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Pine Tree Substrate: an Alternative and Renewable Substrate for Horticultural Crop Production

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Keywords: container substrate, ground trees, loblolly pine, N-immobilization, peat alternative, pine bark, pine chips, potting media, wood substrate, WoodGro™

Abstract

Due to supply restrictions, rising costs, and increasing environmental concerns over the use of horticultural substrates like peat moss (P) and pine bark (PB), the need for alternative materials that are renewable and economical are currently being investigated in the United States. A wood based substrate prepared by grinding whole delimbed pine logs (*Pinus taeda* L.) has recently been developed and investigated as a viable substrate alternative. Loblolly pine is an abundant and fast growing native tree species to the southeastern United States. Research has been conducted on the pine tree substrate (PTS) (registered as WoodGro™) to determine physical properties, plant growth and fertility management, decomposition rates, and post-transplant (landscape) performance of plants grown in PTS. Research conducted from 2004 through 2007 has shown that PTS can be manufactured to have desirable physical properties needed for optimal plant growth of a wide range of woody and herbaceous crops. Fertility investigations of plants grown in PTS show that additional fertilizer is required, but growth can be achieved similar to that in traditional P and PB substrates. Observations of PTS indicate little or no shrinkage or substrate decomposition occurring with greenhouse crops or even after 2 years for woody nursery crops. Landscape evaluations of various plants grown in PTS show no quality or performance differences than plants grown in other substrates. With proper preparation and cultural management practices PTS can be a reliable, consistent, renewable, and economical alternative to traditional substrates for both nursery and greenhouse crop production.

INTRODUCTION

Pine bark (PB) and peat moss are the two most common substrate components currently used for container crop production in the southeastern United States. The availability and cost of PB remain unpredictable and the cost of peat moss substrates continues to rise due to transportation costs and growing environmental concerns over the mining of peat bogs in Canada and Europe. Alternative substrates produced from wood have been investigated as suitable substrates or substrate components in horticulture crop production. European research in this area has been conducted for two decades, resulting in numerous successful commercialized wood substrates (Gumy, 2001). Recent research in the United States has also shown the potential for using wood substrates in the production of numerous horticultural crops (Boyer et al., 2007; Jackson et al., 2008; Wright et al., 2006). The objective of this research has been the development of a substrate produced from trees that can meet the needs of the horticulture industry by providing a cost effective and reliable alternative to traditional substrates. This paper reports some of the extensive research that has been conducted at Virginia Tech on the development of PTS.

MATERIALS AND METHODS

Substrate Preparation and Physical Properties

Pine tree substrate of different particle sizes was prepared by grinding coarse pine chips (approximately 2.5×2.5×0.6 cm) from freshly harvested delimbed loblolly pine logs in a hammer mill fitted with different screen sizes: 1.59, 2.38, 3.18, 4.76, 6.35 mm. Physical properties of each substrate were determined using the NCSU Porometer as described by Fonteno and Bilderback (1993). Available (AW) and unavailable (UW) water at 1500 kPa was determined on four replicate samples of each substrate. Substrate saturated hydraulic conductivity (SHC) was determined on all substrates using a modification of the constant pressure method described by Klute and Dirksen (1986).

Plant Growth Trial

1. Fertilizer Rate – Japanese Holly. The objective of this research was to study the effect of increasing fertilizer rate on growth of Japanese holly in PTS compared to PB. On 17 Aug, 2005, Japanese holly (*Ilex crenata* Thunb. 'Compacta') 10 cm tall liners in 64 cm^3 containers were potted in 2.8 L plastic containers containing either PB or PTS. Pine tree substrate was produced using a 4.76 mm screen in a hammer mill and was amended with 5% (by volume) 16/30 particle size calcined clay and 0.6 kg/m^3 $CaSO_4$. Osmocote Plus (15N-3.9P-10K) (9-month release with micronutrients) (O.M. Scott Horticulture Products, Marysville, Ohio) was incorporated in PB and PTS at rates of 3.5, 5.9, 8.3, or 10.7 kg/m^3, respectively. Plants were greenhouse grown and irrigated as needed. Average day and night temperatures in the greenhouse were 26/22, respectively. On November 22 shoots were severed at the substrate surface and dried at 65°C for 4 days, and weighed.

