Assessing Alternative Organic Amendments as Horticultural Substrates for Growing Trees in Containers[1]

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Abstract

Conventional substrates for nursery plant production typically are soilless media that are comprised of low bulk density material with either organic or synthetic components. These mixes aim to provide a lightweight medium that provides acceptable water holding capacity and nutrient retention and create a suitable environment for root proliferation and biomass growth. In an effort to identify alternatives to traditional container substrates, a comparative amendment study was conducted to observe changes in media qualities and plant growth response of *Aronia melanocarpa* 'Viking' and *Acer saccharum* over a period of 16 months. Materials used to amend traditional medium included composted green waste, biosolids and wood chips, biochar, aerated compost tea and vermicompost. The results of this study found that all amendments performed equally as well as control (NULL) treatments for root, shoot and total biomass production for both *Aronia melanocarpa* 'Viking' and *Acer saccharum*. After a period of 16 months, significant changes in biochemical properties had occurred in mediums amended with biochar, wood chips, composts and biosolids. This study provides data on a variety of alternative materials that can be used as substitutes for traditional greenhouse medium in production of nursery tree stock.

Index words: aerated compost tea, biochar, biosolids, carbon to nitrogen ratio, compost, dissolved organic carbon, electrical conductivity, fertilizer, microbial biomass carbon, control, active carbon, microbial respiration, leaf fluorescence, soil water tension, total nitrogen, total organic carbon, volumetric water content, wood chips, water holding capacity.

Species used in this study: 'Viking' black chokeberry [*Aronia melanocarpa* (Michx.) Elliott]; sugar maple (*Acer saccharum* Marshall).

Significance to the Horticulture Industry

This paper explores the use of a variety of alternative materials (biochar, biosolids, compost, wood chips and fertilizer) as a supplement to a peat-based greenhouse medium. A comprehensive assessment of these materials was conducted to determine biochemical properties, water release characteristics and effect of substrate additions on growth of container-grown trees. This research indicates that these alternative materials can successfully be used as a partial substitute for sphagnum peat moss and composted pine bark to grow *Aronia melanocarpa* 'Viking' and *Acer saccharum* in containers. Many of the amendments assessed in this paper performed as well and in some cases better than the traditional peat plus pine bark horticultural substrate. The results of this paper are promising, considering the future supply of sphagnum peat moss and composted pine bark are in question, and that the potential environmental degradation associated with the harvest of these materials could be avoided.

Introduction

Two common amendments that are used as horticultural substrates for growing trees in containers are sphagnum peat moss (SPM) and composted pine bark (CPB). The long-term sustainability of the use of these products as horticultural substrates is in question and predicted to decrease in the future (Lu et al. 2006). This study was designed to investigate a series of traditional and novel soil amendments, their biochemical properties, water release characteristics and suitability for growing trees. Study and analysis of these alternative materials is being undertaken to determine viable alternatives to SPM and CPB as horticulture substrates.

Sphagnum peat moss refers generically to a diversity of individual species in the moss genus *Sphagnum*. Sphagnum peat moss has widely been used in nursery production because of its ideal pH, plant available nutrients and high water holding capabilities (Robertson 1993). Although a large portion of SPM is used by the horticultural industry (Carlile 2004), homeowners also make up a significant portion of SPM consumers (Carlile 2004) (Riviere et al. 2008). Environmental concerns for the harvesting of SPM vary depending on the region of the world where it is grown and include destructive removal practices that prevent regeneration (Diaz and Wladimir 2012) and harvesting in environments with unsuitable characteristics for regenerative growth such as altitude, climate or shade (Whinam and Buxton 1997). Furthermore, its harvest can contribute to greenhouse gas emissions. Undisturbed soils with SPM are substantial sinks of C and its harvest results in a release of that C to the atmosphere (Cleary et al. 2005).

Composted pine bark is commonly used on its own or mixed with sand, SPM or perlite as a horticultural substrate. Composted bark is used by container growers for its inexpensive cost compared to other growing medium, low pH and low bulk density. Composted pine bark is recommended over non-composted pine bark to avoid transmission of plant pathogens and as a stabilized product that avoids accumulation of phytotoxic compounds. The high temperature thermophilic phases of the

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bark compost process mediate a fungicidal effect, limiting the continuance of certain plant pathogens (Hoitink 1982). Furthermore, CPB has been shown to suppress certain disease infestations over the use of peat alone such as *Fusarium* (Pera and Calvet 1989). Although use of CPB has become a standard in the horticultural industry, concerns have been expressed about its long-term availability as a soilless medium.

With increasing demand for SPM and CPB for use as a horticultural substrate, availabilities are projected to decrease in the future (Lu et al. 2006). Research is ongoing to identify alternative materials to supplement and/or supplant SPM and CPB as a substrate. Some common amendments that have been examined for these purposes include wood chips (WC), composts (COM), biosolids (BS) and biochar (BC).

Wood chips. WC has been used as an alternative amendment in a horticultural substrate. Although WC is commonly used, concerns for WC have included the phytotoxic effect of polyphenolic compounds on plants grown in a WC medium as well as nitrogen immobilization (Rau et al 2006). The use of WC of various particle sizes and in combination with other soil amendments have been investigated. A study found that coarse pine (*Pinus taeda* L.) WC in combination with hammer-milled fine particle WC or other amendments (sand, aged pine bark or peat moss) can create substrates that perform equally well to peat moss alone or CPB for growing 'Inca Gold' marigolds (*Tagetes erecta* L.), 'Snowmound' spirea (*Spiraea nipponica* Maxim.) or 'Girard's Pleasant White' azalea (*Rhododendron x hybrid*) (Jackson et al. 2010). Woody plant species *Taxodium distichum* (L.) Rich., *Acer saccharinum* (L.) and *Pistacia chinensis* (Bunge) growing in 5 to 20% wood chips showed a similar growth response to a control medium, indicating WC acceptability as an amendment at these ratios. However, decreasing plant performance was observed in mixes containing >40% WC (Starr et al. 2012). Pine chips alone or in a blend performed equally as CPB as evaluated by shoot and root growth of 'Chesapeake' Japanese holly (*Ilex crenata* Thunb.) (Wright and Browder 2005). 'Inca Gold' marigold and 'Karen' azalea (*Rhododendron obtusum* (Lind.) Planch) showed mixed results of using pine WC alone or a blend indicating that the recommended use of WC chips as an ideal horticultural substrate might be plant species specific (Wright and Browder 2005). Wright and Browder (2005) concluded that pine WC did not contain phytotoxic levels of nutrients and had an acceptable pH for plant growth. Mechanically ground pine WC chips and CPB in combination with fertilizer performed equally well compared to traditional pine bark and peat moss substrates in plant growth response as demonstrated by equivalent shoot dry weight of 'Compacta' Japanese holly (and 'Delaware Valley White' azalea (Jackson et al. 2008). Equivalent plant growth for 'Cocktail Vodka' begonia (*Begonia x semperflorens*-cultorum hort.), 'Kingswood Torch' coleus (*Solenostemon scutellarioides* (L.) Codd), 'Dazzler White' impatiens (*Impatiens walleriana* Hook. f.) 'Bonanza Yellow' marigold, 'Aztec Gold' marigold (*Tagetes erecta* L.), 'Wave Purple' petunia (*Petunia x hybrid*) 'Red Hot Sally' salvia (*Salvia splendens* Sellow ex Nees) and 'Cooler Pink' vinca (*Catharanthus roseus* (L.) G. Don) was found when comparing ground pine tree and pine bark substrates with nitrogen fertilizers (Wright et al. 2009). However, it was suggested that increased microbial activity may lead to nitrogen (N) immobilization in a pine WC substrate and plants growing in this substrate might require increased fertilization (Jackson et al. 2008). Mechanisms for altered plant growth in WC substrates are variable and not often identified in studies. One study found increased plant growth in a blend of peat moss and WC and reasoned that the effect was associated with increased water-holding capacity in the medium (Boyer et al. 2008). However, in this study the increased water-holding capacity may have been attributed to the peat moss addition.

