Multistate Evaluation of Plant Growth and Water Use in Plastic and Alternative Nursery Containers

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SUMMARY. Containers made from natural fiber and recycled plastic are marketed as sustainable substitutes for traditional plastic containers in the nursery industry. However, growers' acceptance of alternative containers is limited by the lack of information on how alternative containers impact plant growth and water use (WU). We conducted experiments in Michigan, Kentucky, Tennessee, Mississippi, and Texas to test plant growth and WU in five different alternative containers under nursery condition. In 2011, 'Roemertwo' wintercreeper (*Euonymus fortunei*) were planted in three types of #1 (≈1 gal) containers 1) black plastic (plastic), 2) wood pulp (WP), and 3) recycled paper (KF). In 2012, 'Green Velvet' boxwood (*Buxus sempervirens* × *B. microphylla siebold* var. *koreana*) was evaluated in 1) plastic, 2) WP, 3) fabric (FB), and 4) keratin (KT). In 2013, 'Dark Knight' bluebeard (*Caryopteris × clandonensis*) was evaluated in 1) plastic, 2) WP, and 3) coir fiber (Coir). Plants grown in alternative containers generally had similar plant growth as plastic containers. 'Roemertwo' wintercreeper had high mortality while overwintering in alternative containers with no irrigation. Results from different states generally show plants grown in fiber containers such as WP, FB, and Coir used more water than those in plastic containers. Water use efficiency of plants grown in alternative containers vs. plastic containers depended on plant variety, container type, and climate.

Plastic is the most commonly used material for containers in nursery and greenhouse operations. Schrader (2013) estimated that the green industry uses over 750 million kilograms of petroleum plastic for containers per year. Plastic containers are lightweight, easy to ship, and inexpensive (Helgeson et al., 2009). However, the disposal of plastic containers has raised concerns about the sustainability of this product. Today, the primary method of plastic container disposal is still in the landfill, and long-term risks of soil and groundwater contamination from ultraviolet light stabilizers and additives used in plastic products are unknown (Hopewell et al., 2009; Teuten et al., 2009). In 2012, 32 million tons of plastic waste were generated; however, only 9% of the total plastic was recovered for recycling (U.S. Environmental Protection Agency, 2014).

Containers made from various new materials such as bioplastic, coir, poultry feathers, paper fibers, rice hulls, and processed cow manure have

emerged as alternative options to plastic containers (Hall et al., 2010; Nambuthiri et al., 2015a). As plant growth is an important factor in growers' consideration when choosing containers, experiments have been carried out to investigate the impact of alternative containers on plant growth. Evans and Hensley (2004) reported that the shoot dry weight of impatiens (*Impatiens walleriana*) and vinca (*Catharanthus roseus*) plants in poultry feather containers was greater than that of peat and plastic containers when they were irrigated according

to plant need. When the plants received uniform irrigation regardless of container types, vinca had a greater shoot dry weight grown in plastic containers than peat or feather containers, and there was no difference for impatiens. Lopez and Camberato (2011) evaluated poinsettia (*Euphorbia pulcherrima*) growth in alternative and plastic containers, finding poinsettia grown in molded fiber had better growth compared with wheat starch-derived bioresins and plastic containers when irrigated as necessary with water-soluble fertilizer. Kuehny et al. (2011) found that 'Score Red' geranium (*Pelargonium × hortorum*) had the greatest shoot growth in 5-inch plastic containers compared with bioplastic and rice straw containers when they were irrigated as necessary.

Since growers are also pressured to evaluate WU with increasing demand, regulation, and cost of water (Beeson et al., 2004; Koeser et al., 2013), research has compared WU in alternative and plastic containers. Evans and Hensley (2004) found that when vinca and impatiens were irrigated according to plant needs, plants grown in poultry feather and peat containers required more irrigation than that of plastic containers. Koeser et al. (2013) evaluated plant growth and WU for nine different alternative containers. Findings from their research suggest the more porous containers (wood fiber, manure, and straw) required higher irrigation amounts and produced smaller plants. McCabe et al. (2014) found the WU efficiency of 'Rutgers' tomato (*Solanum lycopersicum*) grown in paper-fiber containers with two coats of polyurethane was greater than that grown in paper-fiber containers with one coat of polyurethane and uncoated containers.

