Comparison of Aged and Fresh *WholeTree* as a Substrate Component for Production of Greenhouse-Grown Annuals[1]

Whitney G. Gaches[2], Glenn B. Fain[3], Donald J. Eakes[4], Charles H. Gilliam[4], and Jeff L. Sibley[4]
Auburn University, Department of Horticulture,
Auburn, AL 36849

Abstract

WholeTree (WT) is a potential renewable greenhouse substrate component created by chipping and milling all aboveground portions of a pine tree (*Pinus taeda* L.). While research regarding the viability of WT as an alternative substrate component is widely available to growers, the potential benefits of aging WT remain unclear. The growth of Dreams White petunia (*Petunia ×hybrida* 'Dreams White') and Little Hero Yellow marigold (*Tagetes patula* 'Little Hero Yellow') in 1:1 (by vol) fresh WT:peat (FWTP) and 1:1 (by vol) aged WT:peat (AWTP), as well as physical properties of AWTP and FWTP were evaluated. For Experiment 1, AWTP had 17.6% particles greater than 3.2 mm as opposed to 12.4% for FWTP. In Experiment 2, this trend was reversed with 8.1% of AWTP particles greater than 3.2 mm and 20.4% for FWTP. For Experiment 1, AWTP had 90.5% total porosity (TP) as compared to 94.4% with FWTP. Air Space (AS) for AWTP was less than FWTP; AWTP had 10% more container capacity (CC) than FWTP. Bulk Density (BD) was similar in Experiment 1. There was no difference in TP in Experiment 2; however, all other physical properties followed a similar trend to Experiment 1. In both experiments marigolds grown in AWTP generally had a lower leachate pH and a higher EC than those grown in FWTP; a trend which was similar in petunia although differences were not present throughout the entire study. Marigolds grown in AWTP had 33% more blooms and 44% greater dry weight than those grown in FWTP, a trend similar in petunias. Aged WT in this study provided a more suitable substrate component for greenhouse grown marigolds and petunias than fresh WT.

Index words: alternative substrate, greenhouse production, wood chips, wood fiber, peat, pine tree, *Pinus taeda*, annuals.

Species used in this study: *Petunia ×hybrida* Vilm. 'Dreams White'; *Tagetes patula* L. 'Little Hero Yellow'.

Significance to the Nursery Industry

Greenhouse growers commonly purchase substrate components in bulk and store them for use throughout the season. Common materials such as peat, perlite, and vermiculite are relatively stable with little change during storage. With the introduction of *WholeTree* (WT) to greenhouse producers, one important question is whether WT should be used fresh or should use be delayed for some period of time for aging. In our studies, petunias and marigolds grown in aged WT were larger with more blooms than those grown in fresh WT. Growers using WT substrate to grow annuals should age the material prior to use for best plant response. Based on the results of this study, fresh WT, milled and placed in bulk bags, should not be used fresh but should be allowed to age for a period of time prior to the production of greenhouse annuals.

Introduction

Since the introduction of the Cornell peat-lite mixes in the 1920s, greenhouse substrates have been primarily peat based. The United States imports most of its peat from Canada and the United Kingdom; however, the cost of peat continues to rise as transportation costs increase and poor weather negatively affects peat harvests. Environmental interest groups have stepped up to protect peat bogs in Europe and Canada, and Great Britain even set a goal of reducing peat production by 90% before the end of 2010 (1). Reduced supply and increased cost of peat continue to concern greenhouse growers.