Compost. Compost refers to a diverse set of materials that are comprised of a mix of organic rich feedstocks (yard waste, food scraps, manure and biosolids) that have stabilized through an aerobic decomposition process. Compost has been investigated as an alternative to traditional horticultural substrates, such as a greenhouse medium (Abad et al. 2001).

Amendment of composted green waste at a rate 25 to 50% (v/v) with a greenhouse mix (sand, peat, sawdust) resulted in adequate qualities (air filled porosity, water holding capacity, bulk density) for container ornamental plant production (Burger et al. 1997). Plant dry weight of 'Bellavista F1′ begonia (*Begonia semperflorens* Link & Otto), *Mimulus* 'Magic x hybridus', 'Maestro' salvia (*Salvia splendens* Sellow ex Nees) increased with additions of 25 to 50% green waste and sewage sludge compost mixed with a peat substrate (Grigatti et al. 2007). A study with compost mixed in a SPM-based medium has shown that increased height growth of tomatoes (*Solanum lycopersicum* L.) was related to improved water-holding capacity in the substrate (Prasad and Maher 2001). Growth of *Begonia* with compost was found to be comparable to growth in peat (van der Gaag et al. 2007).

Although studies often report positive effects on plant growth with compost as a horticultural substrate, this is not always the case. Compost mixed at high rates (>50%) had negative effects on plant growth, which was associated with increased pH, excessive K availability and reduced N availability (Prasad and Maher 2001). *Cyclamen* plants had few flowers in compost-amended soils compared to SPM-based medium, possibly attributed to low N availability in these composts (van der Gaag et al. 2007). Plant growth of a series of ornamental plants did not differ when grown in 100% composted green waste compared to a soilless medium (Burger et al. 1997).

Vermicompost. Vermicompost refers to a type of compost that is derived from various feedstocks that have been digested by worms and subsequently excreted as castings. The composting process includes both the worm casting process as well as a mesophilic stage where further decomposition continues at elevated heat levels. Several studies have been conducted examining vermicompost as a substitute or addition to traditional peat based potting mixes for greenhouse plant production. Feedstocks for vermicompost include kitchen waste, paper waste (Warman and Anglopez 2010) and animal manures from sheep, cattle and horses (Hidalgo and Harkess 2002). Duration of the composting process has additionally been explored (Warman and Anglopez 2010). Vermicompost has been reported to improve soil fertility via increased organic carbon, nutrients and microbial activity (Adhikary 2012). Improvements in substrate physical condition with vermicompost include decreased bulk density, increased aggregate stability, porosity and water-holding capacity (Adhikary 2012). Mixed plant growth responses have been found with differing quantities of vermicompost amended to a peat-based greenhouse medium. Plant response has included increased growth with vermicompost amendments (Hidalgo and Harkess 2002, Paul and Metzger 2005), no differences compared to a standard medium (Arancon et al. 2004, Lazcano and Dominguez 2010) and decreases in growth (Zaller 2007, Lazcano and Dominguez 2010). Differences in growth rate and amendment have been shown to be influenced by selection of plants being grown (Zaller 2007).

Aerated compost tea. Compost have been utilized to raise and extract microorganisms that are directly applied to horticultural substrates. Under aerobic conditions, this product is called aerated compost tea (ACT) and is supposedly meant to reinvigorate the biology of the substrate after additions. Aerated compost tea is produced by re-circulating water in a brewer containing bagged organic compost and maintaining an aerobic environment, facilitating suspension of microorganisms (bacteria, fungi, flagellates, amoebae, ciliates and nematodes) and mineral nutrients into solution (Litterick et al. 2004). Brew cycles are typically continued for 24 hours after which teas are used to water horticultural or agricultural crops in containers or for field application. Aerated compost tea has been studied for its effects on control of plant diseases with findings of positive suppressive qualities (Scheuerell and Mahaffee 2002, Scheuerell and Mahaffee 2004, Haggag and Saber 2007). Effects of ACT on plant growth have also been studied (Haggag and Saber 2007). Potential benefits of ACT use in horticultural substrates may include improved microbial activity and biomass. However, no studies have examined its efficacy for the use.

Biosolids. Biosolids are solid organic products that are derived from waste water treatment facilities and fit the criteria for use as a recyclable biological product (Agency 1994). Biosolids are commonly used as a fertilizer and or soil conditioner in agricultural (Sanchez-Monedero et al. 2004), horticultural (Lu et al. 2012) and silviculture settings (Henry and Cole 1997). Risk concerns associated with use of biosolids include transmission of human pathogens (Gibbs et al. 1997 , Eastman et al. 2001), accumulation and contamination of heavy metals (Basta and Sloan 1998, Brown et al. 1998, Sanchez-Monedero et al. 2004), and as a source of organic pollutants (Brown et al. 1998, Rufus et al. 1996, Harrison et al. 2006, Clarke and Smith 2011). Due to these concerns, the United States Environmental Protection Agency (EPA) provides guidance and regulations for the land application of biosolids (Agency 1994).

Biosolids have been studied to investigate their suitability as a horticultural substrate for the growing of container-grown woody plants. In these studies, biosolids were composted alone (Hicklenton et al. 2001) or combination with woodchips (Bugbee 2002), sawdust (Zubillaga and Lavado 2001), yard trimmings (Wilson et al. 2001) or pruning waste (Ostos et al. 2008) before being mixed with a peat or bark based medium and utilized for plant production. These studies focused on the effects of the biosolid amendments as they relate to plant growth response and changes to a growing medium's physical and biochemical properties. Plant growth response factors include growth (Bugbee 2002), aerial biomass (Zubillaga and Lavado 2001) foliar nutrient levels (Hicklenton et al. 2001) stem length, leaf area, days to flower and growth index (Wilson et al. 2001) and root and shoot dry weight (Ostos et al. 2008).

Physical and biochemical properties included chemical composition, bulk density, soluble salt, pH, (Hicklenton et al. 2001) electric conductivity (EC), particle density, air filled porosity, container capacity, total porosity (Wilson et al. 2001) organic matter, C/N ratio (Ostos et al. 2008) and leachate potential of heavy metals (Cu, Zn, Pb, Cd) (Xia et al. 2007). Plant response was dependent on the given cultivar under investigation but generally when a peat based media was combined with 25% to 75% biosolids an improvement in growth was observed. In medias that included higher percentages of biosolids (50% to 100%), issues were observed such as chlorosis (Bugbee 2002), decreased moisture contents in media (Wilson et al. 2001) and leaching of nitrate and phosphorus levels that exceeded standards for drinking water (Xia et al. 2007).

Biochar. Biochar is a solid material obtained from thermochemical conversion of biomass in an oxygen-limited environment (Lehmann and Joseph 2015). This process results in the maintenance of high carbon content in the form of aromatic rings in the organic materials. Investigation into biochar has focused on its use as an amendment for improving soil quality and as a long-term carbon sink (Lehmann et al. 2006). Several studies have examined the use of varying amounts biochar as an amendment to traditional soilless medium for nursery or greenhouse plant production.

