Effect of Reduced Irrigation on Growth and Flowering of Coneflower and Sneezeweed

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SUMMARY. Reduced irrigation (RI) can be used to reduce irrigation volume as well as to control plant growth. The timing and duration of RI applications can affect overall plant growth and flowering. Knowledge of plant response to RI can allow growers to control growth and plant form. The objective of this study was to quantify flower and overall plant growth of ‘PAS702917’ coneflower (*Echinacea purpurea*) and ‘Helbro’ sneezeweed (*Helenium hybridum*) in response to RI. A soil-moisture sensor automated irrigation system was used to apply four irrigation treatments: RI and well-watered (WW) controls (25% or 38%) and two alternating treatments to apply RI for either the first 2 weeks (25% followed by 38%, RIWW treatment) or final 4 weeks (38% followed by 25%, WWRI treatment) of the 6-week study. For the sneezeweed experiment, RI was reduced to 20%. For coneflower, peduncle length was greater for the WW (36.8 cm) and RIWW treatments (35.7 cm) than the RI (27.0 cm) and WWRI treatments (26.6 cm). Shoot dry weight, compactness, leaf area, and flower number were not significant. For sneezeweed, WW plants were taller (57.2 cm) and had greater shoot dry weight (49.8 g) than plants in other treatments. WW plants also had more flowers (99) than WWRI (63) and RI (67) plants, which were more compact. Total leaf area did not differ between treatments for either species. Total irrigation volume was greatest for WW plants (5.2 and 15.1 L/plant for coneflower and sneezeweed, respectively), with RI at any point during the experiment resulting in water savings.

Reducing irrigation applications in container production is necessary for growers to adapt to decreasing water supplies, reduce the environmental impact of production, and comply with a growing number of regulations regarding nursery and greenhouse water use, fertilizer applications, and nutrient levels in runoff (Chappell et al., 2013; Fulcher et al., 2016). However, growers often prefer to overapply rather than

underapply irrigation and fertilizer out of concern that lower amounts could negatively affect growth (Million et al., 2007; Owen et al., 2008). Improved knowledge of plant water requirements and more efficient irrigation systems allow plants to be produced with not only RI but also reduced labor, fertilizer, pesticides, growth regulators, and production-related energy inputs (Lichtenberg et al., 2013). There is also a growing preference of consumers for plants produced more sustainably (Behe et al., 2013).

Consumers expect good-quality, uniform, healthy plant material at a reasonable cost (Brand and Leonard, 2001; Guo et al., 2018). Visual appearance is an important consumer quality for ornamental container

plants (Brand and Leonard, 2001). Consumers often purchase plants based on the perception that plant health and visual appearance correspond. Uniform growth, leaves on lower branches, dense foliage, leaf color, and bloom quality can all affect the visual appearance and appeal of a plant to consumers (Brand and Leonard, 2001; Glasgow et al., 1998). In a survey of consumers in New England states, the top characteristic they looked for in a retail establishment was “healthy, fresh, and well-maintained plants” (Brand and Leonard, 2001).

Plant quality control can be a large component of container plant production as uneven growth and poor branching may lead to customer rejection of plant material or poor sales (Koniarski and Matysiak, 2013). Lack of uniformity of plant material can result from uneven irrigation distribution, variation in pruning from person to person, or plant growth regulator application variability by species, substrate, and application timing. Hand pruning is also labor intensive, and plant growth regulators will potentially be restricted due to concerns over chemical use in production, necessitating alternative means of growth control (Kaufmann et al., 2000). Reduced irrigation applications can be used as a method of plant growth control and to improve crop quality (Koniarski and Matysiak, 2013); however, this requires knowledge of species-specific water requirements and uniform irrigation applications. Too little water can result in reduced leaf size, short internodes, reductions in flower size, fewer flowers, and an overall reduction in plant quality (Sánchez-Blanco et al., 2002). Conversely, undesirable plant growth, including excessive growth, long internodes, and large

