Growing Media for the Nursery Industry: Use of Amendments in Traditional Bark-Based Media

S.L. Warren and T.E. Bilderback
North Carolina State University
Department of Horticultural Science
Raleigh, North Carolina
USA

J.S. Owen, Jr.
Oregon State University
North Willamette Res. and Ext. Center
Aurora, Oregon
USA

Keywords: bark, substrate amendment, physical properties, chemical properties

Abstract

Bark may become a limited resource due to a changing timber industry in conjunction with its use as an effective energy source. Identifying alternative components that can be used as substrate supplements to extend bark supplies may be one of the better solutions as this should require minimal changes in current nursery production practices. Two experiments consisting of pine bark amended with four rates [0, 15, 30, and 45% (by vol.)] of composted cotton stalks/swine waste (CCSW) or composted residential household waste (Fluff®) were conducted to identify materials to serve as alternative components. No micronutrients or dolomitic limestone amendments were added to these substrates. For comparison to a common commercial substrate, 8 pine bark: 1 sand (by vol.) (PBS) was amended with 0.9 kg m^{-3} dolomitic limestone and 0.7 kg m^{-3} micronutrient fertilizer. *Cotoneaster dammeri* C.K. Schneid. 'Stogholm' (cotoneaster) was grown for 19 weeks. All substrates were top-dressed with 5 g N per container with a commercial controlled release fertilizer (CRF). Top dry weight of cotoneaster increased linearly with increasing rates of CCSW. Top dry weight of cotoneaster grown in 15, 30, and 45% CCSW was significantly greater than cotoneaster grown in PBS. Substrate solution pH was maintained between 5.3 and 6.1 throughout the season in all substrates. Electrical conductivity increased linearly with increasing rate of CCSW, with the highest EC of 2.81 dS m^{-1} recorded at 15 days after initiation (DAI). CCSW could replace the micronutrient fertilizer, dolomitic limestone and phosphorus in the CRF. Total porosity, container capacity, available, and unavailable water increased linearly with increasing rate of CCSW. Top and root dry weight of cotoneaster were unaffected by rate of Fluff®, nor were there any significant differences from PBS. Substrate solution pH increased linearly with increasing rates of Fluff®. Electrical conductivity increased with increasing rate of Fluff®, with the highest EC of 1.7 dS m^{-1} recorded at 15 DAI. Fluff® was able to replace the micronutrient fertilizer and dolomitic limestone. Physical properties were unaffected by rate of Fluff®. Adding Fluff® helped to maintain structural integrity of the substrate during the study.

INTRODUCTION

Peat moss and softwood bark have been the backbone of containerized nursery stock substrates for decades. Both softwood bark and peat have evolved over the years resulting in substrates with improved physical and chemical properties to maximize crop growth (Tables 1 and 2). Today, the evolution of these substrates continues due to external forces, and not necessarily production needs. Peat is perceived as a limited natural resource which requires the industry to look at alternative materials to be used as a substitution or extender (Riviere et al., 2008). Bark, like peat, may become a limited resource due to a changing timber industry in conjunction with a shift to bark being used as an energy source (Wenliang et al., 2006). The similar evolutions of these two major substrate components have resulted in the testing and use of alternative materials which can be used to extend peat or bark supplies. Identifying alternative components that can be used as substrate supplements to extend bark and peat supplies may be one of the better solutions as this should require minimal changes in current nursery production practices.

Most materials that might be used as substrate extenders fall into one of two categories: organic or inorganic. Many studies have investigated the use of organic materials as extenders for peat moss and bark including animal, cotton gin, wood by-products, municipal leaf and sewage sludge, rice hulls, and spent mushroom compost. These materials require composting commonly before the materials have acceptable physical and chemical properties. Most composted organic materials have similar positive attributes consisting of (1) high water holding capacity (WHC), (2) plant available P, Ca, Mg, and micronutrients; and (3) can raise substrate pH. Concerns with using this material are high levels of electrical conductivity (EC), pH, and WHC. These concerns usually can be ameliorated by adjusting the rate of amendment. To examine the positive and negative attributes of substrate amended with composted organic material we used a composted combination of cotton stalks and swine waste.

The average American produces over 1.6 kg of solid waste per day with the production of garbage estimated to increase by 5% per year. The use of recycled municipal waste in container production would provide the nursery industry with an inorganic substrate amendment of unlimited supply. However, municipal garbage is not one of the first alternatives that come to mind. The merits of using composted household garbage were not evident when studies began, and there were considerable doubts that a composted residential household waste could be used as a substrate extender. On the surface, the problems with such a material seemed endless. To examine the positive and negative attributes of substrate amended with composted inorganic material we used a composted residential household waste.

