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Evaluation of composted biosolid waste as an amendment to a standard horticultural nursery mix for container grown *Callicarpa* and *Ilex* production

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Abstract

Growth of *Callicarpa dichotoma* (Lour.) 'Early Amethyst' and *Ilex glabra* (L.) 'Compacta' liners were evaluated in substrate containing 20, 40, 60, 80 and 100% composted biosolids as compared to a 3:2:1 (v:v:v) pine bark:peat:sand horticultural mix. Biosolid waste substrate amended with biosolids had higher pH, EC, nitrate, bulk density and container capacity compared to a standard horticultural nursery mix. Total porosity and air-filled capacity were greater for the control compared to substrate amended with biosolids. The effects of substrate amended with composted biosolids on growth varied for each species. *Callicarpa dichotoma* "Early Amethyst' liners grown in substrate amended with 20, 40 and 60% biosolid waste had greater shoot and root dry weight and a better visual evaluation compared to the control. *Ilex glabra* 'Compacta' liners grown in the control (standard nursery mix) had greater shoot and root dry weight and a better visual evaluation compared to any biosolid amended substrate. It was concluded that substrate amended with biosolid waste can be utilized for the container production of plants, however, its usage may be species specific.

Key words: Biosolids, sewage sludge, *Callicarpa, Ilex*, pH, electrical-conductivity, nitrate.

Introduction

Sphagnum peat is a major organic component of container substrate utilized in the nursery industry. Due to the physical and chemical qualities of peat, it is a valuable component in container substrate for the production of ornamental plants. Peat is extracted from peatlands, which are a vital part of a healthy environment. Peat vegetation rids water of heavy metals, pollutants, pathogens, excess nutrients, and stores atmospheric carbon dioxide. It also provides a natural habitat for several animal and bird species. The excavation of peat can be harmful to the biodiversity, hydrological cycle, and purification of water in the area of harvest (Grundling and Dada, 1999). Furthermore, the cost of peat has risen over the past several years (Wilson *et al.*, 2001a).

Given these factors, the nursery industry has increased its interest toward exploring alternative amendments to utilize in traditional potting media (Wilson *et al.*, 2002). 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), poultry litter (Fulcher *et al.*, 2002), kenaf stem core (Wang, 1994), spent mushroom compost (Chong *et al.*, 1991) and recycled municipal waste (Kahtz and Gawel, 2004). 2.2 million tons of biosolids (sewage sludge) is incinerated or buried in landfills each year in the United States, while at the same time new environmental regulations are making space in landfills a scarcity (Rosen *et al.*, 1993). Biosolids are the treated solid organic matter comprised of private or community wastewater that can be beneficially utilized as a substrate amendment in the nursery industry (US EPA, 1999).

Plants have been shown to successfully grow in substrate that incorporates composted biosolids (Wootton *et al.*, 1981). The usage of biosolids separately and mixed with other components such as municipal leaf waste (Bugbee *et al.*, 1991) and yard waste (Wilson *et al.*, 2003; Wilson *et al.*, 2001b) has also been explored. The utilization of biosolids in this manner could aid in the conservation of peatlands, and reduce land needed for the disposal of biosolids while providing the nursery industry with an inexhaustible alternative substrate amendment.

Several potential benefits of biosolids as a substrate amendment are recognized. Biosolids are a source of nutrients (Rosen *et al.*, 1993; Falahi-Ardakani *et al.*, 1987), improve the qualities of substrate (EPA, 1999) and may be a substitute for moss peat (Rosen *et al.*, 1993). Composted biosolids decompose at a slow rate, therefore releasing nutrients at a steadier rate compared to non-composted biosolids (USDA, 1998). Root rot diseases are also suppressed in substrates that are amended with biosolids (Hoitink *et al.*, 1997). In addition, composted biosolids are potentially economically feasible (Bugbee and Frink, 1989; Vega-Sanchez *et al.*, 1987).

Potential barriers in beneficial usage of biosolids include public reluctance based upon potential health and environmental concerns (US EPA, 1999). These concerns are based upon disease causing pathogens which can be found in untreated wastewater and biosolids. In addition, odors are also a potential problem.

