Impact of Biocontainers With and Without Shuttle Trays on Water Use in the Production of a Containerized Ornamental Greenhouse Crop

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SUMMARY. **Nine commercially available biocontainers and a plastic control were evaluated at Fayetteville, AR, and Crystal Springs, MS, to determine the irrigation interval and total water required to grow a crop of 'Cooler Grape' vinca (*Catharanthus roseus*) with or without the use of plastic shuttle trays. Additionally, the rate at which water passed through the container wall of each container was assessed with or without the use of a shuttle tray. Slotted rice hull, coconut fiber, peat, wood fiber, dairy manure, and straw containers were constructed with water-permeable materials or had openings in the container sidewall. Such properties increased the rate of water loss compared with more impermeable bioplastic, solid rice hull, and plastic containers. This higher rate of water loss resulted in most of the biocontainers having a shorter irrigation interval and a higher water requirement than traditional plastic containers. Placing permeable biocontainers in plastic shuttle trays reduced water loss through the container walls. However, irrigation demand for these containers was still generally higher than that of the plastic control containers.**

The greenhouse industry relies on a wide range of containers when producing commodities like flowering potted crops, perennials, annual bedding plants, and vegetable transplants. Petroleum-based plastics (plastic) are the most common materials used in container fabrication. Advantages of using plastic include its durability, resistance to mildew and algae growth, and the ability to mold it into a variety of shapes and sizes. After use, plastic containers used in greenhouse production are typically discarded. As a result, large volumes of plastic waste are stored at greenhouse sites or sent to landfills. Biocontainer use offers one potential solution to this solid waste issue. Biocontainers consist of plant- or animal-byproduct-based containers that break down quickly when planted into the soil or placed into a compost pile.

The greenhouse industry generally categorizes biocontainers as being plantable or compostable (Evans and Hensley, 2004; Evans et al., 2010). Plantable biocontainers are those that allow plant roots to grow through their walls and may be directly planted into the final container, the field, or the planting bed. Compostable biocontainers cannot be planted into the soil because plant roots cannot physically break through container walls, or the biocontainers do not degrade quickly enough to allow plant roots to grow through the container walls. As such, these containers must be removed before planting. If placed in a compost pile, they will decompose in a relatively short time (Mooney, 2009).

There are numerous commercially available plantable biocontainers. Composted dairy manure containers (CowPot Co., Brodheadsville, PA) are made of composted, compressed cow manure held together with a binding agent. Peat containers (Jiffy Products, Kristiansand, Norway) consist of peat and paper fiber. Paper containers (Western Pulp Products, Corvallis, OR and Kord Products, Lugoff, SC) are made from paper pulp with a binder. Rice straw containers (Ivy Acres, Baiting Hollow, NY) are composed of 80% rice straw, 20% coconut fiber, and a proprietary natural adhesive as a binder. Wood fiber containers are composed of 80% cedar fibers and 20% peat and lime (Fertil International, Boulogne Billancourt, France). Coconut fiber containers are made from the medium and long fibers extracted from coconut husks and a binding agent (ITML Horticultural Products, Brantford, ON, Canada).

Compostable biocontainers tend to be more impervious to water than their plantable counterparts. One type of compostable biocontainers available for greenhouse production is a rice hull container made of ground rice hulls with a binding agent (Summit Plastic Co., Tallmadge, OH). Another group of compostable biocontainers

Mention of trade names implies no endorsement of the products mentioned nor criticism of similar products not mentioned.

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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
3.7854	gal	L	0.2642
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

are constructed from wheat starch-based bioplastics that are thermoformed into containers (TerraShell, Summit Plastic Co.). Additional containers made from soy-based bioplastics are also under development (Currey et al., 2013).

Categorized as compostable containers above, ricehull and bioplastic containers may be modified so they function as plantable products. Rice hull containers are produced with slots and holes in their sides to allow roots to penetrate into the surrounding soil after installation. Bioplastic sleeves lack a bottom and may have slits in the side walls to serve a similar function. These modifications allow the plant to survive even if the container remains intact for a growing season or more.