In an effort to minimize the environmental impact of peat harvesting, European research began focusing on wood fiber alternatives, such as Fibralur® and Toresa®. Wood fiber products performed as well as standard mixes (13, 20) in independent reports from European researchers. Research results in the U.S. followed a similar trend. Wright and Browder (24) reported that chipped pine logs ground through a hammer mill showed promise as an alternative substrate for greenhouse grown crops, with marigolds grown in the wood fiber substrate having similar dry weights to those grown in a standard mix. This new substrate showed suitable physical characteristics (21) yet required additional fertilizer in the growth of greenhouse annuals (25). Boyer et al. (4) reported that Clean Chip Residual (CCR) was a suitable wood fiber alternative for growing greenhouse annuals. CCR is a high wood content residual material left over after pine trees are processed into clean chips for use by paper mills. Another alternative substrate component high in wood fiber is *WholeTree* (WT), created from entire pine trees harvested at the thinning stage (8). All above ground portions of the tree are chipped and ground to crop specifications; thus, WT consists of approximately 80% wood, 15% bark, and 5% needles (3). Fain et al. (9) reported that WT substrates derived from loblolly pine (*Pinus taeda* L.), slash pine (*Pinus elliottii* Englem.), or longleaf pine (*Pinus palustris* Michx.) have potential as alternative sources for producing short-term horticultural crops. Studies indicate that with adequate starter nutrient charge, WT serves as an acceptable substrate component replacing the majority of peat in greenhouse production of petunia and marigold (10).

On the west coast, douglas fir bark (DFB) has been a standard substrate component in the nursery industry for decades. While both fresh and aged DFB is used, Buamscha et al. (3) reported that geraniums (*Pelargorum ×hortorum*

[1]Received for publication on June 16, 2010; in revised form September 22, 2010. The authors would like to express gratitude to **The Horticulture Research Institute, 1000 Vermont Ave., NW, Suite 300, Washington, DC 20005**, for partial funding of this project.

[2]Former Graduate Student, Department of Horticulture.
[3]Assistant Professor, Department of Horticulture. gbf0002@auburn.edu.
[4]Professors, Department of Horticulture.

Bailey 'Maverick Red') grow larger and absorb more N when grown in aged DFB compared to fresh DFB. Fresh DFB was debarked within 48 hours of harvest; aged DFB was collected from large piles that had been stored at the processing site for approximately 7 months. These storage piles were exposed to ambient climate and received no additional inputs such as fertilizer, irrigation, or aeration (5).

Other organic substrate components have been evaluated to determine the effects of aging or composting the material. Johnson and Bilderback (17) reported that fresh peanut hulls had twice as many large (> 6.4 mm) particles as compared to aged peanut hulls. Aged peanut hulls had approximately 50% of its particles between 4.75 and 1.0 mm while fresh peanut hulls had only 36% of its particles in this range. Aged peanut hulls had greater air space (AS) and less container capacity (CC) than fresh peanut hulls. Aged peanut hulls yielded higher shoot and root dry weights than fresh peanut hulls. The method of aging peanut hulls was not described.

Bilderback (2) reported that as pine bark is aged particle size decreases, increasing moisture retention. In this experiment, particle size distribution appeared to be influenced more by longer periods of aging than by sieving or grinding procedures. Dueitt and Newman (7) reported that fresh and aged rice hulls are an acceptable peat moss substitute in greenhouse substrates. The addition of aged rice hulls reduced AS initially, and substrate containing fresh rice hulls initially had greater AS than aged. These observations were reversed at the conclusion of the study; attributed to substrate shrinkage during the growth period. The method of aging the rice hulls was not described.

For horticultural pine bark, aging refers to the stockpiling and weathering of bark after milling but prior to its use (21). For growers using WT as a substrate, the material would likely be stockpiled for the duration of its use, just as pine bark or peat is stored. Aging WT during this storage may impact plant response. While research has been reported on the viability of WT as an alternative to peat (8, 9, 10, 12, 22), there is no information on what effects aging WT might have on plant growth. Previously reported work either used freshly milled chips or the dates of milling and chipping were not specified; therefore no information is available on the effects of extended bulk storage of WT.

This research project resulted from numerous observations by the authors. In previous experiments the authors noticed an increase in plant growth in bedding annuals in aged WT as compared to those in fresh WT (12). The objective of this study was to monitor the temperature fluctuations in fresh WT in bulk storage bags and to determine substrate physical properties and plant growth response of marigolds and petunias grown in aged WT and fresh WT.