Biosolid stabilization is achieved typically by the addition of quicklime (CaO) or hydrated lime ($Ca[OH]_2$), which is added to either liquid biosolids before dewatering or mixed with dewatered biosolids (US EPA, 1999). These types of lime stabilization procedures meet 40 CFR Part 503 rules governing land application of biosolids.

The primary objectives of this study were to evaluate incorporation of biosolids upon 1) substrate electrical-conductivity (EC), pH and nitrate over a four-month period, 2) examine physical characteristics, and carbon (C) and nitrogen (N) ratios of substrate amended with differing volumes of biosolids and 3) to examine the final shoot and root total dry weights of two different species grown in the substrate. These factors were monitored in order to develop a horticultural nursery mix amended with composted biosolids suitable for containerized shrub production.

Materials and methods

Biosolids produced by Waste Water Treatment Plant of Cookeville, Tennessee was utilized in this project. Biosolids utilized in this study underwent a lime-envessel pasteurization process and met the United States Environmental Protection Agency Federal Register Rules and Regulations Part 503; standards for the use or disposal of sewage sludge (US EPA, 1999). The biosolids were dewatered and quicklimed (CaO) to raise the pH to 12 or above, and pasteurized to produce class A biosolids. The biosolids were then allowed to compost under outdoor conditions for 75 days. A primary goal of composting biosolids is to produce a more stable, less-odorous source of organic matter (Rosen *et al.*, 1993).

Uniform *Callicarpa dichotoma* 'Early Amethyst' and *Ilex glabra* 'Compacta' liners (approximately 7.5 cm tall) were potted in 1-gallon (2.19 L) containers filled with 3:2:1 (v:v:v) pine bark: peat : sand mix with composted biosolids. For purposes of this study each species was evaluated as a separate experiment. The biosolids were screened to 3.0 cm and incorporated at rates of 0 (control), 20, 40, 60, 80 and 100% by volume. C and N values were determined before the addition of six grams of 14N-4.2P-11.6K (14-14-14) Osmocote with micronutrients, topdressed on all containers. Plants were grown under a 30 % shadecloth. Three-hundred milliliters of water was supplied twice daily via individual spray emitters. The study was conducted at the Tennessee State University Otis L. Floyd Nursery Crop Research Center in McMinnville, Tennessee.

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 15, 30, 45, 60, 75 and 90 days after treatment (DAT). Leachate EC and pH were measured with a Myron Ultrameter™ Model 6P (Myron L Company, Carlsbad, California). Nitrate readings and a visual assessment of each plant were taken 30, 60 and 90 DAT. An Accumet AR 25 and electrode were used to record nitrate readings. The visual assessment was given a scale of 1-5 as follows: 1) plant died, 2) plant was near death or lost many leaves, 3) average looking plant, moderate growth, 4) good growth, few if any problems and, 5) Excellent growth, healthy leaves, no signs of chlorosis or nutrient problems. At the end of the project plants were harvested at the soil level. Container medium was washed from the roots. Dry shoot and root weights were recorded after drying at 70 ˚C for 72 h.

Three replications of each substrate treatment (0, 20, 40, 60, 80 and 100%) were evaluated for total bulk density, container capacity, total porosity, percent moisture and air-filled porosity. The North Carolina State University Porometer was utilized to determine the above mentioned substrate physical properties. Percent moisture was determined by drying a known amount of substrate at 105˚C for 24 h and weighing before and after. Container capacity was calculated by dividing the weight of the wet substrate by the volume of the pot. Standard procedures were utilized to determine bulk density, total porosity, and air-filled porosity (North Carolina State University and Fonteno and Bilderback, 1993). Total C and N concentrations were determined by a CNS analyzer (Carlo-Erba NA-1500;BICO, Burbank, California).

The experimental design was a randomized complete block design. Each treatment was replicated 6 times. All data within each experiment were subjected to an analysis of variance (ANOVA). Dunnett's test were utilized to compare treatments with the control (0% biosolids). The control was a standard horticultural nursery mix.