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Units			
To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
29.5735	fl oz	mL	0.0338
0.0929	ft ²	m ²	10.7639
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
6.4516	inch ²	cm ²	0.1550
28.3495	oz	g	0.0353
93.0102	oz/ft	g·m ⁻¹	0.0108
7.4892	oz/gal	g·L ⁻¹	0.1335
0.9464	qt	L	1.0567
4.9289	teaspoon(s)	cm ³	0.2029
(°F - 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

variation in leaf size, can result from overapplication of water and fertilizer (Koniarski and Matysiak, 2013). Plants with uneven growth are less likely to sell in a retail setting and may require additional labor and resources to improve salability. Water stress during shipping and while in a retail setting can also result in unsalable plants due to reduced visual appeal (Hall et al., 2011). Another benefit of deficit irrigation is the potential to help plants gain tolerance to drought stress conditions that may be encountered during shipping, in a retail nursery, or in a home landscape setting (Cameron et al., 2008; Guo et al., 2018).

The production of more compact plants could also influence shipping costs (Burnett and van Iersel, 2008). Container plants are often stacked or racked during shipping (Eaton and Appleton, 2014), meaning smaller, more compact plants create the potential to fit more plants on a truck. It is beneficial to both producers and consumers if more plants can fit onto a truck because it helps distribute shipping costs onto more plants.

Sensor-controlled irrigation studies have shown the relationship between plant growth and substrate volumetric water content (VWC) threshold for many ornamental plants, including ‘Panama Red’ hibiscus (*Hibiscus acetosella*), gardenia (*Gardenia jasminoides*), lantana (*Lantana camara*) ‘Siskiyou Pink’ gaura (*Gaura lindheimeri*), ‘Mini Penny’ hydrangea (*Hydrangea macrophylla*), rosemary (*Rosmarinus officinalis*), canadian columbine (*Aquilegia canadensis*), and ‘Bath’s Pink’ cheddar pinks (*Dianthus gratianopolitanus*) (Bayer et al., 2013, 2014, 2015; Burnett and van Iersel, 2008; van Iersel et al., 2009; Zhen et al., 2014). The timing of deficit irrigation applications has been reported to affect flower bud development along with controlling plant growth. Flowering has been either promoted or inhibited depending on the species and degree of water stress (Alvarez et al., 2009, 2013; Cameron et al., 1999; Koniarski and Matysiak, 2013; Sharp et al., 2009). More information is needed on the timing of deficit irrigation applications on the growth and flowering of ornamental species to best use this method. The objective of this study was to determine

the effectiveness of RI timing on growth, flowering, and quality of the popular herbaceous perennials coneflower and sneezeweed.

Materials and methods

Research was conducted in a glass greenhouse at the University of Massachusetts in Amherst, MA, from 5 Apr. 2017 to 1 Aug. 2017 as two separate experiments. Irrigation treatments and data collection were the same in both experiments. Greenhouse air temperature setpoints were 70 °F during the day and 65 °F at night during the experimental period. The greenhouse was set for a 16-h daylength.

Plant material

Expt. 1. Rooted cuttings of coneflower were obtained from Pioneer Gardens Inc. (Deerfield, MA) and potted up on 5 Apr. 2017. Cuttings were planted in 3-qt black plastic containers filled with a commercial substrate containing bark, peat, dolomitic limestone, a wetting agent, and starter nutrients (Fafard RSI Nursery Mix; Sun Gro Horticulture, Agawam, MA). Containers were topdressed with 11 g of 18N–2.6P–6.6K controlled-release fertilizer (Nutricote Total 18–6–8, 180 d; Chisso-Ashai Fertilizer Co., Tokyo, Japan). Plants were hand-watered for 3 weeks to allow root establishment before irrigation treatments were initiated on 26 Apr. 2017. Treatment setpoints were switched on 11 May 2017, and the experiment was concluded on 8 June 2017. Plants

experienced varying degrees of iron deficiency due to the pH of irrigation water and were treated one time with a foliar application of iron (Fe) chelate [Sequestrene 330 Fe (10% Fe); BASF Corp., Ludwigshafen, Germany] at a rate of 1 teaspoon/gal.