MATERIALS AND METHODS

Composted Cotton Stalks/Swine Waste (CCSW)

This study, a randomized complete block design with four replications and five plants per replication, was conducted on a gravel pad at North Carolina State University, Raleigh. The treatments were aged (~1 year) pine bark (<1.3 cm) amended with four rates [0, 15, 30, and 45% (by vol.)] of composted cotton stalks/swine waste (CCSW). No micro-nutrients or dolomitic limestone amendments were added. For comparison to a commercial substrate, 8 pine bark: 1 sand (by vol.) (PBS) was amended with 0.9 kg m^{-3} dolomitic limestone and 0.7 kg m^{-3} micronutrient fertilizer (MicroMax, The Scotts Co., Maryville, OH). All plants were top-dressed with 5 g N per container with a commercial controlled release fertilizer (CRF) (17N-2.2P-8.2K, 6 month CRF, Purcell Technologies, Sylacauga, AL).

Uniform rooted cuttings of *Cotoneaster dammeri* C.K. Schneid. 'Stogholm' (cotoneaster) were potted into 3.8 L containers on 15 April 2005. Irrigation volume to maintain a 0.2 leaching fraction (LF = irrigation volume leached ÷ irrigation volume applied) was applied via overhead irrigation daily. Leaching fraction for each treatment/ replication was determined weekly and adjusted accordingly. Irrigation water contained NO_3-N, NH_4-N, phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and alkalinity at 0.10, 0.96, 0.5, 7.0, 10.0, 4.0, and 20.0 mg L^{-1} respectively, with a pH of 7.4. After 19 weeks, roots were washed free of substrate and each plant was separated into tops and roots. Dry weights were obtained following drying at 65°C until plant weight remained unchanged. Leaves of plants were ground separately via a Foss Tecator Cyclotec™ 1093 sample mill (Analytical Instruments, LLC, Golden Valley, Minn.) to pass ≤0.5 mm sieve. Mineral nutrient [nitrogen (N), P, K, Ca, Mg, sulfur (S), boron (B), copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn)] analysis of leaves was conducted by the North Carolina Department of Agriculture (NCDA), Raleigh. Nitrogen concentrations were determined by oxygen combustion with an elemental analyzer (NA 1500, CE Elantech Instruments, Milan, Italy). All other mineral nutrient concentrations were determined by EPA Method 200.7 with an ICP spectrophotometer (Optima 3300 DV ICP Emission Spectrometer; Perkin Elmer Corp., Wellesley, Mass.), following open-vessel nitric acid (HNO_3) digestion in a microwave digestion system (CEM Corp., Matthews, NC).

Physical property analyses were conducted at the Horticultural Substrates Laboratory, Department of Horticultural Science, N. C. State Univ., Raleigh. On 15 April 2005, fourteen 347.5 cm^3 cylindrical aluminum rings (7.6 cm dia, 7.6 cm ht) and fourteen 101.4 cm^3 cylindrical aluminum rings (7.6 cm dia., 2.2 cm ht) of each substrate were inserted into individual 3.8 L fallow containers and placed on a simulated nursery pad under micro-irrigation. After 9 weeks seven 347.5 cm^3 cylinders and seven 101.4 cm^3 cylinders with intact, naturally compacted substrates were extracted. Physical properties [total porosity (TP), air space (AS), container capacity (CC), available water (AW), unavailable water (UW), and bulk density (D_b)] were determined as described by Tyler et al. (1993). The same analyzes were conducted at the end of the study (19 weeks) with the remaining seven aluminum rings.

Substrate solution samples were collected at 15, 45, 75, 105 and 135 days after treatment initiation (DAI) using the pour through nutrient extraction procedure (Wright, 1986). Substrate solution pH and EC measurements were obtained using an Acument pH/eV benchtop meter (Fischer Scientific, Springfield, N.J.). The substrate solutions collected at 15, 75, and 135 DAI were analyzed for mineral nutrient concentrations (N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, Zn, and Na) by the NCDA. All variables were tested for differences using regression analysis [SAS version 8.01 (SAS Inst. Inc., Cary, NC)]. The control substrate (8 pine bark: 1 sand) was separated from the CCSW amended substrates via Dunnett's test, P=0.05.

