Evaluation of *WholeTree* as an Alternative Substrate Component in Production of Greenhouse-Grown Annuals

by

Whitney Nicole Griffin

A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
May 14, 2010

Approved by

Glenn B. Fain, Chair, Assistant Professor Department of Horticulture
Donald J. Eakes, Professor Department of Horticulture
Charles H. Gilliam, Professor Department of Horticulture
Jeff L. Sibley, Professor Department of Horticulture

Abstract

The physical properties and growth of greenhouse annuals in chipped pine log (CPL) and *WholeTree* (WT) alternative substrate components were evaluated. Both wood-fiber alternatives have been reported as suitable for the greenhouse production of annuals; however, the two had not yet been compared. CPL is composed of a pine log while WT is composed of all aboveground portions of a pine tree, including wood, bark, needles, and branches. Plants grown in WT and CPL perform similarly - while minor differences in physical properties were present, these had no apparent affect on plant growth as plant response data were generally similar. Interestingly, we did find differences between experiment 1 and experiment 2 – the plants in both substrates were larger in experiment 2, even though there were no treatment differences. This led to the hypothesis that aging a wood fiber substrate may be beneficial to plant growth, leading to the second experiment

In a second experiment, physical properties and growth of greenhouse annuals in aged and fresh *WholeTree* substrate were evaluated. In both experiments aged material was aged a minimum of 90 days while fresh material was used no more than 2 days past processing. Plants grown in aged WT had higher growth indices, more blooms, greater dry weights, and greener leaves than those grown in fresh WT. In physical properties, aged WT had less air space and a greater container capacity than fresh WT. While the overwhelming differences in plant response may be attributed to physical properties, we

felt that there may be some chemical present in the needles in fresh WT that had a phytotoxic effect on plant growth.

The potential phytotoxicity of aged and fresh WT was evaluated in a third experiment. Lettuce seeds were germinated in increasing concentrations of aged or fresh pine needle leachate. There were no differences in germination percentage; however, radicle length was longer in seeds germinated in aged needle leachate compared to those germinated in fresh needle leachate. This indicates that the differences in aged and fresh WT may be attributed to a phytotoxic chemical response.

Acknowledgements

The author would like to thank God for the many blessings and the personal growth that resulted from this work. Thanks also to Drs. Glenn B. Fain, Charles H. Gilliam, and Jeff L. Sibley for their insight, guidance, and support during the planning and implementation of this research. Heartfelt gratitude and love expressed to Dr. Donald J. Eakes and family for the love, discipleship, and prayers during my tenure at Auburn. Thanks to Bess Eakes for the home-cooked biscuits and kindness every Tuesday morning. You all are not only an inspiration to me, but are my family away from home. Thanks to Ashley Baker and Jess Busch for assistance with research and data.

To my parents- I would not have made it this far if not for your continued love and support. I’m a far cry from the kid you moved to college, but I hope I always make you proud. And to my fiancé, Brint- you and I both know I never would have finished this research or this manuscript on time if it weren’t for you. You helped with the physical labor, the data collection, and the moral support. Your words of encouragement and prayers of support were more than I could have ever hoped for. You provided unconditional love for the last two years, and I’ll spend my next sixty years showing the same to you.

Table of Contents

List of Tables

Chapter I

Chapter II

Chapter III

List of Figures

Chapter III

Chapter IV

I. LITERATURE REVIEW

Introduction

Container substrates and their components are a vital resource for the greenhouse industry. In general, growers need substrates that are consistent (little variability in composition from load to load), reproducible, available, easily handled, and cost effective (23). Desirable chemical and physical properties of the substrate and its components are also important. The purpose of a container substrate is to physically support the plant and to supply adequate oxygen, water, and nutrients for root functions (19). Physical properties that are important include total porosity, water holding capacity, air space, bulk density, and particle size distribution while important chemical properties are pH, soluble salts concentration, and cation exchange capacity (19).

Today, greenhouse substrates in the United States are primarily Canadian peat moss with some percentage of pine bark, vermiculite, or perlite added to achieve the desired physical properties; however, due to declining availability and increasing costs of these materials a need for a suitable alternative has become more prevalent. Over the last few decades many materials have been investigated as substrate alternatives or amendments. Some alternatives that have been evaluated to date include spent tea grinds (43), cowpeat (25), vegetable waste compost (31), municipal solid waste compost (28), and cotton gin composts (9).

Pine Bark Resources and the Green Industry

Pine Bark usage in greenhouse and nursery operations. Bark is widely used in horticulture as a primary component in most nursery and greenhouse substrates, and often comprises as much as 75% to 100% (by volume) of nursery substrates (28). With the economic development after World War II bark developed into a profitable segment known as the “horticulture bark industry” (18) and was used mostly for landscaping. Shortly thereafter research determined that pine bark was also suitable as a substrate amendment as a shift to ‘soilless’ substrates was gaining momentum.

Pine Bark supplies in the United States. In the late 1970’s the horticulture industry realized the pressure of limited bark supplies as alternative uses for pine bark began to rise in popularity as a response to the energy crisis (36). An in-depth review of U.S. bark generation and the implications of those supplies to the horticulture industries (29) painted a somewhat gloomy outlook on the future of pine bark as a substrate component. Lu’s findings illustrated a 1% (approximately 5 million acres) loss in U.S. timberland from 1952 to 2002, coupled with a projected U.S. population increase of 126 million over the next fifty years. The result is a projected net loss of 15 million acres of timberland, or 3% by 2050. As harvestable timberland decreased between 1991 and 2001, U.S. timber harvest decreased 12%; however, the southern region experienced an increase of 6% during this decade. Estimates are that the next fifty years will see a 29% increase in total timber harvest; however, even with the expected modest increase of bark generation over the next fifty years, regional variability and freight costs will prove to be limiting factors, increasing the cost of available bark. The overall trend implicates less availability and affordability of bark for the horticulture industry with current and expected economic conditions.

Peat Resources and the Green Industry

Peat usage in greenhouse and nursery operations. Greenhouse substrates have been primarily peat based since the introduction of the Cornell Peat-Lite mixes in the early 1960’s (5). Peat is ideal because it is largely inert, pathogen-free, and increases water-holding capacity while decreasing the weight of the substrate (39). The Green Industry uses three common classifications to further describe peat: peat moss, sphagnum moss, and reed-sedge peat. Peat moss is very acid (pH 3.8 to 4.3) (39). Sphagnum moss is the young residue or live portion of the plant. Commonly called ‘top moss’, sphagnum moss is most often used for plant shipment, propagation, or to line hanging baskets. Finally, reed-sedge peat is formed principally from sedges, reeds, and other swamp plants and has a low moisture-retention capacity (39). Sphagnum mosses are preferred for horticultural operations (11), and there are many considerations in the selection of a peatland for production of horticultural-grade peat including: the quality of the peat, an average depth of at least 2 meters, a total area of at least 50 ha, proximity to a transportation infrastructure, and climatic factors such as consecutive days without rainfall for harvesting (11). An International Peat Society survey from 1999 noted that Canada ranked first in the world production of horticultural peat, just ahead of Germany (Table 1). In 1999 peat exports in Canada were valued at nearly $170 million (35). The United States represents between 85 and 90 percent of the export market for all peat produced in Canada. Production in Canada has undergone a steady growth over the last two decades. In 1987, imports from Canada represented 35% of consumption. Consumption rose to 44% by 1990 and 54% by 1998 (35). The main peat production season in Canada is late May to mid-September. Production can be severely inhibited by abnormally wet spring or summer weather, resulting in significant variation in annual production (11). In 2008, poor weather conditions limited peat production causing shortages throughout the U.S. (Greg Young, personal communication).

While the United States imports most of its peat from Canada, some sources of horticultural peat are European in nature. Rising transportation costs negatively affect the profitability for growers regardless of the peat source (8). Shifts to sustainability and environmental awareness are also negatively impacting peat production. In Europe, an anti-peat movement has begun to protect the bogs and surrounding wetland habitats. In fact, Great Britain has a 2010 goal of reducing peat production by 90% (1). While the declining availability of peat negatively affects growers in the United States, our dependence on peat has been questioned for some time. Barkham (2) reported that there is no longer a need to use peat for the wide variety of garden, commercial, horticultural, and landscape uses for which it has been promoted over the last 30 years.