2. Fertilizer Rate – Chrysanthemum. An experiment was conducted to determine comparative fertilizer requirements for chrysanthemum (*Chrysanthemum* × *grandiflora* 'Baton Rouge') grown in either PTS or a commercial peat substrate. On 15 Oct. 2005 single rooted cuttings of 'Baton Rouge' chrysanthemum were potted in containers filled with the following substrates: a commercial substrate composed of 45% (V/V) peat, 15% (V/V) perlite, 15% (V/V) vermiculite, and 25% (V/V) pine bark (Fafard, Anderson, S.C.), supplemented with dolomitic lime at 3.5 kg/m^3 and $CaSO_4$ at 0.6 kg/m^3, and PTS. The commercial substrate did not contain a pre-plant fertilizer charge other than the limestone and $CaSO_4$. The PTS substrate was produced using a 4.76 mm screen in the hammer mill and incorporated with 0.6 kg/m^3 $CaSO_4$. Plants were glasshouse grown with day/night temperatures set at 26/22°C. Plants in each substrate were watered at the same time as needed depending upon weather conditions. Plants were fertilized with each watering by applying 250 ml of 50, 100, 200, or 300 mg/L N from a 20N-4.4P-16.6K fertilizer (Scotts Company, Marysville, Ohio) containing 12% nitrate (NO_3-N) and 8% ammonium (NH_4-N). This study was arranged in a completely randomized design with five single container replications per treatment per fertilizer rate.

3. Peat Moss (P):Pine Tree Substrate (PTS) Ratio. An experiment was conducted to determine if adding various amounts of peat to PTS would increase plant growth, and to determine the quantity of fertilizer required as percent peat in PTS increased. The PTS was produced using a 4.76 mm screen in the hammer mill and amended with peat (Premier Pro-Moss) (Premier Tech, Quebec, Canada) at the following levels as percent of the total volume: 0 to 100% in 10% increments. Substrates were amended with 3.5 kg/m^3 dolomitic lime and 0.6 kg/m^3 $CaSO_4$ prior to mixing. Marigold seedlings were transplanted into 1 L plastic containers with the different substrates. Plants were glasshouse grown and all treatments were fertilized at each watering (250 ml of beaker-applied) with 50, 100, 200, or 300 mg/L N using a 20N-4.4P-16.6K fertilizer. After 4 weeks plants were harvested and dry weights determined. This experiment was a completely randomized design with two single container replications per treatment per fertilizer rate.

Nitrogen Immobilization

Pine tree substrate was incorporated with 0.6 kg/m^3 $CaSO_4$. Peat and pine bark were incorporated with 3.5 kg/m^3 dolomitic lime and 0.6 kg/m^3 $CaSO_4$. Containers were filled with each respective substrate and fertilized three times per week with a 200 mg/L NO_3-N fertilizer derived from $Ca(NO_3)_2$ and KNO_3. Substrate samples were prepared weekly for nitrogen drawdown index (NDI) testing to determine N-immobilization (Handreck, 1992). Substrate CO_2 efflux (respiration) rates (μmol $CO_2 \cdot m^{-2} \cdot s^{-1}$) were determined at the end of the experiment for each substrate using a LI-6200 infrared gas analyzer (Licor, NE, USA). Substrate CO_2 efflux is considered an assessment of microbial metabolic activity and is an indicator of the potential for N-immobilization to occur (Wang, 2003). This experiment was a completely randomized design with six single container replications per treatment per weekly N-immobilization test.

