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Evaluating Pulp and Paper Sludge as a Substitute For Peat Moss in Container Media[1]

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Abstract

Pulp and paper sludge from a newsprint mill was composted for 6 weeks and evaluated as a substitute for peat moss in container media. One-year-old seedlings of lilac (*Syringa vulgaris* L.) and amur maple (*Acer tataricum* L. ssp. *ginnala* (Maxim.) Wesm.) as well as rooted cuttings of cistena plum (*Prunus* x *cistena* Hansen) were planted in #1 plastic pots that contained a pine bark and sand mixture (2:1 by vol) or pine bark and sand amended with either 25% or 50% peat moss or composted paper sludge. A 75% compost medium that consisted of composted paper sludge and sand (3:1 by vol) was also used in the study. Plant height was measured every 4 weeks. After 14 weeks of growth, shoot dry weight and final plant height were measured. All plants in compost-amended media grew as well as or better than those in peat-amended media, regardless of the species grown. Lilac plants in 25% compost produced almost double the amount of shoot dry weight and were 80% taller than plants in the bark:sand or 25% peat media. Maple plants in 50% compost produced at least 33% more shoot dry weight than those in either peat-amended medium. Plum cuttings in 25% compost grew at least 53% taller than those in either peat-amended medium. These results demonstrated that composted paper sludge from newsprint production was a worthy substitute for peat moss in a container medium for the three species tested.

Index words: substrate amendment, potting mix, compost, newsprint sludge.

Species used in this study: common lilac (*Syringa vulgaris* L.); amur maple (*Acer tataricum* L. ssp. *ginnala* (Maxim.) Wesm.); and cistena plum (*Prunus* x *cistena* Hansen).

Significance to the Nursery Industry

Peat moss is an important component in soilless potting media, and its price can vary from \$77 to \$154 per m^3 (\$60 to \$120 per yd^3) depending on the grade and quantity ordered. This expense has forced growers to seek other sources of organic amendments. Nursery stock producers need organic amendments that resist decomposition, provide proper aeration and water-holding capacity, are nontoxic to plants and people (workers and customers), and support plant growth. Our study has shown that plants grown in media amended with up to 75% composted paper sludge grew as well as or better than plants grown in peat-amended media. Although most chemical and physical characteristics of compost-amended media were suitable, cation exchange capacity and water-holding capacity of these media need to be checked before planting.

Pulp and paper sludge from a particular paper mill should be relatively consistent during the year, providing growers with a possible low cost amendment. In fact, since the paper industry has a sludge disposal problem, nurseries may receive the material for free or be paid to take it. Sludges vary from mill to mill and have different characteristics depend-

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ing on the type of paper production. Given the suitable attributes of pulp and paper sludge from newsprint processing (i.e., lack of heavy metals, toxic organic compounds, and pathogens), container growers should consider using this material for plant production.

Introduction

The U.S. paper industry generates approximately 2 million dry metric tons of pulp and paper sludge per year, of which about 17% is from newsprint processing (1). Most paper sludge is either burned or land applied, either at landfills or farming operations. Environmental concerns and governmental regulations, however, have created a significant cost burden for disposing sludge from paper production. Land application of raw paper sludge has been practiced for a number of years, and paper sludges have been used as soil amendments or conditioners in agriculture, forestry, and mine reclamation (7, 15, 20, 21). In addition, Chong and Cline (4) have recently shown that four species of landscape plants grew well in two sources of raw paper sludge. Sludges from various mills, however, differ significantly in physical and chemical characteristics, depending on the paper production process (2, 3).

The woody, fibrous nature of primary sludge from pulp and paper processing may make this material suitable as a component in soilless potting media. Composting the paper sludge may be beneficial for plant production since this process can reduce the C:N ratio of the material to around 30:1 and improve plant growth (2). Composting the paper sludge would also help stabilize the material (2).