One significant problem with peat moss is the difficulty to initially wet the material. Peat moss is hydrophobic and repels water. Some suppliers treat peat moss with a wetting agent to combat this problem. Peat moss is often mixed with other components to obtain structure and prevent substrate shrinkage; two common components are vermiculite and perlite. Vermiculite is a sterile, heat-expanded micaceous material. Vermiculite must reach temperatures of over 1800°F in order to expand, which then provides structure to substrates and coarser textures. Perlite is a sterile, heat-expanded volcanic rock, which provides structure to substrates. While vermiculite has relatively high CEC, impacting the substrate chemical properties, perlite does not contribute to the chemical properties of a substrate. Perlite expansion is also dependent on temperatures of over 1800°F. Unlike many organic components, perlite does not decay except through physical destruction.

A Shift to Sustainability

Effects on the Green Industry. The green industry has seen a recent shift to sustainability, following numerous other industries in the United States. VeraFlora™ is a certification program that provides sustainability performance standards for growers and handlers of cut flowers and potted plants. These sustainability standards apply to all facets of the industry from propagation and production to transportation and shipping. With the increased emphasis on sustainability, certain substrate components have come under scrutiny, i.e. the production of vermiculite and perlite which require an immense amount of heat energy and uses valuable fossil fuels, also neither material are considered sustainable.

Alternatives to Peat

European Alternatives. Europe has recognized a need for sustainable alternative substrates for quite some time. In 1999, at least seven well-known wood fiber products were marketed in Europe. That same year, Germany revealed that over 253,000 m^3 of wood-fiber products are marketed annually (17). Fibralur® is one such product, available in Spain. Fibralur® is derived from carrying out a thermal-mechanical treatment on wood chips. Muro, et al. (33) reported no difference in tomato yield for crops grown in Fibralur® as compared to those grown in perlite mixes. Toresa® is another wood-based alternative substrate comprised primarily of pine and spruce species and is available in Switzerland. Self-described by the company as self-impregnated wood borne from live, peeled coniferous wood, Toresa® is a widely marketed substrate with over seven different mixes available to date (www.toresa.de). Gruda and Schnitzler (16) reported that the physical properties of wood-fiber based substrates were similar to peat with the exception of water retention, in which peat outperformed the wood-fiber substrates.

Alternatives in the United States. Over the last few years several alternative substrate components have been investigated in the United States. Parboiled rice hulls (13), spent tea grinds (43), peanut hulls (21), and cowpeat (25) are only a few examples. Each of these alternative substrates and substrate amendments are organic in nature and utilize a material that may otherwise be considered waste – more evidence of the Green Industry's shift to sustainability.

Wood-Based Alternatives in the United States. Research into wood-based alternatives has been going on for decades. MacDonald and Dunn (30) reported that composted sawdust could be used to improve soil conditions in the production of corn, soybean, and cabbage. Unfortunately, the specific type of sawdust was not reported. Still et al. (42) reported that chrysanthemums grown in composted 15 - year old white oak sawdust at a 400 ppm N rate were comparable to those grown in a standard soil:peat:perlite mix. Conover and Poole (10) reported that the inclusion of *Melaleuca quinquenervia* bark increased the noncapillary pore space in low quality peats during the production of foliage plants. Later in 1985, hardwood chips obtained by grinding entire dormant *Quercus stellata* and *Ulmus pumila* proved a potential alternative for container plant production (22). The hardwood chips were passed through a hammer mill with a 7.6 cm x 7.6 cm screen; yielding particles up to 2.5 cm in length and 0.3 to 0.6 cm in width. Unlike Still et al. (42), additional nitrogen resulted in no difference in growth as compared to a standard pine bark mix. The addition of Micromax® increased the visual rating of *Pyracantha* x 'Mojave' in the elm substrate, but in the oak substrate a general decline occurred with increasing Micromax®. Micromax® is a patented trace element fertilizer containing all necessary trace elements to ensure optimal plant growth. While the addition of certain trace elements can affect substrate pH, the authors of the article did not address why the addition of Micromax® may have impacted plant growth. Decreasing drainable pore space after each growing season implicated decomposition of the growing substrate; however, root ratings at the end of the test were not different. While the evaluation of hardwood substrate components progressed through the years, no single hardwood species or method of producing the substrate ever emerged as superior.

Shortly after Kenna and Whitcomb (22) reported *Quercus stellata* and *Ulmus pumila* were satisfactory hardwood alternatives, Laiche and Nash (24) were the first to suggest the utilization of pine wood as an alternative or amendment to standard mixes. In an experiment utilizing a standard mix, pine bark with wood, and whole pine tree chips without bark there was a similar trend in plant growth indices among all treatments: the standard mix was superior to pine bark with wood, and both of those treatments were superior to pine chips without bark. Laiche and Nash (24) went on to hypothesize that the results were due to the size of the pine chips; the chips had not been passed through a hammer mill, but had simply been ground to about 0.5 in chips. They suggested if the pine chips were decreased in size, then water holding capacity and nutrient retention would increase, producing different results. The idea of pinewood-based substrates becoming an alternative for pine bark was not revisited again until 2005.

In 2005, Wright and Browder (47) reported that chipped pine logs obtained by grinding a loblolly (*Pinus taeda* L.) log to a particle size suitable for container substrate could be a potential substrate for greenhouse crops. Shoot dry weight for marigold (*Tagetes erecta* Big. 'Inca Gold') grown in 75:25 pine chip:pine bark was equal to those grown in 100% pine bark, and both were greater than those grown in 100% pine chips. Nutrient analyses showed that no toxic nutrient levels were associated with the pine chips, and the pH and EC levels in the pine chip substrates were acceptable. By milling the wood chips into a finer texture, a substrate-grade wood fiber material was finally achieved. Wright, et al. (48) reported that a greenhouse crop grown in chipped pine logs (CPL) was comparable to that grown in a standard peat-lite mix if additional fertilizer was added to the pine substrate. Researchers hypothesized that the requirements for additional N fertilization could be attributed to increased porosity, lower EC, and lower CEC in CPL. Additional requirements also could be attributed to microbial N immobilization of the CPL. Requirements for additional N fertilization followed the trend established by Still et al. (42). Also in 2008, Jackson, et al. suggested that physical properties similar to those of peat could be attained in CPL substrates when hammer-milled with a 2.38 mm screen. The same study reported that poinsettias produced in three different pine substrates and a peat moss control had similar dry weights and growth indices when fertilized with a 300 ppm N fertilizer solution. By this time it was clear that wood fiber substrates were a definite possibility, at the cost of additional fertilization.

Another wood-fiber alternative for greenhouse producers is Clean Chip Residual (CCR). A by-product of the forestry industry, CCR is the material left over after pine trees are processed into clean chips (used for making paper products and bioenergy) and is approximately 50% wood, 40% bark, and 10% needles (6). Growth indices and shoot dry weights for ageratum (*Ageratum houstonianum* Mill. ‘Blue Hawaii’) grown in CCR-based substrates were similar to those grown in standard pine bark mixes (7). Ageratum leaf chlorophyll content in plants grown in CCR-based substrates was similar or greater than those of plants grown in standard mixes. Boyer et al. (6) results were consistent with results reported by Wright and Browder (47), Wright et al. (48), and Jackson et al. (20) where annuals grown in wood fiber substrates have similar growth to plants grown in a standard mix.

