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Biocontainer Water Use in Short-term Greenhouse Crop Production

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SUMMARY. In recent years, biocontainers have been marketed as sustainable alternatives to petroleum-based containers in the green industry. However, biocontainers constructed with plant materials that are highly porous in nature (e.g., peat, wood fiber, straw) tend to require more frequent irrigation than conventional plastic products. As irrigation water sources become less abundant and more expensive, growers must consider water consumption in any assessment of their economic and environmental viability. This project evaluated plant growth and total water consumption for nine different biocontainers (seven organic alternatives, and two recently developed bioplastic alternatives) and a plastic control used to produce a short-term greenhouse crop, 'Yellow Madness' petunia (*Petunia ×hybrida*). Dry shoot weight and total water consumption differed by container type, with some of the more porous containers (wood fiber, manure, and straw) requiring more water and producing smaller plants by the end of the trial period. Intuitively, the more impervious plastic, bioplastic, and solid rice hull containers required the least irrigation to maintain soil moisture levels, though shoot dry weights varied among this group. Shoot dry weight was highest with the bioplastic sleeve and slotted rice hull containers. However, the latter of these two containers required a greater volume of water to stay above the drying threshold. Findings from this research suggest the new bioplastic sleeve may be a promising alternative to conventional plastic containers given the current production process.

Although biocontainers (i.e., plant material-based containers) have emerged as a response to excessive plastic landfill waste, their adoption in the green industry could significantly increase crop watering requirements. Water availability has traditionally been an issue associated with arid and semi-arid production sites (Feres et al., 2003). However, this issue is quickly becoming a major environmental and economic consideration for all horticultural enterprises, regardless of climate. With demand, regulation, and cost of water all projected to increase (Beeson et al., 2004), growers will be subject

to increasing pressure to assess their overall water use and identify areas to improve efficiency and reduce waste.

In their review of irrigation management techniques, Feres et al. (2003) identified deficit irrigation

[i.e., irrigation at a level below the rate of evapotranspiration (ET)], irrigation runoff reclamation, and the reduction of ET as the three main strategies for conserving water in horticultural production. Deficit irrigation is largely limited to field-grown crops and large-container production, given the ability of the plants to draw upon relatively large soil moisture reserves (Feres and Soriano, 2007; Feres et al., 2003). Compared with these production systems, the small volumes of pots and trays commonly used to produce floral and foliage crops limit their overall water-holding capacity and the rooting space available to the plant. Moreover, growers use deficit irrigation in times of limited water supplies to maintain survival rather than maximize growth (Feres and Soriano, 2007). This loss in yield potential (i.e., biomass) is largely unacceptable when producing high-value ornamental greenhouse crops (Feres et al., 2003).

Although deficit irrigation plays a very limited role in floriculture production, ET reduction and irrigation water reclamation may have important implications for greenhouse growers, especially those intending to adopt biocontainers in their operations. Although not the focus of this work, water reclamation in horticulture can be effectively implemented through the adoption of an ebb-and-flood (sub-irrigation) system which recirculates water and fertilizer runoff (Dole et al., 1994; Dumroese et al., 2006; Morvant et al., 1998). Ebb-and-flood-irrigated 'Florida Sun Jade' coleus (*Solenostemon scutellarioides*) shoot dry weight remained similar among seven different biocontainers (i.e., bioplastic, coir, manure, paper, peat, straw, and wood fiber) and a conventional petroleum-based plastic control (Koeser et al., 2013). However, the study found that the high rate of fertilization and container wetting-drying pattern associated with subirrigation can cause a significant loss of puncture strength

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
2.54	inch(es)	cm	0.3937
16.3871	inch ³	cm ³	0.0610
28.3495	oz	g	0.0353
1	ppm	mg·L ⁻¹	1
(°F - 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

in wood fiber and paper biocontainers over time (Koeser et al., 2013). Despite the reduction in container integrity, the use of ebb-and-flood irrigation may still be a viable option for conserving water in biocontainer greenhouse production, especially if containers are supported in plastic shuttle trays.