This research expands on past efforts to evaluate suitability of alternative

Units			
To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
10	%	g·L ⁻¹	0.1
29.5735	fl oz	mL	0.0338
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
0.4536	lb	kg	2.2046
1	mmho/cm	mS·cm ⁻¹	1
0.9072	ton(s)	Mg	1.1023
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

and plastic containers by comparing them in five states. The objectives of this research were to assess plant growth and biomass in alternative and plastic containers under different nursery environments. In addition, we evaluated the WU characteristics of three woody ornamental plants in alternative and plastic containers under outdoor nursery conditions.

Material and methods

SITE SPECIFICATION AND EXPERIMENTAL DESIGN. This research was conducted at Michigan (lat. 42.7°N, long. 84.5°W, elevation 866 ft), Kentucky (lat. 38.1°N, long. 84.5°W, elevation 1043 ft), Mississippi (lat. 32.0°N, long. 90.3°W, elevation 489 ft), and Texas (lat. 31.7°N, long. 106.3°W, elevation 3737 ft) during 2011–13. Tennessee (lat. 35.9°N, long. 83.9°W, elevation 896 ft) joined the experiment in 2013. A one factor completely randomized experimental design was used. Each container type (treatment) was randomly assigned to one of three irrigation zones (replicate). Within each irrigation zone, there were 15 containers (sub replicate). Containers were spaced 10 inches apart and located in the middle of the irrigation

zone with guard plants surrounding the border to minimize edge effects.

PLANT MATERIAL AND TREATMENTS. ‘Roemertwo’ wintercreeper, ‘Green Velvet’ boxwood, and ‘Dark Knight’ bluebeard were used for experimental years 2011, 2012, and 2013, respectively. Growing season start dates, end dates, and fertilizer information for each experimental site are shown in Table 1. Plants were potted up on the first day of the experiment. At the end of each growing season, for each container type, 12 plants were randomly selected and destructively harvested. The stems and leaves were separated, and roots were washed with water until no visible substrate particles were attached. Plants were oven dried and then the dry weight was recorded. In Michigan, Kentucky, and Mississippi, remaining plants were kept in the hoop house covered with plastic film over the winter with no irrigation applied during winter to follow common Michigan nursery practice. In Tennessee and Texas, plants were kept in the hoop house covered with plastic film and irrigated as needed during winter. Mortality was recorded in May of the following year for all states.

Container substrate consisted of 85% pine bark:15% sphagnum peat (vol:vol) (Renewed Earth, Otsego, MI). Over 83%, 63%, 52%, and 23%

of the substrate particles passed through a 9.5-, 6.4-, 4.8-, and 2.4-mm screens, respectively, with only 7% passing through a 1-mm screen. Container treatments in 2011 were: 1) plastic, 2) WP, and 3) KF. Container treatments in 2012 were 1) plastic, 2) WP, 3) FB, and 4) KT. Container treatments in 2013 were 1) plastic, 2) WP, and 3) Coir. A detailed description of the containers is provided in Table 2.

IRRIGATION APPLICATION AND DAILY WATER USE Overhead irrigation with 100% head-to-head overlap was used for all locations except Texas. The average irrigation rate for Michigan, Kentucky, Tennessee, and Mississippi were 27.9, 42.0, 53.9, and 44.8 mL·min⁻¹, respectively. Irrigation uniformity for Michigan, Kentucky, Tennessee and Mississippi were 82.0%, 85.8%, 71.0%, and 83.7%, respectively.

In Michigan, Kentucky, and Mississippi, two substrate moisture sensors (model EC5; Decagon Devices, Pullman, WA) were inserted at 45° angles into the center of two containers for each irrigation zone to measure volumetric substrate moisture content (θ). The sensors were calibrated by correlating readings with container weight change during a substrate dry down cycle. Sensor readings were recorded by a data logger (model CR1000;

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Table 1. Growing season start date, end date, fertilizer type, and rate of alternative containers study at Michigan, Kentucky, Tennessee, Mississippi, and Texas from 2011 to 2013.