One of the major areas of research on biocontainers has been to compare irrigation requirements to those of traditional plastic containers. Evans and Karcher (2004) found that when comparing peat, feather fiber, and plastic containers, the peat containers had the highest rate of water loss through the container walls, and both feather fiber and peat containers required more water and more frequent irrigation when growing a crop than did the traditional plastic containers. When various biocontainers and plastic containers were compared, the crops grown in peat and wood fiber containers had the highest water usage (Evans et al., 2010), but the frequency of irrigation and amount of water used was not significantly different among bioplastic, rice hull, and traditional plastic containers. Beeks and Evans (2013) reported the total irrigation volume required to grow a single 'Rainier Purple' cyclamen (*Cyclamen persicum*) planted in a 6-inch container for 15 weeks ranged from 15.75 L for the plastic container to 24.19 L for a wood fiber container. While the wood fiber containers tested required a greater amount of water than the plastic containers to grow the cyclamen, all other containers evaluated had a similar irrigation demand as the control. Beeks and Evans (2013) also reported that the irrigation interval ranged from 0.6 d for the wood fiber container to 1.3 d for the plastic container. Peat, dairy manure, wood fiber, and rice straw containers had irrigation intervals that were shorter than a plastic control container. The bioplastic, solid ricehull, slotted ricehull, paper, and coconut fiber containers tested had irrigation intervals similar to the plastic control container.

Although research has been conducted on biocontainers to compare water use as compared with plastic controls, all of the studies to date evaluated individual containers placed freely and unprotected on bench surfaces. However, in most cases, particularly with small sizes, containers are usually placed in plastic shuttle trays for ease of handling and spacing. These trays would inevitably affect evaporation from the porous container walls and overall plant water use. Consequently, the objective of this study was to evaluate water use of various biocontainers placed freely on a bench compared with biocontainers placed in plastic shuttle trays. The results of this work can be applied by growers who are concerned both with the water consumed and waste generated as a result of their production efforts.

Materials and methods

Experiments were conducted at University of Arkansas, Fayetteville (lat. 36.08°N) and Mississippi State University Truck Crops Experiment Station, Crystal Springs (lat. 31.99°N) during the months of June and July. Two sites were used to compare patterns of water use given differences in greenhouse conditions and individuals watering plants. The containers evaluated in these experiments are described in Table 1.

In the first experiment, containers were filled with an LC1 substrate (SunGro Horticulture, Agawam, MA) that was composed of 80% sphagnum peat and 20% perlite and adjusted to a pH of 5.8 using dolomitic limestone. Containers were filled to 1 cm from the container rim with the substrate. The substrate was top-irrigated to saturation and allowed to drain to container capacity. Additional substrate and water was added as needed to set the substrate to container capacity and filled to 1 cm from the container rim. Six-leaf plugs (#177 square with plug volume of 5 mL) of 'Cooler Grape' vinca were transplanted into the containers. Containers were placed in a greenhouse either individually directly on expanded metal benches or into individual plastic shuttle tray pockets cut from an appropriately sized tray and then on the benches. This resulted in a factorial design with 10 container treatments and two shuttle-tray treatments (with or without shuttle tray) for a total of 20 treatment combinations.

Temperature set points for greenhouses were 18 °C for the initiation of heating and 22 °C for the initiation of cooling. Plants were grown under ambient light levels and photoperiods occurring at each location during the study. Containers were irrigated individually by hand with a fertilizer solution when the substrate moisture level decreased to 40% or lower (v/v) using a water sensor (Waterscout SM100; Spectrum Technologies, Plainfield, IL) on the soilless setting at 21 °C. The fertilizer solution was formulated using a 15N–2.2P–12.5K fertilizer (15–5–15 Cal Mag; Everiss International, Geldermalsen, The Netherlands) and contained 250 $mg \cdot L^{-1}$ nitrogen. At each irrigation, containers were placed on plastic drain trays, and 250 mL of the fertilizer solution was applied to the substrate. Drainage from the container was collected in the plastic drain trays. The experiment was ended for a given container when the plant in that container developed to anthesis (i.e., the plants were market ready).

The total volume of solution that drained was subtracted from the total volume of solution applied during the experiment to provide the total volume of solution required to grow the vinca crop. The number of irrigation applications divided by the days to anthesis provided the average irrigation interval in days.