Composted Residential Household Waste (Fluff®)

Fluff® is a composted residential household waste (Bouldin and Lawson, McMinnville, TN). The study was conducted on a gravel pad at N. C. State University, Raleigh. The experiment consisted of four treatments in a randomized complete block design with four replications and 10 plants in each replication. The treatments were aged pine bark (<1.3 cm) amended with four rates [0, 15, 30, and 45% (by vol)] of Fluff®. No micronutrients or dolomitic limestone amendments were added. For comparison to a common commercial substrate, 40 containers of 8 pine bark: 1 sand (by vol.) were amended on a m^3 basis with 0.9 kg dolomitic limestone and 0.7 kg micronutrient fertilizer (MicroMax) and incorporated into the compost rate design. All plants were top-dressed with 5 g N per container with a commercial CRF (17N-2.2P-8.2K, 6 month CRF, Purcell Technologies).

Uniform rooted cuttings of cotoneaster were potted into 3.8 L containers on 15 April 2005. Irrigation; physical properties; substrate solution samples; cotoneaster harvesting, and mineral nutrient analysis; statistical analysis were identical to CCSW.

RESULTS AND DISCUSSION

Composted Cotton Stalks/Swine Waste Compost (CCSW)

Top dry weight of cotoneaster increased linearly with increasing rate of CCSW, whereas root dry weight increased quadratically with increasing CCSW (Table 3). In addition, top dry weight of cotoneaster grown in 15, 30, and 45% CCSW was significantly greater than cotoneaster grown in PBS, a traditional pine bark substrate.

Foliar N and K concentration were unaffected by CCSW nor were there any differences from the control (PBS) indicating the compost did not release enough N and K during the growing season to affect plant nutrient concentration (data not presented). In contrast, foliar P concentration increased linearly with increasing CCSW (Table 4). Also, foliar P concentration of cotoneaster grown in 15, 30, and 45% CCSW was greater than the foliar P concentration of cotoneaster grown in PBS. Composted organic materials typically are an excellent source of P. Similarly, foliar Ca and Mg concentration increased linearly with increasing CCSW and both foliar Ca and Mg concentration of cotoneaster grown in 30 and 45% CCSW were significantly greater than the foliar Ca and Mg concentration of cotoneaster grown in the control. Thus, CCSW proved to be an adequate source of Ca and Mg as no limestone was added to these treatments.

Foliar Cu concentration of cotoneaster increased linearly with increasing rate of CCSW, whereas foliar Fe and Mn decreased with increasing rate of CCSW. Foliar Cu concentrations of cotoneaster grown in 0 and 15% CCSW were significantly lower than the control. Thus, it required ≥30% CCSW to provide Cu on an equivalent basis to MicroMax. Foliar Fe and Mn concentrations grown in 15 and 30%, and 0, 15, 30, and 45%, respectively were significantly lower than the foliar Fe and Mn concentration of the control plants. These results might be cause for concern had not top growth increased with increasing CCSW and cotoneaster grown in 15, 30, and 45% were significantly larger that the control. The decreasing foliar Fe and Mn concentrations could be a result of dilution with increasing growth. Foliar concentration of S (mean=1.2 mg g^{-1}), B (mean=53 µg g^{-1}), and Zn (mean=53 µg g^{-1}) were unaffected by CCSW nor were they significantly different from the control (data not presented).

At 15 and 45 DAI, pH of the substrate solution increased linearly with increasing rates of CCSW, whereas at 75, 105, and 135 DAI, pH was unaffected by CCSW (Table 5). Increasing pH with increasing rate CCSW may have accounted for the decreasing foliar Fe and Mn concentration with increasing CCSW, as substrate solution Fe and Mn concentration usually decrease with increasing pH. Except for minor differences between the CCSW substrates and the control at 15 DAI, pH was maintained between 5.3 and 6.1 throughout the season which is ideal. Peterson (1981) reported nutrient availability in organic container substrate is optimal at a pH range of 5.0 to 6.0. These data indicated that CCSW amended pine bark at rates as low as 15% will provide equivalent liming equivalencies as 0.9 kg m^{-3} dolomitic limestone.

Electrical conductivity increased with increasing rate of CCSW at all sample times except 75 DAI (Table 5). This increase in EC may also be responsible for the increase in top growth with increasing rate of CCSW. The highest EC was 2.81 dS m^{-1} recorded at 15 DAI. When using composts which include animal waste EC needs to be monitored in the early part of the season as high EC levels can be a problem. During the growing season, an EC range of 0.5 dS m^{-1} to 2.0 dS m^{-1} is considered appropriate assuming the EC is representative of all essential elements being present.