State	Start date	End date	Fertilizer type	Fertilizer rate (g/container) ^z
2011 Season				
Michigan	16 June 2011	26 Oct. 2011	17.0N–3.5P–6.6K ^y	8
Kentucky	15 May 2011	1 Oct. 2011	19.0N–2.2P–7.5K ^y	8
Mississippi	25 May 2011	31 Oct. 2011	17.0N–3.5P–6.6K ^y	8
Texas	10 June 2011	18 Oct. 2011	15.0N–9.0P–12.0K ^x	8
2012 Season				
Michigan	23 June 2012	28 Oct. 2012	17.0N–3.5P–6.6K	8
Kentucky	1 May 2012	2 Oct. 2012	19.0N–2.2P–7.5K	8
Mississippi	11 May 2012	30 Oct. 2012	17.0N–3.5P–6.6K	8
Texas	14 June 2012	30 Oct. 2012	15.0N–9.0P–12.0K	5
2013 Season				
Michigan	1 June 2013	17 Oct. 2013	17.0N–3.5P–6.6K	8
Kentucky	18 May 2013	12 Oct. 2012	19.0N–2.2P–7.5K	8
Tennessee	3 June 2013	24 Oct. 2012	19.0N–4.0P–8.0K ^w	12
Mississippi	10 May 2013	30 Oct. 2013	17.0N–3.5P–6.6K	8
Texas	31 May 2013	16 Oct. 2013	15.0N–9.0P–12.0K	5

^z1 g = 0.0353 oz.

^yRelease period of 3 to 4 mo. fertilizer (Harrell's, Lakeland, FL).

^xRelease period of 5 to 6 mo. (Osmocote CRF; Scotts, Marysville, OH).

^wRelease period of 5 to 6 mo. fertilizer (Harrell's).

Table 2. Container type, abbreviation, product name, constructed material, volume (gal), and manufacturer of containers used in 2011, 2012, and 2013 alternative container studies.

Container type	Abbreviation	Product name ^z	Constructed material	Volume (gal) ^z	Manufacturer
Black plastic	Plastic	PS 400-SM	Polyethylene	1	Nursery Supplies, Chambersburg, PA
Wood pulp	WP	7X7 RD	Molded recycled paper	1	Western Pulp Products, Corvallis, OR
Recycled paper	KF	Kord 07.50 Fiber Grow Pot	Recycled paper	1	ITML Horticultural Products, Middlefield, OH
Fabric	FB	Root pouch 15–20 mo.	Recycled plastic fiber mixed with natural materials	0.9	Central Bag & Burlap, Denver, CO
Keratin	KT	Keratin container	Recycled plastic with poultry feather	0.8	Horticultural Research Institute, Washington, DC
Coir fiber	Coir	QuickStart 8" Retail Nursery Pot	Coconut fiber	1	PlantBest, Markham, ON, Canada

^z1 inch = 2.54 cm, 1 gal = 3.7854 L.

Campbell Scientific, Logan, UT) every 15 min. The data logger was programmed using CRBasic Language with support software (LoggerNet, Campbell Scientific). In this experiment, WU was calculated by the equation: $WU = (\theta_{AI} - \theta_{BI}) \times \text{container volume}$. θ_{AI} was θ measured 5 min after irrigation application and θ_{BI} was θ measured right before the next irrigation event. The substrate used in this study resulted in gravitational water drainage from the sensor zone after 5 min. The data logger was programmed to calculate irrigation time using the average WU divided by application rate in each irrigation zone and then trigger the solenoid to irrigate. Irrigation was split into two applications per day initiated at 0700 and 1900 HR. For each experimental day, daily water use (DWU) was the sum of the two WU measurements taken at 0700 and 1900 HR. On the first day of experiment every year, the containers were irrigated to saturation, after given adequate time for the containers to drain, the data logger program was set to take the first measurement of θ as θ_{AI} initial value.