Although studies on the effects of reclaimed water on biocontainer greenhouse production are limited, the effects of container on ET, as well as drainage, have been more widely documented (Bilderback, and Fonteno, 1987; Evans and Karcher, 2004; Evans et al., 2010; Spomer, 1974). In comparing horticulture crops grown in peat, feather, and plastic containers watered uniformly across pot type, Evans and Hensley (2004) found that plants grown in plastic containers, which were impervious to water loss, had higher aboveground biomass than those grown in the peat- and feather-derived containers. However, when all container types were irrigated separately based on need, which resulted in more frequent water application to the peat and feather containers, growth in biocontainers was comparable and even superior to growth in a conventional plastic container depending on species grown (Evans and Hensley, 2004). Evans and Karcher (2004) found the volume of water required to grow a variety of crops was significantly lower in the plastic control as compared with those in the feather and peat containers. Similarly, more frequent watering was required for the peat and feather containers. This increased water demand corresponded with higher rates

of water loss through the sides of the containers tested (Evans and Karcher, 2004). Evans et al. (2010) tested an expanded array of biocontainers to assess irrigation frequency and cumulative water demand. In doing so, the authors found that, with the exception of a relatively impermeable solid rice hull container, all biocontainer alternatives required more frequent irrigation and more overall water to maintain the minimum moisture level threshold.

Decreases in ET must coincide with unchanged or even increased plant growth to truly reduce water use in horticulture production (Feres et al., 2003). As such, this project evaluates both plant dry shoot weight and cumulative water use at the end of the 5-week trial period. Our study expands on past efforts to assess water demand in biocontainers through the inclusion of a pair of newly marketed bioplastic alternatives, a bioplastic container, and bioplastic sleeve. In adopting biodegradable, plant-based plastics, container producers hope to emulate the advantages of petroleum-derived products (i.e., durability and imperviousness), whereas appealing to environmentally conscious consumers and growers. The insights gained from this work will better inform growers who need to reduce water use at their facilities and will ultimately contribute to future water-use models.

Materials and Methods

CONTAINERS. Ten container types (one plastic control, seven organic alternatives, and two bioplastic alternatives) were used in this study (Table 1 and Fig. 1). A 4-inch standard pot was used as the plastic control. For the biocontainer alternatives, pots with comparable volumes were selected for inclusion in the trial. Variations in volume shown in Table 1 reflect the realities a commercial grower would face when looking for alternatives to standard plastic pots.

EXPERIMENTAL DESIGN, GROWING CONDITIONS, AND PLANT CARE. This study was conducted in a greenhouse setting at the University of Illinois at Urbana-Champaign (lat. 40°6'N, long. 88°13'W, USDA Hardiness Zone 5b). 'Yellow Madness' petunia served as a representative short-term floricultural crop for this greenhouse trial. The trial began on 26 May 2012 and concluded after 5 weeks. The

experiment was arranged as a completely randomized design, with an individual potted 'Yellow Madness' petunia serving as the experimental unit. Each container type was replicated 20 times, for a total of 200 containers used in the design.

Each container (replicate) was filled with a commercial soilless growing mix (LC1 Mix; Sun Gro Horticulture Canada, Vancouver, BC, Canada) and one 'Yellow Madness' petunia plant. Potted plants were placed on plastic drain trays and spaced widely on greenhouse benches to facilitate the watering of individual experimental units. Given this wide spacing, no border row was deemed necessary. Also, a unique characteristic of the bioplastic sleeves is that they have no bottom. The design relies on the use of a multipocket shuttle/carry tray to keep potting mix in place until root growth is sufficient to maintain stability. To account for this, individual pocket bottoms were cut out from a shuttle/carry tray with a 1-cm lip and placed between the containers and the drain tray.

Plants were grown under supplemental light conditions (13 h daily in the absence of natural light/photon flux levels over 600 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) with minimum day- and nighttime temperatures set at 24 °C and 18 °C, respectively. The median temperature over the course of the water-use study was 27 °C, with a maximum of 33 °C recorded on 28 June 2012 and minimum of 17 °C recorded on 7 June 2012. Relative humidity during the study period ranged from 24.6% to 90.5%, with a median value of 64.2%. Median photosynthetic photon flux at 1200 HR was 471 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$.

Irrigation was supplied by hand using a beaker on an as-needed basis at the treatment (i.e., container type) level. This threshold was defined as the point when soil moisture levels at or below 40% were detected for a given container type. Initially, soil moisture was assessed using an electronic soil moisture sensor (ThetaProbe ML2x; Delta-T Devices, Cambridge, UK). However, repeated measurements within the same soil space can lead to questionable measurements as air spaces/channels form in the media. As such, this work followed methods described in past research, relying on visual indicators

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Table 1. Container type, product name, approximate volume, and manufacturer information for nine biocontainers and a plastic control used in the trial. ‘Yellow Madness’ petunias were grown in a greenhouse for 5 weeks to assess the effect of container type on dry shoot weight and watering demand.