Peat moss is an important component in soilless media, but its expense has forced nursery stock producers to examine other organic materials for their usefulness in potting mixes. In addition, peat bog mining may be limited in the future since these bogs serve as important sites for CO_2 fixation from the atmosphere (6) and environmental groups are concerned about the ecological impact of mining peat bogs. The stability and organic content of the composted paper sludge may allow growers to use it as a substitute for peat moss in container media. The objective of this study was to determine if composted pulp and paper sludge from newsprint processing could be used as a substitute for peat moss in container media.

Materials and Methods

Pulp and paper sludge used in this study came from a newsprint mill and was composted as described previously (2). The sludge was a mixture (3:1 by vol) of primary sludge (woody fibers derived directly from the paper-making process) and secondary sludge (activated sludge from waste treatment processing at the mill). The sludge was composted for 6 weeks, and tomato plants grown in the compost produced 90% of the shoot biomass of control plants grown in peat moss (2). The sludge had low concentrations of heavy metals and Na (2), a pH of 6.1, a cation exchange capacity (CEC) of 61 cmol(+)·kg^{-1}, a C:N ratio of 29:1, and electrical conductivity (EC) value of 2.4 dS·m^{-1}. The sludge lacked chlorinated organic compounds since it was a by-product from refiner mechanical/chemimechanical pulp processing. Other chemical properties of the composted sludge are described elsewhere (2). The compost was stored outdoors in covered, 30-gal plastic containers for 2 years before use.

Pine bark [<13 mm, (<0.5 in)] was mixed with sand and either peat moss or composted paper sludge on a volume basis. The control mix consisted of bark:sand (2:1 by vol). The 25% peat or compost media consisted of bark:sand:peat or composted sludge (2:1:1 by vol), whereas the 50% peat or compost mixes consisted of bark:sand:peat or composted sludge (2:1:3 by vol). A 75% compost mixture consisted of sludge:sand (3:1 by vol). All mixes were amended on a m^3 (yd^3) basis with 3.2 kg (6 lb) dolomite, 0.94 kg (1.7 lb) Micromax micronutrient fertilizer, and 3.2 kg (5.9 lb) Osmocote 18N–3P–10K (18–6–12).

Analyses of initial chemical properties of all media were conducted at the Holm Research Laboratory at the University of Idaho following standard procedures. Sample pH was measured in a saturated paste (12). Available phosphorus was determined by colorimetric analysis (14), and available potassium was measured by inductively coupled plasma (ICP) emission spectroscopy after extraction with sodium acetate (10). Nitrate-N and ammonium-N in the media were measured by colorimetric analysis of a saturated $CaSO_4$ extract on a continuous flow analyzer (9). The C, H, and N contents of the media were measured with a Leco CHN 600 analyzer (11). Cation exchange capacity (CEC) (ammonium acetate method) and electrical conductivity (EC) were determined as described by Rhoades (16, 17). Electrical conductivity and pH of each medium were determined (via the saturated paste method) for three randomly selected pots for each species and each medium after the experiment ended.

Initial physical properties were determined on four random samples of each medium. Bulk density was measured by filling a small beaker to the top, dropping it four times from a height of 8 cm (3.1 in), and then refilling to the top (a modification of ASTM E 873–82). The medium was dried at 100C (212F) and weighed. Aeration and water-holding capacity of all media were measured as described by Holstead (8). Total porosity of amended soil was the sum of aeration and water-holding capacity.

One-year-old seedlings of common lilac (*Syringa vulgaris* L.) and amur maple (*Acer tataricum* L. ssp. *ginnala* (Maxim.) Wesm.) as well as rooted cuttings of cistena plum (*Prunus* x *cistena* N.E. Hansen) were planted in 3-liter (#1) plastic containers. The three species were planted in each medium, except for the plum cuttings which were not planted in the 75% compost mix due to insufficient numbers of plants. Potted plants were watered and placed on a gravel pad at the Parker Research Farm, Moscow, ID. One week after planting, eight of the most uniform plants (with regard to height)

Table 1. Initial physical characteristics of container media.