For the Tennessee site, the irrigation method was the same as described above except that the plants were watered only once per day at 0800 HR. At the Texas site, the plants were watered the same as described above in 2011; in 2012 and 2013, the plants were hand watered twice daily at 0700 and 1300 HR (≈ 500 mL). The DWU was determined by weighing the containers at 0830 HR, which is 1.5 h after irrigation and again at

Fig. 1. Daily water use of 'Roemertwo' wintercreeper grown in WP (alternative container made from recycled paper by Western Pulp Products, Corvallis, OR), KF (alternative containers made from recycled paper by ITML Horticultural Products, Middlefield, OH) and plastic containers from 16 June 2011 (Day 0) to 26 Oct. 2011 at Michigan; 1 mL = 0.0338 fl oz.

0830 HR on the next day and irrigation was withheld for 24 h on days when container weights were taken.

PLANT GROWTH INDEX AND WU EFFICIENCY. Plant growth index (GI) was measured about every 2 weeks. Growth index was calculated as $GI = (\text{height} + \text{width } 1 + \text{width } 2)/3$, where the plant height was taken from the rim of the container to the highest point of the plant, width 1 was the width of the plant in the north to south direction and width 2 was the width of the plant in the west to east direction using fixed pot labels to maintain orientation.

To further investigate plant response to irrigation volume, water use efficiency (WUE) was calculated as

plant biomass divided by cumulative DWU. Because of a disease issue, Mississippi, Texas, and Kentucky locations had high mortality of plants in 2011, so only data in 2011 from Michigan is presented. Tennessee joined the experiment in 2013.

LEACHATE ELECTRICAL CONDUCTIVITY AND pH. Electrical conductivity (EC) and pH were measured about every month using the pour through method described by Yeager (2003). A plastic tray was placed under the container 30 min after irrigation was applied, then 200 mL reverse osmosis water was added to the container, a bulb syringe was used to extract leachate from the tray and release it onto the sensor of a Cardy

Twin EC Meter and Cady Twin pH Meter (Horiba, Kyoto, Japan). This measurement was only carried out in Michigan from 2011 to 2013; therefore, only data from Michigan was presented.

STATISTICAL ANALYSIS. Growth index, EC and pH were analyzed as repeated measurements using PROC MIXED procedure of SAS (version 9.2; SAS Institute, Cary, NC). When significant at the 0.05 level, treatment means on each measurement day were separated using a *t* test in the PDIF option of the LSMEANS statement and the SLICE option of PROC MIXED ($\alpha = 0.05$). Daily water use and WUE were analyzed using PROC GLM procedure of SAS and, when significant, means were separated using Tukey's test at 0.05 significance level.

Results and discussion

Daily water use

2011 (ONLY DATA FROM MICHIGAN ARE PRESENTED). The DWU of plants in WP and KF containers was similar to that of plastic containers in the beginning of the season but generally higher than that of plastic containers after day 50 (Fig. 1). The seasonal daily average DWU of wintercreeper grown in WP, KF, and plastic containers was 225.6, 144.0, and 60.0 mL, respectively. The average DWU of plants grown in WP containers was the largest vs. that in plastic containers was the lowest. Frequent rainfall occurred from day 60 through most of the fall contributing to the low WU for plastic containers, while fiber containers were degrading over the season and likely had greater water permeability as the season progressed. The maximum air temperature was typically between 23 and 28 °C in that period and could also contribute to the low WU of plastic containers.