Container type	Product name ^z	Volume (cm ³) ^z	Manufacturer
Plastic	Dillen 04.00 Standard Thinwall Green	480	Myers Industries Lawn & Garden Group, Middlefield, OH
Bioplastic	TerraShell™ 10 cm H Wheat Pot	473	Summit Plastic Co., Akron, OH
Coir	Coir 4.0” Std Fiber Gro Pot	406	Dillen Products, Middlefield, OH
Manure	#4 Square CowPot	450	CowPots Manufacturing and Sales, East Canaan, CT
Peat	4” Jiffy Pot	379 ^x	Jiffy Products of America, Lorain, OH
Bioplastic sleeve (Sleeve)	4.5” Standard Assembled SoilWrap®	709 ^x	Ball Horticultural Co., West Chicago, IL
Slotted rice hull	4.5” NetPot	591	Summit Plastic Co.
Solid rice hull	Rice Pot 4”	473	Summit Plastic Co.
Straw	Not available	646 ^x	Ivy Acres, Baiting Hollow, NY
Wood fiber	10 × 10-cm Round Individual Fertilpot	430 ^x	Fertil SAS, Boulogne Billancourt, France

^zAs indicated in manufacturers online/print catalog.

^x1 cm³ = 0.0610 inch³.

^yNot included in manufacturer specifications; volume approximated.

Fig. 1. Images of container treatments used to grow a short-term crop of ‘Yellow Madness’ petunia. Plants were grown under greenhouse conditions for 5 weeks to gauge the effect of container type on irrigation demand. Containers used included (A) plastic control, (B) bioplastic, (C) coir, (D) manure, (E) peat, (F) sleeve, (G) slotted rice hull, (H) solid rice hull, (I) straw, and (J) wood fiber.

of drying (e.g., the graying of the soilless mix surface) to determine water need after the first week (Evans and Hensley, 2004; Evans et al., 2010; Kuehny et al., 2011). Water was applied as needed to saturate the growing mix and container wall and allow for some measurable drainage (≈ 250 to 400 mL depending on container volume). Water use was calculated as the difference between the volume of water applied and the volume of water lost through drainage.

Plants were fertilized weekly with a 150 ppm 10N–6.5P–8.3K fertilizer solution (10–15–10 All Purpose Fertilizer; Schultz Co., Bridgeton, MO). The fertilizer solution was applied to each plant weekly when watering was required.

MEASUREMENTS AND DATA ANALYSIS. Cumulative water use and

irrigation frequency were recorded as measures of water demand. Final plant growth was measured as shoot dry weight. Water content and dry shoot weight were each analyzed as univariate, one-way analysis of variance (ANOVA) in R [version 2.14.2 (R Core Team, 2012)]. Before analysis with ANOVA, correlation between the two response variables was calculated using the COR.TEST function. Correlation was deemed not significant ($P = 0.47$) with Pearson’s correlation coefficient calculated as 0.05. To control experimental-wise error rate, a Bonferroni adjusted $\alpha = 0.025$ was adopted for each of the two ANOVAs. Diagnostic plots confirmed that the residuals for both analyses met the assumptions of normality and equal variances. Mean separation for significant factors was conducted using

a protected Fisher’s least significant difference test ($\alpha = 0.05$). These comparisons were made using the LSD.TEST function provided in the agricolae package [version 1.1–2.11 (de Mendiburu, 2012)].

Results and discussion

Results indicated that both total water use ($P < 0.0001$) and dry weight ($P < 0.0001$) varied with container type. As expected, containers made from more porous materials used greater volumes of water than the largely impervious plastic, bioplastic, and solid rice hull containers (Fig. 2). Among these three containers, differences in water use were not significant.

Of the three containers that required the least water (i.e., plastic, bioplastic, and solid rice hull containers), plants grown in the plastic control had the highest dry shoot weight. Within this group, mean shoot dry weight was similarly diminished for the bioplastic and solid rice hull containers (Fig. 3). Mean shoot dry weight in the bioplastic container fell midway between the other two containers, performing slightly, though not significantly, greater than plants in the solid rice hull containers, but significantly less than those in the control.