Medium	Bulk density ($g{\cdot}cm^{-3}$)	Aeration %	Water-holding capacity %	Total porosity %
Bark:Sand[z]	0.78a[y]	19.6d	37.4c	57.0e
25% Peat	0.52b	20.7d	39.0c	59.7de
50% Peat	0.41d	21.4cd	43.7b	65.2bc
25% Compost	0.50bc	24.6ab	37.7c	62.3cd
50% Compost	0.40d	26.6a	42.6b	69.2ab
75% Compost[x]	0.44cd	23.3bc	49.3a	72.6a

[z]Bark:sand mixture (2:1 by vol).

[y]Means followed by different letters within a column are significantly different at $P<0.05$ by Fisher's LSD procedure.

[x]Compost:sand mixture (3:1 by vol) lacked bark.

of each species were selected for the experiment. Plants were arranged in a randomized complete block design with four blocks and two replications (plants) within a block. All plants received about 1200 ml (40 oz) of water every third day by trickle-irrigation with spray stakes. Supplemental fertilization was not provided.

The experiment began on June 10, 1993, and ended on September 23, 1993, for a total of 14 weeks. Plant height was measured on the first day of the study and every 4 weeks thereafter until the end of the experiment at which time final height was measured. Plant shoots were severed at the medium surface and were dried at 70C (158F) for 72 hr. After drying, plant leaves were removed from the stems, ground, and sent to a commercial laboratory (Scotts Company Testing Laboratory, Allentown, PA) for analysis by ICP spectroscopy. Samples were prepared by using a dry ashing procedure before analysis.

Analysis of variance, using procedure GLM in SAS/STAT (18), was completed for chemical and physical properties of all container media, total change in plant height, shoot dry weight, and foliar nutrient content. Significant differences between treatment means were determined by using Fisher's Protected Least Significant Difference (LSD) procedure at the 5% significance level.

Plant height growth over time was analyzed by using regression techniques to determine differential growth rates of plants in various media. Residual mean squares, predicted sums of squares, and lack of fit analysis were essential statistical criteria used to measure the adequacy of fit for the models considered (13). Studentized residuals were plotted against time and against predicted values to examine the validity of regression assumptions for the specified models. A full model dummy variable contrast procedure (19) was used to compare height growth rates of plants in peat- or sludge-amended media. All statistical computations were completed using SAS/STAT (18).

Results and Discussion

Media physical properties. Physical characteristics of the media varied depending on the substrates used. The bark:sand medium had the highest average bulk density compared to the other media (Table 1). As the amount of peat or composted paper sludge increased in the medium, the bulk density generally decreased.

Media amended with paper sludge were better aerated, on average, than those amended with peat moss or the bark:sand control mix, although the 75% compost and 50% peat media contained similar amounts of air space (Table 1). Water-holding capacities of media amended with 25% peat moss or compost were similar to that of the bark:sand mix but were significantly lower than those amended with 50% peat or compost (Table 1). The 75% compost mix had the highest average water-holding capacity of all the media. Total porosity of the media increased as the amount of composted paper sludge or peat moss increased in the media. Total porosity of the 75% compost medium was the highest but similar to that of the 50% compost mix (Table 1). The bark:sand mix had the lowest total porosity. Overall, aeration and water-holding capacity of the peat- or compost-amended media were within acceptable ranges (8).

Based on visual observations and previous work (unpublished data), media amended with this type of composted paper sludge maintained their volumes, regardless of the amount of paper sludge used in the mixture. The absence of shrinkage with this particular woody paper sludge makes it desirable for use as an amendment for container media.

Media chemical properties. Chemical properties of the potting media varied depending on which substrate (peat moss or composted paper sludge) was used in the mix. In general, medium pH decreased as the amount of peat moss or compost in the mix increased (Table 2). The bark:sand and 25% compost media had the highest average initial pH (4.6), whereas the 50% peat and 75% compost media had the lowest average pH of all mixes. Although the pH varied significantly among different media, the pH range was small (from 4.2 to 4.6) and probably had little, if any, effect on

Table 2. Initial and final pH of container media at planting and the end of the experiment.