2012. The average seasonal plant DWU in plastic and alternative containers varied by state (Fig. 2). Within all states, plant DWU in KT containers was the lowest compared with that of other containers. This was because KT containers had container walls that were nearly impervious and a smaller container volume. Plants in WP containers had the highest WU in Mississippi and Texas. In Kentucky, plants in FB containers had highest DWU, while plants in plastic

Fig. 2. Seasonal average daily water use in 2012 of 'Green Velvet' boxwood grown in WP (alternative container made from recycled paper by Western Pulp Products, Corvallis, OR), KT (alternative container made from keratin by Horticultural Research Institute, Washington, DC), plastic, and FB (alternative container made from a mixture of recycled plastic fiber and natural material by Central Bag & Burlap, Denver, CO) containers at Michigan, Kentucky, Mississippi, and Texas. Bars with the same letter are not significantly different according to Tukey's significance test ($\alpha=0.05$); 1 mL = 0.0338 fl oz.

Fig. 3. Seasonal average daily water use in 2013 of 'Dark Knight' bluebeard grown in WP (alternative container made from recycled paper by Western Pulp Products, Corvallis, OR), Coir (alternative container made from coir fiber by PlantBest, Markham, ON, Canada), and plastic containers at Michigan, Kentucky, Tennessee, Mississippi, and Texas. Bars with the same letter are not significantly different according to Tukey's significance test ($\alpha = 0.05$); 1 mL = 0.0338 fl oz.

containers had the highest DWU in Michigan.

2013. The difference between seasonal average plant DWU in alternative containers and plastic containers was similar in Mississippi, Texas, and Kentucky (Fig. 3). In Mississippi, Texas, and Kentucky, plants in Coir containers had the greatest DWU, while plants in plastic containers had the lowest. In Michigan, DWU of plants grown in plastic containers was greater than that of WP and Coir containers. Conversely, in Tennessee, DWU of plants grown in WP containers was greater than that of plastic and Coir containers.

Evans and Hensley (2004) found that the rate of water loss through the container wall was a major factor affecting WU. The differences of plant DWU in alternative and plastic containers in this study were generally supported by the relative side wall porosity found in each container under controlled environmental conditions (Nambuthiri et al., 2015b), where water loss was greatest in FB and Coir containers, intermediate in WP, and least in plastic and KT containers. Supraoptimal root temperatures in plastic containers for all states except Michigan (Nambuthiri et al., 2015b) may have resulted in the higher DWU in plastic for Michigan than for other states.

Plant growth and dry weight

2011 (ONLY DATA FROM MICHIGAN ARE PRESENTED). The final GI of wintercreeper in 2011 was 18.8 cm with no difference between treatments. There were no differences in dry leaf, shoot, and root weights between treatments (Table 3). The mortality rate of plants grown in WP, KF and plastic was 2%, 2%, and 13% on 11 Oct. 2011 and increased to 52%, 52%, and 15% on 6 June 2012, respectively. Since there was no irrigation supply in the Michigan hoop houses during winter, the higher mortality rate of plants grown in WP and KF containers over the winter could be attributed to faster desiccation of substrate in fiber containers than plastic containers.

2012. The average final GI of boxwood in Mississippi, Kentucky, and Michigan was 20.4, 20.0, and 16.7 cm, respectively, with no difference between treatments. In Texas, where plants were watered ≈ 500 mL daily regardless of container types, the

final GI of plants grown in KT, plastic, FB, and WP containers was 15.9, 14.9, 12.4, and 14.1 cm, respectively. Plants grown in KT containers had the greatest growth while

those in FB containers had the least growth. Plants grown in plastic and WP containers had intermediate growth. The mortality for boxwood was zero for all states.

Table 3. Dry leaf, stem, root, and total weight of 'Roemertwo' wintercreeper grown from 16 June 2011 to 26 Oct. 2011 in three container types at Michigan.

Container type ^z	Leaves wt (g) ^y	Stem wt (g)	Root wt (g)	Total wt (g)
Plastic	1.4	3.0	4.2	8.6
WP ^y	2.8	4.2	7.0	14.0
KF ^x	2.7	3.3	5.3	11.3
	NS ^x	NS	NS	NS

^zWP = alternative containers made from recycled paper (Western Pulp Products, Corvallis, OR), KF = alternative containers made from recycled paper (ITML Horticultural Products, Middlefield, OH)

^y1 g = 0.0353 oz.

^xMeans with ns in the same column are not different. Means separated by Tukey's significance test ($\alpha = 0.05$).