Biochar addition caused changes to the physical characteristics of soilless medium, such as improving hydraulic conductivity and increasing air porosity (Dumroese et al. 2011). Increases in C/N ratios (Dumroese et al. 2011) pH, bulk densities and electrical conductivities have been observed in biochar-amended peat compared to traditional peat substrates (Vaughn et al. 2013). A biochar-enhanced peat-based medium used to grow poplar (*Populus sp*.) has been shown to have similar CEC and exchangeable K as vermiculite and has been trialed as a replacement. Root biomass has been strongly correlated with CEC and shoot biomass with K uptake in poplars. (Headlee et al. 2014).

Peat-based media enhanced with biochar supplements has been shown to be a suitable substrate for growing a

Table 1. **Biochemical properties of amended substrates at the time of planting. EC is electrical conductivity, TN is total nitrogen, TOC is total organic carbon, C/N is carbon to nitrogen ratio, MBC is microbial biomass carbon, RES is microbial respiration, POX-C is potassium permanganate oxidizable carbon, NULL is no treatment, ACT is aerated compost tea, BC is biochar, WC is wood chips, COM is compost and BS is biosolids.**

Substrate	Parameter							
	pH	EC (uS cm^{-1})	TN (%)	TOC (%)	C/N	MBC (mg kg^{-1})	RES (mg kg^{-1} d^{-1})	POX-C (mg kg^{-1})
NULL	6.47	45.1	0.58	17.0	29.5	548	552	6,605
FERT	6.52	38.2	0.63	20.5	32.7	269	826	6,359
ACT	6.73	31.9	0.44	33.2	76.0	389	843	6,304
BC1	6.83	32.4	0.40	41.4	104.7	308	446	4,506
BC2	6.34	25.6	0.53	43.5	82.4	78	344	3,950
WC	6.71	30.6	0.85	23.3	27.5	617	678	5,832
COM1	6.60	98.4	0.91	14.4	15.8	282	303	4,159
COM2	6.92	70.2	1.30	22.7	17.4	370	483	6,028
COM3	6.07	47.5	1.38	26.7	19.4	106	362	6,888
BS	5.69	57.3	1.17	16.6	14.2	176	528	4,853

diversity of container-grown plants for nursery production (Tian et al. 2012) (Gu et al. 2013, Locke et al. 2013, Headlee et al. 2014, Steiner and Harttung 2014), Nieto et al. 2016). Plants grown in peat-based media enriched with biochar has shown growth performance that is equal to (Gu et al. 2013, Headlee et al. 2014, Steiner and Harttung 2014) or greater (Tian et al. 2012, Nieto et al. 2016) than peat alone. In pine bark media with biochar additions, a positive linear relationship has been observed with increased plant fresh and dry weight with increased quantities of biochar (Gu et al. 2013).

By contrast, a study by Fascella et. al. in 2015 found no significant differences in plant height, number of leaves and shoots produced by 'Serena' euphorbia (*Euphorbia x lomi* Rauh*)* growing in a peat-based media amended with biochar. Media with high biochar additions (45% and 60%) did show increased root length and flower production over the course of their study and found that the total number of marketable plants increased in media with 60% biochar. As was similar in other studies, the bulk density and pH of substrates increased with increased biochar additions (Fascella 2015).

The purpose of this study was to examine efficacy of alternative amendments (WC, COM, BS and BC) to a traditional horticultural substrate made from SPM and CPB. In addition, the effects of adding inorganic fertilizer (FERT) and ACT to the standard horticultural substrate was studied to determine if these additions would make the standard mix more productive for growing trees. The null hypothesis was that substrate quality would not differ with these amendments and consequently tree health and growth would also not differ with alternative amendments as compared to a traditional SPM substrate. An alternative hypothesis is that these amendments may improve substrate quality leading to increased tree performance. Support for alternative amendments (WC, COM, BS and BC) would be attained if either the null or alternative hypothesis were supported with this research. Compared to the NULL treatment, improvements in substrate quality and tree growth and health would be necessary for supporting the use of FERT and/or ACT in horticultural substrates for growing trees.

Materials and Methods

Treatments. Two experiments were conducted to test the stated hypotheses. These experiments included ten treatments as alternative horticultural substrates. The control (NULL) was a 100% potting mix with no nutrient addition. The potting mix contained 40% SPM, 40% CPB, 10% perlite and 10% vermiculite (SunGro Horticulture, Agawam MA). The seven solid treatments included three composts (COM1, COM2 and COM3), a biosolid (BS), two biochars (BC1 and BC2) and a wood chip (WC) substrate, all of which were mixed with potting substrate at a 1:1 volume ratio at planting. The last two treatments were an aerated compost tea (ACT) and an inorganic fertilizer (FERT) added to a 100% potting mix. Biochemical properties of the treated substrates are listed in Table 1.

The three compost treatments were commercially produced products: COM1 (Organomix, Midwest Organics, Inc., McHenry, IL), COM2 (Activated Compost with Microlife, Purple Cow Organics, Inc., Middleton, WI) and COM3 (Wiggleworm Soil Builder, Union Grove, WI). The Midwest Organics product (COM1) is made of leaves, grass, woodchips and cow manure. The Purple Cow product (COM2) is made from leaves, alfalfa fiber, greensand, rock salts, macronutrients, micronutrients and worm castings. The Wiggleworm product (COM3) is made entirely from earthworm castings. Wood chips (WC) were from assorted hardwood trimmings at The Morton Arboretum, Lisle, IL. Tree trimmings were chipped in a wood-chipper, ground in a tub-grinder, and piled for a period of approximately nine months. The pile of wood chips was turned monthly during this period.

The biosolids (BS) were attained from the Downers Grove Sanitary District in Downers Grove, IL. Metal contents of the biosolids met the Illinois Environmental Protection Agency Class A standards for land application. The biosolids contained (mg· kg^{-1} dry weight): 1.5 Ar, 1.9 Cd, 20 Cr, 514 Cu, 25 Pb, 276 Mn, 1.8 Me, 9 Mo, 16 Ni, 4.9 Se, and 440 Zn.

Two biochars were tested in this experiment. The first biochar (BC1) was a by-product of an outdoor biomass gasifier hydronic heater (Chip Energy, Goodfield, IL). The feedstock for BC1 was wood pellet from waste wood (wood pallets, etc.) and gasification temperature was approximately 600 C (1,112 F) for seven to ten days. The second biochar (BC2) was produced from pine feedstock (*Pinus taeda*, *P. palustris*, *P. echinata*, *P. elliotti*) with pyrolysis time of one hour at 550 C (1,022 F) in a pyro-torrefaction style kiln. BC2 was obtained from a commercial producer that is no longer in operation (New Earth Renewable Energy).