Medium	pH Initial	pH Final
Bark:Sand[z]	4.6a[y]	6.5bc
25% Peat	4.4b	6.6b
50% Peat	4.3c	6.8a
25% Compost	4.6a	6.6b
50% Compost	4.4b	6.4c
75% Compost[x]	4.2c	6.1d

[z]Bark:sand mixture (2:1 by vol).

[y]Means followed by different letters within a column are significantly different at $P < 0.05$ by Fisher's LSD procedure.

[x]Compost:sand mixture (3:1 by vol) lacked bark.

Table 3. Initial chemical characteristics of container media.

Medium	CEC (cmol(+)·kg^{-1})	C:N ratio	Available P (µg·g^{-1})	Available K (µg·g^{-1})	NO_3-N (µg·g^{-1})	NH_4-N (µg·g^{-1})
Bark:Sand[z]	6.9c[y]	32.1a	77d	602b	336d	313d
25% Peat	13.7b	30.6ab	108c	782b	573cd	528bc
50% Peat	29.3a	29.4ab	177a	1082a	798bc	742a
25% Compost	8.9c	31.5a	106c	787b	645bcd	392cd
50% Compost	14.0b	24.5b	131b	1084a	1361a	549b
75% Compost[x]	8.0c	17.4c	90cd	753b	890b	725a

[z]Bark:sand mixture (2:1 by vol).

[y]Means followed by different letters within a column are significantly different at $P<0.05$ by Fisher's LSD procedure.

[x]Compost:sand mixture (3:1 by vol) lacked bark.

plant growth. Electrical conductivities of all media were similar, and the mean initial EC (averaged over all mixes) was 2.8 $dS \cdot m^{-1}$ (data not shown).

Final pH of the media differed significantly, but final EC of the media were similar (data not shown) and averaged 1.11 $dS \cdot m^{-1}$. By the end of the experiment, the 50% peat medium had the highest average pH, whereas the 75% compost medium had the lowest average pH (Table 2). As with the initial pH range, the final pH range was relatively small (pH 6.1 to 6.8) and probably had little effect on plant growth.

Peat moss used in the media improved CEC of the mixtures (Table 3). For instance, the 50% peat medium had the highest average CEC. The 50% compost medium had an average CEC similar to that of the 25% peat mix, indicating that the CEC of the compost was about half that of peat moss. Cation exchange capacity of the individual bark and composted sludge components were similar (50 and 61 $cmol(+) \cdot kg^{-1}$, respectively, unpublished data) as reflected by the average CECs of the bark:sand and 75% sludge media.

The C:N ratios of media amended with at least 50% compost were significantly lower than that of the bark:sand mix (Table 3). The 75% compost medium had the lowest average C:N ratio (17:1) compared to the other media. Compost stability is important if carbon-rich organic materials are used in container media, particularly soilless mixes, since N can be immobilized in the medium and plant growth stunted if the medium has a C:N ratio > 30:1 (22). Container media should have C:N ratios ≤ 20:1, which is considered to be a desirable level for plant growth (5).

The amounts of available P and K as well as NO_3-N and NH_4-N levels in the media generally increased as the amount of peat moss or composted paper sludge increased (Table 3). The 50% peat medium had the highest average amount of available P, whereas the bark:sand and the 75% compost media had the lowest average amount of this element. Media amended with either 50% peat or 50% compost had the highest amounts of available K; on average, these media contained at least 37% more available K than any of the other media. Amending the medium with 50% peat moss or 50% or more composted paper sludge increased the NO_3-N level of the mix. Media amended with peat moss or composted paper sludge also contained more NH_4-N compared to the bark:sand mix, except for the medium amended with 25% compost (Table 3). The 50% peat and 75% compost mixes contained the highest average levels of NH_4-N. The 50% sludge mix contained high concentrations of several nutrients, and media with high levels should be monitored and may need amelioration before planting since high concentrations of some minerals can be toxic to plants or leached. In particular, NO_3-N levels should be carefully followed since this form of N can readily leach from some media causing environmental concerns.