Table 4. Shoot and root dry weight of 'Green Velvet' boxwood grown in four container types at Michigan, Kentucky, Mississippi, and Texas.

Container types ^z	Michigan ^y	Kentucky ^y	Mississippi ^y	Texas ^y
	Shoot dry wt (g) ^x			
Plastic	14.2	11.9 a ^w	14.0	11.8 a
KT	15.7	12.0 a	12.3	11.5 a
WP	15.5	10.3 b	13.8	8.7 b
FB	14.3	10.5 b	14.0	8.6 b
	NS ^y		NS	
Container types ^z	Root dry wt (g)			
	Michigan ^y	Kentucky ^y	Mississippi ^y	Texas ^y
Plastic	9.9 a	9.5 b	10.6 a	8.7a
KT	8.3 a	10.0 a	7.8 b	6.6 b
WP	9.2 a	9.9 a	10.5 a	7.1 ab
FB	8.9 a	8.5 c	8.0 a	6.3 b

^zKT = alternative container made from keratin (Horticultural Research Institute, Washington, DC), WP = alternative container made from recycled paper (Western Pulp Products, Corvallis, OR), FB = alternative container made from a mixture of recycled plastic fiber and natural material (Central Bag & Burlap, Denver, CO).

^yPlants were grown in Michigan from 23 June 2012 to 28 Oct. 2012, from 1 May 2012 to 2 Oct. 2012 in Kentucky, from 11 May 2012 to 30 Oct. 2012 in Mississippi, and from 14 June 2012 to 30 Oct. 2012 in Texas.

^x1 g = 0.0353 oz.

^wMeans with the same letter in the same column are not different. Means separated by Tukey's significance test ($\alpha = 0.05$).

^yMeans with ns in the same column are not different. Means separated by Tukey's significance test ($\alpha = 0.05$).

Table 5. Shoot and root dry weight of 'Dark Knight' bluebeard grown in three container types at Michigan, Kentucky, Tennessee, Mississippi, and Texas.

Container types ^z	Michigan ^y	Kentucky ^y	Tennessee ^y	Mississippi ^y	Texas ^y
	Shoot dry wt (g) ^x				
Plastic	21.9	32.1	56.0 a ^w	41.6	8.8
Coir	20.8	28.2	55.1 a	38.5	7.6
WP	20.6	34.8	45.3 b	37.3	8.1
	NS ^y	NS		NS	NS
Container types ^z	Root dry wt (g)				
	Michigan ^y	Kentucky ^y	Tennessee ^y	Mississippi ^y	Texas ^y
Plastic	23.7 a	26.8 a	26.4	24.1	11.7 a
Coir	16.9 b	14.8 b	24.9	23.2	12.3 a
WP	20.3 ab	24.4 a	26.0	23.9	8.5 b
			NS	NS	

^zCoir = alternative container made from coir fiber (PlantBest, Markham, ON, Canada), WP = alternative container made from recycled paper (Western Pulp Products, Corvallis, OR).

^yPlants were grown from 1 June 2013 to 17 Oct. 2013 in Michigan, from 18 May 2013 to 12 Oct. 2013 in Kentucky, from 3 June 2013 to 24 Oct. 2013 in Tennessee, from 10 May 2013 to 30 Oct. 2013 in Mississippi and from 31 May 2013 to 16 Oct. 2013 in Texas.

^x1 g = 0.0353 oz.

^wMeans with the same letter in the same column are not different. Means separated by Tukey's significance test ($\alpha = 0.05$).

^yMeans with ns in the same column are not different. Means separated by Tukey's significance test ($\alpha = 0.05$).

Table 6. Water use efficiency of ‘Roemertwo’ wintercreeper, ‘Green Velvet’ boxwood, and ‘Dark Knight’ bluebeard grown in six container types at Michigan, Kentucky, Mississippi, and Texas.