Aerated compost tea was made with a KIS compost tea brewer (Keep It Simple, Inc., Redmond, WA). A mesh bag was filled with 500 g (1.1 lbs) of compost (Organomix, Midwest Organics, Inc.) and 500 g (1.1 lbs) of a commercially produced compost tea package consisting of 80% organic nutrients, 20% natural minerals derived from feather meal, bone meal, cottonseed meal, sulfate of potash-magnesia, alfalfa meal, kelp, soy meal, and mycorrhizae (Keep It Simple, Inc., Redmond, WA). The brewer was filled with 19 L (5.02 gal) of water. Humic acid at 25 g (0.88 Oz) and soluble seaweed powder at 25 g (0.88 Oz) were added to the water at the start of the brew (Keep It Simple, Inc., Redmond, WA). During the 24-hour brew cycle, dissolved oxygen, temperature, pH, and electrical conductivity were measured every hour. Dissolved oxygen remained above 6 mg$\cdot$ kg^{-1}, with a mean value of 7 mg$\cdot$ kg^{-1} throughout the brew cycle. Mean temperature, pH, and electrical conductivity were 21 C (69.8 F), 5, and 2,000 μS cm^{-1}, respectively. On average (10 brews) the ACT contained only a fraction of the total number of microorganisms that were in the compost itself: 2,000 μg bacteria g^{-1}, 5 μg fungi$\cdot$ g^{-1} (mean hyphae diameter of 3 μm), 2,000 flagellates g^{-1}, 1,000 amoebae g^{-1}, 10 ciliates g^{-1}, and 0.1 nematodes g^{-1}. The ACT was delivered in nine applications at 0.50 liters (0.13 gal) (*Acer*) and 0.15 liters (0.04 gal) (*Aronia*) on 6/20/11, 7/11/12, 7/28/11, 9/2/11, 4/6/12, 7/25/12, 8/8/12, 8/22/12 and 9/19/12.

The fertilizer (FERT) treatment was 1.2 g (0.04 oz) (*Acer*) and 5.2 g (0.18 oz) (*Aronia*) of NK fertilizer (2.2 kg N$\cdot$100 m^{-2} or 4.5 lbs N$\cdot$1,000 ft^{-2}), which was thoroughly mixed into the potting substrate at planting (ANSI 1998, Smiley et al. 2002). The NK fertilizer (30-0-12) contained 30% total N (15% water insoluble N) from nitroform and urea. The NK fertilizer also contained 12% K from K_2SO_4, 0.10% Fe, 0.05% Mn, 0.05% Cu, and 0.05% Zn.

Experiment I. Experiment I was a full factorial with two species, *Acer saccharum* and 'Viking' chokeberry, ten treatments (including a NULL control) and five replicates for a total of 100 experimental units. Prior to planting, the main roots were pruned to a standardized 10 cm (4 in) length, fine roots ($\leq$2 mm in diameter) removed, and stems were pruned to a 30 cm (11.81 in) length. *Aronia* trees were planted into 11.4 liter (3 gal) containers and *Acer* into 7.6 liter (1 gal) containers. Trees were planted on 6/15/11 and then destructively sampled on 10/30/12. Trees were well-spaced and randomly placed in a Quonset hut at The Morton Arboretum, Lisle, IL USA. Trees were watered weekly throughout the growing seasons at three and two liters for the 11.4 and 7.6 liter containers, respectively. On a bi-weekly basis, all weeds were removed by hand, dried at 60 C (140 F) for three days and mass was determined. No species or treatment differences were observed for weeds during the experiment and total dry weed biomass ranged from 10 to 330 mg per pot.

Measurements of leaf fluorescence were made on 7/7/11, 7/13/11, 7/19/11, 7/25/11, 8/2/11, 8/10/11, 8/17/11, 8/24/11, 9/1/11, 9/7/11, 9/15/11, 9/23/11, 5/9/12, 7/23/12, 8/15/12, 8/28/12 and 9/13/12. On each date, five leaves for each tree were measured with a chlorophyll meter (SPAD-502, Spectrum Technologies, Aurora, IL). At the conclusion of the experiment, trees were carefully separated from the pots and substrates. Tree roots were carefully washed with deionized water to remove all substrate. Roots were photographed and scanned (WinRHIZO software, Regent Instruments, Inc., Quebec, Canada). Trees were partitioned into shoot and root fractions, and both fractions were dried at 60 C (140 F) for five days and weighed to determine biomass in those fractions.

At the conclusion of Experiment I, substrates separated from roots were passed through a 6-mm screen and homogenized for further characterization. The pH and electrical conductivity (EC) in μS cm^{-1} were measured in 1:1 and 1:5 (soil:deionized water) pastes, respectively (Model Orion 5-Star, Thermo Fisher Scientific Inc., Waltham, MA). Total nitrogen (Brown et al 2012) and organic C (TOC) were determined by automated dry combustion with a CN analyzer (Vario ELIII, elementar Analysensysteme, Hanau, GER). Microbial biomass C was measured by chloroform fumigation-extraction (Anderson and Domsch, 1989, Wu et al. 1990) with K_{EC} of 0.38 (Joergensen and Mueller 1996). Base and fumigated samples were extracted with 0.5 M K_2SO_4 and the dissolved organic C in extracts analyzed with a TOC analyzer (Model 1010, OI Analytical, College Station, TX USA). Microbial respiration (RES) was the CO_2 evolution measured during the ten-day aerobic incubations (sans roots), sequestered in NaOH traps, and titrated to a phenophalthein endpoint with 0.25 N standardized HCl (Parkin et al. 1996). Labile C was assessed by measuring permanganate oxidizable C (POX-C) following Weil et al. (2003) and Culman et al. (2012).

Experiment II. Experiment II was a single factorial with ten treatments (including a NULL control) and five replicates for a total of 50 experimental units. In this experiment water retention characteristics of these different substrates without the influence of vegetation were assessed. This drying experiment ran for 32 days beginning on 6/24/13.

Ten substrates were mixed and placed in 11.4 liter containers. For this experiment, ACT was applied only once at the beginning of the experiment. The holes at the bottom of the containers were covered with a thin tissue paper in order to prevent loss of growing medium during the experiment from the bottom of the pot. A 20-cm (7.87 in) long time domain reflectometry (TDR) probe (Soil-Moisture Equipment Corporation, Santa Barbara, CA) was inserted and buried at a 45° angle from the surface. A 2.5 cm (0.98 in) lysimeter (SoilMoisture Equipment Corporation, Santa Barbara, CA) was installed in the pot in a location as to not interfere with the TDR probe and so that the porous cup was centered in the pot at a 10 cm (3.93 in) depth.

After placing substrates and equipment into pots, substrates were hand compacted. Water or compost tea for the ACT treatment was slowly added until full saturation, identified as the point in which the first drops of water ran through the bottom of the pot. The amount of water or ACT added to the substrates to reach full saturation was approximately four liters. The pots were randomly placed on a greenhouse bench and the greenhouse was set at 20 C (68 F) with a light regime of 14 light and 10 dark hours. Daily measurements of mass for water loss, volumetric water content (TRASE, SoilMoisture Equipment Corporation, Santa Barbara, CA) and soil water potential (Infield 7, Soil Measurement Systems, LLC, Tucson, AZ) were made between 8 and 10 am.

At the conclusion of Experiment II, substrates were passed through a 6-mm screen and homogenized. Subsamples weighing 100 g (3.53 oz) were taken from each sample and pooled by treatment. The composite samples were sent to Cornell Soil Health Testing Laboratory for substrate water curve characterization. Soil water release curves were generated to quantify soil water holding capacity. To represent field conditions and the presence of variously sized organic matter particles, soils were passed through an 8 mm (0.3 in) sieve. Sieved soils were divided by sample splitter to achieve homogeneity and broken into five different groups for analysis. Soils were placed on pressure plate cells in rings 7 cm (2.75 in) in diameter. Soils in rings were watered until they reached field capacity. Plates were placed into a pressure plate extractor (Soil Moisture Equipment Corporation, Santa Barbara, CA).