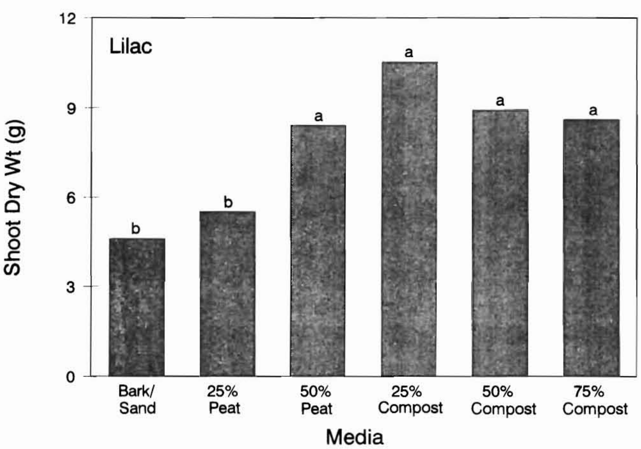

Fig. 1. Effects of potting media on shoot biomass production by 1-year-old lilac seedlings. The media were mixed as follows: bark:sand (control mix) (2:1 by vol); 25% peat or compost consisted of bark:sand:peat moss or composted paper sludge (2:1:1 by vol); 50% peat or compost consisted of bark:sand:peat moss or composted paper sludge (2:1:3 by vol); and 75% compost consisted of composted paper sludge:sand (3:1 by vol). Mean separation by Fisher's LSD procedure $P < 0.05$ (n = 8).

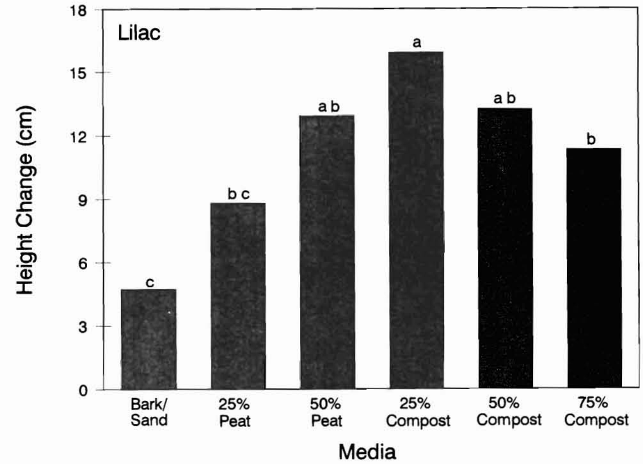

Fig. 2. Effects of potting media on total height change of 1-year-old lilac seedlings. Media and statistics are described in Fig. 1.

Plant growth. All plants grown in compost-amended media grew as well as or better than those in peat-amended media, regardless of the species grown. Lilac plants grown in compost-amended media produced at least 36% more shoot dry weight than those planted in the bark:sand or 25% peat mixes (Fig. 1). Lilacs grown in compost-amended media also grew taller than those grown in the bark:sand mix but were similar in average height to those in peat-amended media, with the exception of seedlings in the 25% compost mix (Fig. 2). Moreover, seedlings in 25% compost produced almost twice as much shoot biomass and were 80% taller than those grown in the bark:sand or 25% peat media (Figs. 1 and 2).

Amur maple seedlings grown in compost-amended media were similar in height to those grown in the other media, and the plants grew an average of 48.6 cm during the experiment (data not shown). Maple seedlings grown in 50% or 75% compost, however, produced almost twice as much shoot dry weight as those grown in the bark:sand or 25% peat media (Fig. 3). In addition, seedlings grown in at least 50% compost produced 34% or 20% more shoot biomass, on average, than those grown in 50% peat or 25% compost, respectively.