Post-Transplant Landscape Performance

On 4 May 2006 begonia (*Begonia* × *semperflorens-cultorum* 'Cocktail Whiskey') and vinca (*Catharanthus roseus* 'Cooler Pink') plugs were potted in 3.7 L plastic containers containing either PB or PTS and greenhouse grown until 5 June. Pine tree substrate was preplant amended with 0.6 kg/m^3 $CaSO_4$. Pine bark was preplant amended with 0.6 kg/m^3 $CaSO_4$ and 3.5 kg/m^3 dolomitic lime. Plants were fertilized as needed with 200 mg/L N to maintain an electrical conductivity of 1.0-1.5 dS/m. On 5 June plants were transplanted into landscape trial beds and fertilized by top-dressing with three different rates of 12-6-8 (12N-2.6P-6.6K) controlled release fertilizer. Fertilizer rates were 0, 0.6, and 1.2 kg/m^2, respectively. After 10 weeks, growth index (height + widest width + perpendicular width/3) was determined for begonia and vinca and shoot dry weights were determined on all species.

Data Analysis

The significance of the data in the tables and figures are represented by letters. The same letters indicate no significant difference between treatments. Data were subjected to analysis of variance (ANOVA), means separation was performed using Least Significance Differences (SAS Institute, Inc., version 9.1) and regression analysis was performed using SigmaPlot (version 9.01 SPSS Inc., Chicago, Ill).

RESULTS AND DISCUSSION

Substrate Preparation and Physical Properties

Volumic air space was about 2 times lower and volumic container capacity (amount of water held after irrigation and drainage) was about 1.5 times higher for the 1.59 screened substrate compared to the 6.35 mm screened substrate (Table 1). These results are supported by Gruda and Schnitzler (2004) who demonstrated that a more finely ground wood fiber substrate, compared to a coarsely ground one, had approximately half the air content and twice the content of easily available water. Percent air space and container capacity of peat and the 1.59 mm PTS were not different showing that PTS with these important physical properties can be formulated to match existing commercial peat substrates. Available water at 1500 kPa increased as screen size decreased and was 9% higher for the 1.59 mm PTS compared to peat. Pine tree substrate bulk density was not influenced by screen size, but bulk density was lower for peat than for PTS, likely due to the perlite component of peat.

Plant Growth Trials

1. Fertilizer Rate – Japanese Holly. There was a significant substrate x fertilizer rate interaction (P>0.0009) for shoot dry weight: at fertilizer rates of 3.5 and 5.9 kg/m^3, shoot dry weight was higher for PB than PTS; at 8.3 kg/m^3 dry weight was about equal for the two substrates; at 10.6 kg/m^3 dry weight was higher for PTS than PB (Fig. 1). Substrate solution electrical conductivity (EC) increased with increasing fertilizer rate, and at any particular fertilizer rate levels were higher in PB than in PTS (data not shown). This study demonstrates that a higher rate of fertilizer is required (1.8–2.4 kg) to achieve plant growth in PTS comparable to plant growth in PB. Lower substrate solution EC for PTS compared to PB has been reported previously by Wright and Browder (2005) and is likely to be due to lower cation exchange capacity (CEC) of PTS compared to PB as well as higher microbial immobilization in PTS compared to PB.

2. Fertilizer Rate – Chrysanthemums. Maximum shoot dry weight and growth index for chrysanthemums grown in peat occurred at about 200 mg/L N with no increase from 200 to 300 mg/L N (Fig. 2) (Wright et al., 2007). Plant growth in PTS continued to increase up to 300 mg/L N where it was similar to plants grown in peat at 200 mg/L N (Fig. 2). Other work has also shown the need for additional fertilizer when growing herbaceous plants in wood substrates (Handreck, 1993b; Gruda and Schnitzler, 1999). The higher fertilizer requirement (300 versus 200 mg/L N) for PTS compared to peat is likely due to higher N-immobilization in PTS compared to peat and a higher CEC in peat than in PTS.