Soil samples in the pressure chambers equilibrated until water stopped escaping the sample. The range of negative pressures used to determine water release characteristics included: -10 kPa, -30 kPa, -100 kPa, -300 kPa and -1500 kPa. Appropriate pressure plate cells extractors were used for each different negative pressure. After samples reached equilibrium, samples were removed and gravimetric water content was measured. Soils were dried for a period of 24 hours at 105 C (221 F) and weighed to determine difference in gravimetric water content. Difference in gravimetric water content between wet and dry were calculated and used to determine water content at each negative pressure for the water release curves and water holding capacity calculations following (Tuller and Or 2004).

Statistical analyses. The effects of treatment on soil and tree properties were individually tested using Standard Least Squares and ANOVA, with treatment as the main effect and species (Experiment I only) as blocking variables. Differences among treatments for each of the tested variables were compared using Tukey-Kramer HSD, α=0.05. Assumptions of normality were tested using a Shapiro-Wilk test ($P>0.05$) and homogeneity of variance tested using a Levene's test ($P>0.05$). When necessary, soil and tree responses were transformed using natural log, square, square root, exponential, and reciprocal functions prior to analyses to address ANOVA violations. A sequential Bonferroni inequality was applied to the critical P-values to control for false positives (Type I error) associated with multiple testing (Rice, 1989). Relationships among soil and tree response were assessed using least squares linear regression and multivariate modeling ($P<0.05$). Statistical analyses were conducted using SAS JMP 7.0 software (SAS Inc., Cary, NC).

Table 2. Probability>F from ANOVA $_{(N,\ df)}$ for treatment $_{(9,\ 9)}$ and species $_{(1,\ 1)}$ and treatment by species $_{(9,9)}$ effects (α=0.05) for tree properties and substrate biochemical properties. Probability>F from ANOVA $_{(N,\ df)}$ for treatment $_{(9,\ 9)}$ and date $_{(34,\ 34)}$ and treatment by date $_{(306,\ 306)}$ effects (α=0.05) for substrate water properties. POX-C is potassium permanganate oxidizable carbon.

Parameter	Treatment	Species	Treatment x Species
Leaf fluorescence (SPAD)	<0.0001	<0.0001	<0.0001
Shoot biomass (g)	<0.0001	<0.0001	0.0044
Root biomass (g)	0.0002	<0.0001	0.0220
Total biomass (g)	<0.0001	<0.0001	0.0052
Root/shoot	<0.0001	<0.0001	<0.0001
pH	<0.0001	0.0126	0.9398
Electrical conductivity (uS cm^{-1})	<0.0001	0.5605	0.2601
Total N (%)	<0.0001	0.8606	0.3052
Total organic C (%)	<0.0001	0.5031	0.9734
C/N	<0.0001	0.2915	0.3397
Microbial biomass C (mg kg^{-1})	<0.0001	0.0002	0.1771
Microbial respiration (mg kg^{-1} d^{-1})	<0.0001	0.5501	0.9261
POX-C (mg kg^{-1})	<0.0001	0.2062	0.7975
Volumetric water content (Θ) (%)	<0.0001	<0.0001	<0.0001
Water tension (Ψ) (kPa)	<0.0001	<0.0001	<0.0001
Water lost (g d^{-1})	<0.0001	<0.0001	<0.0001

Results and Discussion

The goal of this study was to characterize various amendment materials that could be used to supplement traditional greenhouse media for growing of nursery trees. The results and discussion section will interpret substrate biochemical and water properties as well as tree performance parameters to evaluate the efficacy of each alternative amendment for these purposes. Each of these amendments will be compared to the control (NULL) and to other amendments tested in this research.

Wood chips. Compared to other amendments and the NULL, relatively low values for tree biomass and leaf fluorescence were observed for both species with WC treatment (Tables 2 and 3). For example, total biomass was significantly lower for WC compared to FERT, ACT, BC and BS treatments for *Aronia* trees (Fig. 1). However, root/shoot ratios were relatively high for *Acer* trees growing in the WC substrate, albeit not significantly different from the NULL treatment. Although trees growing in the WC treatment may appear less vigorous, it is important to consider that a higher root/shoot ratio may be a better indicator of tree survival once planted in the landscape. A tree with a higher root/shoot ratio might be better positioned to acquire the water and nutrients required by the rest of the plant.

Compared to the NULL treatment, total N, TOC and microbial biomass carbon (MBC) were greater with the WC treatment (Tables 2 and 4). Compared to other treatments and the NULL, labile C and microbial indices

Table 3. **Properties of container-grown trees after 16 months of growing in ten different substrates. Lower-case letters indicate significant differences in using Tukey-Kramer HSD mean separation tests. NULL is no treatment, ACT is aerated compost tea, BC is biochar, WC is wood chips, COM is compost and BS is biosolids.**

Substrate	Leaf fluorescence (SPAD)	Shoot biomass (g)	Root biomass (g)	Total biomass (g)	Root/shoot ratio
Acer saccharum					
NULL	34.4 abcd	28.8 ab	27.2	56.0	0.94 abc
FERT	33.5 bcd	43.9 ab	38.0	81.8	0.86 abcd
ACT	35.1 abc	36.9 ab	32.5	69.4	0.87 abcd
BC1	31.4 cd	26.3 ab	26.3	52.6	1.0 ab
BC2	35.8 abc	33.6 ab	21.9	55.5	0.66 cde
WC	30.4 d	21.2 b	22.1	43.3	1.1 a
COM1	33.3 cd	45.9 ab	27.8	73.7	0.61 de
COM2	37.9 a	40.0 ab	23.3	63.3	0.59 de
COM3	37.8 ab	49.7 ab	32.0	81.8	0.70 bcde
BS	33.3 cd	52.3 a	28.0	80.3	0.53 e
Aronia melanocarpa					
NULL	50.5 b	117.5 abc	75.0 ab	192.6 abc	0.64
FERT	54.2 ab	148.9 ab	91.4 a	240.4 ab	0.61
ACT	49.9 bc	140.4 ab	84.5 a	224.9 ab	0.61
BC1	44.5 d	104.5 bc	68.8 ab	173.2 bc	0.68
BC2	52.1 b	139.4 ab	85.2 a	224.6 ab	0.61
WC	45.7 cd	81.9 c	44.8 b	126.7 c	0.56
COM1	50.0 bc	104.9 bc	60.5 ab	165.4 bc	0.58
COM2	50.7 b	107.9 bc	71.2 ab	179.1 abc	0.68
COM3	54.5 ab	129.6 abc	74.1 ab	203.8 abc	0.57
BS	57.2 a	169.1 a	87.7 a	256.8 a	0.52

tended to be greater with the WC treatment. Values for other soil properties like pH, total C and N with the WC treatment tended to be intermediate compared to other treatments (Table 1). Values for substrate water properties like θ, ψ and water loss with the WC treatment were also intermediate compared to the other the treatments (Tables 2 and 5). In the 32-day drying experiment, θ and ψ in the WC treatment remained relatively constant, with ψ never less than -12 and θ higher than 15% (Fig. 2).

Due to high C/N ratios, N immobilization has been found with incorporation of WC into horticultural medium (Jackson and Wright 2007, Jackson et al. 2008). Associated with N immobilization, Jackson & Wright (2007) found significantly higher soil respiration rates. Respiration rates were greatest with the WC treatment and significantly greater than FERT, BC1, BC2, COM1, COM3 and BS. Although N immobilization was not directly measured, it could help to account for a significant decrease in leaf fluorescence (SPAD) of *Aronia melanocarpa* grown in a wood chip-amended medium.