At 15 DAI, substrate total N solution concentration increased with increasing rate of CCSW with 15, 30, and 45% CCSW greater than PBS (Table 6). At 45 and 135 DAI, substrate total N solution concentration was unaffected by CCSW nor were there any differences from PBS indicating CCSW was no longer releasing significant N. However, substrate P, K, Ca, Mg, S, B, Cu, Zn, and Na increased linearly with increasing rate of CCSW at all sample dates. Significance from PBS varied with rate of CCSW and nutrient. This data supports the ability of CCSW to replace the micro-nutrient fertilizer and dolomitic limestone.

Total porosity, CC, AW, and UW increased with increasing rate of CCSW (Table 7). In addition, all substrates amended with CCSW had greater TP and less AW compared to the control. In contrast, AS and D_b decreased with increasing rate of CCSW. Air space was greater and D_b was less in CCSW amended substrates compared to the control.

The key to engineering substrates for optimal physical properties relies on maintaining a balance particularly between AS and AW. A 20 to 30% AS is preferred for nursery size containers (Yeager et al., 2007). Thus, AS for 0% CCSW was very high at 63 DAI (33% AS) and barely inside the range at 135 DAI (30%). In contrast, PBS was on the low end of the range at both 63 (23% AS) and 135 DAI (21%). Air space for 15, 30, and 45% amended substrate fell between 0% CCSW and the control. As AS decreases in substrates during a growing season, a reciprocal increase in CC usually occurs. Except for 45% CCSW which remained unchanged, these substrates increased 3 to 5% in CC from 63 to 135 DAI which was associated with the decline in AS. However, CC remained within normal ranges. Most organic based substrates including pine bark decrease in AS during production conditions with adequate irrigation and fertilizer application.

At 63 DAI, 0, 15, and 30% CCSW had lower AW compared to the control. At 135 DAI, all CCSW amended substrates had lower AW than the control. D_b decreased linearly with increasing rate of CCSW (Table 7). Bulk density of all CCSW substrates was significantly lower than PBS. Changes in D_b reflect the stability of substrate components. The D_b of all CCSW amended substrates decreased 4 to 9% from 63 to 135 DAI indicating the particles were decomposing and reducing the volume of the substrate, whereas the PBS substrate changed very little from 63 to 135 DAI illustrating the advantage of amending an organic material with an inorganic aggregate such as sand.

As illustrated with CCSW data, organic components decompose over time, which can produce unacceptable physical properties. One solution is to add inorganic components such as perlite, pumice, sand, or calcined clay which are stable and decompose little when used in potting substrates. Blending these stable components with organic components can decrease changes in physical properties over time by dilution. This, in turn, preserves the number of large pores, thus helping to maintain structural integrity of the substrate.

Composted Household Waste Compost (Fluff®)

Top and root dry weight of cotoneaster were unaffected by rate of Fluff® nor were there any significant differences from PBS (data not presented). Likewise, foliar N, P, and K concentration of cotoneaster were unaffected by Fluff® nor were there any differences from the control (8 pine bark: 1 sand) (Table 8). Thus, Fluff® provided minimal plant available N, P and K. In contrast, foliar Ca concentration increased linearly with increasing Fluff®. Also, foliar Ca concentration of cotoneaster grown in 15, 30, and 45% Fluff® was greater than the foliar Ca concentration of cotoneaster grown in pine bark: sand. However, foliar Mg concentration was unaffected by rate of Fluff® nor where there any significant differences from PBS. Thus, Fluff® proved to be an adequate source of Ca and Mg as no limestone was added to these treatments.

Similarly to results from CCSW, foliar B, Cu, and Zn concentration of cotoneaster increased linearly with increasing rate of Fluff®, whereas foliar Mn decreased with increasing rate of Fluff®. However, only foliar Zn concentration of cotoneaster grown with 30 and 45% Fluff® and foliar Mn Concentration at all rates of Fluff® were significantly different from PBS. Foliar concentration of S (mean=1.1 mg g^{-1}), Fe (mean=66 µg g^{-1}), and Na (mean=1.4 mg g^{-1}) were unaffected by Fluff® nor were they significantly different from PBS (data not presented).