3. Peat Moss:PTS Ratio. Shoot dry weight of marigolds grown in PTS fertilized with 50, 100, and 200 mg/L N increased as the percent peat increased (Fig. 3). However, the dry weight of plants fertilized at 300 mg/L N did not increase with an increasing peat amendment since the higher fertility rate provided sufficient nutrients without the addition of peat. Results are consistent with Wright et al. (2007) demonstrating the suitability of PTS as an alternative substrate when additional fertilizer (300 versus 200 mg/L N) is required for herbaceous crops unless peat is incorporated at rates of at least 40 percent. Growers would need to choose whether to add peat or additional fertilizer to PTS for optimal plant growth.

Nitrogen Immobilization

Results from the NDI show that PB and PTS have significantly higher rates of N-immobilization occurring over 4 weeks than peat (Fig. 4). Pine bark had 29% of the plant available N lost to microbial immobilization over 4 weeks while PTS lost 68% respectively. N-immobilization did occur in peat during the first two weeks (Fig. 4), but the total loss was only 13%. The severity of N-immobilization decreases during the four weeks for all substrates. Substrate respiration rates were highest in PTS followed by PB indicating increased microbial activity in these substrates. Microbial activity (as measured by the CO_2 efflux) in PTS was twice as high as PB and nearly five times higher than peat (data not shown), likely due to the higher cellulose carbon content of both PTS and PB compared to peat which has a higher lignin carbon content (lignin is more resistant to microbial decay than is cellulose). Results indicate that additional fertilizer applications are needed to supply sufficient N to counter microbial immobilization and plant needs (Handreck, 1993a), as shown above.

Post-Transplant Landscape Performance

There were no statistical differences in growth index of begonia or vinca grown in PB or PTS (data not shown). There were also no visible differences in plant size between PB and PTS grown plants for both species after eleven weeks in trial beds. Consistent with these results, numerous woody and herbaceous perennial plant species grown in PTS have also been evaluated in the landscape demonstrating no apparent post-transplant differences in plant quality after 2-3 years. This includes no rapid breakdown of the rootballs (3.7, 18.5, and 55.5 L containers) and no visual sign of N deficiencies when fertilized adequately.

CONCLUSION

Although there is an added production cost associated with extra fertilizer, there are cost advantages with PTS compared to peat and PB substrates. For example PTS can be ground to a particle size that will provide acceptable water and aeration levels in the substrate (comparable to peat and PB), without the added expense of incorporating perlite or vermiculite which are often added to commercial substrates. Unlike PB, composting/

aging of PTS is not needed, making it readily immediately available after production. Also, PTS can be produced across much of the United States where loblolly pine trees can be grown, reducing transportation costs associated with peat and PB.

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Tables

Table 1. Physical and hydraulic properties of a commercial peat and pine tree substrates (PTS) produced with a hammer mill fitted with five screen sizes (1.59, 2.38, 3.18, 4.76, 6.35 mm).

Substrates	Drainage[z] (ml)	Air space[y] (% V/V)	Container capacity[x] (% V/V)	Total porosity[w] (% V/V)	Bulk density (g/cm^{-3})[v]	Available water[u] (% V/V)	Unavailable water[t] (% V/V)	Saturated hydraulic conductivity[s]
Peat	58 a[r]	16.8 a	68.4 a	85.1 a	0.12 b	46.1 b	22.3 a	42 b
PTS								
1.59[q]	63 a	18.2 a	65.1 a	83.3 a	0.15 a	50.4 a	14.7 b	96 a
2.38	81	23.2	62.5	85.7	0.15	42.8	19.7	-
3.18	110	31.8	54.8	86.6	0.15	33.6	21.3	153
4.76	109	31.3	47.9	79.2	0.15	25.7	22.3	106
6.35	136	39.1	43.3	82.4	0.15	19.8	23.5	176
Significance[p]	L***	L***	L***	NS	NS	L***	L***	L**
	Q***	Q***	Q***	NS	NS	Q***	Q***	Q**

[z]Drainage = Amount (ml) water drained from each substrate after saturation before container capacity was reached.

[y]Air space was the volume of water drained from the sample ÷ volume of the sample.

[x]Container capacity was (volume of water lost after oven drying) ÷ volume of cylinder.

