Growth of Barberry Liners in Media Amended with Noncomposted Recycled Waste

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SUMMARY. One-year-old 'Royal Burgundy' barberry (*Berberis thunbergii* var. *atropurpurea*) liners were potted in 1-gal (3.8-L) containers. Container media consisted of noncomposted recycled waste mixed at rates of 0% (control), 25%, 50%, 75%, and 100% by volume with a (by volume) 3 pine bark : 2 peat : 1 sand media. Treatments were replicated eight times. Three grams (0.1 oz) of Osmocote 13-10-13 (13N-4.37P-10.8K) with micronutrients were topdressed on all containers. Media electrical conductivity (EC) and pH readings were recorded every fifteen days over the course of 5 months. Dry shoot, root, and total weights were recorded at the end of the project and a foliar analysis was performed for nutrient and metal content. Results indicate a general trend of higher EC with greater volumes of recycled waste. EC levels for the control and 25% treatment were within recommendations for the optimal plant growth of plants for the duration of the study. All treatments had an acceptable pH level for plant growth. Nitrogen levels were below the recommended foliar analysis sufficiency range. Levels of phosphorus and potassium were above or within the recommended foliar analysis sufficiency range. Metals were below or within recommended ranges for all treatments. Total dry weights revealed no statistical difference between the control, 25%, 50%, and 75% treatments. This study indicates that 25% noncomposted recycled waste could be used in container media for production of 'Royal Burgundy' barberry.

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According to the U.S. Department of Health and Human Services the average American produces over 4 lb (1.8 kg) of solid waste per day (Taylor, 1999). In addition, Taylor (1999) cites that the production of garbage is estimated to rise by 5% per year. Due to the cost and availability issues surrounding traditional potting media, the nursery industry will benefit from inexpensive media amendments that have favorable characteristics for the growth of plants. The use of recycled waste in container production would provide the nursery industry with a media amendment of unlimited supply.

Over the years numerous materials have been proposed and marketed as potential container media amendments. Some of the amendments tested include coconut coir (Evans, 2002; Meerow, 1994), rubber tire chips (Jarvis et al., 1996), recycled paper (Craig and Cole, 2000), municipal leaf and sewage sludge waste (Bugbee et al., 1991; Rosen et al., 1993; Wootton et al., 1981), poultry litter (Fulcher et al., 2002), kenaf stem core (Wang, 1994), biosolid-yard waste (Wilson et al., 2003) and spent mushroom compost (Chong et al., 1991). Some amendments are proving to be unsuitable due to the high degree of variability and the likelihood of containing hazardous materials such as glass and heavy metals (Evans et al., 1996). In addition, high soluble salt levels limit some amendments from being usable (Wang, 1994). Due to the variety of amendments available it is important to understand the benefits and limitations of each material.

To be a useful amendment in container production the substrate EC, which is a measure of soluble salts and pH, should be within ranges that will promote plant vigor and growth. Furthermore, foliar nutrient levels should not be adversely affected by the amendment. Media derived from recycled waste may be a marketable substrate amendment in container production. One concern with recycled waste is the potential for high levels of soluble salts, which frequently leads to phytotoxicity and inhibited growth. EC levels higher than 2.0 to 3.0 dS·m⁻¹ will result in necrosis (Rosen et al., 1993), stunted growth or death in many plant species. Furthermore, guidelines suggest that EC levels should fall between 0.2 and 1.0 dS·m⁻¹ for fertilizer salts (Ruter and Garber, 1993; Southern Nursery Association, 1997). However, research has

shown that soluble salts rapidly leach from immature compost utilized in container production minimizing the adverse effects on woody ornamentals (Raymond et al., 1998). Electrical conductivity levels in recycled waste must be evaluated before the material can be utilized in container production.