At all sample dates, pH of the substrate solution increased linearly with increasing rates of Fluff® (Table 9). Increasing pH with increasing rates of Fluff® may have accounted for the decreasing foliar Mn concentration with increasing Fluff® as substrate solution Mn usually decreases with increasing pH. Pine bark (0% Fluff®) and 15% Fluff® remained within optimal pH (5.2 to 6.2) during the experiment, however the 30% Fluff® substrate was initially above 6.2 and the 45% Fluff® remained over 6.2 for the duration of the study even though pH tended to decrease overtime. Therefore, management to optimize pH for higher rates of Fluff® may include incorporated elemental sulfur or iron sulfate to equilibrate alkaline cations. These data indicate that Fluff® amended PB at rates as low as 15% will provide equivalent liming as 0.9 kg m^{-3} dolomitic limestone.

Electrical conductivity increased with increasing rate of Fluff® at all sample times (Table 9). The highest EC was 1.7 dS m^{-1} recorded at 15 DAI. In contrast to the organic compost (CCSW), EC should not be problem with the inorganic component. During the growing season, an EC range of 0.5 dS m^{-1} to 2.0 dS m^{-1} is considered appropriate assuming the EC is representative of all essential elements being present.

At 15 DAI, substrate nutrient concentrations of all nutrients except P increased linearly with increasing rates of Fluff® (Table 10). However by 75 DAI, only total N, K, Ca, S, Cu, Fe, and Na solution concentration increased with increasing rate of Fluff®. By 135 DAI, all substrate nutrient concentrations except Cu and Mn were unaffected by rates of Fluff®. Substrate solution nutrient concentrations that were significantly different from PBS varied with rate of Fluff® and nutrient. These data support the ability of Fluff® to replace the micronutrient fertilizer and dolomitic limestone.

All of the physical properties except D_b were unaffected by rate of Fluff® (data not presented). However, total porosity, CC, AS, and UW of the Fluff® amended substrates were significantly greater than the control substrate, whereas AW and D_b of the Fluff® amended substrates were significantly less than PBS (data not presented).

Air space at 135 DAI for 0% Fluff® and PBS at 23 and 20%, respectively, was marginally low for optimal plant growth. Most organic based substrates including PB decrease in AS during production conditions due to decomposition. In contrast, the 15% Fluff® substrate increased from 31 to 32% AS, 45% Fluff® was essentially unchanged in AS and 30% Fluff® decreased 1% during the experimental period. Thus, Fluff® provided stability to the substrate throughout the entire production cycle. Unlike most compost which consist mainly of organic materials, there may be enough inorganic material, i.e. plastics in Fluff® to provide some stability. The 45% Fluff® had the most consistent physical properties most likely due to the dilution of the PB.

Even though substrates amended with Fluff® had lower AW than the control, it did not take more water to produce an equivalent size plant. Water required to produce the plants during the study (mean=2695 ml) was unaffected by rate of Fluff® nor were they significantly different from the control (data not presented). Physical properties of the aged PB used in this study benefited by the addition of Fluff®. A 45% addition of Fluff® to PB provided nearly optimal physical properties and appeared to be the most stable with the least physical property changes compared to the other test substrates.

CONCLUSIONS

Both CCSW and Fluff® can be used to extend pine bark substrates. In this case both these materials provided adequate micronutrients, Ca, Mg and pH adjustment. However, while CCSW may serve as additional source of nutrients growers should be diligent about checking EC levels as they could be excessive. CCSW will decompose similarly to the traditional substrates which could lead to degrading physical properties. Fluff® while providing minimal N, P, and K aided in maintaining acceptable physical properties during the production cycle.

Literature Cited

Bilderback, T.E., Warren, S.L., Owen, J.S. and Albano, J.P. 2005. Healthy substrates need physicals too! HortTechnology 15:747-751.

Peterson, J.C. 1981. Modify your pH perspective. Florists' Rev. 169:34-35, 92-93.

Riviere, L.-M., Michel, J-C. and Charpentier, S. 2008. Growing media in horticulture. Acta Hort. 779:33-38.

Wenliang, Lu, Sibley, J.L., Gilliam, C.H., Bannon, J.S. and Zhang, Y. 2006. Estimation of U.S. Bark Generation and Implications for Horticultural Industries. J. Environ. Hort. 24:29-34.

Yeager, T.H., Gilliam, C.H., Bilderback, T.E., Fare, D.C., Niemiera, A.X., Tilt, K.M. and Warren, S.L. 2007. Best management practices guide for producing container-grown plants. Southern Nurs. Assoc., Marietta, Ga.

Tables

Table 1. Physical properties of common soilless substrates.