Materials and Methods

Fresh loblolly pine (*Pinus taeda* L.) WT chips were obtained from a pine plantation in Macon County, AL, by chipping freshly cut 20–25 cm (8–10 in) caliper trees with a Woodsman Model 334 Biomass Chipper (Woodsman, LLC Farwell, MI). Chips were then ground in a hammermill (Meteor Mill #40, Williams Patent Crusher and Pulverizer Co., Inc St. Louis, MO) to pass a 0.95 cm (0.375 in) screen on January 19, 2009, to produce fresh WT substrate. Material produced was placed in three separate 1.73 m^3 (63 ft^3) polypropylene bulk bags and stored in full sun. Temperature sensors were placed inside the center of each bag during filling, as well as on the outside of each bag to obtain inside bag temperature and ambient temperature for comparisons. Data loggers (WatchDog® Datalogger Model 450, Spectrum Technologies, Inc Plainfield, IL) were attached to sensors to record temperatures at 30 min intervals for 69 days. For both experiments, WT was collected from the center of each bag, mixed together and utilized as aged WT. On April 22, 2009, fresh loblolly trees from the same pine plantation were harvested, processed, and utilized the same way as aged WT. On April 24, 2009, 2 days after the fresh WT was processed and 94 days after the aged WT was processed, uniform plugs of Little Hero Yellow marigold (*Tagetes patula* 'Little Hero Yellow') and Dreams White petunia (*Petunia* ×*hybrida* 'Dreams White' were transplanted from 144 plug flats into 0.95 liter (1 qt) plastic pots and grown until June 5, 2009. Plants were grown in an aged WT:peat substrate (1:1 by vol) (AWTP) or fresh WT:peat substrate (1:1 by vol) (FWTP). Peat was obtained from Sun Gro Horticulture (Bellevue, WA). Both substrate treatments were amended with 2.97 $kg \cdot m^{-3}$ (5 $lbs \cdot yd^{-3}$) crushed dolomitic limestone, 0.89 $kg \cdot m^{-3}$ (1.5 $lbs \cdot yd^{-3}$) 7-2-10 N-P-K nutrient charge (GreenCare Fertilizers, Kankakee, IL), and 154.7 $mL \cdot m^{-3}$ (4 $oz \cdot yd^{-3}$) AquaGro®-L (Aquatrols Corporation, Paulsboro, NJ). Plants were placed on a raised bench in a twin walled polycarbonate greenhouse under full sun and hand watered as needed. Plants were liquid fed beginning 10 days after potting (DAP) utilizing a 250 ppm N 20-10-20 liquid fertilizer (GreenCare Fertilizers, Kankakee, IL) every other watering. Data loggers were installed to capture actual greenhouse temperatures at 30 min intervals for the duration of the study. Greenhouse temperature daily average highs and lows were 29/21C (85/70F). Plants were arranged in a randomized complete block design with twelve blocks and three samples per block per treatment. Each species was a separate experiment.

Particle size distribution was determined by passing a 100 g air-dried sample through 12.5, 9.5, 6.35, 3.35, 2.36, 2.0, 1.4, 1.0, 0.5, 0.25, and 0.11 mm sieves with particles passing the 0.11 mm sieve collected in a pan. Sieves were shaken for 3 min with a Ro-Tap sieve shaker [278 $oscillations \cdot min^{-1}$, 159 $taps \cdot min^{-1}$ (Ro-Tap RX-29; W.S. Tyler, Mentor, OH)]. Substrate physical properties [bulk density (BD), air space (AS), container capacity (CC), and total porosity (TP)] were determined for AWTP and FWTP using the North Carolina State University Porometer Method (11).