Expt. 2. Rooted cuttings of sneezeweed were obtained from Pioneer Gardens Inc. and planted on 26 May 2017. Cuttings were planted in 3-qt black plastic containers filled with a commercial substrate (Fafard RSI Nursery Mix). Containers were topdressed with 15 g of 18N–2.18P–6.6K controlled release fertilizer (Osmocote Blend 18–5–8, 3–4 month; ICL Specialty Fertilizers, Dublin, OH). The fertilizer was changed from the previous species to account for the pH issue with the irrigation water discovered during the coneflower experiment. Plants were hand-watered for 3 weeks to allow root establishment before irrigation treatments were initiated on 16 June 2017. Treatment setpoints were switched on 30 June 2017. The experiment was concluded on 1 Aug. 2017.

Treatments and data collection

There were four substrate water content treatments for the coneflower experiment: a well-watered (WW) control (38%), an RI control (25%), altering water content from WW to RI (38% to 25%; WWRI) after 2 weeks and altering water content from RI to WW (25% to 38%; RIWW) after 2 weeks (Fig. 1). Treatments were the same for the sneezeweed

Fig. 1. Substrate water content treatments over the course of the 44- and 47-d experiments. Well-watered and reduced irrigation controls for coneflower were maintained at volumetric water contents of 38% and 25%, respectively. Well-watered–reduced irrigation and reduced irrigation–well-watered treatments had the volumetric water content setpoint changed after 2 weeks. Irrigation treatments were the same for sneezeweed except that the reduced irrigation was lowered to 20%.

Table 1. Growth measurements for coneflower and sneezeweed in response to irrigation treatments at the conclusion of the 44- and 47-d experiments. Compactness was calculated as shoot dry weight/shoot length. Well-watered (WW) and reduced irrigation (RI) controls for coneflower were maintained at volumetric water contents of 38% and 25%, respectively. Well-watered – reduced irrigation (WWRI) and reduced irrigation – well-watered (RIWW) treatments had the volumetric water content setpoint changed after 2 weeks. Irrigation treatments were the same for sneezeweed except the reduced irrigation was lowered to 20%.

Treatment	Peduncle length (cm) ^z	Shoot dry wt (g) ^z	Compactness (g·m ⁻¹) ^z	Leaf area (cm ²) ^z	Flowers (no.)
Coneflower					
WW	36.8 a ^y	14.1 a	0.039 a	1487.6 a	9.33 a
RIWW	35.7 a	14.4 a	0.039 a	1101.5 a	8.07 a
WWRI	26.6 b	11.1 a	0.035 a	939.7 a	8.88 a
RI	27.0b	12.8 a	0.046 a	1122.4 a	8.0 a
<i>P</i>	0.006	0.53	0.13	0.11	0.34
Sneezeweed					
WW	57.2 a	49.8 a	0.087 a	4395.1 a	99.3 a
RIWW	48.3 c	32.7 b	0.066 ab	2955.0 a	77.1 ab
WWRI	51.2 b	32.0 b	0.062 b	2479.3 a	63.3 b
RI	51.3 b	30.7 b	0.06 b	2334.6 a	67.9 b
<i>P</i>	0.002	0.001	0.05	0.06	0.02

^z1 cm = 0.3937 inch, 1 g = 0.0353 oz, 1 g·m⁻¹ = 0.0108 oz/ft, 1 cm² = 0.1550 inch².

^yMeans 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.

experiment except that the RI was changed to 20% to provide greater water stress.