Water use efficiency (g·L ⁻¹) ^z					
2011 ‘Roemertwo’ wintercreeper	Michigan				
Plastic	1.1 a ^y				
WP ^x	0.6 a				
KF ^x	0.5 a				
2012 ‘Green Velvet’ boxwood	Michigan	Kentucky	Mississippi	Texas	
Plastic	0.7 b	0.7 a	0.8 a	0.8 a	
KT ^x	1.2 a	0.7 a	0.9 a	0.9 a	
WP	0.8 b	0.7 a	0.6 b	0.5 c	
FB ^x	0.9 ab	0.5 b	0.6 b	0.6 b	
2013 ‘Dark Knight’ bluebeard	Michigan	Kentucky	Tennessee	Mississippi	Texas
Plastic	0.9 b	2.6 a	1.8 a	1.8 a	0.5 a
Coir ^x	0.9 b	1.4 b	1.8 a	1.3 b	0.4 b
WP	1.3 a	2.2 a	1.4 b	1.5 b	0.3 b

^z1 g·L⁻¹ = 0.1%.

^yMeans with the same letter in the same column are not different. Means separated by Tukey’s significance test ($\alpha = 0.05$).

^xWP = alternative container made from recycled paper (Western Pulp Products, Corvallis, OR), KF = alternative containers made from recycled paper (ITML Horticultural Products, Middlefield, OH), KT = alternative container made from keratin (Horticultural Research Institute, Washington, DC), FB = alternative container made from a mixture of recycled plastic fiber and natural material (Central Bag & Burlap, Denver, CO), Coir = alternative container made from coir fiber (PlantBest, Markham, ON, Canada).

Fig. 4. Leachate EC of ‘Green Velvet’ Boxwood grown in WP (alternative container made from recycled paper by Western Pulp Products, Corvallis, OR), plastic, KT (alternative container made from keratin by Horticultural Research Institute, Washington, DC), and FB (alternative container made from a mixture of recycled plastic fiber and natural material by Central Bag & Burlap, Denver, CO) containers on experimental days 23, 42, 57, 85, 116, and 114 (day 0 = 14 May 2012). Means with the same letter within the same date are not significantly different according to Tukey’s significance test ($\alpha = 0.05$); NS indicates no difference in electrical conductivity between container types within the same date; 1 mS·cm⁻¹ = 1 mmhos/cm.

The shoot and root dry weight of boxwood grown in KT, plastic, FB, and WP containers varied by states (Table 4). In Michigan, there were no differences in dry weight due to treatments. In Mississippi, there were no

differences in shoot dry weight, but plants grown in plastic, WP and FB containers had greater dry root weight than that of KT containers. In Texas, plants grown in plastic and KT containers had higher shoot dry

weight than WP and FB and higher root dry weight in plastic than KT and FB. In Kentucky, plants grown in plastic and KT containers had a higher shoot dry weight vs. WP and FB containers and higher root dry weight in KT and WP than plastic and FB. Evans and Hensley (2004) reported that when irrigation was applied as needed, plants grown in poultry feather containers had a greater growth than those in plastic containers. The poultry feather containers used in their experiment consisted of 15% craft paper and 85% processed feather fiber, which provided an available nitrogen resource to the plants. However, there was no indication that the poultry feather component in KT containers contributed to plant growth in the current experiment.

2013. The final GI of bluebeard grown in plastic, Coir, and WP containers in Michigan, Kentucky, Mississippi, and Tennessee was 35.0, 40.4, 40.0, and 58.3 cm, respectively, with no difference between treatments. In Texas, plants grown in plastic and Coir containers had greater GI compared with that in WP containers. For dry shoot weight, there was no difference between treatments in Michigan, Mississippi, Texas, and Kentucky (Table 5). In Tennessee, plants grown in plastic and Coir containers had a greater dry weight than that of WP containers. For dry root weight, there was no difference between treatments in Mississippi and Tennessee. In Michigan and Kentucky, plants grown in plastic containers had greater growth than that of WP containers. In Texas, plants grown in plastic and WP containers had greater growth compared with that of Coir containers. There was no mortality of bluebeard in any state in Nov. 2013. In May 2014, the mortality of bluebeard remained zero for Tennessee and Mississippi. In Texas, the mortality of bluebeard in plastic containers increased to 4%. Michigan and Kentucky lost the majority of the plants due to winter kill regardless of treatment.