Bark	Total porosity (%)	Air space (%)	Container capacity (%)	Available water (%)	Unavailable water (%)	Bulk density ($g\cdot cm^{-3}$)
Pine bark	87	25	61	26	36	0.19
Pine bark: sand (8:1)	83	26	57	23	34	0.32
Peat moss	90	18	71	-	-	0.10
Peat moss: perlite (1:1)	86	29	56	-	-	0.15
Fir bark	85	23	62	37	25	0.25
Fir bark:peat:	83	20	65	37	25	0.25
pumice (5:3:2)	84	21	63	37	26	0.25
Target range	50-85	10-30	45-65	25-35	25-35	0.19-0.27

Bilderback et al., 2005.

Table 2. Chemical properties of pine bark, composted cotton stalks/swine waste (CCSW), and Fluff®.

	--------------------- $mg\cdot g^{-1}$ ---------------------						$dS\ m^{-1}$
Pine bark	4	1	1	4	1	1	2.3
CCSW	58	17	13	28	11	3	3.7
Fluff®	-	0.01	3	0.2	0.4	0.003	4.0
	Fe	Mn	Zn	Cu	B	Na	pH
	---------------------- $\mu g\cdot g^{-1}$ ----------------------						
Pine bark	1442	62	34	5	8	313	4.1
CCSW	2331	368	671	384	25	1022	6.8
Fluff®	6	4	3	1	2	642	7.8

[z]EC=electrical conductivity.

Table 3. Effect of pine bark amended with cotton stalk/swine compost (CCSW) on top and root dry weight of Skogholm cotoneaster.

CCSW	Top dry weight	Root dry weight
% by vol.	--------------------- g	---------------------
0	88	19
15	107*[z]	18
30	107*	18
45	121*	23*
8:1[y]	95	19
Significance[x]		
Linear	***	*
Quadratic	NS	**

[z]*Significantly different from the 8:1 substrate based on mean separation by Dunnett's test, P=0.05.

[y]8 pine bark: 1 sand substrate. This substrate not included in regression analysis.

[x]NS, *, **, *** nonsignificant or $P\leq0.05$, $P\leq0.01$, $P\leq0.001$, respectively.

Table 4. Effect of pine bark amended with cotton stalk/swine compost (CCSW) on foliar mineral nutrient concentration of cotoneaster.

CCSW	P	Ca	Mg	Cu	Fe	Mn	Na
% by vol.	----------- $mg \cdot g^{-1}$		-------------	------------ $\mu g \cdot g^{-1}$		-------------	$mg \cdot g^{-1}$
0	1.4	9.0	3.3	4.5*	69	328*	1.4
15	1.6*[z]	12.2*	3.9	4.7*	50	282*	1.2
30	1.8*	12.9*	4.7*	4.9	45*	246*	0.9
45	2.3*	12.7*	5.3*	5.9	43*	187*	0.9
8:1[y]	1.2	9.9	3.6	7.9	77	492	1.3
Linear[x]	***	**	***	*	***	***	***
Quadratic	NS	**	NS	NS	**	NS	NS

[z]*Significantly different from the 8:1 substrate based on mean separation by Dunnett's test, P=0.05.
[y]8 pine bark: 1 sand substrate. The control substrate not included in regression analysis.
[x]NS, *, **, *** nonsignificant or $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$ respectively.

Table 5. Effect of pine bark substrates amended with cotton stalk/swine compost (CCSW) on substrate solution pH and EC measured 15, 45, 75, 105, and 135 days after treatment initiation.

	Days after treatment initiation									
CCSW	15	45	75	105	135	15	45	75	105	135
% by vol.	pH					EC (dS m^{-1})				
0	5.5	5.8	6.2	5.9	5.6	0.42	0.33	0.26	0.24	0.27
15	5.3*[z]	5.8	6.0	6.0	6.0	1.34*	0.54	0.25	0.38	0.49
30	5.7	6.0	6.1	6.0	5.6	1.67*	0.61	0.35	0.45	0.66*
45	6.0*	6.1	6.2	6.1	6.0	2.81*	1.35*	0.34	0.90*	0.84*
8:1[y]	5.6	5.9	5.9	6.0	6.0	0.67	0.33	0.45	0.23	0.28
Significance										
Linear[x]	***	***	NS	NS	NS	***	**	NS	***	**
Quadratic	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z]*Significantly different from the 8:1 substrate based on mean separation by Dunnett's test, P=0.05.
[y]8 pine bark: 1 sand substrate. The control substrate not included in regression analysis.
[x]NS, *, **, *** nonsignificant or $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$ respectively.

Table 6. Effect of pine bark amended with cotton stalk/swine compost (CCSW) on substrate total N, P, K, Ca, Mg, S, B, Cu, Mn, Zn, and Na solution concentration.