WholeTree is an alternative substrate made from whole pine tree above-ground portions: wood, bark, needles, and cones, approximately 80% of which is wood fiber. The trees are usually young (10 to 15 years old) and come from thinning or salvage operations where young plantations have not been managed well, have been damaged by storms or pine beetles, or are clear-cut in order to re-plant. Trees are chipped and then ground with a hammer mill to pass through a 0.374 in screen. Fain et al. (14) reported that *WholeTree* serves as a suitable alternative for annual vinca production. *Catharanthus roseus* “Raspberry Red Cooler’ grown in pine bark, loblolly pine whole tree, slash pine whole tree, and longleaf pine whole tree substrates all had similar growth indices. Shoot dry weights were 15% greater for plants grown in one hundred percent pine bark after 60 days, with no differences in growth indices or leaf greenness. *Catharanthus roseus* ‘Little Blanche’ had similar results in the same test, along with a suggestion that petunia and marigold could be grown in *WholeTree* substrates with additional starter fertilizer (15). The advantages of *WholeTree* include sustainability and availability to horticultural production areas, adjustability of the final product to tailor it for specific applications, and consistent quality.

Aged or Fresh?

Similar forestry byproducts. 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. (4) reported that geraniums (*Pelargorum* x *hortorum* Bailey ‘Maverick Red’) grow larger and absorb more N when grown in aged DFB compared to fresh DFB. For the study, 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. Storage piles of DFB were exposed to ambient climate and received no additional inputs such as fertilizer, irrigation, or aeration (Buamscha et al. 2008).

Other organic alternatives. Other organic substrate components are usually evaluated to determine the necessity of aging or composting the material. Johnson and Bilderback (21) 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 and less container capacity than fresh peanut hulls. While statistical differences between the two components were not present, aged peanut hulls yielded higher shoot and root dry weights than fresh peanut hulls. The method of aging peanut hulls was not described. Bilderback (3) reported that as pine bark is aged, particle size decreases, increasing moisture retention. Particle size distribution appeared to be influenced more by longer periods of aging than by sieving or grinding procedures. Dueitt and Newman (12) reported that fresh and aged rice hulls are an acceptable peat moss substitute in greenhouse substrate. The addition of aged rice hulls reduced the air space initially, and substrate containing fresh rice hulls initially had greater air space as compared to substrate containing fresh rice hulls. These observations were reversed at the conclusion of the study. Dueitt and Newman (12) attributed this to substrate shrinkage during the growth period. The method of aging the rice hulls was not described.

Phytoxocities Associated with ***Pinus spp.***

Research reporting phytoxicities linked to Pinus spp. Professor Hans Molisch is considered the modern Father of Allelopathy, having coined the term in 1937 to refer to biochemical interactions between all types of plants including microorganisms (32). A modern definition defines allelopathy as any direct or indirect harmful effect by one plant on another through production of chemical compounds that escape into the environment (37); however, in the more recent edition of his book, Rice refers back to Molisch's original definition to allow the term allelopathy to include both harmful and beneficial interactions between plants and microorganisms (38).

With the previous definition in mind, several investigators have reported on the allelopathic effects of *Pinus spp.* on other plants. Nektarios et al. (34) reported that allelopathic potential of *Pinus halepensis* Mill. needles is greatest with fresh needles, moderate in senesced needles, and low in decaying needles in a bioassay using fresh, senesced, and decaying pine needle leachate with *Avena sativa* as the biosensor plant.

The dynamics of ponderosa pine stands in North Dakota were studied to determine the influence of plant-produced chemicals on nitrification (27). Low levels of nitrate-nitrogen relative to ammonium-nitrogen and low numbers of *Nitrosomas* and *Nitrobacter* in the soils suggested that nitrification rates were low which could not have been pH related, as the soils were alkaline. Evidence in the study suggested that the reduction in nitrate synthesis was due to the production and subsequent transfer of allelochemicals to the soil. Several compounds inhibitory to nitrification were found in extracts from ponderosa pine needles, bark, and A-horizon soils (27).

Early work at the USDA Bureau of Soil demonstrated that various leachates of oak, pine, chestnut, tuliptree, dogwood, maple, and cherry were inhibitory to wheat seedling transpiration or growth (26, 41), but this work was never followed up.

Monoterpenes and other allelochemicals in Pinus spp. Whittaker and Feeny (45) identified five major categories of plant-produced chemical inhibitors: phenylpropanes, acetogenins, terpenoids, steroids, and alkaloids. Terpenoids, or terpenes, consist of five-carbon isoprene units linked together in various ways and with different types of ring closures, functional groups, and degrees of saturation (40). Monoterpenes consist of C_{10} hydrocarbons and are the major constituents of many pine resin oils (46). Potential sources of monoterpenes include leaf litter, canopy, and roots exudates. Leachate from pine leaf litter is thought to be the largest source (46). As allelopathic agents, they are thought to inhibit plant growth and germination in several plant communities (46).

In 1986, White began research on monoterpene inhibition of the nitrogen cycle (44). He hypothesized that vegetation in ponderosa pine forests inhibited nitrification by releasing volatile terpenes that retarded the oxidation of ammonium. White used 'trapped vapor' experiments to assay the effects of vapors on nitrification in soils from burned plots. Soil from non-burned plots placed in sealed jars containing soil from burned plots reduced nitrification by 87%. A single water extraction of unburned forest floor reduced nitrification by 17%. Vapors from a mixture of five major monoterpenes found in the pine resin completely inhibited nitrification (44).

Statement of Research Objectives

The objective of this thesis was to compare *WholeTree* substrate and Chipped Pine Log substrates for use as an amendment or replacement in greenhouse-grown container crops. *WholeTree* and Chipped Pine Log substrates have not adequately been compared to determine differences in physical properties or plant response to determine which may provide the most desirable results for growers. Evaluation of *WholeTree* and Chipped Pine Logs led to the hypothesis that aging *WholeTree* does in fact affect its physical properties and ability to produce marketable greenhouse-grown annuals. Potential benefits of aging *WholeTree* prior to its utilization in greenhouse operations were investigated, ultimately leading to the suggestion that growers should age

WholeTree prior to utilization. In examining what may be causing the vast differences in plant response in aged and fresh *WholeTree,* a phytotoxicity bioassay was performed to test for any chemical toxins rendered ineffective during the aging process.

Literature Cited

1. Appleby, M. 2009. Peat usage – the discussion continues. *Horticulture Week* 27 March 2009.
2. Barkham, J.P. 1993. For peat's sake: Conservation or exploitation? Biodiv. Conserv. 2:556-566.
3. 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.
4. 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.
5. Bohlin, C. and P. Holmberg. 2004. Peat-dominating growing medium in Swedish horticulture. Acta Hort. 644:177-181.
6. Boyer, C.R. 2008. Evaluation of clean chip residual as an alternative substrate for container-grown plants. Dissertation. Auburn University, AL. 204 Pages.
7. 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.
8. Carlile, W.R. 2004. Growing media and the environment lobby in the UK 1997-2001. Acta Hort. 644:107-113.

9. Cole, D.M., J.L. Sibley, E.K. Blythe, D.J. Eakes, and K.M. Tilt. 2002. Evaluation of cotton gin compost as a horticultural substrate. Proc. Southern Nursery Assn. Res. Conf. 47:274-277.
10. Conover, C.A. and R.T. Poole. 1983. Utilization of *Melaleuca quinquenervia* as a potting medium component for greenhouse production of foliage plants. HortScience 18:886-888.
11. Canadian Sphagnum Peat Moss Association Bulletin. 2009. Harvesting Peat in Canada. http://www.peatmoss.com/pm-harvest.php.
12. 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.
13. Evans, M.R. and M. Gachukia. 2004. Fresh parboiled rice hulls serve as an alternative to perlite in greenhouse crop substrates. HortScience 39:232-235.
14. Fain, G.B., C.H. Gilliam, J.L. Sibley, and C.R. Boyer. 2008a. WholeTree substrate and fertilizer rate in production of greenhouse-grown petunia (*Petunia* x *hybrida*) and marigold (*Tagetes patula*). HortScience 43:700-705.
15. Fain, G.B., C.H. Gilliam, J.L. Sibley, and C.R. Boyer. 2008b. WholeTree substrates derived from three species of pine in production of annual vinca. HortTechnology 18:13-17.
16. Gruda, N. and W.H. Schnitzler. 2003. Suitability of wood fiber substrate for production of vegetable transplants. Scientia Horticulturae 100:309-322.
17. Gumy, N. 2001. Toresa and other wood-fibre products; advantages and drawbacks when used in growing media. Proc. International Peat Symposium. Pp. 39-46.