The experimental design for each location was a completely randomized design with eight replications of each treatment combination. Each location was analyzed separately because of differences in containers used (straw containers were omitted from the Mississippi location), greenhouse type, and environmental conditions that could not be controlled (e.g., light intensity). For each location, response factors, which were assumed to be correlated (i.e., watering interval and total volume), were assessed via the COR.TEST function in R version 3.0.0 (R Development Core Team, 2013). Multivariate analysis of variance (MANOVA) using the MANOVA function was first run to assess significance of treatment combinations. Once the significance of treatments and interactions were confirmed with this approach, we proceeded to carry out two univariate analysis of variance (ANOVA) tests using the AOV function. When appropriate, mean separation tests were run for the two treatments (i.e., container type and absence/presence of tray) using the TESTINTERACTIONS function from the PHIA (post hoc interaction analysis) package in R (De Rosario-Martinez, 2013). A false discovery rate adjustment was adopted to account for the multiple comparisons made at this stage in analysis. At each iteration of the above analyses, the necessary diagnostic checks were performed to assess the appropriateness of the tests conducted.

A second experiment was conducted using the same biocontainers, tray treatments, and experimental locations as for the first experiment. Containers were filled to 1 cm from the container rim with the substrate. The substrate was top-watered to saturation and allowed to drain to container capacity. Additional substrate and water was added as needed to have the substrate at container capacity and filled to 1 cm from the container rim, but care was taken to avoid saturating container walls. After drainage ceased, containers were either sealed with paraffin wax (Fisher Scientific, Fair Lawn, NJ) on drainage holes and the substrate surface, or were left unsealed. The containers were weighed following the application of wax. Containers were then either placed directly on a greenhouse bench or placed into individual shuttle trays and then placed on a bench. This resulted in two wax treatments and two shuttle-tray treatments for a total of four treatment combinations for each container type. Containers were weighed at 24-h intervals for 14 d to determine water loss. Cumulative water loss data were initially visualized as a series of lattice plots (Figs. 1 and 2) using the GGLPLOT2 function in R (Wickham, 2009). These plots guided final linear model building (one model

Table 1. Container type, product name, volume, and manufacturer of container used to evaluate water usage and water loss in a greenhouse environment with and without the use of shuttle trays.

Container type	Product name[z]	Volume (cm^3)[z]	Manufacturer
Plastic	Dillen 4.0 standard thinwall green	480[y]	Myers Industries, Middlefield, OH
Bioplastic	TerraShell 10cm H wheat pot	473[y]	Summit Plastic Co., Akron, OH
Coconut fiber	Coir 4.0-inch fiber gro pot	406[y]	Dillen Products, Middlefield, OH
Dairy manure	Number 4 square CowPot	450[y]	CowPots of America, Lorain, OH
Peat	4-inch Jiffy Pot	379[x]	Jiffy Products of America, Lorain, OH
Bioplastic sleeve	4.5-inch standard assembled SoilWrap	709[x]	Ball Horticultural Co., West Chicago, IL
Solid rice hull	4-inch rice pot	473[y]	Summit Plastic Co.
Slotted rice hull	4.5-inch NetPot	591[y]	Summit Plastic Co.
Straw	Straw pot	646[x]	Ivy Acres, Baiting Hollow, NY
Wood fiber	10 × 10-cm round Fertilpot	430[x]	Fertil, Boulogne Billancourt, France

[z]1 inch = 2.54 cm, 1 cm = 0.3937 inch, 1 cm^3 = 0.0610 $inch^3$.
[y]As indicated in manufacturers on-line or print catalogs.
[x]Not included in manufacturers' catalogs. Volume approximated by substrate displacement.