Growth of certain species is affected by media pH more than the amount of substrate amendment added (Bugbee, 1996). Substrate pH values regulate ion uptake by plants; this includes metal ions (Lepp and Eardley, 1978). Optimum pH recommendations for nutrient uptake by plants ranges from 5.0 to 6.0 (Southern Nursery Assn. 1997) and 5.2 to 6.2 (Ruter and Garber, 1993). The pH of recycled waste is usually alkaline, which limits availability of heavy metals, but may stimulate micronutrient deficiencies (Rosen et al., 1993). However, the high organic content of recycled waste can act as a complexing agent, which may increase the availability of some micronutrients (Bar-Ness and Chen, 1991).

Heavy metals are also a concern, but sorting procedures can keep metals in the recycled waste to levels that are safe and acceptable for the nursery industry. The U.S. Environmental Protection Agency (EPA) has issued recommendations for the maximum permissible levels in recycled waste products (Fitzpatrick et al., 1998). Cadmium (Cd) and lead (Pb) are the two metals that are commonly singled out as potentially highly toxic to animals and humans. Russo and Brennan (1979) report that Cd can be toxic to plants; this is in contrast to Chaney (1990) who reports that Cd can accumulate with no toxicity problems. However, if animals or humans consume enough plant material that contains excessive amounts of Cd, health problems may occur. Lead does not accumulate in plants to any level that is detrimental to their growth and the main concern to animals and humans is through digestion (Rosen et al., 1993). Cox and Rains, as reported in Lepp and Eardley (1978), report that the addition of lime to soil reduced Pb and Cd uptake in corn (*Zea mays*). Other metals of concern that may have phytotoxic effects include aluminum (Al), copper (Cu), iron (Fe), nickel (Ni) and zinc (Zn). Toxicity of many of these metals are species specific and some are toxic to plants at levels lower than those required for toxicity in animals. Toxicity effects may

directly impact growth of a plant, influence availability of another nutrient or alter normal physiological functioning within the plant (Mills and Jones, 1996). In addition, complex interactions may result when several metals are present (Lepp and Eardley, 1978).

The primary objectives of this study were to evaluate incorporation of noncomposted recycled waste on 1) substrate EC and pH over a 5-month period, 2) final shoot, root and total dry weights, 3) final foliar nitrogen (N), phosphorus (P) and potassium (K) concentrations, and 4) final foliar metal concentrations of Al, Cd, Cu, Fe, Pb, Ni, and Zn. These factors were monitored to evaluate noncomposted recycled waste as a potential substrate for container plant production and, to determine what percentage of noncomposted recycled waste is most beneficial.

Materials and methods

WastAway Services, LLC, McMinnville, Tenn. produced the noncomposted recycled waste used in this project. The production of the recycled waste begins with raw residential refuse. It undergoes a proprietary process and results in an odorless, aseptic material that resembles attic insulation. We elected to examine noncomposted recycled waste due to the reduction of cost and production time as compared to composted recycled waste.

Uniform 'Royal Burgundy' barberry liners were potted in 1-gal containers into a (by volume) 3 pine bark : 2 peat : 1 sand mix with noncomposted recycled waste. The recycled waste was incorporated at rates of 0% (control), 25%, 50%, 75%, and 100% by volume. Three grams of Osmocote 13-10-13 (Scotts Co., Marysville, Ohio) with micronutrients were topdressed on all containers. A low amount of fertilizer was applied to reduce the amount of soluble salts that were recorded from

the noncomposted recycled waste while still supplying the plants with nutrients. Each treatment was replicated eight times. The experimental design was a randomized complete-block design. Plants were grown in a poly-house and received a natural photoperiod; controls were set to maintain a minimum temperature of 72 °F (22.2 °C) and a maximum of 84 °F (28.9 °C). Three-hundred milliliters of water was supplied twice daily via individual spray emitters. This project was conducted at the Otis L. Floyd Nursery Research Center, McMinnville, Tenn.