18. Haynes, R.W. 2003. An analysis of the timber situation in the United States: 1952-2050. USDA Forest Service, Pacific Northwest Research Station, Gen. Tech. Rep. PNW-GTR-560.
19. Ingram, D.L., R.W. Henley, and T.H. Yeager. 1991. Growth media for container grown ornamental plants. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. August 1991. 21 pages.
20. 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.
21. 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.
22. Kenna, S.W. and C.E. Whitcomb. 1985. Hardwood chips as an alternative medium for container plant production. HortScience 20: 867-869.
23. Klock-Moore, K.A., G.E. Fitzpatrick, and G. Zinati. 2000. Container production of ornamental horticultural crops. BioCycle 41(11):58-60.
24. Laiche, A.J. and V.E. Nash. 1986. Evaluation of pine bark, pine bark with wood, and pine tree chips as components of a container plant growing media. J. Environ. Hort. 4:22-25.
25. Li, Q., J. Chen, R.D. Caldwell, and M. Deng. 2009. Cowpeat as a substitute for peat in container substrates for foliage plant production. HortTechnology 19:340-345.

26. Livingston, B.C., C.A. Jensen, J.F. Breazeale, F.R. Pember, and J.J. Skinner. 1907. Further studies on the properties of unproductive soils. U.S. Department of Agriculture, Bureau of Soils Bulletin 36:1-71.
27. Lodhi, M.A.K. and K.T. Killingbeck. 1980. Allelopathic inhibition of nitrification and nitrifying bacteria in a ponderosa pine (*Pinus ponderosa* Dougl.) community. Amer. J. Bot.67:1423-1429.
28. Lu, Wenliang. 2008. Utilization of municipal solid waste compost in horticulture. Dissertation. Auburn University, AL. 199 Pages.
29. Lu, W., J.L. Sibley, C.H. Gilliam, J.S. Bannon, and Y. Zhang. 2006. Estimation of U.S. bark generation and implications for horticultural industries. J. Environ. Hort. 24:29-34
30. MacDonald, W.A. and S. Dunn. 1953. Sawdust composts in soil improvement. Plant and Soil 4: 235-247.
31. Mazuela, P., M.C. Salas, and M. Urrestarazu. 2005. Vegetable waste compost as substrate for melon. Commun. Soil Sci. Plant Anal. 36:1557-1572.
32. Molisch, H. 1937. “Der Einfluss einer Pflanze auf die andere-Allelopathie.” Fischer, Jena. 132 pages.
33. Muro, J., I. Irigoyen, P. Samitier, P. Mazuela, M.C. Salas, J. Soler, and M. Urrestarazu. 2005. Wood fiber as growing medium in hydroponic crop. Acta Hort. 697:179-185.
34. Nektarios, P.A., G. Economou, and C. Avgoulas. 2005. Allelopathic effects of *Pinus halepensis* needles on turfgrasses and biosensor plants. HortScience 40:246-250.

35. Paquette, J. And Y. Gauthier. 2000. Non-metal mines SIC 062, 1999. Statistical Service of Canada. Ottawa, Ontario.
36. Penick, E.B., Jr. 1980. Future of the horticultural bark industry in the United States. Proceedings NO. P-80-27, Forest Products Research Society, Madison, WI.
37. Rice, E.L. 1974. Allelopathy. Academic Press, New York. 170 pages.
38. Rice, E.L. 1984. Allelopathy: Second Edition. Academic Press, New York. 424 pages.
39. Robbins, J. A. and M. R. Evans. 2005. Growing media for container production in a greenhouse or nursery part 1 components and mixes. University of Arkansas Extension Service.
40. Robinson, T. 1983. The organic constituents of higher plants. 5th Ed. Cordus Press, North Amherst, Massachusetts.
41. Schreiner, O. and J.J. Skinner. 1911. Lawn soils. U.S. Department of Agriculture, Bureau of Soils Bulletin 75:1-55.
42. Still, S., J. B. Gartner, and T.D. Hughes. 1972. Effect of sawdust age and nitrogen application on chrysanthemums grown in white oak sawdust media. Forest Products J. 22:111-114.
43. Wells, D.E., J.L. Sibley, J.L. Evers, C.H. Gilliam, and W.A. Dozier. 2009. Utilization of spent tea grinds as a substrate components in container production. Proc. Southern Nursery Assn. Res. Conf. 54:176-179.
44. White, C.S. 1986. Volatile and water-soluble inhibitors of nitrogen mineralization and nitrification in a ponderosa pine ecosystem. Biology and Fertility of Soils 2:97-104.

45. Whittaker, R.H. and P.P. Feeney. 1971. Allelochemics: chemical interactions between species. Science 171:757-770.

46. Wood, S.E. 1996. Loss of foliar monoterpenes from *Umbellularia californica* leaf litter and their influence on nitrification potential in soil beneath the trees. University of California, Davis. 151 pages.

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

48. Wright, R.D., B.E. Jackson, J.F. Browder, and J.G. Latimer. 2008. Growth of chrysanthemum in a pine tree substrate requires additional fertilizer. HortTechnology 18:111-115.

Table 1. Peat Production by Country in 1999. Based on an International Peat Society survey.

Country	**Energy Use**	**Horticulture Use**
	(1 = 1000 cubic meters	
Belarus	10,281	764
Canada	0	10,317
Czech Republic	0	171
Estonia	2,955	3,484
Finland	23,483	2,420
Germany	0	9,473
Hungary	0	212
Ireland	13,959	2,400
Lithuania	1,189	819
Norway	0	120
Poland	0	750
Russia	11,283	1,115
Sweden	2,700	1,400
Ukraine	1,758	315
South Africa	0	42
United Kingdom	40	2,500
United States	0	1,421
TOTAL	**67,648**	**37,723**

II. A COMPARISON OF *WHOLETREE* AND CHIPPED PINE LOG SUBSTRATES

Abstract

WholeTree (WT) and chipped pine logs (CPL) are potential new sustainable greenhouse substrate components made by milling chipped pine trees and/or pine logs (*Pinus taeda* L.). Two experiments were conducted to evaluate the growth of *Catharanthus roseus* L. 'Grape Cooler' and *Impatiens walleriana* Hook. 'Dazzler Apricot' in 1:1 (v:v) WT:peat (WTP) and 1:1 (v:v) CPL:peat (CPLP), and to compare physical properties of those substrates. In Experiment 1 WTP had 76.8% Container (CC) Capacity and 96.4% Total Porosity (TP) while CPLP had 72.4% CC and 90% TP; Air Space (AS) and Bulk Density (BD) were similar. In Experiment 2 there were no differences in physical properties. In Experiment 1 EC peaked at 14 days after potting (DAP) and decreased through the remainder of the study. At 0 DAP pH ranged from 4.2 – 4.3 and increased to a range of 6.4 to 6.8 at 42 DAP. This trend was similar in Experiment 2, except that EC peaked at 7 DAP. In impatiens, plants were similar in Experiment 1 but those grown in WTP in Experiment 2 had bloom counts of 37.3 compared to 27.9 for plants grown in CPLP. With vinca, in Experiment 1 plants grown in CPLP had a dry weight of 7.3 g as compared to 6.9 g for plants grown in WTP, but there were no differences in Experiment 2. Results indicate that growers could use CPL and/or WT interchangeably, depending on available resources

Index Words: alternative substrate, greenhouse production, wood chips, wood fiber, peat, substrate

Species Used in this Study: *Catharanthus roseus* L. 'Grape Cooler'; *Impatiens walleriana* Hook. 'Dazzler Apricot'

Significance to the Industry

In recent years, wood-based alternative substrate components have been introduced to growers as viable, renewable alternatives to peat in greenhouse production, including Chipped Pine Logs (CPL) and *WholeTree* (WT). CPL is obtained by chipping and grinding a pine log that has been delimbed; WT is obtained by chipping and grinding all aboveground portions of a pine tree. Independent studies comparing CPL and WT to peat-lite mixes are similar; however, a comparison of the two substrate components has not yet been reported. This research was conducted to compare the physical properties as well as plant response of two annual species to both substrates in order to characterize differences in plant growth response, if any, between WT and CPL. Availability of WT and CPL to growers may be different regionally; results indicate that growers can use WT and CPL interchangeably.