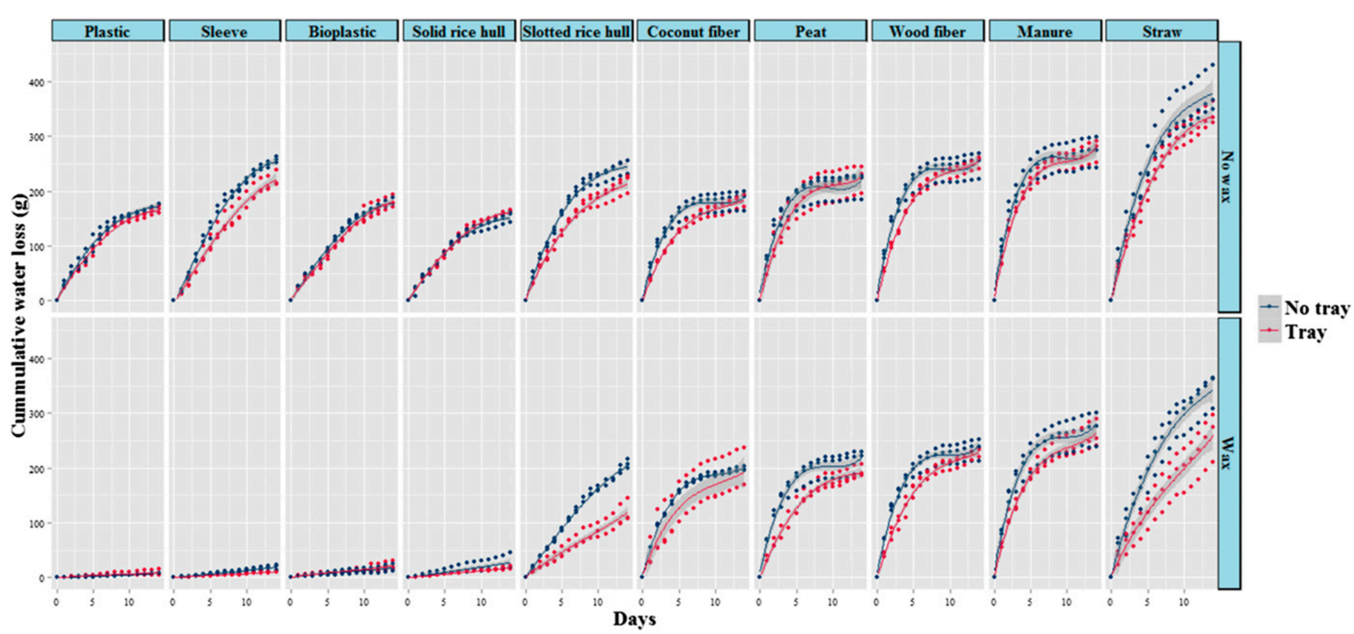

Fig. 1. Cumulative water loss lattice plots for plastic and biocontainers placed in a greenhouse (Fayetteville, AR) environment for 14 d. Points represent individual data values. Lines represent predicted curve from models. Gray shaded area represents the 95% confidence intervals; 1 g = 0.0353 oz.

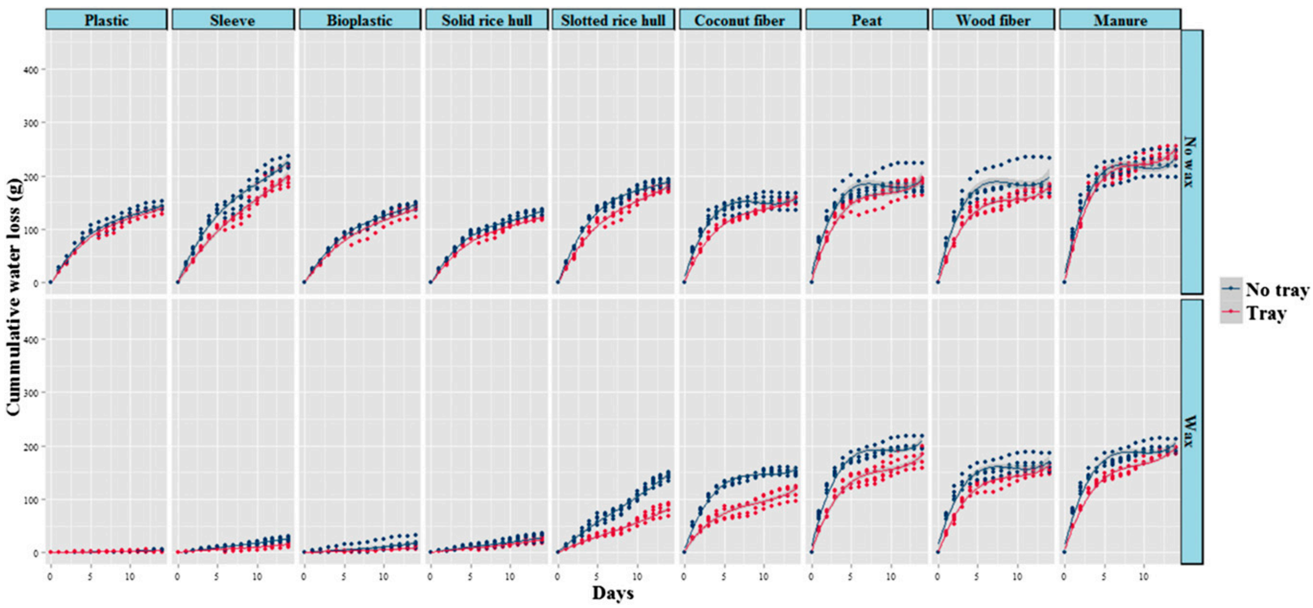

Fig. 2. Cumulative water loss lattice plots for plastic and biocontainers placed in a greenhouse (Crystal Springs, MS) environment for 14 d. Points represent individual data values. Lines represent predicted curve from models. Gray shaded area represents the 95% confidence intervals; 1 g = 0.0353 oz.

