Impact of Biocontainers on Plant Performance and Container Decomposition in the Landscape

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Summary. **As the green industry is moving toward sustainability to meet the demands of society, the use of biocontainers as alternatives to petroleum-based plastic containers has drawn significant attention. Field trials of seven plantable biocontainers (coir, manure, peat, rice hull, soil wrap, straw, and wood fiber) were conducted in 2011 and 2012 at five locations in the United States to assess the influence of direct-plant biocontainers on plant growth and establishment and the rate of container decomposition in landscape. In 2011, container type did not affect the growth of any of the three species used in this study with an exception in one location. The three species were 'Sunpatiens Compact Magenta' new guinea impatiens (*Impatiens* ×*hybrida*), 'Luscious Citrus' lantana (*Lantana camara*), and 'Senorita Rosalita' cleome (*Cleome* ×*hybrida*). In 2012, the effect of container type on plant growth varied with location and species. Cleome, new guinea impatiens, and lantana plants grown in coir and straw containers were in general smaller than those in peat, plastic, rice hull, and wood fiber containers. After 3 to 4 months in the field, manure containers had on average the highest rate of decomposition at 88% for all five locations and two growing seasons. The levels of decomposition of other containers, straw, wood fiber, soil wrap, peat, coir, and rice hull were 47%, 46%, 42%, 38%, 25%, and 18%, respectively, in descending order. Plantable containers did not hinder plant establishment and posttransplant plant growth. The impact of container type on plant growth was smaller compared with that of location (climate). Similarly, the impact of plant species on pot decomposition was smaller compared with that of pot material.**

Petroleum-based plastics are the most common materials used for greenhouse and nursery container construction. With limited opportunities for recycling, plastic containers are often destined for the landfill and present a significant solid waste issue for the green industry. In California alone, Hurley (2008) estimated that greenhouse and nursery growers disposed more than 11,800 tons of plastic trays, flats, and containers annually. As the green industry is moving toward sustainability to meet the demands of society, the use of biocontainers as alternatives to plastic containers has drawn significant attention, especially because they do not have the same disposal issues as plastic containers.

A wide variety of biocontainers are available in the market (Table 1). Biocontainers are generally classified as being either plantable or compostable (Evans and Hensley, 2004; Evans et al., 2010). Plantable biocontainers are designed to allow roots to grow through the container walls and into the surrounding soil. These containers readily decompose after being directly installed in the landscape (Evans et al., 2010). In contrast, compostable biocontainers do not decompose quickly enough to allow roots to physically break through container walls. As such, these containers must be separated from the plant at transplanting (Mooney, 2009).

Plants can be exposed to stresses such as extreme temperature, mechanical injury, and changes in growing environment when they are transplanted into the landscape. These stresses adversely impact plant growth and can lead to a condition known as transplant shock (Koeser et al., 2009; McKay, 1996). Proponents of plantable biocontainers suggest that their use limits root system disruption and reduces transplant shock (Evans and Hensley, 2004; Evans and Karcher, 2004).

Biocontainers have been linked to both decreased growth and increased need for irrigation in greenhouse production. Evans and Hensley (2004) reported that shoot dry weights of 'Janie Bright Yellow' marigold (*Tagetes patula*), 'Cooler Blush' vinca (*Catharanthus roseus*), 'Orbit Cardinal' geranium (*Pelargonium* ×*hortorum*), and 'Better Boy' tomato (*Solanum lycopersicum*) grown in feather and peat containers were lower than those grown in plastic containers. However, a greenhouse study has shown that dry weights of 'Yellow Madness' petunia (*Petunia* ×*hybrida*) grown in slotted rice hull and bioplastic sleeve containers matched or exceeded those of a conventional

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
0.0929	ft^2	m^2	10.7639
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
6.4516	inch^2	cm^2	0.1550
28.3495	oz	g	0.0353
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

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Table 1. Type of biocontainers used in the experiment to evaluate the impact of container type on plant performance and container decomposition under landscape conditions in five locations [University of Illinois at Urbana-Champaign (IL); University of Kentucky, Lexington (KY); Mississippi State University, Crystal Spring (MS); Texas A&M University at El Paso (TX); West Virginia University, Morgantown (WV)]. Plastic containers were used as a control.

Container	Product name[z]	Composition[y]	Volume (cm^3)[w]	Diam (cm)[z]	Ht (cm)	Manufacturer
Coir	Coir 4.0 inch Std Fiber Gro Pot	Coconut husk	406	14.4	10.2	Dillen Products, Middlefield, OH
Manure	#4 Square CowPot	100% composted cow manure	450	14.2	10.5	CowPots, East Canaan, CT
Peat	4 inch Jiffy Pot	Canadian sphagnum moss and wood pulp	379[x]	12.5	9.8	Jiffy Products of America, Lorain, OH
Rice hull	4.5 inch NetPot	Slotted rice hull	591	14.7	10.5	Summit Plastic Co., Akron, OH
Soil wrap	4.5 inch Standard Assembled SoilWrap	Bioplastic sleeve	709[x]	14.7	10.7	Ball Horticultural Co., West Chicago, IL
Straw	StrawPot	80% rice straw, 20% coco fiber	646[x]	14.0	16.8	Ivy Acres, Baiting Hollow, NY
Wood fiber	10 × 10 cm Round Individual Fertilpot	74% recycled paper	430[x]	15.3	11.5	Fertil, Boulogne Billancourt, France
Plastic	Dillen 04.00 Standard Thinwall Green	Injection-molded plastic	480	13.7	11.3	Myers Industries, Middlefield, OH

[z] As indicated in manufacturers on-line/print catalog; 1 inch = 2.54 cm, 1 cm = 0.3937 inch.
[y] Lopez and Camberato (2011).
[x] Not included in manufacturer specifications.
[w] 1 cm^3 = 0.0610 $inch^3$.

plastic control (Koeser et al., 2013). This was attributed, in part, to the relatively impervious nature of the materials used to construct the slotted rice hull containers and bioplastic sleeves (Koeser et al., 2013).