Leachates were collected (23) and analyzed for pH and electrical conductivity (EC) at 0, 7, 14, 21, 28, 35, and 42 days after potting (DAP). At 7 DAP 3 sub samples per treatment were destructively sampled for soil and foliar nutrient analyses by the Auburn University Plant and Soil Testing Laboratory (Auburn, AL) as described by Hue and Evans (14). Termination data at 42 DAP included substrate shrinkage measured from the top of the container to the substrate surface, plant growth indices [(height + height + width / 3)], bloom counts which included all attached blooms and buds showing color, plant shoot dry weight. A visual root rating on a 1 to 5 scale was also recorded with 1 < 20 % of the substrate interface with roots present, 2 = 20–40%, 3 = 40–60%, 4 = 60–80%, and 5 > 80 % of the container substrate interface with roots present. Data were subjected to T-test ($P = 0.05$) using SAS (Version 9.1; SAS Institute, Cary, NC).

Experiment 2 was conducted similarly with the following exceptions. Fresh WT was processed the same way from the same source on July 5, 2009. Aged WT was collected from the same bulk bags utilized in Experiment 1. Substrates were blended and plugs were potted on July 7, 2009, and grown until August 18, 2009. At 7 DAP sub-samples were subjected to soil analysis (6) by Brookside Laboratories (New Knoxville, OH). Greenhouse temperature daily average highs and lows were 31/23C (88/74F).

Results and Discussion

Substrate aging. After 3 days, the temperature inside the bags nearly doubled from the beginning temperature near 22C (70F) to 50C (122F), and then slowly decreased until day 21 reaching temperature of 8C (47F) (Fig. 1). On day 21, the average temperature inside the bags fell below the ambient temperature outside the bags and remained relatively stable for 48 more days. WholeTree remained in bulk bags until utilized as aged WT; it was aged 94 days in Experiment 1 and 169 days in Experiment 2.

Substrate physical properties. For particle size distribution in Experiment 1 12.7% of particles from AWTP were greater than 3.2 mm, 78.5% between 0.5 mm and 3.2 mm, and 8.8% less than 0.5 mm (Table 1). 12.4% of the particles from FWTP were greater than 3.2 mm while 76.5% were between 0.5 mm and 3.2 mm and 11.1% were less than 0.5 mm. In Experiment 2 8.1% of particles were greater than 3.2 mm, 78.4% were between 0.5 mm and 3.2 mm and 13.5% were less than 0.5 mm while 20.4% FWTP were between 0.5 and 3.2 mm and 12% were less than 0.5 mm. In substrate physical properties, AWTP and FWTP had similar BD. AWTP had a 73.2% CC compared with 65.7% for FWTP, and 17.3% AS as compared to 28.7% for FWTP. AWTP had 90.5% TP while FWTP had 94.4% TP (Table 2). Differences in physical properties may be attributed to particle size, as FWTP had more fine textured particles than AWTP. Particle size distribution followed a similar trend in Experiment 2 to Experiment 1; however, in substrate texture FWTP had more coarse particles than AWTP, while AWTP had more medium particles, likely due to wear on hammer mill blades; resulting in more coarse particles. Both substrates had similar TP, while FWTP again had more AS and less CC than AWTP. These differences are attributed to differences in particle size.

Leachate pH and EC. Substrate leachate pH generally increased through the duration of both experiments in both species, while leachate EC decreased through the duration of both experiments (Table 3), which was expected due to low buffering capacity of WT demonstrated in prior studies (3, 9). In marigold in both experiments at 7 and 14 DAP AWTP leachate EC was higher than FWTP leachate, indicating a higher CEC in AWTP, which in turn may indicate higher rates of plant nutrient absorption (18). Wright and Browder (24) reported decreased EC readings for azaleas grown in chipped pine log substrates after seven to eight weeks, even with weekly applications of fertilizer through irrigation. Wright et al. (25) indicated increased plant growth in chrysanthemums was possible at higher fertility rates in chipped pine log substrate. Lowered substrate nutrient levels in this study was attributed to substrate physical properties or increased N immobilization, possibly due to the increased C:N ratio (24). Other studies also attribute a need for increased fertilization and lower EC readings in wood fiber substrates to increased N immobilization (15).