[w]Total porosity is equal to container capacity + air space.

[v]Bulk density after forced-air drying at 105°C for 48 h.

[u]Available water = container capacity - unavailable water.

[t]Unavailable water based on percent volume of a 7.6×2.54-cm core at 1500 kPa.

[s]Saturated hydraulic conductivity = $\times 10^{-2}$ cm s^{-1}

[r]Means separation between peat and 1.59 mm PTS by LSD, $P<0.05$. Means followed by the same letter are not significantly different ($N=3$).

[q]Hammer mill screen size (mm) used to produce substrates.

[p]Non-significant (NS) or significant at $P<0.01$ (**), or 0.001 (***), respectively.

Figures

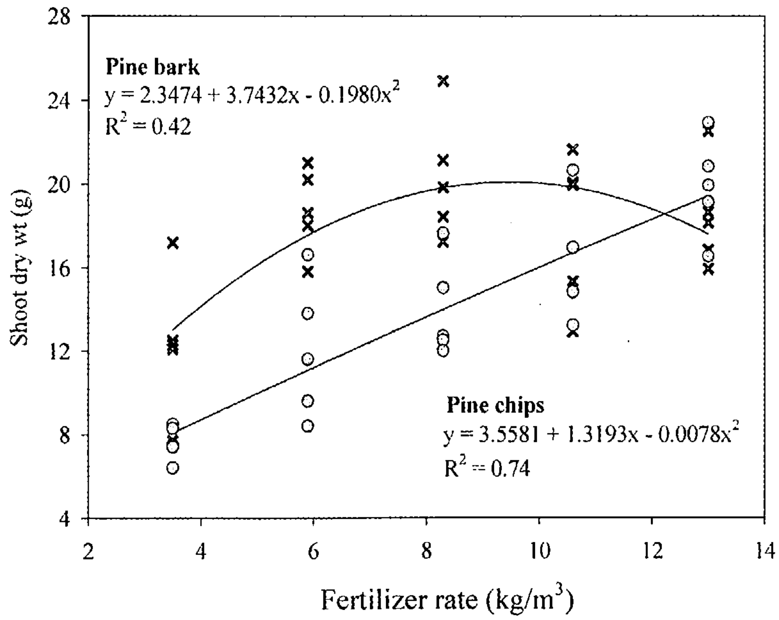

Fig. 1. Shoot dry weights of Japanese holly grown in pine bark (PB) or pine tree substrates (PTS) incorporated with four different rates of Osmocote 15-9-12.

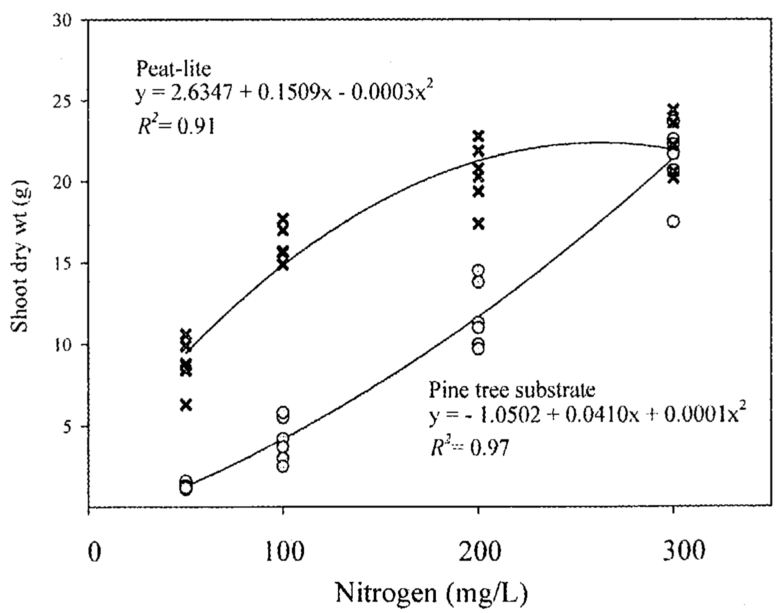

Fig. 2. Shoot dry weight of chrysanthemum 'Baton Rouge' grown in peat-lite (X) or pine tree substrate (O) with four different rates of a 20N-4.4P-16.6K soluble fertilizer.