Introduction

Research into wood-based alternative substrates has been going on for decades (3, 11, 12, 13, 15, 16). While American research into wood fiber alternatives dwindled in the 1990's, European researchers continued to investigate wood fiber as an alternative for the diminishing peat supply. In 1999, at least seven well-known wood fiber products were marketed in Europe. That same year, over 253,000 m^3 (331,000 yd^3) of wood-fiber products was marketed annually in Germany (9). Toresa® is one such product comprised primarily of spruce (*Picea spp.*) and is available in Switzerland. Self-described by the company as self-impregnated wood borne from live, peeled coniferous wood, Toresa® is a widely marketed substrate with over seven different blends available to date. Fibralur® is another wood fiber alternative substrate, available in Spain, and is derived from carrying out a thermal-mechanical treatment on wood chips. Tomatoes grown in Fibralur® were similar in fruit yield as compared to those grown in perlite mixes (14). Gruda and Schnitzler (8) reported that the physical properties of wood-fiber based substrates were similar to peat with the exception of water retention. Recently, US research has turned once again to wood fiber substrates when Boyer et al. (2), Fain et al. (4, 5, 6), and Wright and Browder (17) expanded upon earlier work by Laiche and Nash (12). Previous work by Laiche and Nash (12) compared milled pine bark, pine bark with a considerable amount of wood (PBW), and pine tree chips (PTC). Because the material in the study was chipped and not milled, PBW and PTC substrate physical properties were not conducive to plant growth.

Wright and Browder (18) reported that CPL obtained by chipping and grinding a loblolly pine log (*Pinus taeda* L.) could be a potential new greenhouse substrate. *Tagetes erecta* Big. ‘Inca Gold’ grown in 75:25 CPL:Peat had similar dry weights to those grown in 100% peat. A later report indicated a need for additional fertilizer was required in the production of greenhouse annuals in CPL obtained by chipping and grinding a loblolly pine log (18). Also in 2008, Jackson et al. (10) reported that physical properties similar to those of peat could be attained in CPL when hammer-milled using a 0.24 cm (0.09 in) screen.

Another wood-fiber alternative for greenhouse producers is Clean Chip Residual (CCR). A by-product of the forestry industry, CCR is the material left over after pine trees are processed into clean chips (used for making paper products and boiler fuel) and is approximately 50% wood, 40% bark, and 10% needles (1). Growth indices and shoot dry weights for ageratum (*Ageratum houstonianum* Mill. ‘Blue Hawaii’) grown in CCR-based substrates were similar to those grown in standard pine bark mixes (2). Ageratum leaf chlorophyll content in plants grown in CCR-based substrates was similar or greater than that of plants grown in standard mixes. Results of Boyer et al. (2) work were consistent with results reported by Wright and Browder (18), Wright et al. (19), Fain et al. (5) and Jackson et al. (10) where annuals grown in wood fiber substrates have similar growth to plants grown in a standard mix.

WholeTree (WT) is another wood fiber alternative substrate component created from entire pine trees harvested at the thinning stage. All above ground portions of the tree (wood, bark, and needles) are chipped and later ground to crop specifications; thus, WT consists of approximately 80% wood, 15% bark, and 5% needles. Fain et al. (4, 5) reported that WT substrates derived from three different pine species (*Pinus taeda* L., *Pinus elliotti* Engelm., and *Pinus palustris* Mill.) have potential as an alternative source for producing short-term horticultural crops. Studies also indicate that with adequate starter nutrient charge, WT serves as an acceptable substrate component for replacing the majority of peat in greenhouse production of petunia (*Petunia* x*hybrida* Vilm.) and marigold (*Tagetes patula* L.) (6). Petunia dry weight was greatest for any substrate containing peat with a 7-3-10 starter fertilizer rate of 2.37 kg/m^3 (4 lb/yd^3) or greater, except petunia grown in WT at 3.56 kg/m^3 (6 lb/yd^3) had shoot dry weights as high as any other treatment. Marigold dry weights were similar for WT at the 2.37 $kg \cdot m^{-3}$ starter fertilizer rate and for all treatments containing peat except 4 WT:1 peat with no starter fertilizer (6).

Materials and Methods

Experiment 1. Fresh 20 – 25 cm (8 – 10 in) diameter loblolly pine trees from a pine plantation in Macon County, Alabama were chipped with a Woodsman Model 334 Biomass Chipper (Woodsman, LLC Farwell, Michigan) and ground with a Williams Crusher Hammer Mill (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 WT substrate. On the same day loblolly pine trees were cut and delimbed leaving the log and bark portions of the tree, which was then chipped and ground in the same way as the WT chips to produce chipped pine log substrate (CPL). The two substrates were placed in separate 1.78 m^3 (63 ft^3) woven polypropylene bulk bags and placed in the sun. On February 18, 2009, 30 days after the WT and CPL were processed, uniform plugs of vinca (*Catharanthus roseus* L. 'Grape Cooler') and impatiens (*Impatiens walleriana* Hook. f. 'Dazzler Apricot') were transplanted from 144 plug flats into 0.95 L (1 qt) plastic containers and grown until April 1, 2009 in a twin walled polycarbonate greenhouse in full sun. Plants were grown in a 1 WT:1 peat substrate (v:v) (WTP) or 1 PC:1 peat substrate (v:v) (CPLP). Peat was obtained from SunGro Horticulture (Bellevue, Washington). Both substrates were amended with 2.97 $kg{\cdot}m^{-3}$ (5 $lbs{\cdot}yd^{-3}$) crushed dolomitic limestone, 0.89 kg/m^3 (5 lbs/yd^3) 7-2-10 N-P-K nutrient charge (GreenCare Fertilizers, Kankakee, Illinois), and 154.7 mL/m^3 (4 oz/yd^3) AquaGro®-L (Aquatrols Corporation, Paulsboro, New Jersey). Plants were placed on a greenhouse bench 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 every other watering (GreenCare Fertilizers Kankakee, Illinois). Greenhouse temperature daily average highs and lows were 29/21°C (85/70°F).

Substrate physical properties including bulk density (BD), air space (AS), container capacity (CC), and total porosity (TP) were determined for WTP and CPLP using the North Carolina State University Porometer Method (7). Particle size distribution was also determined for WTP and CPLP 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/min, 159 taps/min (Ro-Tap RX-29; W.S. Tyler, Mentor, Ohio)]. Leachates were collected using the Virginia Tech Extraction Method (17) and analyzed for pH and electrical conductivity (dS/cm^1) (EC) at 0, 7, 14, 21, 28, 35, and 42 DAP. Termination data, at 42 DAP, included final plant growth indices [(height + height + width/3)] and substrate shrinkage measured from the top of the container to the substrate surface, final bloom counts, leaf greenness using a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, New Jersey), plant shoot dry weights, and root ratings based on a 0 to 5 scale, with 0 indicating no roots present on the substrate surface and 5 indicating roots visible at all portions of the container substrate interface.

Plants were arranged in a randomized complete block design with twelve blocks and three samples per block per treatment. Data were subjected to T-test (P=0.05) using SAS (Version 9.1; SAS Institute, Cary, North Carolina).

Experiment 2. Experiment 2 was conducted to validate results of Experiment 1, and was conducted similarly with the following exceptions. The WT and CPL material used in Experiment 2 was collected from the same bulk bags utilized in Experiment 1, and peat was obtained from Lambert Peat Moss, INC (Riviere-Ouelle, Quebec, Canada). Plugs were planted on June 12, 2009 and the experiment was terminated on August 3, 2009.

Results and Discussion

Experiment 1. There were particle size differences in only three sieve sizes (1.0 - 2.0 mm, 0.5 -1.0 mm, and 0.25 -0.5 mm) (Table 1). Particle size distribution data was grouped into texture sizes (>3.2 mm being coarse, <0.5 -3.2 mm> being medium, and <0.5 mm being fine). For CPLP, 76.51% of particles were in the medium texture range, compared to 70.51% of the WTP; conversely, 24.88% of the WTP particles were fine textured, compared to only 19.57% of the CPLP. The greater percentage of fine particles present in WTP is likely due to the needles and small twigs on the WT when milled. For WT, CC and TP were higher than CPLP (Table 2).