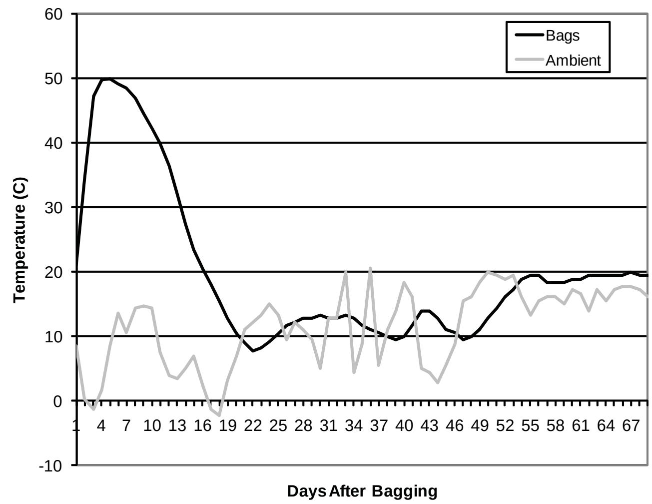

Fig. 1. Average temperature gradient inside and outside of bulk bags of *WholeTree* substrate.

Plant growth response. At 7 DAP plants in AWTP were visually larger and greener than plants in FWTP; however, this was more evident in marigolds than petunias. Plants

Table 1. Particle size distribution of aged and fresh *WholeTree* substrates amended with peat.

Sieve opening (mm)	Experiment 1			Experiment 2		
	AWTP[z]	FWTP[y]		AWTP	FWTP	
	(% dry weight)		Significance[x]	(% dry weight)		Significance
> 6.4	6.2	3.9	**	3.9	7.7	***
3.2–6.4	6.5	8.5	**	4.2	12.7	***
2.0–3.2	20.4	23.6	***	16.8	21.4	***
1.0–2.0	42.5	36.4	**	40.7	31.3	***
0.5–1.0	15.6	16.5	NS	20.9	14.9	***
0.25–0.5	6.7	8.5	***	10.7	10.0	NS
0.105–0.25	1.6	2.0	**	2.6	1.9	***
< 0.105	0.5	0.6	NS	0.2	0.1	NS

[z]1:1 aged *WholeTree*:peat.
[y]1:1 fresh *WholeTree*:peat.
[x]**, *** represents significance when P ≤ 0.01 or 0.001, respectively. NS denotes no significance. (n = 3).

Table 2. **Physical properties of aged and fresh *WholeTree* substrates amended with peat.**[z]

	(% volume)						(g·cm⁻³)	
	Air space		Container capacity		Total porosity		Bulk density	
Substrate	Expt. 1	Expt. 2	Expt. 1	Expt. 2	Expt. 1	Expt. 2	Expt. 1	Expt. 2
AWTP[y]	17.3	13.2	73.2	77.0	90.5	89.2	0.114	0.104
FWTP[x]	28.7	21.9	65.7	66.8	94.4	88.8	0.116	0.110
Significance[w]	***	**	***	***	*	NS	NS	*

[z]Analysis performed using the North Carolina State Porometer Method.

[y]1:1 (v:v) aged *WholeTree*:peat.

[x]1:1 (v:v) Fresh *WholeTree*:peat.

[w]*,**,*** represent significance when P ≤ 0.05, 0.01, or 0.001, respectively. NS denotes no significance (n = 3).

Table 3. **Effects of aged and fresh *WholeTree* substrates amended with peat on pH and electrical conductivity in two greenhouse- grown annuals.**