per location) using the LM function. Diagnostic residual plots were used to assess that all underlying assumptions for the analyses were met. All conclusions were based on $\alpha = 0.05$ level of Type I experimental error.

Results and discussion

First experiment. For both the Arkansas and Mississippi locations, total water use varied by container type [Arkansas ($P < 0.0001$), Mississippi ($P < 0.0001$)] and tray use [Arkansas ($P < 0.0001$), Mississippi ($P = 0.0024$)]. At the Arkansas site only, the interaction between the two main effects was also significant [Arkansas ($P = 0.0300$), Mississippi ($P = 0.5781$)]. Similarly, average irrigation interval at each site varied by container type [Arkansas ($P < 0.0001$), Mississippi ($P < 0.0001$)]. Irrigation intervals were significantly different between the two tray treatments (i.e., tray or no tray) at the Arkansas site ($P = 0.0006$) and nonsignificant/marginally significant at the Mississippi site ($P = 0.0679$). The container type × tray interaction term was not significant at Arkansas ($P = 0.2306$) and nonsignificant/marginally significant at Mississippi ($P = 0.0660$).

At the Arkansas location, when grown without or with a shuttle tray, vinca plants grown in dairy manure, wood fiber, peat, coconut fiber, and straw containers required more water (supplied as fertilizer solution) to develop to anthesis than those grown in the plastic control container (Table 2). When grown without or with shuttle trays, plants grown in bioplastic, rice hull containers, and the sleeve required similar amounts of water to reach anthesis as those grown in the plastic control. Placing the biocontainers in shuttle trays reduced the water requirement particularly for dairy manure, wood fiber, peat, coconut fiber, straw, and the sleeve containers (Table 2). The significant interaction terms appeared to reflect the magnitude of watering reduction associated with plastic tray use. All containers in trays showed some measurable reduction in average total water used and increase average watering interval as compared with the same container without tray. However, these differences ranged from being nonsignificant in the more impervious containers (e.g., plastic, bioplastic, and solid rice hull) to significant in the porous biocontainer

Table 2. Mean total water required to grow a vinca crop from six-leaf stage to anthesis using various container types with or without plastic shuttle trays (No tray/Tray). Plants were grown in a polycarbonate-glazed greenhouse in Fayetteville, AR.

	Mean total water required (mL)[z]		
	Shuttle-tray treatment		
Container type	No tray	Tray	*P* value[y]
Plastic	1,409.4 de[x]	1,177.2 c	0.3025
Bioplastic	1,208.6 e	1,173.8 c	0.8768
Dairy manure	2,858.4 a	2,330.8 a	0.0209
Wood fiber	2,671.8 ab	2,268.4 a	0.0753
Peat	2,267.0 bc	1,778.0 b	0.0319
Coconut fiber	2,190.8 c	1,771.4 b	0.0646
Straw	2,938.4 a	1,753.8 b	0.0001
Solid rice hull	1,156.2 e	1,142.4 c	0.9510
Slotted rice hull	1,419.8 de	1,201.4 c	0.3319
Sleeve	1,722.0 d	1,208.8 c	0.0245

[z]1 mL = 0.0338 fl oz.
[y]Probability value for testing significance of tray vs. no tray within container type.
[x]Means within columns (within tray treatment) that were significantly different are followed by different letters using to the TESTINTERACTION function from the PHIA package (De Rosario-Martinez, 2013) in R version 3.0.0 (R Development Core Team, 2013) to compute a series of false discovery rate-adjusted contrasts.

alternatives (e.g., straw, peat, and dairy manure).

At the Mississippi location, vinca plants grown in dairy manure, wood fiber, peat, and coconut fiber containers required more water to develop to anthesis than those grown in the plastic control container (Table 3). The straw container was not included at the Mississippi location.