Rooted cuttings of cistena plum grown in sludge-amended media grew better than those in the bark:sand mix and better than those in the 25% peat medium. For example, cut-

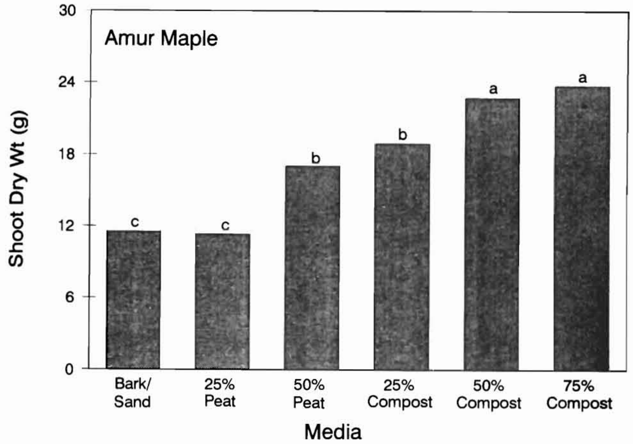

Fig. 3. Effects of potting media on shoot biomass production by 1-year-old amur maple seedlings. Media and statistics are described in Fig. 1.

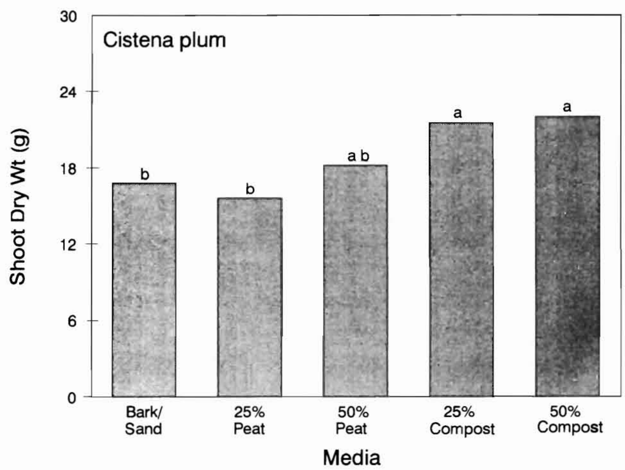

Fig. 4. Effects of potting media on shoot biomass production by rooted cuttings of cistena plum. Media and statistics are described in Fig. 1.

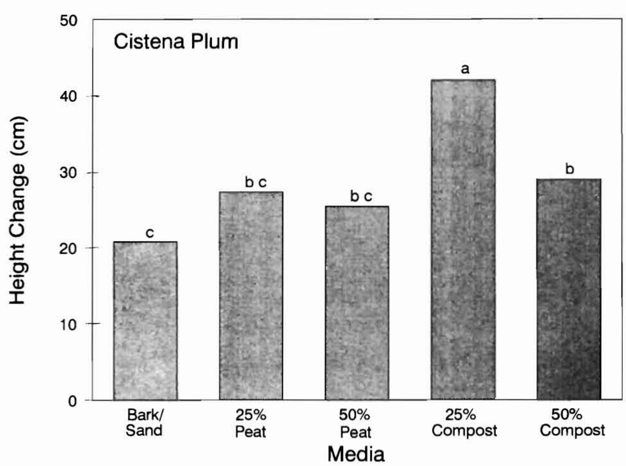

Fig. 5. Effects of potting media on total height change of rooted cuttings of cistena plum. Media and statistics are described in Fig. 1.

tings in compost-amended media produced similar amounts of shoot dry weight to those in the 50% peat medium but at least 27% more shoot biomass, on average, than those in the bark:sand or 25% peat media (Fig. 4). In addition, plum cuttings grown in compost-amended media grew taller than those in the bark:sand mix (Fig. 5). Cuttings in the 25% compost medium grew 53% taller than plants in peat-amended media (Fig. 5).

Several linear and nonlinear regression models were considered to quantify plant height growth over time in different media. A simple linear regression model of the form height = a + b(time) provided an adequate fit to the data based on minimum residual mean squares, minimum predicted sum of squares, and structure of residuals (data not shown). In the regression equation above, the estimated regression coefficient for slope (b) measured the height increment per unit of time and thus, is referred to as plant height growth rate in the following discussion.