There were minor differences in leachate pH and EC in the plant response test (Table 3). For both species, substrate shrinkage, growth index, bloom count, dry weight, root rating, and leaf greenness were all similar (Table 4). The only difference in plant response was dry weight: vinca grown in CPLP had a 6.5% greater shoot dry weight than those grown in WTP; however, plant dry weights for impatiens were similar.

Experiment 2. There were no differences in particle size distribution for WTP compared to CPLP in Experiment 2 (Table 1); however, there was an obvious shift from Experiment 1 to Experiment 2 in particle texture (coarse vs. fine). In Experiment 1, the majority of the particle sizes were medium or fine textured in both substrates. In Experiment 2, the majority of the particle sizes were coarse or medium textured (Table 1). Coarse textured particles made up 22.46% of the dry weight in WTP compared to 20.7% in CPLP. In Experiment 1 these percentages were 4.62% and 4.18%, respectively. Differences in particle size distribution could be attributed to different peat moss sources for Experiment 1 and Experiment 2. The particle size and texture of the peat used in Experiment 2 was coarser than peat used in Experiment 1 (data not shown). However, differences in particle size distribution had no effect on substrate physical properties, as there were no differences in total porosity, air space, container capacity, or bulk density (Table 2) in Experiment 2. While the peat used in Experiment 2 was a coarser texture, it still contributed to water holding capacity and other physical properties.

In the plant response test, vinca grown in CPLP had a higher pH at 7 and 28 DAP (Table 5). All other pH and EC measurements for vinca in experiment 2 were similar. With impatiens, all pH and EC measurements were similar except for 21 DAP, where plants grown in CPLP had a higher pH than WTP.

Vinca had similar shrinkage, growth index, SPAD readings, bloom counts, root ratings, and dry weight in both substrates (Table 6). Impatiens plants grown in WTP had more blooms and greater root ratings than plants grown in CPLP. Shrinkage, growth index, leaf greenness, and dry weights were all similar in impatiens.

Results from these experiments indicate that CPL and WT can be used interchangeably. While minor differences in physical properties and plant response did occur, growth indices and leaf greenness were similar in both species, suggesting that plants grown in CPL and WT are equally marketable. Our data supports previous independent findings by Wright and Browder (18) and Jackson, et al. (10) that CPL is an appropriate alternative to peat-based substrates for container grown annuals, and by Fain et al. (4, 5, 6) that WT is also a suitable alternative. The most interesting results from this study were perhaps the shift in plant dry weights for both species in both substrates from Experiment 1 to Experiment 2. While the only statistical difference in plant growth occurred in vinca in Experiment 1, the dry weight tripled for vinca from Experiment 1 to Experiment 2, and in impatiens the dry weight nearly doubled from Experiment 1 to Experiment 2. In vinca, bloom counts also tripled from Experiment 1 to Experiment 2.

Because the substrate material utilized in both experiments came from the same bulk bags, we hypothesize that aging the substrate components may help to break down potential harmful chemicals present in the material that may have suppressed plant growth in Experiment 1. In Experiment 1 the material had been aged 30 days; in Experiment 2 the material had been aged 144 days. More research is needed to further investigate the benefits, if any, of aging a wood-fiber substrate component; however, CPL and WT are both viable options for greenhouse growers to extend peat supplies.

Literature Cited

1. Boyer, C.R. 2008. Evaluation of clean chip residual as an alternative substrate for container-grown plants. Auburn University, AL. 204 Pages.
2. 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.
3. Conover, C.A. and R.T. Poole. 1983. Utilization of *Melaleuca quinquenervia* as a potting medium component for greenhouse production of foliage plants. HortScience 18:886-888.
4. 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.
5. 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.

6. 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* x*hybrida* Vilm.) and marigold (*Tagetes patula* L.). HortScience 43:700-705.
7. 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.
8. Gruda, N. and W.H. Schnitzler. 2003. Suitability of wood fiber substrate for production of vegetable transplants. Scientia Horticulturae 100:309-322.
9. Gumy, N. 2001. Toresa and other wood-fibre products; advantages and drawbacks when used in growing media. Proc. International Peat Symposium. Pp. 39-46.
10. 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.
11. Kenna, S.W. and C.E. Whitcomb. 1985. Hardwood chips as an alternative medium for container plant production. HortScience 20:867-869.
12. Laiche, A.J. and V.E. Nash. 1986. Evaluation of pine bark, pine bark with wood, and pine tree chips as components of a container plant growing media. J. Environ. Hort. 4:22-25.
13. Lu, Wenliang. 2008. Utilization of municipal solid waste compost in horticulture. Auburn University Dissertation. 199 pages.
14. Macdonald, W.A. and S. Dunn. 1953. Sawdust composts in soil improvement. Plant and Soil 4:235-247.
15. Muro, J.I. Irigoyen, P. Samitier, P. Mazuela, M.C. Salas, J. Soler, and M. Urrestarazu. 2005. Wood fiber as growing medium in hydroponic crop. Acta Hort. 697:179-185.

16. Still, S., J.B. Gartner, and T.D. Hughes. 1972. Effect of sawdust age and nitrogen application on chrysanthemums grown in white oak sawdust media. Forest Products J. 22:111-114.

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

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

19. 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.

Table 1. Particle size distribution of *WholeTree* (WT) and Chipped Pine Log (CPL) substrates amended with peat.

Sieve Opening	Experiment 1			Experiment 2			Exp. 1 vs. Exp. 2
	WTP[z]	CPLP[y]		WTP	CPLP		
(mm)	(% dry weight)		Significance	(% dry weight)		Significance	Significance
>6.4	0.80	0.64	NS[x]	13.59	11.80	NS	***
3.2-6.4	3.81a	3.54	NS	8.87	8.90	NS	***
2.0-3.2	21.52	20.84	NS	24.19	26.23	NS	**
1.0-2.0	24.77	28.65	***	39.40	38.85	NS	***
0.5-1.0	24.22	26.74	***	9.04	8.91	NS	***
0.25-0.5	20.06	16.14	***	3.36	3.67	NS	***
0.105-0.25	4.20	2.84	NS	1.13	1.13	NS	***
<0.105	0.62	0.59	NS	0.43	0.50	NS	NS
Coarse[w]	4.61	4.18	NS	22.46	20.70	NS	NS
Medium	70.51	76.51	**	72.63	73.99	NS	**
Fine	24.88	19.57	**	4.92	5.30	NS	**

[z] 1:1 *WholeTree* :Peat.

[y] 1:1 Chpped Pine Logs:Peat.

[x] **,*** represent significance when P≤0.01, or 0.001, respectively. NS denotes no significance using analysis of variance.

[w] Particle texture, with particles >3.2mm coarse, <0.5-3.2> medium, and <0.5 fine.

Table 2. Physical properties of *WholeTree* (WT) and Chipped Pine Log (CPL) substrates amended with peat.[z]

	(% volume)						($g{\cdot}cm^{-3}$)	
Substrate	Air Space		Container Capacity		Total Porosity		Bulk Density	
	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
WTP[y]	19.6	19.6	76.8	76.8	96.4	96.0	0.12	0.13
CPLP[x]	17.6	17.7	72.4	72.4	90.0	90.0	0.12	0.13
Significance	NS [w]	NS	**	NS	*	NS	NS	NS

[z] Analysis performed using the NCSU porometer.

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

[x] 1:1 (v:v) Chipped Pine Logs:peat.

[w] *,** represent significance when $P \leq 0.05$ or 0.01 respectively. NS denotes no significance using analysis of variance.

Table 3. Effects of *WholeTree* (WT) and Chipped Pine Log (CPL) substrates amended with peat on pH and electrical conductivity in two greenhouse-grown annuals (Experiment 1).