A soil moisture sensor-controlled irrigation system, based on that described by Nemali and van Iersel (2006) was used for irrigation. Soil moisture sensors (10HS; Decagon Devices, Pullman, WA) were inserted into two pots in each of the 12 lines at a 45° angle into the center of the substrate so that the entire sensor was in the substrate. The 24 sensors were connected to a multiplexer (AM16/32B; Campbell Scientific, Logan, UT) 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 using a substrate specific calibration [$VWC = -0.4207 + 0.0009 \times \text{output (V)}$] using the method described by Nemali et al. (2007). When both sensors in a line were below the line VWC threshold (20% or 38%), the datalogger signaled the relay driver (SDM16AC/DC controller; Campbell Scientific) to open the appropriate solenoid valve (Rainbird, Azusa, CA). Plants were irrigated for 1 min, applying 35 mL of water via drip tubing connected to pressure-compensated drip

emitters (Netafim USA, Fresno, CA). 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 (from the substrate to the tallest growing point), width (the widest diameter and 90° from the widest diameter), and number of flowers were measured biweekly. For the majority of the experiment plant height was the peduncle length. Leaf area was measured using a leaf area meter (LI-3100C; LI-COR, Lincoln, NE). Shoots were cut off at the substrate surface and dried at 50 °C for 1 week, after which dry weight was determined. Compactness was calculated as shoot dry weight/plant height. Growth index (GI) was calculated as follows: $(\text{height} + \text{width } 1 + \text{width } 2) \div 3$ (Warsaw et al., 2009). Relative chlorophyll content was measured using a chlorophyll meter (SPAD 502DL Plus; Konica Minolta, Osaka, Japan). Stomatal conductance (g_s) was measured using a leaf porometer (SC-1; Decagon Devices). Water use efficiency (WUE) was calculated as grams shoot dry weight/irrigation volume (Flax et al., 2018).

Experimental design and data analysis

The experiment was designed as a randomized complete block with four treatments (substrate VWC set points) and three replications for a total of 12 plots with five pseudoreplicate plants each. Data were analyzed using the PROC GLM procedure of SAS (version 9.4; SAS Institute, Cary, NC) with $P = 0.05$ considered statistically significant. Treatment means were separated using Tukey's honestly significant difference.

Results and discussion

Coneflower peduncle length was greater for the plants receiving the WW [(mean $\pm$ SD) 36.8 $\pm$ 2.6 cm] and RIWW (35.7 $\pm$ 3.8 cm) irrigation treatments than for plants receiving the RI (27.0 $\pm$ 2.2 cm) and WWRI (26.6 $\pm$ 5.3 cm) treatments (Table 1). Sneezeweed peduncle length was greatest for plants receiving the WW irrigation treatment (57.2 $\pm$ 1.7 cm) and least for plants receiving the RIWW (48.3 $\pm$ 4.7 cm) treatment. There was no difference in shoot dry weight for coneflower. Sneezeweed shoot dry weight was greatest for plants receiving the WW treatment with shoot dry weight reduced by 34%, 36%, and 38% for the RIWW, WWRI, and RI treatments, respectively. Sneezeweed was more compact for the WWRI and RI treatments than the WW treatment, which was not different from the RIWW treatment. Compactness was not significant for coneflower.

Plant height (peduncle length) responses are similar to other reports, which reported that plant height decreased with drought severity or lower VWC. Height and shoot dry weight of carnation (*Dianthus caryophyllus*), cheddar pinks, and rosemary all decreased with increasing level of water stress (Álvarez et al., 2009; Zhen et al., 2014). Niu et al. (2007) found that shoot dry weight of big bend bluebonnet (*Lupinus havardii*) generally increased with VWC, but there was not a significant difference for the 20%, 25%, and 33% setpoints. Conversely, 'New Gold' lantana and cardinal flower (*Lobelia cardinalis*) height and shoot dry weight did not differ for plants irrigated to container capacity, exposed to two drought cycles, or exposed to one of two timings of drought cycle (Starman and Lombardini, 2006). 'Henry

Fig. 2. Growth index (GI) of sneezeweed receiving one of four irrigation treatments. Well-watered (WW) and reduced irrigation (RI) controls maintained volumetric water contents of 38% and 20%, respectively. Well-watered – reduced irrigation (WWRI) and reduced irrigation – well-watered (RIWW) treatments had the volumetric water content setpoint being maintained changed after 2 weeks (indicated by the arrow). GI was calculated as follows: (height + width 1 + width 2) ÷ 3. Means followed by the same letters are not different according to the Tukey’s honestly significant difference tests, ns = not significant (n = 3); 1 cm = 0.3937 inch.