Most plantable biocontainers are made from highly porous materials (e.g., peat, wood fiber, or manure) that may provide little resistance to water loss from the root zone to the surrounding soil in the landscape (Koeser, 2013). Furthermore, it is believed that some biocontainers (e.g., peat) may wick water up out of the root zone if not sufficiently buried (Kuehny et al., 2011). 'Cooler Blush' vinca and 'Dazzler Rose Star' new guinea impatiens plants grown in feather and peat containers required more water and more frequent irrigations than those grown in plastic containers (Evans and Karcher, 2004). Evans et al. (2010) also observed that the amount of water required to produce a geranium crop was significantly higher and the average irrigation intervals were shorter for peat, wood fiber, coir, manure, and straw containers than for traditional plastic containers.

Plantable biocontainers are designed to degrade in field soil. This rate of decomposition must be slow enough to meet the needs of growers during greenhouse production, but fast enough not to impede plant establishment, root growth, and future landscape aesthetics and uses. To date, a few studies have addressed the rate at which plantable pots degrade after placement in the landscape (Evans et al., 2010). Decomposition of peat and feather containers was significantly affected by container type and the species grown in the container (Evans and Karcher, 2004). In landscape trials held in Pennsylvania and Louisiana, Evans et al. (2010) reported that manure containers had faster decomposition than peat, straw, and wood fiber containers, followed by coir containers. Evans and Karcher (2004) observed that the difference in decomposition between peat and feather containers in which 'Better Boy' tomatoes were planted was insignificant. However, the same study also showed that decomposition was higher for feather containers than for peat containers in which vinca and marigold were grown. To date, no studies have assessed decomposition of the more recently developed slotted rice hull and bioplastic sleeve in field soils. To address this concern, field trials of seven plantable biocontainers (coir, manure, peat, rice hull, soil wrap, straw, and wood fiber) were conducted in 2011 and 2012 at five locations in the United States with wide variability in climate to assess the impact of containers on plant performance and container decomposition.

Materials and methods

Landscape trials were conducted at research field plots at the University of Illinois at Urbana-Champaign (IL); University of Kentucky, Lexington (KY); Mississippi State University, Crystal Spring (MS); Texas A&M University at El Paso (TX); and West Virginia University, Morgantown (WV) during the 2011 and 2012 growing seasons. All plants were grown in the field plots for the same number of degree days (4630 degree days with a base temperature of 4.5 °C) for all locations. The study period for the 2011 growing season was set as the expected number of degree days based on historic averages from the planting date to the average first freeze date at the coldest trial site (Illinois). This trial period was used again in 2012 for consistency. Mean monthly temperature, light, precipitation, and relative humidity at the five locations for 2011 and 2012 growing seasons were recorded and are shown in Table 2.

Seven types of plantable biocontainers including coir, manure, peat, rice hull, soil wrap, straw, and wood fiber were used in the study (Table 1). Control plants grown in standard thin-walled green plastic pots [13.7 cm

Table 2. Weather conditions during the growing seasons of 2011 and 2012 in five locations [University of Illinois at Urbana-Champaign (IL); University of Kentucky, Lexington (KY); Mississippi State University, Crystal Spring (MS); Texas A&M University at El Paso (TX); West Virginia University, Morgantown (WV)].

Location	IL		KY		MS		TX		WV	
Latitude	40°6'N		37°58' N		31°59'N		31°41'N		39°45'N	
Longitude	88°13'W		84°32'W		90°21'W		106°16'W		79°58'W	
Hardiness zone[z]	5b		6b		8a		8a		6a	
Growing season	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Planting date	17 May	15 June	10 June	23 May	12 May	22 May	16 May	23 May	28 June	25 June
Harvest date	19 Oct.	26 Oct.	10 Oct.	17 Oct.	3 Aug.	10 Sep.	29 Aug.	11 Sep.	9 Oct.	9 Oct.
Air temp (°C)[y]	20.2	20.5	19.3	19.6	26.8	27.0	28.3	29.5	19.5	20.0
Light ($\text{mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$)	NA[x]	NA	31.3	34.9	NA	NA	51.1	48.7	NA	NA
Precipitation (mm)[y]	345.4	385.1	40.3	21.5	238.5	503.2	204.2	93.0	94.0	53.5
Relative humidity (%)	NA	NA	71.2	66.5	NA	NA	27.1	25.1	78.5	72.2

[z] U.S. Department of Agriculture (2012).
[y] ($1.8 \times$ °C) + 32 = °F, 1 mm = 0.0394 inch.
[x] Not applicable.

diameter, 11.3 cm tall, 480 cm^3 volume (Dillen 04.00; Myers Industries, Middlefield, OH)] were removed from containers at transplanting. All biocontainers used in the trials were chosen on the basis of their direct-plant design and commercial availability in sizes similar to the control, standard plastic container.