	0 DAP[z]		7 DAP		14 DAP		21 DAP		28 DAP		35 DAP		42 DAP	
Substrate	pH	EC[y]	pH	EC	pH	EC	pH	EC	pH	EC	pH	EC	pH	EC
***Tagetes patula* 'Little Hero Yellow'**														
Experiment 1														
AWTP[x]	5.09	1.25	5.57	1.25	5.88	1.82	5.92	1.18	5.70	0.48	6.29	0.19	6.39	0.24
FWTP[w]	5.10	1.56	5.90	1.06	6.33	1.15	6.27	1.08	5.91	0.40	6.44	0.18	6.46	0.16
Significance[v]	NS	NS	**	**	***	*	***	NS	***	NS	***	NS	NS	**
Experiment 2														
AWTP	5.38	2.05	5.35	2.04	5.80	1.99	5.96	2.37	6.05	2.67	6.29	0.94	6.36	0.86
FWTP	5.52	1.91	5.66	1.46	6.12	1.54	6.32	1.63	6.42	1.70	6.22	0.88	6.33	0.79
Significance	NS	NS	***	**	**	**	**	**	**	**	NS	NS	NS	NS
***Petunia ×hybrida* 'Dreams White'**														
Experiment 1														
AWTP	5.09	1.25	5.48	1.77	6.05	1.34	5.94	0.95	5.67	0.71	6.29	0.18	6.35	0.34
FWTP	5.10	1.56	5.79	1.69	6.31	1.13	6.30	0.72	5.90	0.39	6.39	0.16	6.37	0.18
Significance	NS	NS	***	NS	**	NS	***	NS	**	**	**	NS	NS	*
Experiment 2														
AWTP	5.38	2.05	5.69	1.84	5.87	1.98	5.94	2.02	5.99	1.94	6.38	0.38	6.36	0.31
FWTP	5.52	1.97	5.96	1.91	6.16	1.77	6.28	1.93	6.05	2.02	6.55	0.43	6.42	0.38
Significance	NS	NS	NS	NS	**	NS	***	NS	NS	NS	NS	NS	NS	NS

[z]Days after potting.

[y]Electrical conductivity (dS-cm) of substrate solution using the pourthrough method.

[x]1:1 (v:v) aged *WholeTree*:peat.

[w]1:1 (v:v) fresh *WholeTree*:peat.

[v]*,**,*** represent significance when P ≤ 0.05, 0.01, or 0.001, respectively. NS denotes no significance (n = 8).

Table 4. **Substrate nitrogen and phosphorus content in aged or fresh *WholeTree* substrate amended with peat.**[z]

	Experiment 1			Experiment 2		
	AWTP[y]	FWTP[x]		AWTP	FWTP	
	(ppm)		Significance[w]	(ppm)		Significance
Nitrogen	38.8	14.3	**	10.1	0.12	***
Phosphorus	23.0	15.7	***	12.3	6.4	**

[z]Data at 7 days after planting.

[y]1:1 (v:v) aged *WholeTree*:peat.

[x]1:1 (v:v) fresh *WholeTree*:peat.

[w]**,*** represent significance when P ≤ 0.01 or 0.001, respectively. NS denotes no significance (n = 3).

Table 5. Effects of aged and fresh *WholeTree* substrates amended with peat on growth of two greenhouse-grown annuals.

Substrate	Shrinkage[z]	GI[y]	Bloom count[x]	Dry weight (g)[w]	Roots[v]
			***Tagetes patula* 'Little Hero Yellow'**		
			Experiment 1		
AWTP[u]	10.5	20.6	14.5	6.6	3.5
FWTP[t]	11.9	16.1	9.6	3.7	1.9
Significances	*	***	***	***	***
			Experiment 2		
AWTP	11.6	22.3	19.2	18.2	—
FWTP	13.7	17.4	11.1	8.5	—
Significance	NS	***	***	***	—
			***Petunia ×hybrida* 'Dreams White'**		
			Experiment 1		
AWTP	10.7	30.8	14.0	6.3	3.1
FWTP	10.5	23.2	8.2	3.5	3.0
Significance	NS	***	***	***	NS
			Experiment 2		
AWTP	13.5	27.0	24.5	18.4	4.0
FWTP	10.9	21.3	11.5	9.6	2.8
Significance	NS	***	***	***	*

[z]Shrinkage in millimeters measured from the top of the container to the top of the substrate surface.

[y]Growth index in centimeters [(height + width + perpendicular width) / 3].