The Virginia Tech pour-through method was used to collect leachate solution from the container substrate (Wright, 1986). EC and pH readings of leachate samples were taken 7, 22, 37, 52, 67, 82, 97, 112, 127, and 142 d after treatment (DAT). Irrigation water was also collected at the same time. Leachate EC and pH were measured with a Myron Ultrameter (model 6P; Myron L Co., Carlsbad, Calif). At the end of the project plants were harvested at the soil level. Fully expanded new foliage was collected for foliar analysis. Container medium was washed from the roots. Dry shoot and root weights were recorded after drying at 158.0 °F (70 °C) for 72 h. Foliar composition data represent combined samples from all replicates of each treatment.

Dried tissue samples were digested for metal analysis in a microwave digestion vessel with concentrated metal grade nitric acid. An aliquot from this solution was analyzed with an ICP Perkin Elmer Sciex Elan 6000 (Shelton, Conn.) using the conditions and requirements of the EPA method 200.8 (EPA, 1994). For N, P, and K dried tissue samples underwent a wet oxidation digestion method on a BD40 block digester (Westco Scientific Instruments, Danbury, Conn.). N and P determination underwent a colorimetric determination on a continuous flow Alpkem 3000 (OI

Analytical, College Station, Texas). K determination was done by flame atomic absorption on a Perkin Elmer AA100. All foliar analyses were conducted at the University of Georgia Lab for Environmental Analysis (Athens).

Regression analysis for the dry total, root or shoot weight as the dependent variable and treatment, EC and pH as the independent variables were not significant (SPSS base 10.0; SPSS, Chicago). Correlation coefficients revealed significant relationships between treatment and root, shoot and total dry weights (data not presented). Relationships between EC and root, shoot and total dry weights were also significant. In contrast, relationships between pH and root, shoot, and total weights were nonsignificant (data not presented). Therefore, EC, pH, shoot, root and total weight means for the 25%, 50%, 75%, and 100% treatments were compared to the control by Dunnett's test. Levels of significance were set at $P = 0.05$. Values presented for the 25%, 50%, 75%, and 100% treatments are the relative increase or decrease as compared to the nontreated (0%) control.

Results and discussion

EC. Data collected 7 DAT showed the 100% noncomposted recycled waste treatment had an EC reading 1.97 dS·m⁻¹ greater than the control (Table 1). The 50% and 75% noncomposted recycled waste treatments had readings that were 0.77 and 1.17 dS·m⁻¹ greater than the control, respectively. Readings for the 50%, 75%, and 100% treatments are in excess of recommendations for soluble salt levels in the container production of plants (Ruter and Garber, 1993; Southern Nursery Assn., 1997). Wilson et al. (2001) cited salt levels as being problematic in several alternative substrate amendments. Initial EC readings fell within the recommended range for the 25% treatment at 0.46 dS·m⁻¹ greater than the control, which had an

Table 1. Electrical conductivity (EC) readings by days after treatment of media amended with noncomposted recycled waste. Values reported for the 25%, 50%, 75%, and 100% (by volume) noncomposted recycled waste treatments are the relative increase or decrease as compared to the nontreated (0%) control.

Treatment (% by vol)	EC reading (dS·m ⁻¹) by days after treatment									
	7	22	37	52	67	82	97	112	127	142
0%	0.43	0.19	0.20	0.20	0.22	0.28	0.19	0.23	0.24	0.19
25	0.46	0.13	0.11*	0.04	0.02	-0.01	0.04	0.01	0.01	0.03*
50	0.77*	0.47*	0.22*	0.08*	0.05*	0.02	0.05*	0.03	0.03	0.04*
75	1.17*	0.80*	0.35*	0.16*	0.09*	0.05	0.07*	0.07*	0.06*	0.06*
100	1.97*	0.87*	0.50*	0.31*	0.22*	0.16*	0.16*	0.17*	0.15*	0.15*

^aValues in first row are actual EC readings of treatment.

*Dunnett's test significant at $P = 0.05$ when compared to the control (0%).