	Catharanthus roseus 'Grape Cooler'													
	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
WTP[x]	4.34	1.82	5.08	1.89	5.40	2.16	6.12	1.09	5.89	1.14	5.98	0.73	6.46	0.69
CPLP[w]	4.24	1.42	5.12	2.05	5.34	2.53	5.74	1.34	5.63	1.30	5.82	0.86	6.44	0.45
significance	NS[v]	NS	NS	NS	NS	*	**	NS	*	NS	*	NS	NS	NS
	Impatiens walleriana 'Dazzler Apricot'													
WTP	4.34	1.82	5.24	1.91	5.45	1.95	5.90	1.24	6.09	0.84	6.02	0.87	6.82	0.35
CPLP	4.24	1.42	5.16	2.30	5.35	2.37	5.72	1.65	5.97	1.01	5.97	0.76	6.55	0.37
significance	NS	*	NS	*	*	***	**	*	NS	NS	NS	**	NS	0.37

[z] Days after potting.

[y] Electrical conductivity (dS-cm) of substrate solution using the pourthrough method (n = 12).

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

[v] *,**,*** represent significance when P≤0.05, 0.01, or 0.001, respectively. NS denotes no significance using analysis of variance.

[w] 1:1 (v:v) Chipped Pine Logs:peat.

Table 4. Effects of *WholeTree* (WT) and Chipped Pine Log (CPL) substrates amended with peat on growth of two greenhouse-grown annuals (Experiment 1).

Substrate	Shrinkage (mm)[z]	GI (cm)[y]	Bloom Count[x]	Dry Weight (g)[w]	Root Rating[v]	Leaf Greenness[u]
	Catharanthus roseus 'Grape Cooler'					
WTP[t]	9.33	20.31	3.50	6.89	3.67	46.20
CPLP[s]	11.00	20.14	4.17	7.34	3.22	46.00
Significance	NS[r]	NS	NS	*	NS	NS
	Impatiens walleriana 'Dazzler Apricot'					
WTP	11.06	21.58	49.78	5.44	4.50	38.62
CPLP	10.50	21.40	51.09	5.13	4.50	37.96
Significance	NS	NS	NS	NS	NS	NS

[z] Shrinkage in millimeters measured from the top of the container to the top of the substrate surface (n = 12).

[y] Growth index in centimeters [(height + width + perpendicular width)/3] (n =12).

[x] Bloom counts determined by counting all attached flowers and buds showing color (n = 12).

[w] Plant shoot dry weight in grams (n = 12).

[v] Visual root rating on a 0 to 5 scale, 0=no roots present on the substrate surface and 5=roots present on the entire substrate surface (n =12) .

[u] Leaf greenness (chlorophyll content) quantified using a SPAD-502 Chlorophyll Meter (average of three leaves per plant) (n = 12).

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

[s] 1:1 (v:v) Chipped Pine Logs:peat.

[r] *,**,*** represent significance when $P \leq 0.05$, 0.01, or 0.001, respectively. NS denotes no significance using analysis of variance.

Table 5. Effects of *WholeTree* (WT) and Chipped Pine Log (CPL) substrates amended with peat on pH and electrical conductivity in two greenhouse-grown annuals (Experiment 2).

	Catharanthus roseus 'Grape Cooler'													
	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
WTP[x]	4.85	2.03	5.72	3.54	5.96	2.78	6.48	1.22	6.47	1.78	6.41	0.65	6.21	1.39
CPLP[w]	4.95	1.91	5.59	3.52	5.94	3.18	6.41	1.08	6.69	1.11	6.36	0.93	6.09	1.01
Significance	NS[v]	NS	*	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS
	Impatiens walleriana 'Dazzler Apricot'													
WTP	4.85	2.03	5.60	3.65	5.91	3.23	5.89	2.75	6.89	1.45	6.44	1.45	6.46	1.37
CPLP	4.95	1.91	5.67	3.59	5.92	3.23	6.14	2.15	6.64	1.60	6.35	1.29	6.53	1.30
Significance	NS	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 pour-through method (n = 12).

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

[w] 1:1 (v:v) Chipped Pine Logs:peat.

[v] * represent significance when P≤0.05. NS denotes no significance using analysis of variance.

Table 6. Effects of *WholeTree* (WT) and Chipped Pine Log (CPL) substrates amended with peat on growth of two greenhouse-grown annuals (Experiment 2).

Substrate	Shrinkage (mm)[z]	GI (cm)[y]	Bloom Count[x]	Dry Weight (g)[w]	Root Rating[v]	Leaf Greenness[u]
Catharanthus roseus 'Grape Cooler'						
WTP[t]	7.95	20.57	14.61	22.07	3.89	35.00
CPLP[s]	7.56	19.82	13.06	21.25	3.78	31.70
Significance	NS[r]	NS	NS	NS	NS	NS
Impatiens walleriana 'Dazzler Apricot'						
WTP	9.56	16.95	37.30	8.49	3.22	36.99
CPLP	8.78	16.80	27.89	7.77	2.33	34.07
Significance	NS	NS	*	NS	*	NS

[z] Shrinkage in millimeters measured from the top of the container to the top of the substrate surface (n = 12).

[y] Growth index in centimeters [(height + width + perpendicular width)/3] (n = 12).

[x] Bloom counts determined by counting all attached flowers and buds showing color (n = 12).

[w] Plant shoot dry weight in grams (n = 12).

[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 (n = 12) .

[u] Leaf greenness (chlorophyll content) quantified using a SPAD-502 chlorophyll meter (average of three leaves per plant) (n = 12).

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

[s] 1:1 (v:v) Chipped Pine Logs:peat.

[r] * represents significance when $P \leq 0.05$. NS denotes no significance using analysis of variance.

III. GREENHOUSE ANNUALS GROWN IN AGED AND FRESH *WHOLETREE* SUBSTRATE

Abstract

WholeTree (WT) is a potential new renewable greenhouse substrate component created by chipping and milling the 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 and Little Hero Yellow Marigold in 1:1 (v:v) fresh WT:peat (FWTP) and 1:1 (v:v) aged WT:peat (AWTP), as well as physical properties of those substrates were evaluated in a controlled experiment. 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 particles greater than 3.2 mm as opposed to 20.4% for FWTP. For Experiment 1, AWTP had 90.5% Total Porosity (TP) as compared to 94.4% with FWTP. For AWTP there as 17.3% Air Space (AS) as compared to 28.7% with FWTP; AWTP had a greater Container Capacity (CC) than FWTP with 73.2% as compared to 65.7%. 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. In both experiments, plants grown in AWTP resulted in greater growth indices in both

species; similarly, both species had higher bloom counts when grown in AWTP as compared to FWTP. Aged WT in this study provided a more suitable substrate component for greenhouse grown annuals than fresh WT.

Index Words

alternative substrate, greenhouse production, wood chips wood fiber, peat, pine tree, *Pinus taeda*, substrate

Species Used in this Study

Petunia x*hybrida* Vilm. 'Dreams White'; *Tagetes patula* L. 'Little Hero Yellow'

Significance to the Industry

Today, greenhouse growers commonly purchase substrate component materials 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 WT to greenhouse producers, one important unanswered question is the effects of using WT fresh or delaying use for some period of time for storage, as well as monitoring the storage of WT in bulk bags. In our studies, petunias and marigolds grown in aged WT were larger with more blooms than those grown in fresh WT. Growers using WT as an alternative substrate component should age the material prior to use for best plant response.

Introduction

Since the introduction of the Cornell peat-lite mixes in the 1920's, 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. Recently, environmental interest groups have stepped up to protect peat bogs in Europe and

Canada. 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 chip away at growers' profits.

In an effort to minimize the financial impact on growers, European research began focusing on wood fiber alternatives, such as Fibralur® and Toresa®. Wood fiber products performed as well as standard mixes (11, 15), and soon research 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. The new substrate showed suitable physical characteristics (17) yet required additional fertilizer in the growth of greenhouse annuals (25). Boyer et al. (4) reported that Clean Chip Residual was a suitable wood fiber alternative for growing greenhouse annuals, composed of the residual material left over after pine trees are processed into clean chips for use by paper mills. Another wood fiber alternative substrate component is *WholeTree* (WT), created from entire pine trees harvested at the thinning stage (7). 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. Fain et al. (8) reported that WT substrates derived from loblolly pine (*Pinus taeda* L.), slash pine (*Pinus elliottii* Englem.), or longleaf pine (*Pinus palustris* Michx.) have potential an 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 (9).