[x]Bloom counts determined by counting all attached flowers and buds showing color.

[w]Plant shoot dry weight in grams.

[v]Visual root rating on a 1 to 5 scale: 1 = 20% coverage; 2 = 40% coverage; 3 = 60% coverage; 4 = 80% coverage; 5 = 100% coverage.

[u]1:1 (v:v) aged *WholeTree*:peat.

[t]1:1 (v:v) fresh *WholeTree*:peat.

[s]*,**,*** represent significance when $P \leq 0.05$ or 0.001, respectively. NS denotes no significance (n = 8).

in FWTP also showed foliar symptoms of nitrogen and phosphorus deficiency as described by Mills and Jones (19). Substrate analysis showed a higher N and P content in AWTP compared to FWTP (Table 4). Deficiency symptoms and plant growth differences were visible at 7 DAP in Experiment 2 and substrate analysis revealed similar results. These differences may be attributed to nutrient leaching, as AWTP did have less AS than FWTP.

There were no differences in substrate shrinkage except for marigolds in Experiment 1. Marigolds growing in FWTP had greater substrate shrinkage than those growing in AWTP. Marigolds growing in AWTP were 21% larger in Experiment 1 and 22% larger in Experiment 2 than those growing in FWTP. Bloom counts were 33% higher in Experiment 1 and 42% higher in Experiment 2 for marigolds grown in AWTP; similarly, dry weights of marigolds grown in AWTP were 44% greater in Experiment 1 and 53% greater in Experiment 2 (Table 5). Marigold root ratings were higher for those plants growing in AWTP in Experiment 1. Petunias grown in AWTP had 25% greater growth indices, 41% more blooms, and 44% greater dry weights in Experiment 1 than plants grown in FWTP. In Experiment 2, petunias grown in AWTP had 21% greater growth indices, 53% more blooms, and 47% greater dry weights than plants grown in FWTP. In Experiment 2 petunia root ratings were higher for plants grown in AWTP (Table 5). Differences in plant growth may be attributed, at least partly, to differences in substrate physical properties. Increased AS and lower CC in the FWTP could have resulted in increased nutrient leaching as well as a decrease in water availability. Differences may also be attributed to N immobilization. Another explanation may be a plant-plant interaction (or allelopathic relationship) between fresh WT substrate and the plant. We speculate that some chemical compound may be present in fresh WT that is diminished during the aging process. Unpublished work by the authors supports this hypothesis; however, further analysis of fresh and aged WT is necessary. While further studies need to be conducted to confirm the benefits of aging it is our recommendation that *WholeTree* substrates be allowed to go through an initial aging process prior to use. While other studies (16) indicate wood fiber substrates can be used fresh, this study indicates that plant growth response in WT is superior when WT is aged.

Literature Cited

1. Appleby, M. 2009. Peat: The discussion continues. Horticulture Week. March 27, 2009.

2. Bilderback. T.E. 1987. Effect of particle size and aging on moisture retention of pine bark nursery mulches. Proc. Southern Nursery Assn. Res. Conf. 32:49–53.

3. Boyer, C.R.2008. Evaluation of clean chip residual as an alternative substrate for container grown plants. Auburn University Dissertation. 204 pp.

4. Boyer, C.R., G.B. Fain, C.H. Gilliam, T.V. Gallagher, H.A. Torbert, and J.L. Sibley. 2008. Clean chip residual: a substrate component for growing annuals. HortTechnology 18:423–432.

5. Buamscha, M.G., J.E. Altland, D.M. Sullivan, D.A. Horneck, and J.P.G. McQueen. 2008. Nitrogen availability in fresh and aged douglas fir bark. HortTechnology 18:619–623.

6. Denning, J., R. Eliason, R.J. Goos, B. Hoskins, M.V. Nathan, and A. Wolf. 1997. Recommended Chemical Soil Test Procedures. Missouri Agricultural Experiment Station Number 221.