Koeser et al. (2013) reported similar patterns of water use when growing a 5-week crop of 'Yellow Madness' petunia (*Petunia* ×*hybrida*) in 4-inch containers. More porous wood fiber, manure, and straw containers required more water than more impervious plastic, bioplastic, and solid rice hull containers. When grown without or with shuttle trays, plants grown in bioplastic, rice hull containers, and the sleeve required similar amounts of water to reach anthesis as the plastic control. Placing the biocontainers in shuttle trays reduced the water requirement for dairy manure, coconut fiber, and the sleeve containers.

At the Arkansas location, when grown without or with a shuttle tray, the irrigation interval was shorter for dairy manure, wood fiber, peat, and coconut fiber containers as compared with the plastic control container (Table 4). When placed in shuttle trays, the irrigation interval was longer for straw containers and sleeves as compared with the plastic control. Placement of straw containers and sleeves into shuttle trays increased the irrigation interval as compared with containers not placed in shuttle trays.

At the Mississippi location, when grown without a shuttle tray, the irrigation interval was shorter for dairy manure, wood fiber, peat, and coconut fiber containers as compared with the plastic control (Table 5). When placed in shuttle trays, only dairy manure and peat containers had a shorter irrigation interval than the plastic control while slotted rice hull containers and the sleeve had a longer irrigation interval than the plastic control. Placement of wood fiber containers and sleeves into shuttle trays increased the irrigation interval as compared with containers not placed in shuttle trays.

Table 3. Mean total water required to grow a vinca crop from six-leaf stage to anthesis using various container types with or without plastic shuttle trays (No tray/Tray). Plants were grown in a polycarbonate-glazed greenhouse in Crystal Springs, MS.

	Mean total water required (mL)[z]		
	Shuttle-tray treatment		
Container type	No tray	Tray	*P* value[y]
Plastic	1,088.2 de[x]	1,176.4 cd	0.6437
Bioplastic	995.6 e	947.0 cd	0.7987
Dairy manure	2,344.2 a	1,932.8 a	0.0337
Wood fiber	1,872.4 b	1,731.6 a	0.4608
Peat	1,861.8 b	1,614.2 ab	0.1965
Coconut fiber	1,722.0 bc	1,309.6 b	0.0333
Straw	N/A	N/A	N/A
Solid rice hull	1,060.4 de	962.6 cd	0.6081
Slotted rice hull	1,097.2 de	932.8 d	0.3895
Sleeve	1,417.0 cd	1,054.4 cd	0.0604

[z]1 mL = 0.0338 fl oz.
[y]Probability value for testing significance of tray vs. no tray within container type.
[x]Means within columns (within tray treatment) that were significantly different are followed by different letters using to the TESTINTERACTION function from the PHIA package (De Rosario-Martinez, 2013) in R version 3.0.0 (R Development Core Team, 2013) to compute a series of false discovery rate-adjusted contrasts.

Table 4. Mean irrigation interval required to grow a vinca crop from six-leaf stage to anthesis using various container types with or without plastic shuttle trays (No tray/Tray). Plants were grown in a polycarbonate-glazed greenhouse in Fayetteville, AR.

	Mean irrigation interval (d)		
	Shuttle-tray treatment		
Container type	No tray	Tray	*P* value[z]
Plastic	4.0 a[y]	4.6 c	0.1973
Bioplastic	4.7 a	4.3 c	0.4524
Dairy manure	3.0 b	3.1 d	0.7381
Wood fiber	2.7 b	3.5 d	0.0752
Peat	2.7 b	3.2 d	0.3171
Coconut fiber	2.8 b	3.2 d	0.3810
Straw	4.1 a	5.5 b	0.0030
Solid rice hull	4.3 a	4.5 c	0.6161
Slotted rice hull	4.6 a	4.8 c	0.6760
Sleeve	4.8 a	6.1 a	0.0071

[z]Probability value for testing significance of tray vs. no tray within container type.
[y]Means within columns (within tray treatment) that were significantly different are followed by different letters using to the TESTINTERACTION function from the PHIA package (De Rosario-Martinez, 2013) in R version 3.0.0 (R Development Core Team, 2013) to compute a series of false discovery rate-adjusted contrasts.