Duelberg’ mealycup sage (*Salvia farinacea*) and ‘New Wonder’ fan-flower (*Scaevola aemula*) exposed to the same irrigation treatments showed a species-specific response.

The timing and duration of water stress could also contribute to plant growth responses. Koniarski and Matysiak (2013) found that height of rhododendron (*Rhododendron*) cultivars Old Port and Catabiense Boursault was reduced by 21% and 16%, respectively, when deficit irrigation was applied during the vegetative growth phase. Whereas height was only reduced by 8% to 13% for ‘Old Port’ and was not significantly reduced for ‘Catabiense Boursault’ when deficit irrigation was applied during the flowering phase. Álvarez et al. (2013) found geranium (*Pelargonium ×hortorum*) height was least when deficit irrigation was applied during the flowering phase, and there was no difference in plant height if regulated deficit irrigation was applied during the vegetative phase. Geranium shoot dry weight decreased with exposure to deficit irrigation regardless of the timing of the deficit irrigation (vegetative or flowering development phase). Results of this

study are similar to the those of Starman and Lombardini (2006) in that there was a species-specific response to irrigation treatments that likely resulted in differences in species response to water stress and greater RI experiences by sneezeweed.

There was no difference among the treatments in total leaf area for coneflower or sneezeweed (Table 1). Coneflower GI was unaffected by irrigation treatment throughout the experiment (data not shown). Sneezeweed GI was significant at the second and fourth measurement dates (Fig. 2). At the second measurement date, the WW and WWRI treatments were greater than the RI and RIWW treatments. This reflects that the WW and WWRI were both receiving the WW treatment and the RI and RIWW were both receiving the RI treatment at that time. At the fourth measurement date, GI of the RIWW was greater than the WWRI treatment indicating that the switch in substrate water contents that occurred for those treatments increased and decreased the growth rate, respectively.

Plants vary in both morphological and physiological responses to

reduced substrate water content (Kramer and Boyer, 1995). Variability in responses can be attributed to both physiological and morphological adaptations, as well as the ability to acclimate to water stress. Leaf area can be an indicator for drought stress because leaf cell elongation is sensitive to low water potentials (Lambers et al., 2008). Reduced cell elongation due to water stress could also contribute to reduced stem elongation (Taiz and Zeiger, 2010). In this study, RI did not result in a reduction in leaf area for either species; however, differences in peduncle length for both species indicate that cell elongation was affected by treatments. Species differences in response to the changing irrigation treatment may reflect a difference in adaptations and acclimation. For example, coneflower is native to the prairies of the central and southeastern United States and is adaptable to drought (Armitage, 2008). Sneezeweed is intolerant of dry soils and performs best in medium to wet soil. These differences could explain lack of treatment response by coneflower and the greater growth of sneezeweed with the WW treatment.

Number of flowers for sneezeweed was greater for the WW treatment [(mean ± SD) 99 ± 6 flowers] than the WWRI and RI treatments (63 ± 4 and 68 ± 2 flowers, respectively), which were similar to the RIWW treatment [77 ± 7 flowers, $P = 0.02$ (Table 1)]. There was no significant difference in number of flowers for coneflower.

Flowering is sensitive to timing of water stress. Rose (*Rosa ×hybrida*) flower development was most sensitive to drought before petal and stamen initiation (Chimonidou-Pavlidou, 2004). Flowering of geranium was lowest when deficit irrigation was applied during the flowering stage (Álvarez et al., 2013). Conversely, Koniarski and Matysiak (2013) found that ‘Catabiense Boursault’ rhododendron had a higher number of inflorescence buds when deficit irrigation was applied during the flowering stage and that deficit irrigation did not negatively affect number of inflorescence buds of rhododendron cultivars.

