseudoreplicate plants.

4. Conclusions

Reducing production inputs, such as water and fertilizer, has the potential to lower production costs as well as reduce the environmental impact of production. The results of this study add to the body of knowledge on species-specific growth responses to fertilizer rate and substrate VWC. In this study, VWC had a greater effect on growth and flowering of astilbe and coneflower than fertilizer rate. Astilbe is more sensitive to drying which is reflected in reduced shoot dry weight, height, leaf size, and final growth index for plants grown at 18% VWC. Coneflower is sensitive to wet substrates and growth was unaffected by VWC, which suggested that the 18% VWC was sufficient to support growth and that the 40% did not result in excessive moisture that would reduce growth. Number of flowers was significantly affected by VWC for coneflower, this suggested that the 18% VWC treatment either delayed flowering or reduced flowering. The results of this study show the potential for reduced fertilizer and irrigation applications in the production of astilbe and coneflower. Although the lower VWC reduced growth of astilbe, more compact plants can be desirable for shipping. Excessive growth can be a problem during shipping and in the retail setting where stem breakage can impact the sale of plants. These along with other results, show the importance of identifying the species response to lower irrigation (substrate VWC) and fertilizer levels as there is a potential for both growth and flowering to be reduced. Differences in responses could be due to a species' adaptations to water stress and nutrient needs. Additional information on various species will help to identify plants that can be produced with reduced inputs.

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