Table 2. pH readings by days after treatment of media amended with noncomposted recycled waste. Values reported for the 25%, 50%, 75%, and 100% (by volume) noncomposted recycled waste treatments are the relative increase or decrease as compared to the nontreated (0%) control.

Treatment (% by vol)	pH reading by days after treatment									
	7	22	37	52	67	82	97	112	127	142
0 ^z	5.3	6.2	6.2	6.4	6.5	6.6	6.6	7.6	7.0	6.9
25	1.2*	0.3*	0.1	0.0	0.1	0.0	0.0	0.0	-0.1	-0.1
50	1.3*	-0.1	-0.4*	-0.3*	-0.2	-0.2	-0.1*	-0.2*	-0.3*	-0.2
75	1.2*	-0.2	-0.5*	-0.7*	-0.6*	-0.6*	-0.4*	-0.4*	-0.3*	-0.4*
100	1.8*	0.5*	0.3	0.1	0.0	-0.1	0.0	-0.1	-0.1	-0.2

^zValues in first row are actual pH readings of treatment.

*Dunnett's test significant at $P = 0.05$ when compared to 0% treatment.

Table 3. Final foliar concentrations of elements. Values reported for the 0%, 25%, 50%, 75%, and 100% (by volume) non-composted recycled waste treatments as compared to a recommended range of elemental concentrations.

Element	Treatment (%)					Recommended range ^z
	0	25	50	75	100	
N (%)	1.19	1.29	1.06	1.24	1.09	1.53–2.20
P (%)	0.51	0.47	0.38	0.39	0.38	0.13–0.21
K (%)	0.87	0.98	0.98	1.13	0.91	0.76–1.11
Al (ppm) ^y	41.52	41.66	75.28	48.55	98.99	57.0–289.0
Cd (ppm)	0.004	0.007	0.008	0.01	0.017	0.05–0.20
Cu (ppm)	1.03	1.55	1.12	1.42	1.64	2.0–6.0
Fe (ppm)	27.66	33.9	50.24	35.46	41.12	50.0–75.0
Ni (ppm)	0.24	0.43	1.0	0.31	0.38	0.1–1.0
Pb (ppm)	0.08	0.11	0.14	0.21	0.43	0.1–5.0
Zn (ppm)	8.51	9.35	9.81	10.07	10.7	9.0–35.0

^zRecommended ranges are from Mills and Jones (1996).

^yppm = mg·kg⁻¹.

Table 4. Final shoot, root, and total dry weight of 'Royal Burgundy' barberry liners. Values reported for the 25%, 50%, 75%, and 100% (by volume) recycled waste treatments are the relative increase or decrease relative to the nontreated (0%) control.

Treatment (% by vol)	Shoot dry wt (g)	Root dry wt (g)	Total dry wt (g)
0 ^z	9.75	4.95	14.70
25	-1.31	0.58	-0.72
50	-3.37*	-0.93	-4.30
75	-3.21	-0.94	-4.15
100	-4.08*	-1.68*	-5.77*

^zValues in first row are actual weights of treatment; 28.35 g = 1.0 oz.

*Dunnett's test significant at $P = 0.05$ when compared to 0% treatment.

initial reading of 0.43 dS·m⁻¹. The greater amount of recycled waste incorporated into the substrate, the longer the decline in substrate EC took. The 100% non-composted recycled waste treatment did not register a higher EC reading than the previous reading until 112 DAT. The decline of soluble salts is attributed to irrigation provided by individual spray emitters. Throughout the project, the general trend indicated greater EC readings with increasing percentages of recycled waste. This finding is in agreement with the increased incorporation of other alternative amendments into container substrate (Chong et al., 1991; Wilson et al., 2003). Furthermore, the 50%, 75%, and 100% treatments had EC readings that generally were significantly greater than the control throughout the

duration of the study. From 37 DAT, EC levels of all treatments were favorable for plant growth. Therefore the 25% noncomposted recycled waste treatment incorporated was at an optimum EC level beginning 7 DAT.

pH. Commercially produced compost has a pH range of 6.7 to 7.7 (Fitzpatrick et al., 1998). The recycled waste used in this experiment had an initial pH of 7.8 when analyzed by ADAS Laboratories (Woodthorne, England). During this study pH ranged from 5.31 to 7.65 for all treatments. At 112 DAT the control and 25% noncomposted recycled waste treatment had the highest pH at 7.6 (Table 2). The pH of the control continued to rise until 127 DAT. The 75% treatment had the lowest pH beginning 22 DAT until the end of the study.