When combining 3 years data at five experimental locations, plants grown in alternative containers generally had similar growth compared with that of plastic containers. The high mortality of wintercreeper grown in WP and KF containers over the winter in Michigan in 2011

Fig. 5. Leachate pH of 'Green Velvet' Boxwood grown in WP (alternative container made from recycled paper by Western Pulp Products, Corvallis, OR), plastic, KT (alternative container made from keratin by Horticultural Research Institute, Washington, DC), and FB (alternative container made from a mixture of recycled plastic fiber and natural material by Central Bag & Burlap, Denver, CO) containers on experimental days 23, 42, 57, 85, 116, and 114 (day 0 = 14 May 2012). Means with the same letter within the same date are not different. Means separated by Tukey's significance test ($\alpha = 0.05$); NS indicates no difference in pH between container types within the same date.

Fig. 6. Leachate electrical conductivity of 'Dark Knight' bluebeard grown in Coir (alternative container made from coir fiber by PlantBest, Markham, ON, Canada), WP (alternative container made from recycled paper by Western Pulp Products, Corvallis, OR), and plastic containers on experimental days 3, 32, 65, 97, and 129 (day 0 = 1 June 2013). Means with the same letter within the same date are not different. Means separated by Tukey's significance test ($\alpha = 0.05$). NS suggest no difference in EC between container types within the same date; $1 \text{ mS}\cdot\text{cm}^{-1} = 1 \text{ mmho}/\text{cm}$.

indicated that growers should monitor the substrate moisture during winter and irrigate accordingly when using containers with porous side walls.

Water use efficiency

The WUE of wintercreeper, boxwood and bluebeard plants grown in

plastic and alternative containers are shown in Table 6. In 2012, since boxwood grown in KT containers needed less irrigation without compromising biomass quantity, boxwood grown in KT containers generally had higher WUE in all states. McCabe et al. (2014) found

the WUE of 'Rutgers' tomato grown in paper-fiber containers with two coats of polyurethane was greater than that of uncoated containers. The KT containers used in this study had nearly impervious container side walls similar to plastic containers and also had a smaller container volume. These two factors likely contributed to the high WUE of KT containers. In 2013, all states except Michigan had higher WUE for bluebeard when grown in black plastic containers compared with those in Coir and WP containers.

Leachate EC and pH (only data from Michigan are presented)

In 2011, the seasonal average leachate EC and pH were $0.4 \text{ mS}\cdot\text{cm}^{-1}$ and 7.4 with no differences between treatments for any dates measured. In 2012, on days 57 and 85, the substrate EC in KT containers was greater than in FB containers (Fig. 4). The substrate EC in WP and plastic containers were generally intermediate. This could be due to more rapid leaching from FB containers since the FB containers are made from more porous material. In addition, as water evaporated, some of the nutrients could have moved to the container wall. Leachate pH from FB containers was higher than other containers for most of the season (Fig. 5); however, the final leachate pH was similar between treatments. In 2013, EC of the pour through leachate from Coir containers was generally higher than that of WP and plastic containers; however, there was no difference on the first and last data collection day (Fig. 6). The average pH of pour through leachate was 7.9 with no difference between container types for all dates measured.

Conclusions

In summary, plant growth in all alternative containers was similar to those grown in plastic containers in current experiment when irrigation was applied based on WU. The different overwinter mortality between wintercreeper, boxwood, and bluebeard suggests that growers need to consider substrate moisture availability and plant water stress tolerance when containers with high water loss are used in climates where winter irrigation is not typical. Most states found that alternative containers

made from fiber material (WP, KF, FB, and Coir container) used more water than that of plastic and KT containers. The environmental benefit of using alternative containers must be weighed against water usage and cost. Since both water and petroleum are valuable resources with increasing global demand, alternative containers that produce high quality plants with small water usage should be investigated.

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