Overall, these results suggest that substrate properties with the WC do not appear to be unfavorable when compared to the NULL treatment. Wood chips in horticultural substrates might have the ability to supply nutrients and retain water, thus reducing fertilizer and irrigation needs. Successful perennial nursery crop production in WC-amended growing medium has been attributed to increased water holding capacity and decreased substrate air space in medium (Boyer et al. 2008). The relative decrease in plant vigor with WC is concerning, but further study is needed to examine other species responses to wood chips. Wood chips alone or in a blend performed equally as well as CPB but has been shown to be plant species dependent, with some plants showing positive response and others negative (Wright and Browder 2005).

Wood chips should be explored further as alternative amendments to SPM and CPB in horticultural substrates. In particular, experiments with WC in horticultural substrates should examine different types and rates of WC to identify optimal efficacy and more attention should be directed at potential N immobilization. Furthermore, fertilization in combination with WC should be explored to overcome potential N immobilization with WC substrates. Wright et al. (2009) found WC with fertilization to be acceptable substrates for growing annual bedding plants. The supply of WC is likely to be very sustainable. Trimmings from trees and shrubs in urban landscapes are the largest component of municipal solid waste, totaling 25.4 million metric tons in the United States in 2002 (Robert and McKeever 2004). These materials represent an untapped resource that might be recycled and reused as horticultural substrates.

Compost. Three different composts were examined in these experiments and differences in tree performance among the composts and compared to the NULL were minimal. The only tree performance difference observed among the compost treatments was that *Acer* leaves were greener for the COM2 compared to COM1 (Tables 2 and 3). Compared to the NULL the root/shoot ratio was lower for COM1 and COM2.

Conversely, many differences were observed for substrate biochemical and water properties both among the compost treatments and compared to the NULL treatment (Tables 2, 4 and 5). The most striking difference observed was that compared to the NULL, substrate N tended to be higher and C/N tended to be lower for the compost treatments. Aside from the BS treatment, total N contents were highest with the composts. Secondarily, the compost treatments tended to have greater θ compared to the NULL. However, the three composts behaved quite differently in

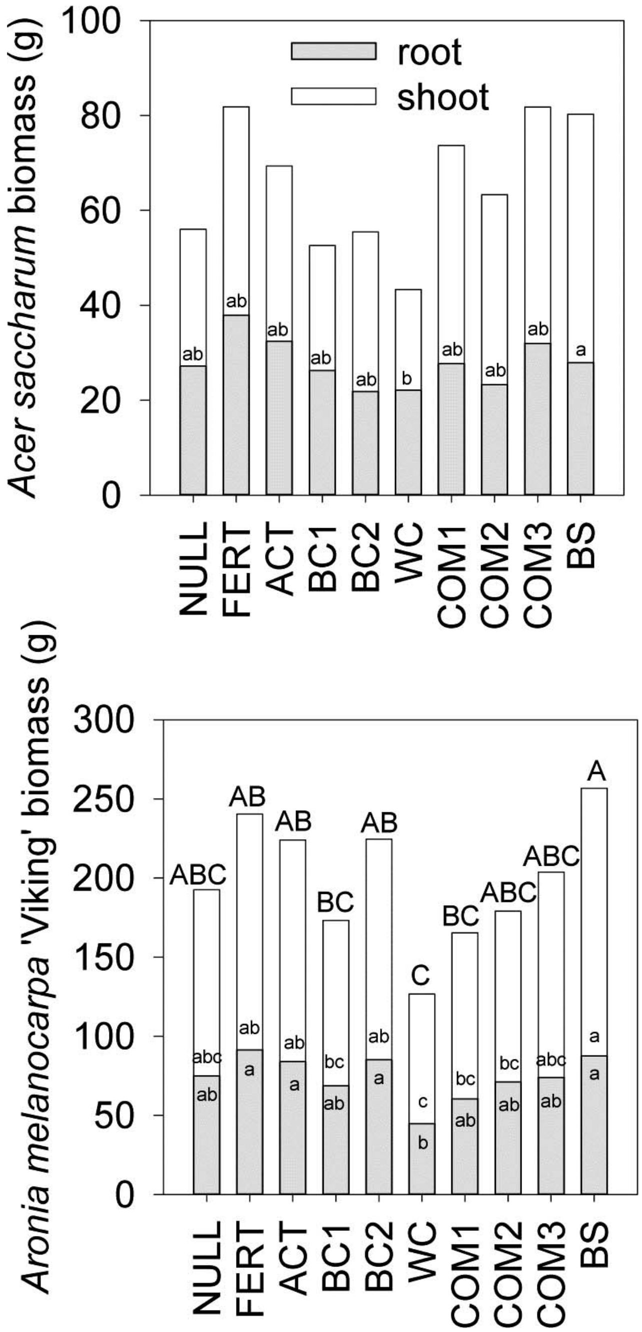

Fig. 1. Root, shoot and total biomass of container-grown *Acer saccharum* and *Aronia melanocarpa* as affected by organic amendments in horticultural substrates. Capital letters indicate significant differences in total biomass using Tukey-Kramer HSD mean separation tests. Lower-case letters indicate significant differences in root or shoot biomass using Tukey-Kramer HSD mean separation tests. NULL is no treatment, ACT is aerated compost tea, BC is biochar, WC is wood chips, COM is compost and BS is biosolids.

the 32-day drying experiment. Both COM1 and COM3 expressed a wide range of ψ while COM2 showing a very narrow range of ψ. The θ for all composts remained above 19%, which was greater than the NULL treatments.

The increase in N and water content with compost treatments might be considered advantageous because it could lead to a reduction in the fertilization and irrigation requirements. However, as noted, no differences were observed comparing biomass and leaf color among the NULL and compost treatments, so it may be that these trees were not limited in N and/or water supply. The increase in soil N with composts might indicate a potential to lose more N via denitrification and/or leaching, both of which would be harmful to the environment.

These results suggest that compost is a viable alternative amendment in horticultural substrates for growing trees. The composts examined in this experiment were derived from a variety of organic materials ranging from cow manure to earthworm castings. The two composts (COM2 and COM3) that included worm castings had higher total N and labile C (POX-C) contents. The cow-manure based compost (COM1) had a greater volumetric water content. More research is needed to determine optimal types and rates of compost amendment in horticultural substrates. Like wood chips, the supply of compost appears to be much more sustainable compared to SPM and CPB amendments in horticultural substrates.

Biochar. The only tree performance differences observed between the two biochars was that the root/shoot ratio was greater for BC1 compared to BC2 and that leaves were greener for BC2 compared to BC1 for *Aronia* (Tables 2 and 3). Leaves were also greener for the NULL treatment compared to BC1 for *Aronia*, but no other differences were observed for tree attributes compared to the biochar treatments. The root/shoot ratios for both species tended to be high for the BC1 treatment. The *Acer* root/shoot ratio for BC1 was significantly greater than BC2, COM1, COM2 and BS. As mentioned with the WC treatment, higher root/shoot ratios might be preferential to help promote tree establishment in the landscape.

Substrate pH was lower and total N was greater with BC2 treatment compared to BC1 (Tables 2 and 4). Both biochar treatments differed substantially in substrate properties compared the NULL treatment. The biochars had greater than twice as much TOC and the C/N ratios were three or more times higher than the NULL substrates. Microbial biomass, respiration and labile C tended to be lower in the biochars compared to the NULL. Consequently, the MBC/TOC ratios were very low with the biochar treatments.