Similar to coneflower in this study, there was no difference in flower number for lantana, cardinal

Table 2. Leaf greenness (SPAD), stomatal conductance (g_s), and total irrigation volumes for coneflower and sneezeweed in response to different irrigation treatments at the conclusion of the 44- and 47-d experiments. Well-watered (WW) and reduced irrigation (RI) controls for coneflower were maintained at volumetric water contents of 38% and 25%, respectively. Well-watered – reduced irrigation (WWRI) and reduced irrigation – well-watered (RIWW) treatments had the volumetric water content setpoint changed after 2 weeks. Irrigation treatments were the same for sneezeweed except the reduced irrigation was lowered to 20%.

	SPAD	g_s (mmol·m ⁻² ·s ⁻¹)	Total irrigation vol (L/plant) ^z	Water-use efficiency (g·L ⁻¹) ^z
Coneflower				
WW	38.6 a ^y	397.3 a	5.2 a	2.8 a
RIWW	41.9 a	388.5 a	4.6 ab	3.1 a
WWRI	40.6 a	368.3 a	3.5 c	3.2 a
RI	41.9 a	443.5 a	3.7 bc	3.5 a
<i>P</i>	0.34	0.06	0.02	0.11
Sneezeweed				
WW	53.6 a	204.8 ab	15.1 a	3.3 b
RIWW	55.9 ab	208.1 a	8.8 b	3.7 b
WWRI	57.2 a	182.6 ab	7.4 b	4.3 a
RI	58.1 a	145.8 b	6.7 b	4.6 a
<i>P</i>	0.005	0.05	0.004	<0.001

^z1 L = 0.2642 gal, 1 g·L⁻¹ = 0.1335 oz/gal.

^yMeans 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.

flower, mealycup sage, or fan-flower whether irrigated to container capacity or exposed to one or two drought cycles (Starman and Lombardini, 2006). Álvarez et al. (2009) found that number of flowers per plant for carnation was not different for plant receiving moderate deficit irrigation or the control. Other studies were similar to the results for sneezeweed. Number of racemes of big bend bluebonnet was reduced for the 12% and 15% VWC treatments by 35% compared with the 20% to 33% treatments (Niu et al., 2007). Alem et al. (2015) found bract size of 'Classic Red' poinsettia (*Euphorbia pulcherrima*) was reduced by 53%, 47%, and 31% for the water deficit treatments. Number of flowers of 'RADrazz' rose and 'Belinda's Dream' were not different for plants maintained at 30% and 40% VWC; however, flower number was reduced by 27% and 86% for the 20% and 10% treatments for 'RADrazz' rose and by 42% and 75% for the 20% and 10% treatments for 'Belinda's Dream' rose (Cai et al., 2014). Species variability, similar to plant growth, indicates species-specific response based on adaptation features, severity of water stress, or ability to acclimate to drought. The degree of RI for coneflower, a drought-adapted species, was not great enough to effect flower development, whereas the degree of RI for sneezeweed, a species intolerant of drought conditions, resulted in

differences in flower development, as represented by flower number.

Leaf greenness of sneezeweed, as determined by leaf SPAD readings, for plants receiving the WWRI and RI treatments were greater than WW treatment, which was similar to RIWW treatment (Table 2). Stomatal conductance of sneezeweed was similar between treatments except RI was lower than RIWW [$P = 0.05$ (Table 2)]. Leaf greenness and g_s were unaffected by irrigation treatment for coneflower.

Increased leaf greenness with RI could be the result of lower leaf water content, increased leaf thickness, or increased leaf chlorophyll content (Martínez and Guiamet, 2004). Similar to this study, heliotrope (*Heliotropium arborescens*) and angelonia (*Angelonia angustifolia*) had higher SPAD reading for plants maintained at 20% VWC than plants maintained at 40% VWC (Guo et al., 2018). SPAD readings of big bend bluebonnet was less for plants receiving the 15% and 20% VWC treatments than for higher VWC treatments (Niu et al., 2007). However, it was concluded that these plants may have reached senescence due to water stress, which would explain reduced greenness.