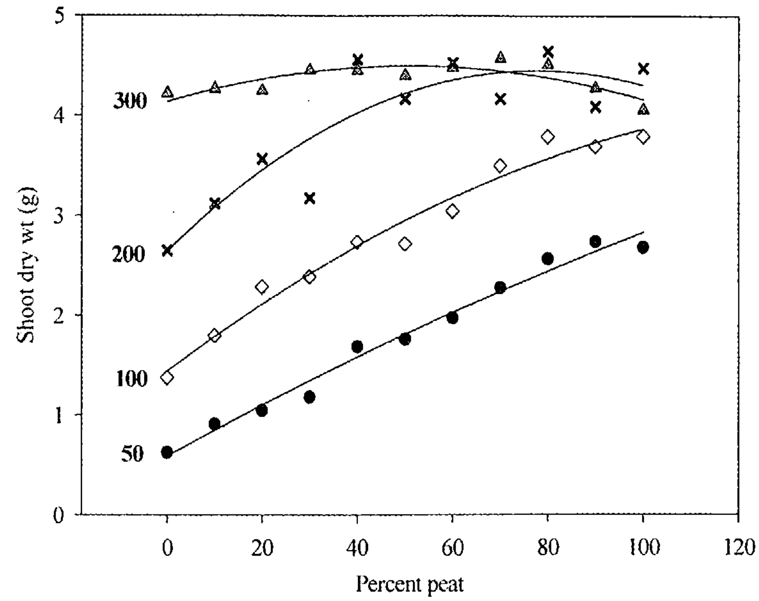

Fig. 3. Shoot dry wt of marigold grown in pine tree substrate amended with varying percentages of peat by volume and fertilized at 50, 100, 200, and 300 mg/L N.

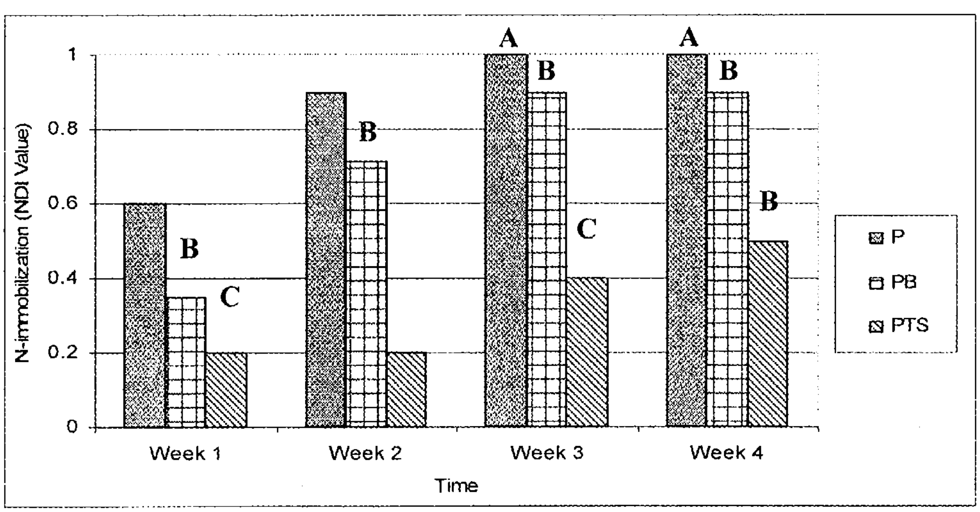

Fig. 4. Nitrogen Drawdown Index (NDI) on peat (P), pine bark (PB), and pine tree substrates (PTS) when fertilized with 200 mg/L N for 4 weeks. NDI values range from 0-1, with 1 representing no N-immobilization, and 0 representing total N-immobilization.