CCSW	Days after treatment initiation								
(% by vol.)	15	75	135	15	75	135	15	75	135
	Total N			P			K		
	---------- mg L^{-1} ----------								
0	2	12	1.4	4	2	1	32	14	4
15	26*[z]	10	1.4	117*	15*	7	147*	19	4
30	53*	19	2.6	221*	20*	35*	302*	29*	8
45	112*	8	1.3	283*	43*	71*	535*	47*	18*
8:1[y]	2	19	1.6	2	2	1	69	18	2
Linear[x]	***	NS	NS	***	***	***	***	***	**
Quadratic	NS	*	NS	NS	NS	NS	NS	NS	NS

(%by vol.)	---------- mg L^{-1} ----------								
0	4*	3	7	2*	2	4	14*	8	31
15	29	5	11	35	4	8	34*	9	35
30	33	5	26*	65	4	21*	54	15	58*
45	35	8	24*	99*	12*	31*	95	15	62*
8:1[y]	42	5	4	31	4	2	92	11	18
Quadratic	*	NS	NS	NS	NS	NS	NS	NS	NS

Rate	B			Cu			Mn		
(% by vol.)	---------- mg L^{-1} ----------								
0	0.12*	0.12	0.06	0.01	0.005	0.008	0.11*	0.02	0.16*
15	0.17*	0.17	0.04	0.06	0.02	0.01	0.45*	0.02	0.04
30	0.31	0.43*	0.09*	0.18*	0.06*	0.03*	0.45*	0.01	0.03*
45	0.41	0.37*	0.11*	0.34*	0.06*	0.04*	0.45*	0.03	0.04*
8:1[y]	0.20	0.25	0.04	0.02	0.01	0.01	1.48	0.04	0.05
Linear[x]	**	***	**	**	***	**	NS	NS	***
Quadratic	*	NS	NS	*	NS	NS	NS	NS	NS

Table 6. Continued.

Rate (% by vol.)	Days after treatment initiation: 15	75	135	15	75	135
	Zn			Na		
	mg L^{-1}					
0	0.07*	0.06	0.06	20	21	55
15	0.20	0.09	0.05	36	25	59
30	0.35	0.09	0.08*	45*	41	95*
45	0.53	0.14	0.12*	60*	60	121*
8:1[y]	0.26	0.10	0.04	25	22	51
Linear	***	**	**	***	*	***
Quadratic	NS	NS	NS	NS	NS	NS

[z]*Significantly different from 8:1 substrate based on mean separation by Dunnett's test, *P*=0.05.
[y]8 pine bark: 1 sand substrate. The control substrate not included in regression analysis.
[x]NS, *, **, *** nonsignificant or *P*≤0.05, *P*≤0.01, *P*≤0.001 respectively.

Table 7. Effect of pine bark amended with cotton stalk/swine compost (CCSW) on physical properties at 63 and 135 days after treatment initiation.

CCSW	Total porosity		Air space		Container capacity		Available water		Unavailable water		Bulk density	
	Days after treatment initiation											
v/v	63	135	63	135	63	135	63	135	63	135	63	135
0	84*[z]	85*	33*	30*	52	55	22*	22*	29*	33*	0.26*	0.24*
15	84*	86*	29*	28*	55	58	24*	25*	30*	32*	0.25*	0.24*
30	85*	87*	29*	27*	56	60	24*	26*	32*	34*	0.23*	0.21*
45	86*	87*	24	25*	62*	62*	29	27*	33*	36*	0.23*	0.21*
8:1[y]	77	80	23	21	54	59	28	29	26	29	0.43	0.44
Linear	***	***	***	***	***	***	***	***	***	***	***	***
Quadratic	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z]Significantly different from the 8:1 substrate based on mean separation by Dunnett's test, *P*=0.05.
[y]8 pine bark: 1 sand substrate. The control substrate not included in regression analysis.
[x]NS, *** nonsignificant or *P*≤0.001 respectively.

Table 8. Effect of pine bark amended with Fluff® on foliar mineral nutrient concentration of Skogholm cotoneaster.