A reduction in g_s is commonly observed in water-stressed plants (Nemali and van Iersel, 2008). This further indicates that the reduced irrigation treatment did not result in water stress for coneflower, which

is adapted to drought. Conversely, water-sensitive sneezeweed had reduced conductance for the RI treatment, indicating water stress. Stomatal conductance decreased linearly with decreasing VWC for canadian columbine. It also decreased with decreasing VWC for cheddar pinks, although the trend was not significant (Zhen et al., 2014). Cai et al. (2014) reported no difference in g_s for 'RADrazz' or 'Belinda's Dream' roses at 30% and 40% VWC. For both cultivars, g_s was lowest at 10% VWC.

Irrigation volume was highest for the WW treatment for both species (Table 2). For sneezeweed WW irrigation volume was greater than all other irrigation treatments ($P < 0.001$). Over the course of the experiment, the WW plants received 15.1 L/plant of water, while the RIWW, WWRI, and RI treatments received 42%, 51%, and 56% less water, respectively. For coneflower WW irrigation volume was greater than RI and WWRI, which was the least. The WW treatment received 5.2 L/plant of water, while the RIWW, RI, and WWRI treatments received 11%, 29%, and 33% less water, respectively. Water use efficiency of sneezeweed was greater for the RI and WWRI treatments (4.6 and 4.3 g·L⁻¹, respectively) than the RIWW and WW treatments [3.7 and 3.3 g·L⁻¹, respectively ($P < 0.001$)]. Water use efficiency was not significant

Fig. 3. Photographs of coneflower (A) and sneezeweed (B) at the conclusion of the 44- and 47-d experiments. Well-watered (WW) and reduced irrigation (RI) controls for coneflower were maintained at volumetric water contents of 38% and 25%, respectively. Well-watered – reduced irrigation (WWRI) and reduced irrigation – well-watered treatments (RIWW) had the volumetric water content setpoint changed after 2 weeks. Irrigation treatments were the same for sneezeweed except the reduced irrigation was lowered to 20%.

for coneflower. Differences in total irrigation volume between species reflects species water requirements; environmental variability during the two experiments would also affect plant water requirements.

For sneezeweed, irrigation volume was substantially reduced for all treatments that included RI at some time during the experiment. The WW plants exhibited signs of exuberant growth that would be undesirable in a retail setting (Fig. 2). Plants in the other treatments had overall better appearance. Water use efficiency was greater for plants that received RI during the second part of the experiment. Increased water use efficiency along with a moderate reduction in peduncle length indicate that RI can be used for growth control and water savings for sneezeweed. For coneflower, irrigation volume was also

reduced for all plants receiving RI. Although water use efficiency was not improved with RI for production of coneflower, the overall lack of impact of RI on plant growth indicates that RI could be used to produce coneflower commercially. Reducing water in the later part of the experiment results in increased water savings without a significant difference in plant growth compared with applying RI earlier in the experiment. These results are similar to other studies that have reported production of salable plants at reduced irrigation volumes (Bayer et al., 2013, 2014, 2015; Burnett and van Iersel, 2008; van Iersel et al., 2009; Zhen et al., 2014).

Irrigation treatment had a species-specific response on growth and flowering of coneflower and sneezeweed. Visually coneflower had more variability, even within an irrigation treatment.

Sneezeweed receiving the WW treatment were very large and not as visually appealing as plants in other treatments (Fig. 3). These plants would be more likely to be damaged during shipping or in a retail setting. Plants receiving the other treatments appeared more uniform. From the results of this study, using RI to alter growth is more effective for species that are not drought tolerant, such as sneezeweed. Drought-tolerant species, such as coneflower, are adapted to water stress and are not as affected by RI. It is possible that a lower substrate water content could affect growth of coneflower and be used for growth control. The results of this study indicate that RI for growth control requires species-specific knowledge of how plant growth is affected by RI and the degree of RI needed to produce a response. Further research is needed to understand if RI during production has long-term impacts on plant growth or improved water stress tolerance in a retail environment.

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