Three species with different water requirements were chosen for the field trials. 'Sunpatiens Compact Magenta' new guinea impatiens has relatively high water-use requirement. 'Luscious Citrus' lantana was included due to its low water-use requirement. 'Senorita Rosalita' cleome is a plant with moderate watering requirements compared with new guinea impatiens and lantana. In Texas, 'Silver Mound' artemisia (*Artemisia schmidtiana*) and 'Nanho Blue' buddleia (*Buddleia davidii*) were used in 2012 trial as the cleome and new guinea impatiens proved to be ill-suited for the site. Plants were transplanted in the field by species to prevent the taller species (i.e., cleome) from crowding or shading the lower growing species (i.e., new guinea impatiens).

Before the start of the trial, plugs purchased from commercial growers were grown to a marketable size (≈3 weeks) under conventional greenhouse conditions at each location. A commercial growing mix consisting of peat, perlite, and vermiculite was used for greenhouse production [Fafard 2 Mix (Illinois) or Sunshine Mix #4 (Texas); Sun Gro Horticulture, Agawam, MA]. Plants were watered whenever needed to prevent water stress in all locations and were fertilized with nutrient solution in the greenhouse before transplanting to the field. The irrigation interval and amount varied with environmental conditions in each location. After reaching marketable size, plants were transplanted into field plots at 2-ft intervals; the biocontainers were left intact on the root ball. Weeds were controlled with black landscaping fabric (Weed-Barrier-Pro; DeWitt Co., Sikeston, MO). Plants in the field plots were well irrigated in all locations via drip irrigation throughout the growing seasons.

At the end of both seasons, all aboveground shoots were collected and oven dried, and shoot dry weights were recorded. The containers were dug, removed from the root ball, cleaned, and dried. Residual pot dry weights were recorded to determine the container decomposition in the landscape. The level of decomposition of the biocontainers was expressed as a percentage of the initial dry weights of new containers of the same type.

The trials were arranged in a completely randomized design per species with 10 plants of each species per container type per year serving as replications and the individual potted plant designated as the experimental unit. Because of this, experimental design each species was analyzed separately. A four-way analysis of variance was conducted to test the influence of types of biocontainers, plant species, locations, and trial seasons on shoot dry weights and percentage of biocontainer decomposition. To test the effect of location on container decomposition in 2012, data from Texas were excluded. Means separation among containers was conducted using Tukey's honest significant difference multiple comparison. All statistical analyses were carried out using SAS software (version 9.1.3; SAS Institute, Cary, NC).

Results and discussion

Shoot dry weight. The shoot dry weights of the three tested plant species (cleome, lantana, and new guinea impatiens) across three different states including Illinois, Mississippi, and West Virginia were significant among plant species ($P < 0.0001$), locations ($P < 0.0001$), type of containers ($P < 0.0001$), and between growing seasons ($P < 0.0001$). All interactions among the four factors were also significant ($P < 0.05$), but interaction of container type with growing season was not ($P = 0.93$). Therefore, all data were analyzed and presented separately by plant species, then growing season, location, and type of containers.

In the 2011 growing season, shoot dry weights of cleome were similar for plants grown in different containers in all locations except Mississippi (Table 3). Cleome plants grown in rice hull containers in Mississippi had the highest shoot dry weights, while those plants in straw containers showed the lowest shoot dry weights, a 25% reduction compared with the highest dry weight. The shoot dry weights of cleome plants in other containers were similar. Cleome plants grown in Mississippi had the greatest shoot dry weights, followed by Illinois, and those in West Virginia and Texas had the least shoot dry weights. The shoot dry weights of cleome plants grown in Mississippi were two times and six times as much as that in Illinois and West Virginia, respectively. In 2012, container type significantly impacted the shoot dry weights of cleome plants grown in Illinois and Kentucky and the shoot dry weights of artemisia plants grown in Texas (Table 3). In Illinois, shoot dry weights of cleome plants grown in manure or soil wrap containers were ≈55% that of the plants in plastic containers. In Kentucky, shoot dry weights of cleome plants grown in straw and wood fiber containers were 58% to 68% that of plants grown in peat containers. In Texas, shoot dry weights of artemisia plants were higher in plastic and rice hull containers than those in straw and wood fiber containers. The shoot dry weights of cleome plants grown in Mississippi were three times, two times, and six times as much as that in Illinois, Kentucky, and West Virginia, respectively. To test the effect of growing seasons on the shoot dry weights of cleome plants, data from Illinois, Mississippi, and West Virginia were further analyzed. Cleome plants performed similarly and accumulated similar shoot dry weights in both 2011 and 2012 growing seasons ($P = 0.96$). From these results, it was obvious that the differences in shoot dry weights of cleome plants due to container type (up to 0.45 times) were much smaller than that due to location (up to six times).