Treatment	N	P	K	Ca	Mg	B	Cu	Mn	Zn
% by vol.	mg g^{-1}					µg g^{-1}			
0	14.1	1.4	14.3*[z]	9.0	3.3	44.8	4.5	328*	45
15	11.4	1.2	11.0	13.9*	2.9	45.0	6.9	232*	80
30	12.9	1.4	12.3	15.8*	3.0	59.1	7.3	182*	97*
45	13.4	1.4	13.0	16.0*	2.9	67.0	9.7	163*	91*
8:1[y]	12.3	1.1	11.5	9.9	3.6	56.1	7.9	492	69
Quadratic	NS	NS	NS	NS	NS	NS	NS	*	**

[z]*Significantly different from the 8:1 substrate based on mean separation by Dunnett's test, P=0.05.
[y]8 pine bark: 1 sand substrate. The control substrate not included in regression analysis.
[x]NS, *, **, *** nonsignificant or $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$, respectively.

Table 9. Effect of pine bark amended with Fluff® on substrate solution pH and EC collected 15, 45, 75, 105, and 135 days after treatment initiation.

Treatments	Days after treatment initiation									
	15	45	75	105	135	15	45	75	105	135
% by vol.	pH					EC (dS m^{-1})				
0	5.5	5.8	6.2	5.9	5.6	0.4	0.3	0.3	0.2	0.3
15	5.8	6.1*	6.0	6.0	5.9	0.7	0.3	0.2	0.4	0.5
30	6.4*[z]	6.5*	6.2	6.3	6.2	1.0	0.5*	0.4	0.3	0.5
45	6.5*	6.9*	6.4	6.6*	6.3	1.7*	0.6*	0.4	0.4*	0.5
8:1[y]	5.6	5.9	5.9	6.0	6.0	0.7	0.3	0.5	0.2	0.3
Linear[x]	***	***	***	***	***	**	**	***	***	***
Quadratic	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z]*Significantly different from 8:1 substrate based on mean separation by Dunnett's test, P=0.05.
[y]8 pine bark: 1 sand substrate. The control substrate not included in regression analysis.
[x]NS, **, *** nonsignificant or $P \leq 0.01$, $P \leq 0.001$, respectively.

Table 10. Effect of pine bark substrates amended with Fluff® on substrate total N, P, K, Ca, Mg, S, Cu, Fe, Mn, and Na solution concentration 15, 75, and 135 days after treatment initiation.

Treatments	Days after treatment initiation								
(% by vol.)	15	75	135	15	75	135	15	75	135
	Total N			P			K		
	mg L^{-1}								
0	2	12	2	4	1	1	34	14	4
15	4*[z]	11	2	3	1	2*	47	11	2
30	5*	17	2	4	2	1	68	36*	3
45	8*	20	2	2	1	0	111*	34*	3
8:1[y]	2	19	2	2	1	1	55	18	2
Linear[x]	**	*	NS	NS	NS	NS	***	**	NS
Quadratic	NS	NS	NS	*	NS	*	NS	NS	NS
Treatments	Ca			Mg			S		
(% by vol.)	mg L^{-1}								
0	4*	3	7	2*	1	4	14*	8	31
15	8*	2*	7	4*	1	2	25*	5*	27
30	15*	6	4	4*	3	2	46	15	27
45	33	9*	11*	8*	2	4	83	18*	43
8:1	42	5	4	31	3	3	81	11	26
Linear	***	***	NS	***	NS	NS	***	***	NS
Quadratic	NS	NS	NS	NS	NS	NS	NS	NS	NS
Treatments	Cu			Fe			Mn		
(% by vol.)	mg L^{-1}								
0	0.01	0.01	0.01	0.29	0.06	0.08	0.11*	0.02	0.06
15	0.37*	0.02	0.03	0.41	0.04	0.05	0.14*	0.01	0.06
30	0.99*	0.17*	0.06	0.90*	0.16	0.03	0.24*	0.02	0.01
45	1.24*	0.30*	0.10	0.82*	0.23*	0.07	0.34*	0.03	0.01
8:1	0.02	0.01	0.01	0.08	0.06	0.08	2.15	1.20	0.05
Linear	**	***	***	**	**	NS	**	NS	**
Quadratic	NS	NS	NS	NS	NS	NS	NS	NS	*

Table 10. Continued.

Treatments (% by vol.)	Days after treatment initiation 15	75	135
	Na		
	mg L^{-1}		
0	20	21	55
15	62*	17	58
30	126*	43*	38
45	265*	58*	83
8:1	25	22	40
Linear	***	***	NS
Quadratic	NS	NS	NS

[z]*Significantly different from the 8:1 substrate based on mean separation by Dunnett's test, P=0.05.
[y]8 pine bark: 1 sand substrate. The control substrate not included in regression analysis.
[x]NS, *, **, *** nonsignificant or $P\leq0.05$, $P\leq0.01$, $P\leq0.001$ respectively.