Second experiment. At both the Arkansas and Mississippi locations, water loss was best fit by a cubic function (Figs. 1 and 2, respectively). When examining the significance of experimental treatments, the application of wax and placement of containers in shuttle trays both reduced water loss from the containers at both locations (Tables 6 and 7; Figs. 1 and 2). However, the application of wax had a greater impact on water loss than did placement into shuttle trays as noted by the associated wax and tray coefficients in Tables 6 and 7.

While statistical results differed across sites, the overall mechanism of water retention or loss was similar. The two water loss figures (Figs. 1 and 2) offer effective visuals for inferring the main modes of water loss for the containers assessed. Once the top and drainage holes were sealed off for the plastic, bioplastic, bioplastic sleeve, and solid rice hull containers, water loss over time was greatly reduced. Intuitively, this indicates water loss for these containers is primarily a function of drainage and evapotranspiration. Of greater interest are the water loss patterns for the remaining containers. Some minor differences aside, the water loss profiles for porous containers are quite similar for the waxed and unwaxed pot pairings—indicating that water loss through the container walls is a main, if not primary, driver of increased water demand (Figs. 1 and 2).

Table 5. Mean irrigation interval required to grow a vinca crop from six-leaf stage to anthesis using various container types with or without plastic shuttle trays (No tray/Tray). Plants were grown in a polycarbonate-glazed greenhouse in Crystal Springs, MS.

	Mean irrigation interval (d)		
	Shuttle-tray treatment[z]		
Container type	No tray	Tray	*P* value[z]
Plastic	4.2 b[y]	4.0 cd	0.5952
Bioplastic	4.8 ab	4.5 bc	0.2266
Dairy manure	3.0 c	3.2 e	0.5952
Wood fiber	3.3 c	4.1 cd	0.0077
Peat	3.4 c	3.2 e	0.5439
Coconut fiber	3.4 c	3.7 de	0.2895
Straw	N/A	N/A	N/A
Solid rice hull	4.4 ab	4.4 bc	1.0000
Slotted rice hull	4.5 ab	4.8 ab	0.3634
Sleeve	4.4 ab	5.1 a	0.0095

[z]Probability value for testing significance of tray vs. no tray within container type.
[y]Means within columns (within tray treatment) that were significantly different are followed by different letters using to the TESTINTERACTION function from the PHIA package (De Rosario-Martinez, 2013) in R version 3.0.0 (R Development Core Team, 2013) to compute a series of false discovery rate-adjusted contrasts.

Table 6. Final model and regression results for cumulative water loss over time in a greenhouse environment (Fayetteville, AR) for biocontainers with and without shuttle trays (Tray). The wax variable indicates that the top and drain holes of a container were sealed with paraffin wax to assess the moisture loss through the container wall.

	Predicted water loss (g)[z]				
Variable	Coefficient	SE	*P* value	95% CI[y] lower	95% CI upper
Intercept	–25.881	4.461	<0.0001	–34.631	–17.130
Wax	–60.520	1.942	<0.0001	–64.329	–56.708
Tray	–19.817	1.942	<0.0001	–23.627	–16.006
Sleeve[x]	16.744	4.344	0.0001	8.223	25.265
Bioplastic[x]	2.706	4.344	0.533	–5.815	11.226
Solid rice hull[x]	–1.844	4.344	0.671	–10.365	6.676
Slotted rice hull[x]	62.911	4.344	<0.0001	54.390	71.431
Coconut fiber[x]	81.544	4.344	<0.0001	73.023	90.065
Peat[x]	101.900	4.344	<0.0001	93.379	110.420
Wood fiber[x]	123.222	4.344	<0.0001	114.701	131.743
Dairy manure[x]	147.116	4.344	<0.0001	138.595	155.637
Straw[x]	154.683	4.344	<0.0001	146.162	163.204
Day	35.734	1.977	<0.0001	31.854	39.613
Day^2	–2.756	0.335	<0.0001	–3.413	–2.098
Day^3	0.081	0.015	<0.0001	0.050	0.111

[z]1 g = 0.0353 oz.
[y]Confidence interval.
[x]Base level = plastic control containers without wax treatment. Adjusted R^2 = 0.8128.

and had similar water requirements and irrigation intervals. These results were consistent with those of Evans and Hensley (2004) who reported that plants grown in peat and feather fiber containers required more water than those grown in plastic, and that peat and feather fiber containers allowed water to evaporate through their container walls at a faster rate than plastic containers. These results were also consistent with Evans et al. (2010) who reported that biocontainers with water-permeable walls lost water through the container wall at a higher rate than those with non-permeable walls such as rice hull and plastic containers. Thus, as has been reported before, biocontainers with water-permeable walls required more frequent irrigation and more water to grow a crop.