The general trend for the duration of the study was for the pH of the control, 25% and 100% treatments to be greater than the other treatments. Although periodically higher than recommendations, leachate pH was acceptable for all treatments and is attributable to the alkalinity of the irrigation water, which averaged 7.26 over the course of the study. Furthermore, no adverse nutrient deficiency symptoms were observed in any of the treatments.

FOLIAR ANALYSIS. Results indicated that N levels for all treatments including the control fell below the recommended sufficiency range (Table 3). This is attributed to the relatively low amount of fertilizer that was applied. Additional N would be needed for all treatments if this noncomposted recycled waste was utilized in the production of 'Royal Burgundy' barberry liners. All treatments were above the recommended sufficiency range for P. Levels of K fell within the recommended sufficiency range for all treatments excluding the 75% treatment which was slightly above recommendations. Based upon these results, a fertilization program with low levels of P and K would only be needed for the health of 'Royal Burgundy' barberry. However nutritional programs would need to be adjusted on a crop-by-crop basis using the noncomposted recycled waste in this study. The find-

ings for N, P and K are similar to the report of Ticknor et al., (1985) utilizing composted sewage, bark and sawdust in potting media for the production of woody ornamental plants.

Metals that have not been shown to be required by plants such as Ni and Pb were within recommended levels for all treatments; however concentrations of Pb increased as the percentage of recycled waste increased. Concentrations of Cd were below the normal range but increased as the percentage of recycled waste increased. Al fell within the recommended ranges with the exception of the control and 25% treatments, which were below recommendations. Fe was below sufficiency range with the exception of 50% treatment, which met the minimum requirements. Cu was below the sufficiency range for all treatments. In addition to being metals, Fe and Cu are also required micronutrients. Additional Fe and Cu would be needed for all treatments if this noncomposted recycled waste were utilized in the production of 'Royal Burgundy' barberry liners. All treatments were within the recommended range for Zn with the exception of the control, which was below the suggested range (Mills and Jones, 1996).

SHOOT, ROOT, AND TOTAL WEIGHT.

There was no significant difference for shoot dry weight in the 25% and 75% treatments compared to the control (Table 4). The 50% and 100% treatments had significantly less dry shoot weight than the control. There was no significant root or total weight difference between the 25%, 50%, and 75% treatments compared to the control. Kahtz and Gawel (2003), using the same noncomposted recycled waste as used in this experiment, report the total weight growth of dwarf inkberry holly (*Ilex glabra* 'Compacta') plants grown in 25% noncomposted recycled waste to be greater than plants grown in a standard nursery mix.

In conclusion, this experiment demonstrated that up to 25% noncomposted recycled waste could be utilized in container media production of 'Royal Burgundy' barberry liners. Similar findings have shown that noncomposted media amendments could be utilized in the successful production of container grown plants (Chong et al., 1991; De Roo, 1975). The adaptation of the plants to the noncomposted recycled waste may be attributed to rapid elimination of soluble salts via daily

irrigation. Although the visual quality of the plants was not objectively rated, the plants grown in the control and 25% noncomposted recycled waste had a more vigorous size and appearance. Elevated salt levels of the 50%, 75%, and 100% treatments during the early stages of this research may have been a contributing factor to the reduced growth of plants. Future research should examine the incorporation of weathered and composted recycled waste in container media. In addition, the influence recycled waste has upon the growth of plants produced under wholesale conditions needs to be explored.

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