Shoot dry weights of lantana plants grown in eight types of containers were not significantly different at all locations in the 2011 growing season (Table 4). Lantana plants grown in Mississippi had the greatest shoot dry weight, whereas those grown in Illinois, Texas, and West Virginia showed similar shoot dry weights. The shoot dry weights of lantana plants grown in Mississippi were two times, four times, and three times as much as that in Illinois, Texas, and West Virginia, respectively. In 2012, shoot dry weights of lantana plants were significantly different among various containers at all locations. In Illinois, shoot dry weights of lantana plants grown in coir containers were 62% that of plants in rice hull, while no differences were found in plants grown in manure, peat, plastic, soil wrap, straw, or wood fiber containers. In Kentucky, lantana plants grown in plastic containers produced the highest shoot dry weight (398 g/plant), while those in straw containers had the least shoot dry weight (273 g/plant). In Mississippi, lantana plants grown in peat, plastic, or rice hull containers had similar shoot dry weights to those in coir, soil wrap, straw, or

Table 3. Shoot dry weight of 'Senorita Rosalita' cleome planted with various types of biocontainers and grown in five locations [University of Illinois at Urbana-Champaign (IL); University of Kentucky, Lexington (KY); Mississippi State University, Crystal Spring (MS); Texas A&M University at El Paso (TX); West Virginia University, Morgantown (WV)] in 2011 and 2012.

	Dry wt in 2011 (g)[z]				Dry wt in 2012 (g)				
Container	**IL**	**MS**	**TX[y]**	**WV**	**IL**	**KY**	**MS**	**TX[y]**	**WV**
Coir	142.4 aB	398.5 abA[x]	23.7 aC	59.8 aC	189.1 abB	230.7 abB	420.3 aA	86.4 ab	50.2 aC
Manure	184.8 aB	379.0 abA	16.7 aD	77.2 aC	110.0 bC	219.6 abB	401.2 aA	89.2 ab	77.9 aC
Peat	192.2 aB	417.5 abA	17.4 aC	62.7 aC	183.5 abC	308.0 aB	422.8 aA	93.2 ab	73.2 aD
Plastic	220.0 aB	392.6 abA	13.6 aD	81.0 aC	204.9 aB	229.9 abB	426.4 aA	122.1 a	58.2 aC
Rice hull	137.6 aB	469.5 aA	15.4 aC	79.4 aB	173.8 abC	265.0 abB	440.5 aA	121.9 a	88.2 aD
Soil wrap	175.8 aB	384.1 abA	14.1 aC	61.8 aC	113.7 bC	269.6 abB	408.0 aA	101.1 ab	48.2 aC
Straw	214.8 aB	349.3 bA	16.7 aC	62.1 aC	168.7 abB	178.7 bB	421.3 aA	85.7 b	60.5 aC
Wood fiber	188.5 aB	380.9 abA	12.3 aC	69.9 aC	169.6 abB	207.1bB	469.1 aA	80.8 b	74.7 aC

[z] 1 g = 0.0353 oz; data in KY was unavailable due to loss of postharvest samples.

[y] 'Silver Mound' artemisia was used in 2012 because 'Senorita Rosalita' cleome died in the middle of the 2011 growing season. They are excluded for multiple comparisons among locations.

[x] Means with same lowercase letters within column (among containers) or uppercase letters within row (among locations) are not significantly different among treatments by Tukey's honest significant difference multiple comparison at $P < 0.05$.

Table 4. Shoot dry weight of 'Luscious Citrus' lantana planted with various types of biocontainers and grown in five locations [University of Illinois at Urbana-Champaign (IL); University of Kentucky, Lexington (KY); Mississippi State University, Crystal Spring (MS); Texas A&M University at El Paso (TX); West Virginia University, Morgantown (WV)] in 2011 and 2012.

	Dry wt in 2011 (g)[z]				Dry wt in 2012 (g)				
Container	**IL**	**MS**	**TX**	**WV**	**IL**	**KY**	**MS**	**TX**	**WV**
Coir	118.8 aB[y]	444.7 aA	98.4 aB	97.1 aB	111.0 bC	313.0 bcdB	691.5 abA	141.5 cC	55.2 bC
Manure	130.6 aB	405.5 aA	78.8 aB	90.5 aB	162.3 abC	282.4 cdB	558.2 bA	132.2 cCD	66.6 abD
Peat	156.2 aB	381.3 aA	74.8 aC	133.5 aBC	126.9 abC	326.7 abcdB	728.5 aA	155.8 bcC	76.6 aC
Plastic	139.8 aB	417.9 aA	71.3 aC	117.8 aBC	147.5 abC	398.0 aB	716.4 aA	291.6 aB	69.6 abC
Rice hull	136.6 aB	482.5 aA	90.5 aB	138.5 aB	178.2 aCD	376.8 abB	735.7 aA	207.3 abcC	83.7 aD
Soil wrap	134.1 aB	400.8 aA	111.1 aB	87.8 aB	159.1 abC	358.4 abcB	675.9 abA	274.1 abB	66.6 abC
Straw	143.9 aB	364.4 aA	83.2 aB	117.0 aB	153.5 abCD	273.4 dB	635.8 abA	228.5 abcBC	55.0 bD
Wood fiber	141.7 aB	450.2 aA	97.4 aB	84.9 aB	137.7 abC	302.2 bcdB	689.4 abA	149.7 bcC	68.3 abC

[z] 1 g = 0.0353 oz; data in KY was unavailable due to loss of postharvest samples.