The wood pellet biochar (BC1) had greater mean θ compared to the NULL, and the mean θ was lowest with BC2 (Tables 2 and 5). Water was held tighter (lower ψ) with the biochars compared to the NULL. The BC2 substrate lost less water over the 32-day drying experiment compared to BC1 and NULL treatment (Figure 2). The BC2 substrate held more water at all water tensions, but total WHC was similar for the biochars and NULL treatments. Overall, the water characteristic curves for the both biochars were quite similar to the NULL treatment.

For *Aronia* growing in BC1, a decrease in SPAD was observed compared to NULL and significantly reduced shoot biomass, total biomass and SPAD was observed when compared to BS. These differences might be associated with the reduced TN, the high C/N ratios observed in BC1 and decreased microbial activity indicated

Table 4. **Biochemical properties of treated substrates after 16 months in containers. Lower-case letters indicate significant differences in using Tukey-Kramer HSD mean separation tests. NULL is no treatment, ACT is aerated compost tea, BC is biochar, WC is wood chips, COM is compost and BS is biosolids.**

Substrate	Parameter							
	pH	EC (uS cm^{-1})	TN (%)	TOC (%)	C/N	MBC (mg kg^{-1})	RES (mg kg^{-1} d^{-1})	POX-C (mg kg^{-1})
NULL	6.49 abcd	23.4 cde	0.54 c	18.0 ef	33.1 b	432 bc	633 ab	6,307 a
FERT	6.48 bcd	38.2 bc	0.58 c	18.7 de	32.9 b	413 bcd	624 bc	6,291 a
ACT	6.53 ab	33.3 bcd	0.49 cd	18.3 ef	40.6 b	416 bcd	686 ab	6,342 a
BC1	6.57 ab	19.1 e	0.40 d	40.4 a	103.4 a	375 bcd	473 d	5,044 bc
BC2	6.15 d	24.1 de	0.55 c	43.0 a	78.7 a	205 d	493 cd	4,410 c
WC	6.52 abc	21.0 de	0.77 b	26.2 bc	35.9 b	683 a	899 a	6,661 a
COM1	6.66 ab	47.1 ab	0.92 b	15.5 f	16.9 d	497 abc	486 d	5,466 b
COM2	6.84 a	39.9 ab	1.18 a	22.4 cd	19.0 cd	564 ab	734 ab	6,462 a
COM3	6.17 cd	34.4 bcd	1.35a	28.6 b	21.8 c	315 cd	502 d	6,681 a
BS	5.52 e	95.4 a	1.36 a	19.7 de	14.5 e	520 abc	568 bcd	5,001 bc

by depressed RES, POX-C and MBC/TOC. Biochar quality can be affected by the feedstock used and temperature at which pyrolysis occurs. A main difference in the biochar was the feedstock, with BC1 being from wood pellets and BC2 from pine residues. In addition, BC1 reached a relatively higher temperature [600 C (1,112 F)] compared to BC2 [550 C (1,022 F)]. Increased temperature and wood-based feedstocks have been associated with decreased mineralization and increased fused aromatic rings (Singh et al. 2012). The high C/N ratio of BC1 was the largest of any amended medium and is likely the result of stabilized carbon that is resistant to microbial degradation. Reductions in microbial activity were observed by depressed RES and POX-C levels in BC1. The combined factors of high C/N, low TN and reduced microbial activity could be the reason why *Aronia* growing BC1 had decreased SPAD compared to NULL and significantly reduced shoot biomass, total biomass and SPAD when compared to BS.

Biochars added to greenhouse medium have shown varying responses for plants growing in amended substrates. Plant biomass has been shown to increase in biochar-amended media (Tian et al. 2012) and contrastingly show no increase in plant dry weight but increases in plant height in amended treatments (Vaughn et al. 2013). Although differences were found between biochars and other amendments, the biochars generally performed as well as the NULL treatment in this study. Consequently, both biochars may be suitable alternatives to potting media for trees. However, it appears that BC2, the biochar derived from pine forest residue and at a lower pyrolysis temperature, would be preferred over BC1, the biochar of wood pellet feedstock. In a biochar synthesis study, Spokas et al. (2012) found that biochars of woody plants with lower pyrolysis temperatures more commonly have positive impacts on performance of agronomic crops. Biochars with woody materials as feedstocks and created at lower temperatures tend to retain more of their structure and absorption capacities. The slightly higher N content found in the BC2 substrate compared to the BC1 might also been a result of the lower pyrolysis temperature with this biochar. The main benefit for using biochar in these horticultural mixes appears to be related to water retention. The higher quality biochar (BC2) lost less water and held more water at greater water tensions. The major drawback for utilizing biochar in these horticultural substrates might be the potential for N immobilization that might occur with the relatively high C/N ratios (>79/1) in these substrates. However, it is worthwhile to reiterate, minimal differences were observed in tree performance when comparing biochars to each other and to the NULL treatment.

Biosolids. Of all the treatments, trees in the BS substrate appeared to be the most vigorous and healthy. The highest values for shoot biomass for both species were observed with the BS treatment (Tables 2 and 3). Leaf fluorescence of *Aronia* was highest with BS. Compared to the NULL

Table 5. **Substrate water properties of treated substrates over 32 days. Lower-case letters indicate significant differences in using Tukey-Kramer HSD mean separation tests. Ψ is water potential, Θ is volumetric water content, WHC is water-holding capacity, NULL is no treatment, ACT is aerated compost tea, BC is biochar, WC is wood chips, COM is compost and BS is biosolids.**

Substrate	Parameter								
	Mean Θ (%)	Mean Ψ (kPa)	Water lost (g d^{-1})	Θ (-10 kPa)	Θ (-30 kPa)	Θ (-100 kPa)	Θ (-500 kPa)	Θ (-1,500 kPa)	WHC (%)
NULL	20.8 f	-6.12 bc	43.8 a	17.6	13.30	9.17	8.22	7.96	9.68
FERT	21.3 ef	-6.74 cd	42.2 a	16.5	13.50	9.36	7.46	7.23	9.32
ACT	21.1 ef	-6.76 cd	44.0 a	18.4	13.00	9.22	7.62	7.41	10.90
BC1	22.4 de	-8.63 de	40.6 a	16.7	12.90	10.10	7.56	6.49	10.20
BC2	14.3 g	-7.52 de	33.0 bc	23.0	15.25	12.90	12.50	12.20	10.80
WC	21.2 ef	-5.58 bc	33.7 b	23.0	18.50	14.90	13.50	12.40	10.50
COM1	29.4 b	-8.54 ef	38.9 ab	14.9	11.80	9.58	8.41	7.64	7.25
COM2	23.9 d	-4.85 ab	38.8 ab	15.1	13.30	10.80	9.87	9.49	5.58
COM3	27.0 c	-9.65 f	44.1 a	19.3	16.50	13.00	12.60	12.10	7.18
BS	33.4 a	-3.77 a	27.2 c	20.9	17.30	14.90	12.60	11.50	9.50