When placed into shuttle trays, the rate of water loss from slotted rice hulls, coconut fiber, peat, wood fiber, manure, and straw containers was reduced as compared with when those containers were evaluated without shuttle trays. Placement of plastic, sleeves, bioplastic, and solid rice hulls containers into shuttle trays had little impact on water loss through the container walls. When placed into the shuttle trays, some of the containers fit tightly into the shuttle trays, and this would have presented a water-impermeable barrier around the biocontainers and thus reduced water loss. In other cases where biocontainers did not fit tightly into the shuttle tray, the surrounding plastic of the shuttle tray would still have created a high humidity boundary layer around the biocontainers and thus reduced evaporative water loss from the biocontainers. The impact of the shuttle tray would have been the greatest on those biocontainers with water-permeable walls and least on those with water-impermeable walls. Therefore, without the use of shuttle trays, many of the biocontainers required more water to grow a crop. The placement of the biocontainers into plastic shuttle trays (generally) reduced the amount of water required and the frequency of irrigation required to grow a crop. However, especially for those containers with water-permeable walls, the use of shuttle trays did not reduce water loss from the container walls to the level of the plastic control containers.

The use of bioplastic and solid rice hull containers did not significantly affect water loss as compared with the plastic control container. However, all other biocontainers increased water loss as compared with the plastic control. The use of peat, wood fiber, manure, and straw containers resulted in the greatest increase in water loss vs. plastic.

Although differences in plant growth as well as substrate surface area may have affected the amount of water required to grow a vinca crop as well as the average irrigation interval, the rate of water loss through the container wall was also a major factor affecting these two variables. Those containers that had the highest rate of water loss through the container walls tended to have the highest water requirement and the shortest irrigation interval. Containers that were relatively impermeable to water, such as rice hull and bioplastic containers, had water loss rates similar to their plastic controls

Table 7. Final model and regression results for cumulative water loss over time in a greenhouse environment (Crystal Springs, MS) for biocontainers with and without shuttle trays (Tray). The wax variable indicates that the top and drain holes of a container were sealed with paraffin wax to assess the moisture loss through the container wall.

	Predicted water loss (g)[z]				
Variable	Coefficient	SE	*P* value	95% CI[y] lower	95% CI upper
Intercept	–7.263	2.593	<0.0001	–12.349	–2.177
Wax	–56.416	1.157	<0.0001	–58.685	–54.146
Tray	–16.448	1.157	<0.0001	–18.717	–14.179
Sleeve[x]	21.298	2.454	<0.0001	16.484	26.112
Bioplastic[x]	0.729	2.454	0.7664	–4.084	5.543
Solid rice hull[x]	1.397	2.454	0.5695	–3.417	6.211
Slotted rice hull[x]	43.416	2.454	<0.0001	38.602	48.230
Coconut fiber[x]	60.266	2.454	<0.0001	55.452	65.079
Peat[x]	97.738	2.454	<0.0001	92.924	102.552
Wood fiber[x]	86.464	2.454	<0.0001	81.651	91.278
Dairy manure[x]	117.953	2.454	<0.0001	113.140	122.76
Day	30.862	1.178	<0.0001	28.551	33.172
Day^2	–2.978	0.199	<0.0001	–3.370	–2.587
Day^3	0.103	0.009	<0.0001	0.086	0.122

[z]1 g = 0.0353 oz.
[y]Confidence interval.
[x]Base level = plastic control containers without wax treatment. Adjusted R^2 = 0.8128.

Conclusion

Biocontainers with water-permeable walls such as slotted rice hull, coconut fiber, peat, wood fiber, dairy manure, and straw containers had higher rates of water loss through the container walls than plastic control containers. This outcome resulted in most of these containers requiring more frequent irrigation and more water to produce a vinca crop than the control plastic containers. Solid rice hull and bioplastic containers, which were relatively impermeable to water, had a similar water loss rates as their plastic controls and had similar water requirements and irrigation intervals. The use of plastic shuttle trays may reduce the amount of water required and the frequency of irrigation required to grow a crop in more permeable biocontainers, but not to a level similar to plastic containers. Even with the use of plastic shuttle trays, biocontainers with water-permeable walls tended to require more frequent irrigation and more water than plastic containers.

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