[y] Means with same lowercase letters within column (among containers) or uppercase letters within row (among locations) are not significantly different among treatments by Tukey's honest significant difference multiple comparison at $P < 0.05$.

wood fiber containers, while they were ≈30% higher than those in manure container. In Texas, shoot dry weights of lantana plants grown in rice hull, soil wrap, and straw containers were similar to those in plastic containers, whereas those in coir, manure, peat, or wood fiber containers were smaller than those in plastic containers. In West Virginia, lantana plants grown in peat and rice hull containers had the greatest shoot dry weights, while those in coir and straw containers had the least shoot dry weights. Lantana plants grown in Mississippi had the highest shoot dry weights, followed by Kentucky, while those in West Virginia had the least shoot dry weights. The shoot dry weights of lantana plants in Mississippi was five times, two times, four times, and 10 times more than that in Illinois, Kentucky, Texas, and West Virginia, respectively. In addition, lantana plants evaluated in Mississippi and Texas yielded greater shoot dry weights in 2012 than in 2011 ($P < 0.0001$), while lantana plants had greater shoot dry weights in 2011 than in 2012 in West Virginia ($P < 0.0001$) and no differences between 2011 and 2012 in Illinois ($P = 0.2$). Similar to cleome, the effect of container type on shoot dry weight was small enough to be neglected compared with the location effect for landscape performance.

New guinea impatiens plants grown in different containers had similar shoot dry weights in all locations except Mississippi in 2011 (Table 5). Shoot dry weights of new guinea impatiens plants grown in containers made with manure, peat, or straw were ≈35% lower than those grown in plastic containers in Mississippi. The shoot dry weights of new guinea impatiens plants grown in coir, rice hull, soil wrap, or wood fiber containers were similar to those in plastic containers. New guinea impatiens plants grown in Illinois had the greatest shoot dry weight, which was two times, three times, five times as much as that in Mississippi, Texas, and West Virginia, respectively. In 2012, new guinea impatiens plants grown in different containers produced similar shoot dry weights in Illinois, Kentucky, Mississippi, and West Virginia. Buddleia was used for the field trial in Texas in 2012 because new guinea impatiens plants died in the middle of the 2011 growing season. The shoot dry weights of buddleia plants grown in plastic containers were 25% to 35% higher than those in manure or straw containers, while similar to those grown in coir, peat, rice hull, soil wrap, and wood fiber containers. New guinea impatiens plants grown in Kentucky and West Virginia had higher shoot dry weights than those in Illinois and Mississippi. Shoot dry weights of new guinea impatiens plants grown in Kentucky and West Virginia were two to three times more than that in Illinois and Mississippi. New guinea impatiens plants grown in Illinois had less shoot dry weights in 2012 than in 2011 ($P < 0.001$), while in West Virginia, higher shoot dry weights were found in 2012 than 2011 ($P < 0.001$). In Mississippi, no differences in shoot dry weights were found between the growing seasons ($P = 0.7$). Again, similar to the other two species, the effect of container type on plant growth was much smaller than that of the location effect. For all three species, in general, plants grown in peat, rice hull, and wood fiber containers had similar to or higher dry weights than those in plastic containers.

The U.S. Center for Applied Horticulture Research (CfAHR, 2010) reported that petunia plants grown in coir and plastic containers were similar in size during the postproduction phase in greenhouse. Ingram and Nambuthiri (2012) observed that rice hull did not negatively impact the shoot development of two sedum (*Sedum hybridum* and *S. spurium*) species and liriope (*Liriope muscari*) during field establishment when compared with plastic containers. They further observed that ajuga (*Ajuga reptans*), lamiastrum (*Lamiastrum galeobdolon*), lamium (*Lamium maculatum*), and sedum plants grown in wood fiber containers and soil wrap containers were similar to those of plants grown in plastic containers, while peat containers yielded smaller plants and slower ground coverage after transplanting in the field than plants grown in wood fiber, soil wrap, and plastic containers (Nambuthiri and Ingram, 2014). Plants grown in this study in containers with highly porous materials (e.g., coir, straw) were generally smaller than those in peat, rice hull, and wood fiber containers (Tables 3–5). Similar results have been reported by CfAHR (2010). They observed that petunia plants grown in coir containers were

Table 5. Shoot dry weight of 'Sunpatiens Compact Magenta' new guinea impatiens planted with various types of biocontainers and grown in five locations [University of Illinois at Urbana-Champaign (IL); University of Kentucky, Lexington (KY); Mississippi State University, Crystal Spring (MS); Texas A&M University at El Paso (TX); West Virginia University, Morgantown (WV)] in 2011 and 2012.

	Dry wt in 2011 (g)[z]				Dry wt in 2012 (g)				
Container	IL	MS	TX[y]	WV	IL	KY	MS	TX[y]	WV
Coir	38.7 aA[x]	35.4 abcA	10.7 aB	15.8 aB	32.5 aB	125.8 aA	41.2 aB	182.7 abc	109.5 aA
Manure	46.6 aA	24.0 cB	10.5 aB	12.4 aB	32.9 aB	130.0 aA	26.5 aB	152.9 bc	109.6 aA
Peat	43.7 aA	24.8 cB	10.2 aB	16.8 aB	25.7 aB	139.2 aA	27.7 aB	155.7 abc	111.2 aA
Plastic	45.9 aA	40.9 aA	5.0 aB	16.0 aB	35.4 aB	151.0 aA	37.0 aB	213.7 a	115.7 aA
Rice hull	50.6 aA	40.4 abA	11.9 aB	13.7 aB	24.0 aB	130.5 aA	38.4 aB	183.0 abc	104.5 aA
Soil wrap	52.3 aA	30.2 abcB	14.1 aC	14.1 aC	30.5 aC	144.2 aA	27.1 aC	208.6 ab	102.8 aB
Straw	59.4 aA	25.5 bcB	10.4 aC	14.1 aBC	37.4 aC	133.6 aA	27.3 aC	131.1 c	103.2 aB
Wood fiber	47.9 aA	38.9 abcA	12.5 aB	11.1 aB	25.9 aB	131.6 aA	39.0 aB	154.6 abc	118.0 aA

[z] 1 g = 0.0353 oz; data in KY was unavailable due to loss of postharvest samples.