Results

Initial pH readings 15 DAT for the *C. dichotoma* 'Early Amethyst' liners revealed that as greater percentages of biosolids were added to the substrate the alkalinity level increased, with the 80 and 100% treatments being significantly greater than the control at 7.8 and 8.9, respectively (Table 1). pH levels generally decreased linearly throughout the duration of the project. pH results were virtually identical for the *I. glabra* 'Compacta' liners (Data not shown).

The *C. dichotoma* 'Early Amethyst' EC of substrate amended with composted biosolids was significantly higher for all treatments compared to the control beginning 15 DAT until conclusion of the project (Table 2). EC reading for the 100% treatment was four and half times greater than the control 15 DAT. However, the EC reading was never above recommended levels for any treatment of either species. The general trend, for all treatments except the control, was for the EC levels to decline or remain relatively constant from 15 DAT until the final reading 90 DAT. The control

Table 1. pH readings by days after treatment for *Callicarpa*. Values presented for the 20, 40, 60, 80 and 100% treatments are the relative increase or decrease as compared to the non-treated (0%) control

Treatment	pH reading by days after treatment					
(% by volume)	15	30	45	60	75	90
0	7.2^z	7.1^z	7.4^z	7.1^z	7.1^z	7.0^z
20	0.2	0.1	0.2**	0.1	0.1*	0.0
40	0.1	0.1	0.2**	0.2*	0.2**	0.2*
60	0.2	0.2	0.2**	0.2**	0.2**	0.2**
80	0.6**	0.2	0.2**	0.2**	0.2**	0.2**
100	1.7**	0.7**	0.4**	0.3**	0.3**	0.2**

^{z}Actual pH reading of treatment.

*, ** Dunnett's test significant at P=0.05 or P=0.01, respectively when compared to 0 % treatment.

Table 2. EC readings by days after treatment for *Callicarpa*. Values presented for the 20, 40, 60, 80 and 100% treatments are the relative increase or decrease as compared to the non-treated (0%) control

Treatment	EC reading by days after treatment (dS m^{-1})					
(% by volume)	15	30	45	60	75	90
0	0.21^z	0.23^z	0.24^z	0.24^z	0.26^z	0.27^z
20	0.28	0.15**	0.25**	0.19**	0.12**	0.18**
40	0.44*	0.34**	0.39**	0.33**	0.20**	0.29**
60	0.52**	0.41**	0.51**	0.45**	0.40**	0.40**
80	0.47*	0.45**	0.47**	0.42**	0.36**	0.41**
100	0.75**	0.40**	0.41**	0.39**	0.43**	0.39**

^{z}Actual EC reading of treatment.

*, ** Dunnett's test significant at P=0.05 or P=0.01, respectively when compared to 0 % treatment.

Table 3. Nitrate readings by days after treatment for *Callicarpa*. Values presented for the 20, 40, 60, 80 and 100% treatments are the relative increase or decrease as compared to the non-treated (0%) control

Treatment	Nitrate readings (ppm) by days after treatment		
(% by volume)	30	60	90
0	9.7[z]	11.9[z]	5.8[z]
20	0.5	4.3	1.3
40	9.2	15.1	2.9
60	18.2**	27.4**	4.7
80	11.0*	26.4**	10.5
100	13.6**	29.3**	21.0**

[z] Actual ppm of treatment.; ** Dunnett's test significant at P=0.05 or P=0.01, respectively when compared to 0 % treatment.

Table 4. Physical properties of composted substrate amended with biosolids. Values presented for the 20, 40, 60, 80 and 100% treatments are the relative increase or decrease as compared to the non-treated (0%) control

Treatment (% by volume)	Bulk density (g cm^3)	Container capacity (% by vol)	Total porosity (% by vol)	Air-filled Porosity (% by vol)	Moisture (%)
0	0.21[z]	56.0[z]	78.8[z]	21.1[z]	25.1[z]
20	0.08**	5.5*	-0.9	-4.6*	11.2*
40	0.16**	7.8**	-2.1	-10.0**	12.5*
60	0.27**	10.6**	-3.5	-14.2**	11.5*
80	0.37**	10.3**	-4.4	-15.1**	9.2
100	0.46**	12.4**	-5.4*	-15.9**	10.7*

[z] Actual measurement of treatment; *, ** Dunnett's test significant at P=0.05 or P=0.01, respectively when compared to 0 % treatment.