7. Dueitt, S.D. and S.E. Newman. 1994. Physical analysis of fresh and aged rice hulls used as a peat moss substitute in greenhouse media. Proc. Southern Nursery Assn. Res. Conf. 39:81–85.

8. Fain G.B., C.H. Gilliam, and J.L. Sibley. 2006. Processed whole pine trees as a substrate for container-grown plants. Proc. Southern Nursery Assn. Res. Conf. 51:59–61.

9. Fain, G.B., C.H. Gilliam, J.L. Sibley, and C.R. Boyer. 2008a. *WholeTree* substrates derived from three species of pine in production of annual vinca. HortTechnology 18:13–17.

10. Fain, G.B., C.H. Gilliam, J.L. Sibley, and C.R. Boyer. 2008b. *WholeTree* substrate and fertilizer rate in production of greenhouse-grown petunia (*Petunia ×hybrida* Vilm.) and marigold (*Tagetes patula* L.). HortScience 43:700–705.

11. Fonteno, W.C., C.T. Hardin, and J.P. Brewster. 1995. Procedures for determining physical properties of horticultural substrates using the NCSU Porometer. Horticultural Substrates Laboratory. North Carolina State University Porometer Manual.

12. Gaches, W.G., G.B. Fain, D.J. Eakes, C.H. Gilliam, and J.L. Sibley. 2010. A comparison of *WholeTree* and chipped pine log substrate components in the production of greenhouse grown annuals. J. Environ. Hort. 28:173–178.

13. Gruda, N. and W.H. Schnitzler. 2003. Suitability of wood fiber substrate for production of vegetable transplants. Scientia Horticulturae 100:309–322.

14. Hue, N.V. and C.E. Evans. 1986. Procedures Used for Soil and Plant Analysis by the Auburn University Soil Testing Laboratory. Dept. of Agronomy and Soils. Serial 106.

15. Jackson, B.E., R.D. Wright, and M.C. Barnes. 2008. Pine tree substrate, nitrogen rate, particle size, and peat amendment affect poinsettia growth and substrate physical properties. HortScience 43:2155–2161.

16. Jackson, B.E., R.D. Wright, and M.C. Barnes. 2010. Methods of constructing a pine tree substrate from various wood particle sizes, organic amendments, and sand for desired physical properties and plant growth. HortScience 45:103–112.

17. Johnson, D.R. and T.E. Bilderback. 1981. Physical properties of aged and fresh peanut hull media and their effect on azalea growth. Proc. Southern Nursery Assn. Res. Conf. 26:42–47.

18. Mengel, K. and E.A. Kirkby. 2001. Principles of Plant Nutrition. 5th ed. Springer Publishing, Inc. New York, NY.

19. Mills, H.A. and J.B. Jones, Jr. 1997. Plant Analysis Handbook II. MicroMacro Publishing, Inc. Athens, GA.

20. Muro, J., I. Irigoyen, P. Samitier, P. Mazuela, M.C. Salas, J. Soler, and M. Urrestarazu. 2004. Wood fiber as growing medium in hydroponic crop. Acta Hort. 697:179–185.

21. Pokorny, F.A. 1975. A physical characterization of pine bark used in three commercial nurseries. Proc. Southern Nursery Assn. Res. Conf. 20:25–27.

22. Witcher, A.L., G.B. Fain, E.K. Blythe, and J.M. Spiers. 2009. The effect of nitrogen form on pH and petunia growth in a *WholeTree* substrate. Proc. Southern Nursery Assn. Res. Conf. 54:428–233.

23. Wright, R.D. 1986. The pour-through nutrient extraction procedure. HortScience 21:227–229.

24. Wright, R.D. and J.F. Browder. 2005. Chipped pine logs: A potential substrate for greenhouse and nursery crops. HortScience 40:1513–1515.

25. Wright, R.D., B.E. Jackson, J.F. Browder, and J. Latimer. 2008. Growth of Chrysanthemum in ground pine trees requires additional fertilizer. HortTechnology 18:111–115.