[y] 'Nanho Blue' buddleia was used in 2012 because 'Sunpatiens Compact Magenta' new guinea impatiens died in the middle of the 2011 growing season. They are excluded for multiple comparisons among locations.

[x] Means with same lowercase letters within column (among containers) or uppercase letters within row (among locations) are not significantly different among treatments by Tukey's honest significant difference multiple comparison at $P < 0.05$.

smaller than those in rice hull containers. This is most likely because coir and straw containers provide little resistance to water loss from the root zone to the surrounding soil in the landscape (Koeser, 2013) and plants grown in such containers often reached the point of incipient wilting between irrigations (Evans and Hensley, 2004). In addition, the air entering the holes of coir and straw containers' wall may kill the plant root tips (Privett and Hummel, 1992), which hinder roots growing into the surrounding soil in the landscape. Although air root pruning encourages new roots to grow behind the pruned portion of the root, reliance on the limited soil space within containers can cause increased moisture stress when combined with the accelerated drainage conditions noted above (Spomer, 1980).

POT DECOMPOSITION. Pot decomposition across three different states including Illinois, Mississippi, and West Virginia were significant among plant species ($P < 0.0001$), locations ($P < 0.0001$), type of biocontainers ($P < 0.0001$), and between growing seasons ($P < 0.0001$). All interactions among the four factors were also significant ($P < 0.004$). Therefore, all data were analyzed and presented separately by plant species, then trial seasons, locations, and type of biocontainers.

In all locations, manure containers had the highest level of decomposition in the field (Tables 6–8). On average, about 96%, 94%, 79%, 83%, and 88% of material in manure containers decomposed at the end of both growing seasons for Illinois, Kentucky, Mississippi, Texas, and West Virginia, respectively. Evans et al. (2010) also observed that manure containers had the highest decomposition percentages of 62% and 48% in the Pennsylvania and Louisiana locations, respectively, when compared with coir, peat, straw, and wood fiber containers. These decomposition levels were much lower than the numbers reported in this study. The differences in pot decomposition percentages between our study and Evans et al. (2010) may be due to the difference in trial period; ours was at least 3 months as compared with 8 weeks in Evans et al (2010). Although lower than manure containers, levels of decomposition of straw, wood fiber, soil wrap, and peat containers showed consistently higher values than coir and rice hull containers, which had the lowest level of decomposition of all the tested containers. There was 47%, 36%, 52%, 48%, and 48% of material in straw and 45%, 50%, 54%, 66%, and 9% of material in wood fiber containers decomposed at the Illinois, Kentucky, Mississippi, Texas, and West Virginia sites, respectively. The level of decomposition of soil wrap was 36%, 37%, 35%, 68%, and 28% for Illinois, Kentucky, Mississippi, Texas, and West Virginia, respectively, while that of peat containers was 34%, 32%, 40%, 49%, and 30%, respectively. The level of decomposition of coir containers was 29%, 35%, 20%, 33%, 8.5% for Illinois, Kentucky, Mississippi, Texas, and West Virginia, respectively, and 17%, 11%, 26%, 15%, and 16% of material decomposed in rice hull containers. Most of these decomposition percentages are higher than those previously reported by Evans et al. (2010). They found that peat, straw, wood fiber containers decomposed 32%, 28%, and 24%, respectively, in Pennsylvania, and 10%, 9%, and 2%, respectively, in Louisiana. In their study, coir containers had the lowest level of decomposition at 4% and 1.5% in Pennsylvania and Louisiana, respectively.

Container decomposition is affected by the container material and nitrogen, moisture, temperature, pH, and microorganisms of the soil in which the containers are planted (Nambuthiri et al., 2013). Differences in decomposition rates of biocontainers in this project may be partially due to the container materials. Those containers composed of materials high in cellulose such as manure had higher rates of decomposition than those composed of materials high in lignin or other difficult-to-decompose components such as coconut fiber and rice hull containers (Evans et al., 2010). CfAHR (2009) also reported that manure container decomposed faster in soil than wood fiber and coir containers. Furthermore, the significant level of nitrogen present in the dairy manure used to formulate the manure containers may have increased microbial activity and subsequent decomposition of the containers (Evans and Karcher, 2004). Decomposition is also affected by the species in the containers ($P < 0.0001$; Evans and Karcher, 2004), and a significant interaction between species and containers was observed ($P < 0.0001$). However, the magnitude of differences in pot decomposition due to species was much smaller compared with that due to container type. In our

Table 6. Pot decomposition of 'Senorita Rosalita' cleome in five locations [University of Illinois at Urbana-Champaign (IL); University of Kentucky, Lexington (KY); Mississippi State University, Crystal Spring (MS); Texas A&M University at El Paso (TX); West Virginia University, Morgantown (WV)] in 2011 and 2012.