All three plant species grew fastest in media amended with 25% or 50% compost (Table 4). The estimated regression coefficients, indicators for the height growth rates of the three species grown, possessed the correct sign (positive) and were significantly different from zero ($P < 0.002$). The height growth rates of lilac seedlings and cistena plum cuttings were highest in 25% compost, whereas those of maple seedlings were highest in 50% compost. Height growth rates of all species were lowest in the bark:sand mix.

Single degree-of-freedom contrasts were used to compare the average height growth rates of individual species in different media (data not shown). These contrasts revealed that the rates of height increase of lilac or plums averaged over peat- or compost-amended media were significantly higher than the growth rate of these species the bark:sand mix ($P < 0.05$). Moreover, height growth rate of lilacs or plums aver-

Table 4. Estimated regression coefficients of height growth rate for three plant species grown in six media.

Medium	Parameter estimate	Std. error of estimates	t value	Prob > |t|
Lilac				
Bark:Sand[z]	0.26	0.08	3.12	0.0020
25% Peat	0.68	0.11	6.09	0.0001
50% Peat	1.02	0.11	9.17	0.0001
25% Compost	1.26	0.11	11.30	0.0001
50% Compost	1.04	0.11	9.33	0.0001
75% Compost[y]	0.89	0.11	8.02	0.0001
Maple				
Bark:Sand	3.28	0.17	19.38	0.0001
25% Peat	3.47	0.24	14.50	0.0001
50% Peat	3.91	0.24	16.33	0.0001
25% Compost	3.88	0.24	16.20	0.0001
50% Compost	4.27	0.24	17.84	0.0001
75% Compost	4.09	0.24	17.07	0.0001
Plum[x]				
Bark:Sand	1.39	0.15	9.47	0.0001
25% Peat	1.93	0.24	8.03	0.0001
50% Peat	1.92	0.21	9.21	0.0001
25% Compost	2.94	0.21	14.11	0.0001
50% Compost	1.96	0.21	9.44	0.0001

[z]Bark:sand mixture (2:1 by vol).
[y]Compost:sand mixture (3:1 by vol) lacked bark.
[x]Plum cuttings were not grown in 75% compost medium.

aged over compost-amended media was significantly higher ($P < 0.05$) than that of these species averaged over the peat-amended media. Although height growth rates averaged over maples grown in peat-amended media were similar to those of plants in the bark:sand mix, height growth rates averaged over maples grown in sludge-amended media were significantly higher ($P < 0.001$) than those of plants grown in the bark:sand mix.

Only a few elements in plant leaves were significantly affected by media (data not shown). Concentrations of K, Mn, and Cu in lilac leaves, Mn in amur maple leaves, and N, P, Ca, Fe, and Zn in cistena plum leaves were affected by media ($P < 0.05$). Even though foliar concentrations of these nutrients were affected by media, sufficient levels of the macroelements and microelements (5) were present in foliage from all three species (data not shown). The total quantity of nutrients in the plants was also calculated to determine if the compost provided minerals to the plants. The compost appeared to supply N, P, and K to lilac and maple plants only (data not shown). Total quantity of these elements in plum cuttings was unaffected by media, however, indicating more definitive experiments are needed to show that the compost provided a reliable source of nutrients.

The type of paper produced at a particular mill will affect the characteristics of the pulp and paper sludge and the resulting compost (2, 3). If nursery stock producers want to use pulp and paper sludge as the principal constituent in potting media, they should thoroughly test the material by completing chemical and physical analyses as well as bioassays (growing nursery stock in the sludge). Paper sludge from newsprint production is relatively benign and suitable for use in container media used for production of some herbaceous and woody species (2). In contrast, sludge from bleached kraft paper production can have a high pH and salt content which can limit the usefulness of this material as a major component in soilless potting mixes for some herbaceous species (3). Paper sludge, whether raw or composted, should be tested before large scale use by growing small numbers of desired species in sludge-amended media.

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