Table 5. Nitrogen and carbon concentrations of composted substrate amended with biosolids. Values presented for the 20, 40, 60, 80 and 100% treatments are the relative increase or decrease as compared to the non-treated (0%) control

Treatment (% by volume)	N(%)	C(%)	C/N ratio
0	0.65[z]	49.9[z]	76[z]
20	0.31*	-13.0*	-39*
40	0.47*	-19.9*	-50*
60	0.64*	-25.7*	-58*
80	0.77*	-29.4*	-62*
100	0.83*	-31.7*	-64*

[z] Actual measurement of treatment; *, ** Dunnett's test significant at P=0.05 or P=0.01, respectively when compared to 0 % treatment.

EC levels slowly increased from 15 DAT until 90 DAT. EC results were virtually identical for the *I. glabra* 'Compacta' liners (Data not shown). Nitrate levels for *C. dichotoma* 'Early Amethyst' were significantly greater for the 60, 80 and 100% treatments compared to the control, 30 and 60 DAT (Table 3). At 90 DAT the 100% treatment was significantly greater than the control. Nitrate levels were greatest with increased amounts of incorporated biosolids. Nitrate levels for *I. glabra* 'Compacta' were statistically similar (Data not shown).

Generally, as the percentage of incorporated biosolids increased the bulk density, container capacity and moisture significantly while the total porosity and air-filled porosity decreased (Table 4). Treatments that had greater amounts of incorporated biosolids significantly contained more N and less C resulting in lower C/N ratios (Table 5).

C. dichotoma 'Early Amethyst' grown in 40 and 60% biosolid amended substrate had the greatest shoot and root weight of any of the treatments, respectively (Table 6). The initial visual evaluation 30 DAT showed the control was the most marketable

Table 6. Growth characteristics of *Callicarpa* and *Ilex* liners grown for four months in composted substrate amended with biosolids. Values presented for the 20, 40, 60, 80 and 100% treatments are the relative increase or decrease as compared to the non-treated (0%) control

Treatment (% by volume)	Shoot dry wt (g)	Root dry wt (g)	Shoot: root ratio
Callicarpa			
0	22.85[z]	13.31[z]	1.73[z]
20	6.73	5.30*	-0.12
40	11.61**	5.60*	0.10
60	16.96**	5.73*	0.40
80	-7.43	-5.61*	0.32
100	-17.87**	-10.83**	0.23
Ilex			
0	8.70[z]	2.22[z]	3.87[z]
20	-4.22	-0.80	-0.72
40	-5.63**	-1.26**	-0.67
60	-5.05*	-0.95*	-1.00
80	-	-	-
100	-	-	-

[z] Actual weight of treatment; *, ** Dunnett's test significant at P=0.05 or P=0.01, respectively when compared to 0 % treatment.

Table 7. Visual evaluation ratings of *Callicarpa* and *Ilex* liners. Values presented for the 20, 40, 60, 80 and 100% treatments are the relative increase or decrease as compared to the non-treated (0%) control

Treatment	Visual evaluation by days after treatment		
(% by volume)	30	60	90
Callicarpa			
0	5.00[z]	4.16[z]	4.08[z]
20	-0.16	0.41	0.33
40	-0.66	0.50	0.58
60	-0.91*	0.25	0.58
80	-3.00**	-1.16**	-0.18
100	-3.90**	-2.06**	-0.48
Ilex			
0	4.25[z]	4.50[z]	4.58[z]
20	0.33	-0.33	-0.83*
40	-0.41	-1.00**	-1.16**
60	-0.41	-1.00**	-1.16**
80	-	-	-
100	-	-	-

[z] Actual measurement of treatment; *, ** Dunnett's test significant at P=0.05 or P=0.01, respectively when compared to 0% treatment.

of all treatments (Table 7). However, upon conclusion of the project, at 90 DAT, the 40 and 60% treatments had the best visual evaluation. In contrast, *I. glabra* 'Compacta' grown in the 0% (control) had the greatest shoot and root weight compared to the treatments that had incorporated biosolids (Table 6). The control also received the best visual evaluation 30, 60 and 90 DAT (Table 7). Five replications grown in each of the 80 and 100% biosolids died during the first 10 days of the project. Therefore, the 80 and 100% treatment that involved *I. glabra* 'Compacta' were excluded from the data analysis.