	Pot decomposition in 2011 (%)					Pot decomposition in 2012 (%)				
Container	IL	KY	MS	TX[z]	WV	IL	KY	MS	TX	WV
Coir	25.8 cB[y]	19.4 bBC	20.5 cBC	39.5 cA	9.8 dC	44.7 bA	42.3 bA	23.4 dAB	12.6 e	13.6 dB
Manure	89.9 aA	82.6 aA	84.0 aA	88.3 aA	85.4 aA	98.2 aA	100.0 aA	94.7 aA	89.7 a	95.9 aA
Peat	28.8 cB	21.6 bB	51.5 bA	57.2 bcA	31.2 bcB	54.0 bA	52.6 abA	45.1 cA	60.4 bc	32.6 cA
Rice hull	12.9 cB	—[x]	25.1 cA	3.8 dC	18.0 cdAB	17.6 cAB	23.2 bAB	29.9 dA	33.2 de	3.6 dB
Soil wrap	48.4 bB	—	53.0 bB	92.7 aA	7.1 dC	24.8 cB	28.3 bAB	22.5 dB	35.5 de	40.2 bcA
Straw	51.1 bA	35.6 bA	56.6 bA	48.0 bcA	45.8 bA	44.9 bA	44.3 bA	53.7 bcA	40.6 cd	52.8 bA
Wood fiber	50.0 bAB	24.1 bBC	64.5 bA	62.2 bA	7.2 dC	50.8 bA	68.6 abA	65.3 bA	68.4 ab	3.2 dB

[z] 'Silver Mound' artemisia was used in 2012 because 'Senorita Rosalita' cleome died in the middle of the 2011 growing season. They are excluded for multiple comparisons among locations.

[y] Means with same lowercase letters within column (among containers) or uppercase letters within row (among locations) are not significantly different among treatments by Tukey's honest significant difference multiple comparison at $P < 0.05$.

[x] Data were unavailable due to loss of postharvest samples.

Table 7. Pot decomposition of 'Luscious Citrus' lantana in five locations [University of Illinois at Urbana-Champaign (IL); University of Kentucky, Lexington (KY); Mississippi State University, Crystal Spring (MS); Texas A&M University at El Paso (TX); West Virginia University, Morgantown (WV)] in 2011 and 2012.

	Pot decomposition in 2011 (%)					Pot decomposition in 2012 (%)				
Container	IL	KY	MS	TX	WV	IL	KY	MS	TX	WV
Coir	16.5 dAB[z]	31.1 bA	26.5 dA	35.0 cA	3.9 eB	34.4 cdA	21.8 cAB	19.7 dAB	25.5 cdAB	6.0 cB
Manure	95.9 aA	85.5 aBC	90.8 aAB	78.9 aC	83.7 aBC	97.9 aA	100.0 aA	93.0 aA	81.9 aB	100.0 aA
Peat	37.6 bcdABC	27.6 bBC	51.0 bcA	42.1 cAB	20.1 cdC	32.5 cdA	40.1 bcA	43.2 cA	42.3 bcA	44.8 bA
Rice hull	21.7 cdAB	34.7 abA	30.5 dA	11.6 dB	23.5 cAB	17.7 dAB	11.7 cB	29.0 dA	21.8 dAB	9.3 cB
Soil wrap	45.1 bcB	91.3 aA	42.5 cdB	92.5 aA	8.2 deC	24.4 dB	13.8 cB	24.2 dB	50.4 bA	64.1 bA
Straw	49.5 bA	45.2 abA	62.5 bA	48.9 bcA	44.1 bA	47.3 bcA	38.2 bcA	58.3 bA	46.8 bA	56.8 bA
Wood fiber	34.3 bcdB	32.1 bB	62.8 bA	63.3 bA	2.6 eC	64.9 bA	58.3 bA	60.9 bA	59.0 bA	11.9 cB

[z] Means with same lowercase letters within column (among containers) or uppercase letters within row (among locations) are not significantly different among treatments by Tukey's honest significant difference multiple comparison at $P < 0.05$.

Table 8. Pot decomposition of 'Sunpatiens Compact Magenta' new guinea impatiens in five locations [University of Illinois at Urbana-Champaign (IL); University of Kentucky, Lexington (KY); Mississippi State University, Crystal Spring (MS); Texas A&M University at El Paso (TX); West Virginia University, Morgantown (WV)] in 2011 and 2012.