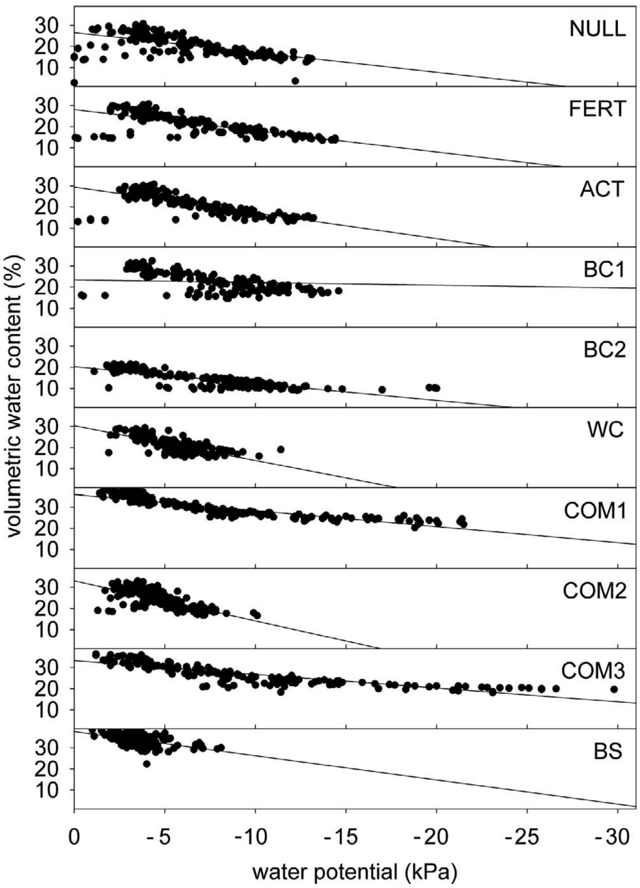

Fig. 2. Substrate moisture characteristic curves for ten treated substrates over the 32-day drying experiment. NULL is no treatment, ACT is aerated compost tea, BC is biochar, WC is wood chips, COM is compost and BS is biosolids.

treatment, leaves of *Aronia* were significantly greener with BS and root/shoot ratio was lower with *Acer*. Many substrate differences were observed comparing BS to the NULL treatment (Tables 2, 4 and 5). Substrate pH was lower, EC was higher, total N was higher, C/N ratio was lower, POX-C was lower, θ was higher, ψ was lower and total water lost was lower with BS compared to the NULL treatment. The water characteristic curve for the BS varied very little over the 32-day drying experiment, ψ never dropped below -8 kPa and θ never dropped below 20% (Figure 2).

As with the composts, the increase in N and water content with BS treatment might be considered advantageous because it could lead to a reduction in the fertilization and irrigation requirements. However, as with the compost treatments, few differences were observed comparing biomass and leaf color among the treatments, so it may be that these trees were not limited in N and/or water supply. In which case, the increase in soil N with BS might indicate a potential negative impact to the environment via denitrification and/or leaching. However, the additional N with the BS might also be immobilized in the microbial population and then slowly released through mineralization. Microbial biomass C tended to be relatively high for BS, suggesting immobilization as a potential mechanism to retain at least a portion of the N from the BS. The BS substrate had a relatively low pH and high EC. However, these values are of minor concern considering they fall within optimal values for container substrates for pH and EC (Yeager et al. 2000).

Substrates with BS have been shown to increase available and total N (Kahn et al. 2005) (Klock-Moore 1999) and decrease pH (Freeman and Cawthon 1999). Increased shoot dry weight and plant height have also been observed with BS amendments (Freeman and Cawthon 1999), including a linear relationship with increased proportions of BS in the medium (Klock-Moore 1999). Additionally, BS compost caused an increase in plant height, plant diameter, leaf area and flower production of *Petunia* and an increase in plant height and aerial biomass of *Vinca* (Zubillaga and Lavado 2001) compared to a traditional peat based substrate. However increased tree performance with BS substrates is not always the case. Roberts (2006) did not find that BS had a significant effect on height, growth and/or biomass (leaf, stem and roots) of container-grown *Acer rubrum* and *Acer saccharum*.

Compost tea and fertilization. Tree performance and substrate properties did not differ with compost tea compared to the NULL treatments (Tables 2, 3, 4 and 5). These results suggest that compost tea did not improve the substrate properties nor provide any observable benefits to the trees growing in them. Minimal evidence has been found for positive effects of compost teas on substrates and trees, so the compost tea findings are not surprising. Scharenbroch (2013) found compost tea to have no effect on tree performance of *Acer saccharum* and *Quercus macrocarpa* growing in three urban soil conditions (Scharenbroch et al. 2013).

The one-time fertilization mixed in the pots at the beginning of the experiments at 2.2 kg N 100 m^{-2} (4.5 lbs N 1000 ft^{-2}) produced no significant differences in tree attributes or substrate properties compared to the NULL treatment. The findings with the fertilizer were unexpected since they are so commonly applied to horticultural substrates with the intent of improving soil fertility and plant performance. A couple of explanations are proposed to explain these findings. First, the N added in the fertilizer might have been immobilized by the microbial population or lost via leaching and/or volatilization before the trees could acquire the nutrients. Immobilization is likely not a valid explanation since MBC values for the FERT treatment were relatively low. The N added in the FERT was as nitroform and urea, which are considered slow-release, but losses can still occur with this N. A second explanation is that the amount of N added in the fertilizer was not sufficient enough to produce significant tree response differences compared to other treatments. Total N content of the treated substrate at the beginning of the experiment in the FERT treatment was 0.63% compared to 0.58% in the NULL treatment, which is a relatively small change. In comparison, total N content for the compost and BS treatments at the beginning of the experiment ranged from 0.91 to 1.38%. It should be noted however that these measurements are TN and the amount of available N was not directly measured in this experiment.

As mentioned, tree performance appeared to the greatest with the BS treatment. It is likely that this increased tree performance with BS was in part linked to increased fertility. However, the increased tree performance with the BS is not likely solely linked to increased fertility. In fact, no significant correlations were detected between total N and leaf fluorescence, shoot biomass, root biomass or total biomass. Significant differences in substrate water properties were also observed with BS and other organic amendments and it is likely the overall increase in substrate quality (chemical, physical and biological properties) is driving improved tree performance. Fertilization only addresses chemical properties and does not directly improve substrate biological and physical properties like microbial populations and water retention.

These results suggest that the overall quality of horticultural substrates can be better improved with organic amendments, such as composts and BS, compared to ACT or FERT. After 16 months and compared to the NULL, FERT and ACT had no effect on substrate chemical, physical and biological properties. Conversely, many of the organic amendments led to relatively long-lasting (16 months) improvements in substrate quality compared to the NULL, FERT and ACT treatments. The costs (monetary and/or environmental) associated with inorganic fertilizers and the energy and labor required to make compost tea does not provide the sufficient return on investment to justify the use of these materials in substrates for growing trees (Scharenbroch and Watson 2014).

The results of this study demonstrate a range of amendments and their suitability as alternative additions to horticultural substrates. In conclusion, this study has shown that many of the organic amendments performed well and in some cases better than the traditional SPM and CPB horticultural substrate for growing trees. The biochar treatments tended to perform as well as the NULL for most response parameters. The composts tended to show slight improvement in tree and substrate properties compared to the NULL treatment. Biosolids had generally improved tree and substrate responses compared to the NULL. Tree responses with WC were generally low, but substrate properties showed favorable responses. Fertilization and compost tea added to the traditional SPM and CPB mix did not lead to any significant differences compared to the NULL. More research is needed to test these materials and other organic amendments as alternatives to SPM and CPB in horticultural substrates. Future research should examine a wider range of tree species with these substrates. Additional study is also suggested to ensure use of these alternative amendments in horticultural substrates is economically feasible and profitable. These results are promising, considering the future supply of SPM and CPB is in question and the potential environmental degradation associated with the harvest of these materials. Finding appropriate alternative and additional uses of organic residuals, like wood chips, composts, biosolids and biochar is considered positive for the environment. Many of these materials end up in landfills and their use as horticultural substrates might help to alleviate filling of landfills.

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