Discussion

The addition of quicklime during the dewatering process greatly contributed to the increased pH levels. Fitzpatrick *et al.* (1998) reported that stabilized biosolids typically had a high pH due to the chemical stabilizers, such as lime, utilized before composting. In addition, they state that the pH of most commercially produced compost ranges from 6.7 to 7.7. The pH recommended for optimum nutrient uptake by plants ranges from 5.0 to 6.0 (Southern Nursery Assoc., 1997) to 5.2 to 6.2 (Ruter and Garber, 1993). However, depending upon the crop and method of fertilization, variations will exist. Therefore, the substrate with 80 and 100% biosolids volumes may have had a detrimental impact upon *C. dichotoma* 'Early Amethyst' root growth and subsequent foliar and overall plant development. Mortality in *I. glabra* 'Compacta' planted in 80 and 100% sewage sludge appears to be due to an excessively alkaline pH. *C. dichotoma* 'Early Amethsyt' appears to be more tolerant of alkaline substrate than *I. glabra* 'Compacta'. The pH values of the 80 and 100% treatments for both plant species were greater than the pH of most commercially produced compost (Fitzpatrick *et al.*, 1998). Furthermore, the control had the lowest pH of any of the treatments for both species.

High soluble salt content has been observed with many substrates that had incorporated biosolids (Chaney *et al.*, 1980). Results revealed that EC levels were higher with greater amounts of sewage sludge incorporated into the substrate. However, EC levels at no point during the project were above recommendations for the best management and growth of either species. This is in contrast to Chaney *et al.* (1980) reporting that soluble salt levels may be problematic in biosolid compost. Research has shown that compost comprised of biosolids and yard waste resulted in the greatest plant growth compared to other composted materials (Fitzpatrick and Verkade, 1991).

Increased growth of *C. dichotoma* 'Early Amethyst' may be attributed to increased NO_3-N, which is presumably derived from nitrification of NH_4-N. Decreased plant growth may be attributable to excessive amounts of NH_4-N and excessively alkaline substrate (Bugbee and Frink, 1989). Excessive levels of NH_4-N and pH may become more favorable to plant growth by further modifying the composting process. The addition of sawdust, for example, during the composting process may help to reduce substrate pH.

Greater bulk densities and container capacities of the biosolid amended substrate compared to the standard nursery mix are attributed to increased amounts of incorporated biosolids. Reduced total porosity and air-filled capacity are also attributed to increased amounts of biosolids. Due to the physical density of biosolid material it tends to reduce air-filled porosity, thus reducing drainage.

Composts with a C/N ratio less than 20 are considered to be optimal for the growth and development of plants (Davidson *et al.*, 1994). Compost with C/N ratios higher than 30 may be immature or lacking stability, which may promote plant phytotoxicity and mineral immobilization (Zucconi *et al*., 1981). Hue and Sobieszczyk (1999) reported that N immobilization was minimal if C/N ratios are maintained between 15 to 20. Given these results, the composted substrate utilized in the study was considered stable and beneficial for the release of N.

Depending upon the plant species, a standard nursery mix amended with biosolids up to 60% or less (by volume) provided an adequate substitute for moss peat for containerized production of *C. dichotoma* 'Early Amethyst'. However, the growth of *I. glabra* 'Compacta' in substrate amended with biosolids was detrimental to the plants' growth and development with the standard nursery mix yielding the best plant growth and development. All *C. dichotoma* 'Early Amethyst' treatments were visually considered marketable. In contrast, only the control and 20% biosolid treated *I. glabra* 'Compacta' plants were visually considered marketable. However, the results demonstrate that there is a potential usage for biosolids in the container production of plants. These results reveal that the use of dewatered biosolids as a substrate amendment for increased plant production is species specific.

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