The wood fiber pot treatment required the highest amount of water to stay above the drying threshold, yet was among the group of containers with plants having the lowest shoot dry weights. As soil moisture was measured manually each morning, there were some days when readings dipped

Fig. 2. Average total water used for 'Yellow Madness' petunia plants grown in nine biocontainers and a plastic control. Plants were grown under greenhouse conditions for 5 weeks to gauge the effect of container type on irrigation demand. Water was applied when soil moisture levels below a watering threshold of 40% were detected for a given container treatment. Error bars depict Fisher's least significant difference; 1 mL = 0.0338 fl oz.

Fig. 3. Average dry shoot weight for 'Yellow Madness' petunia plants grown in nine biocontainers and a plastic control. Plants were grown under greenhouse conditions for 5 weeks to gauge the effect of container type on irrigation demand. Water was applied when soil moisture levels below a watering threshold of 40% were detected for a given container treatment. Error bars depict Fisher's least significant difference; 1 g = 0.0353 oz.

below the 40% threshold. Containers like the coir, peat, manure, and wood fiber pot, which dried quickly and required more frequent watering, had more opportunities to drop below this ideal lower limit (Table 2). In contrast, containers with longer

irrigation intervals (lower irrigation frequencies) were spared from more frequent periods of saturated or water-limiting conditions.

Our work highlights a major advantage of the bioplastic and rice hull containers and marks the first

investigation into the performance of a new biocontainer design, the bioplastic sleeve. With performance comparable to conventional plastic, the bioplastic and rice hull products offer an alternative to petroleum-derived pots with an additional benefit of appealing to environmentally conscious consumers (Hall et al., 2010). Specifically, the bioplastic sleeve appeared to balance water demand and growth in our trial. With the highest shoot dry weight and moderate water use, this container should be tested further using a wider variety of floral and foliage crops.

Any environmental benefits intrinsic to the containers and their production must not be negated by additional environmental impacts in greenhouse production. A true assessment of a container's overall impact on sustainable greenhouse production must account for both water use and yield. This work suggests that more frequent irrigation may be needed for peat, manure, and wood pulp containers to match the levels of growth seen in some of the more impervious alternatives. Future work should address this concern.

In addition, containers of this size are often arranged in plastic shuttle trays during production, as trays make handling and spacing of small potted plants more manageable. These trays typically surround the majority of a container in impervious plastic. When watered, small amounts of irrigation drainage generally accumulate in the base of the tray. This water may be reabsorbed over time if in contact with roots, growing mix, or porous container surfaces. In addition, this water likely contributes to the production of a boundary layer of humid air trapped between the container and tray. Noting these potential benefits, it is likely that some of the differences in water consumption and irrigation frequency documented in past research can be at least partially mitigated with shuttle trays. Research should quantify what benefits, if any, shuttle trays offer with respect to water use and plant growth.

We and others (Evans and Hensley, 2004; Evans and Karcher, 2004; Evans et al., 2010) used standard soilless growing mixes optimized for plastic container usage. However, porous biocontainers likely perform more like unglazed clay pots, which were traditionally filled using potting mixes

Table 2. Average irrigation frequency per week by container type for ‘Yellow Madness’ petunias grown in a greenhouse for 5 weeks to assess the effect of container type on dry shoot weight and watering demand.

Container type	Irrigation frequency (no./wk)	
	Avg	SD
Plastic	2.8	0.49
Bioplastic	2.6	0.80
Coir	3.6	0.49
Manure	3.0	0.63
Peat	3.4	0.49
Sleeve	2.2	0.40
Slotted rice hull	2.4	0.49
Solid rice hull	2.6	0.49
Straw	2.8	0.40
Wood fiber	3.0	0.00

with a slower-draining topsoil and/or sand component. Future testing should investigate biocontainer performance using alternative growing mixes, including mixes with wetting agents and hydrogels designed specifically for use in terra cotta containers (Terracotta Pot & Planter Mix; Osmocote®, Bella Vista, Australia).

Conclusion

In summary, both water use and plant growth differed by container type. The more impervious containers (i.e., control, bioplastic, and solid rice hull) were among the best-performing containers with regard to total water consumption. These three container types, although not linked to the largest mean dry shoot weights, did not underperform with regard to plant growth either. In contrast, reduced

shoot dry weight was associated with some of the fastest drying containers like wood fiber, straw, and manure. Although these results may be a source of concern for growers looking to adopt biocontainers, growing system and potting mix optimization may negate some of the differences observed here. Until such innovation occurs, the relatively new bioplastic sleeve may be a promising option for growers looking to maximize growth and limit water consumption.

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