	Pot decomposition in 2011 (%)					Pot decomposition in 2012 (%)				
Container	IL	KY	MS	TX	WV	IL	KY	MS	TX[z]	WV
Coir	28.6 bcdAB[y]	40.1 abAB	10.5 cB	43.2 cA	12.2 cdB	26.7 cdB	46.5 bA	20.2 dBC	38.3 de	38.3 de
Manure	95.7 aA	93.3 aAB	39.2 abD	78.7 abB	58.6 aC	95.8 aA	100.0 aA	71.1 aB	80.7 a	80.7 a
Peat	23.5 cdBC	48.7 abAB	18.5 cC	50.5 cA	11.4 cdC	34.7 bcA	15.1 cB	30.1 cdAB	43.3 cd	43.3 cd
Rice hull	15.3 dA	4.7 bB	17.9 cA	1.0 dB	20.1 cA	18.9 dA	2.9 cB	22.7 dA	26.7 e	26.7 e
Soil wrap	45.0 bcC	73.7 aB	41.3 aC	92.3 aA	25.7 bcD	26.3 cdAB	20.8 cB	24.8 dAB	33.4 de	33.4 de
Straw	45.7 bA	45.7 abA	36.2 abA	49.5 cA	38.9 abA	46.3 bA	12.0 cB	46.6 bA	56.6 bc	56.6 bc
Wood fiber	29.9 bcdB	38.7 abB	29.9 bB	72.5 bA	2.3 dC	46.1 bAB	60.6 bA	40.2 bcAB	67.2 ab	67.2 ab

[z] 'Nanho Blue' buddleia was used in 2012 because 'Sunpatiens Compact Magenta' new guinea impatiens died in the middle of the 2011 growing season. They are excluded for multiple comparisons among locations.

[y] Means with same lowercase letters within column (among containers) or uppercase letters within row (among locations) are not significantly different among treatments by Tukey's honest significant difference multiple comparison at $P < 0.05$.

study, the level of decomposition in manure and peat containers in which cleome and lantana plants were grown were higher than that of new guinea impatiens (Tables 6–8). Cleome and lantana plants had larger and more vigorous root systems than new guinea impatiens. The physical breakage of biocontainers by cleome and lantana root systems may have resulted in an increased rate of decomposition.

Conclusion

The effect of container type on plant performance varied with climate (location), growing season, and species. Compared with the effect of climate on plant performance, the impact of container type was relatively too small to be concerned in view of landscape aesthetic appearance. Container decomposition was primarily influenced by container type (material) but also influenced by climate and species at relatively smaller magnitude. Manure containers had on average the highest rate of decomposition (88%), followed by straw, wood fiber, soil wrap, peat, coir, and rice hull in descending order.

Literature cited

Center for Applied Horticultural Research. 2009. Center for Applied Horticultural Research 2010 annual report. Ctr. Appl. Hort. Res., Vista, CA.

Center for Applied Horticultural Research. 2010. Center for Applied Horticultural Research 2010 annual report. Ctr. Appl. Hort. Res., Vista, CA.

Evans, M.R. and D.L. Hensley. 2004. Plant growth in plastic, peat, and processed poultry feather fiber growing containers. HortScience 39:1012–1014.

Evans, M.R. and D. Karcher. 2004. Properties of plastic, peat, and processed poultry feather fiber growing containers. HortScience 39:1008–1011.

Evans, M.R., M. Taylor, and J. Kuehny. 2010. Physical properties of biocontainers for greenhouse crops production. HortTechnology 20:549–555.

Hurley, S. 2008. Postconsumer agricultural plastic report. 7 Feb. 2014. <http://www.ciwmb.ca.gov/publications/Plastics/2008019.pdf>.

Lopez, R.G. and D.M. Camberato. 2011. Growth and development of 'Eckespoint Classic Red' poinsettia in biodegradable and compostable containers. HortTechnology 21:419–423.

Koeser, A.K. 2013. Performance and environmental impacts of biocontainers in horticultural crop production systems. Univ. Illinois, Urbana-Champaign, PhD Diss. (abstr.).

Koeser, A.K., S.T. Lovell, M. Evans and J.R. Stewart. 2013. Biocontainer water use in short-term greenhouse crop production. HortTechnology 23:215–219.

Koeser, A.K., J.R. Stewart, G.A. Bollero, D.G. Bullock, and D.K. Struve. 2009. Impacts of handling and transport on the growth and survival of balled-and-burlapped trees. HortScience 44:53–58.

Kuehny, J.S., M. Taylor, and M.R. Evans. 2011. Greenhouse and landscape performance of bedding plants in biocontainers. HortTechnology 21:155–161.

Ingram, D.L. and S. Nambuthiri. 2012. Using plantable containers for selected ground-cover plant production. HortScience 47:S26 (abstr.).

McKay, H.M. 1996. A review of the effect of stresses between lifting and planting on nursery stock quality and performance. New For. 13:363–393.

Mooney, B.P. 2009. The second green revolution? Production of plant-based biodegradable plastics. Biochem. J. 418:219–232.

Nambuthiri, S.S. and D.L. Ingram. 2014. Evaluation of plantable containers for groundcover plant production and their establishment in a landscape. HortTechnology 24:48–52.

Nambuthiri, S.S., R. Schnelle, A. Fulcher, R. Geneve, A. Koeser, S. Verlinden, and R. Conneway. 2013. Alternative containers for a sustainable greenhouse and nursery crop production. Univ. Kentucky Coop. Ext. Serv. HortFact-600.

Privett, D.W. and R.L. Hummel. 1992. Root and shoot growth of 'Coral Beauty' cotoneaster and Leyland cypress produced in porous and nonporous containers. J. Environ. Hort. 10:133–136.

Spomer, L.A. 1980. Container soil water relations: Production, maintenance, and transplanting. J. Arboricult. 6:315–320.

U.S. Department of Agriculture. 2012. USDA plant hardiness zone map. Agricultural Research Service, U.S. Department of Agriculture. 1 Feb. 2014. <http://planthardiness.ars.usda.gov.>.