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* X*hortorum* 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 (3).

Other organic substrate components are usually evaluated to determine the necessity of aging or composting the material. Johnson and Bilderback (13) 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 and 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. Particle size distribution appeared to be influenced more by longer periods of aging than by sieving or grinding procedures. Dueitt and Newman (6) reported that fresh and aged rice hulls are an acceptable peat moss substitute in greenhouse substrate. The addition of aged rice hulls reduced the AS initially, and substrate containing fresh rice hulls initially had greater AS as compared to aged. These observations were reversed at the conclusion of the study, and attributed this to substrate shrinkage during the growth period. The method of aging the rice hulls was not described.

For horticultural pine bark, aging substrate components refers to the stockpiling and weathering of bark after milling but prior to its use (16). For growers using WT as an alternative, the material will be stockpiled for the duration of its use. The weathering of the material during this storage may impact plant response in WT. While research has been reported on the viability of WT as an alternative to peat (7, 8, 9, 21), there is no information on what potential benefits storing WT before using might have on plant growth. All previously reported work used freshly milled chips, and at the time no information was available on the effects of bulk storage or if WT storage has positive or negative effects on plant growth. This research project resulted from numerous observations by the author. On more than one occasion, it appeared that plant response was better in WT that had been stored for some period of time as opposed to freshly processed WT. For the purposes of this study, the definition of aging is as follows: the process of change in the properties of a material occurring over a period of time. The purpose of this study was to monitor the temperature fluctuations in fresh WT in bulk storage bags and to determine substrate physical properties and growth differences of annuals grown in aged WT and fresh WT.

Materials and Methods

Experiment 1. Fresh loblolly pine (*Pinus taeda* L.) WT chips were obtained from a pine plantation in Macon County, Alabama by chipping freshly cut 20 – 25 cm (8 – 10 in) caliper trees with a Woodsman Model 334 Biomass Chipper (Woodsman, LLC Farwell, Michigan). Chips were then ground in Williams Patent Crusher Meteor Mill #40 (Williams Patent Crusher and Pulverizer Co., Inc St. Louis, Missouri) 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, Illinois) 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 and processed the same way and utilized as fresh 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 and Dreams White Petunia were transplanted from 144 plug flats into 0.95 L (1 qt) plastic pots and grown until June 5, 2009. Plants were grown in a 1 aged WT:1 peat substrate (v:v) (AWTP) or 1 fresh WT:1 peat substrate (v:v) (FWTP). Peat was obtained from Sun Gro Horticulture (Bellevue, Washington). Both substrate treatments were amended with 2.97 kg/m^3 (5 lbs/yd^3) crushed dolomitic limestone, 0.89 kg/m^3 (1.5 lbs/yd^3) 7-2-10 N-P-K nutrient charge (GreenCare Fertilizers, Kankakee, Illinois), and 154.7 mL/m^3 (4 oz/yd^3) AquaGro®-L (Aquatrols Corporation, Paulsboro, New Jersey). 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, Illinois) every other watering. Plants were arranged in a randomized complete block design with twelve blocks and three samples per block per treatment. Greenhouse temperature daily average highs and lows were 29/21°C (85/70°F).

Substrate physical properties including 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 (Fonteno et al. 1995). Particle size distribution was also determined for each substrate 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/min, 159 taps/min (Ro-Tap RX-29; W.S. Tyler, Mentor, Ohio)].

Leachates were collected via the Virginia Tech Pour Through Method (19) and analyzed for pH and electrical conductivity (EC) at 0, 7, 14, 21, 28, 35, and 42 DAP. At 7 DAP 3 sub samples per treatment were destructively sampled for soil and plant nutrient analyses by the Auburn University Plant and Soil Testing Laboratory (Auburn, AL) as described by Hue and Evans (12). Termination data at 42 DAP included final plant growth indices [(height + height + width/3)], substrate shrinkage measured from the top of the container to the substrate surface, and final bloom counts which included all attached blooms and buds showing color. Leaf greenness using a SPAD-502 Chlorophyll Meter (Minolta Camera Co., Ramsey, New Jersey) was determined for petunia. Plant shoot dry weight and a visual root rating on a 0 to 5 scale with 0 indicating no roots present on the substrate surface and 5 indicating roots visible at all portions of the container substrate interface were also recorded. Data were subjected to analysis of variance using the general linear models procedures (Version 9.1; SAS Institute, Cary, North Carolina).

Experiment 2. Experiment 2 was conducted to validate results of Experiment 1, and 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 and mixed. Substrates were mixed and plugs were potted on July 7, 2009 and grown until August 18, 2009. At 7 DAP sub-samples were subjected to soil analysis by Brookside Laboratories (New Knoxville, Ohio) as described by NCR Publication 221 (5).

Results and Discussion

Bulk Bag Temperature Fluctuations. Figure 1 illustrates the resulting temperature fluctuations of the inner bag temperatures and ambient temperatures. After just 3 days, the temperature inside the bags nearly doubled from the beginning temperature near 22°C (70°F) to 50°C (122°F), and then slowly decreased until day 21 reaching temperature of 8°C (47°F). On day 21, the average temperature inside the bags fell below the ambient temperature outside the bags and remained relatively stable for the remainder of the aging process. Inner bag temperature spikes thereafter were a result of preceding ambient temperature spikes.

Experiment 1. For particle size distribution, there were differences in the larger sieve opening sizes; AWTP had 17.6% particles greater than 3.2 mm as opposed to 12.4% for FWTP (Table 1). In substrate physical properties, AWTP and FWTP had similar BD. AWTP had a 73.2% CC as opposed to 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. Minor differences in leachate pH and EC are presented in Table 3.

At 7 DAP plants growing in AWTP were visually larger and greener than those plants growing in FWTP. Plants growing in FWTP also showed foliar symptoms of nitrogen and Phosphorus deficiency as described by Mills and Jones (14). Substrate analysis showed a higher N and P content in AWTP compared to FWTP (Table 4). These differences may be attributed to nutrient leaching, as AWTP did have less AS than FWTP.

For both species, plants grown in AWTP had higher growth indices, dry weights, and bloom counts than plants grown in FWTP (Table 5). Marigolds grown in FWTP had more shrinkage than those grown in AWTP, but there were no differences in substrate shrinkage for petunias. SPAD was obtained only for the petunias, as the shape of marigold leaves prevent an accurate SPAD reading. Plants grown in AWTP had higher SPAD measurements than those grown in FWTP (Table 5). Subjective root ratings for petunia were the same for plants grown in AWTP and FWTP; however, marigolds grown in AWTP had substantially higher root ratings than those grown in FWTP (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.

Experiment 2. 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. This may be attributed to wear and tear on hammer mill blades; the as the hammer mill blades are worn down the particles will become more coarse. 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. In Experiment 2 there was a trend for higher leachate EC and lower pH for AWP (Table 6). Plant growth response followed the same trend in Experiment 2 as Experiment 1. Plants grown in AWTP were larger, had greater dry weights, and more blooms than those grown in FWTP (Table 7). 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 this initial aging process.

Literature Cited

1. Appleby, Matthew. Peat: The Discussion Continues. *Horticulture Week* 27 March 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. 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.
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. Denning, J., R. Eliason, R.J. Goos, B. Hoskins, M.V. Nathan, A. Wolf. 1997. Recommended Chemical Soil Test Procedures Number 221.
6. 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
7. 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.

8. 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.
9. Fain, G.B., C.H. Gilliam, J.L. Sibley, and C.R. Boyer. 2008b. *WholeTree* dubstrate and fertilizer rate in production of greenhouse-grown petunia (*Petunia* x*hybrida* Vilm.) and marigold (*Tagetes patula* L.). HortScience 43:700-705.
10. 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.
11. Gruda, N. and W.H. Schnitzler. 2003. Suitability of wood fiber substrate for production of vegetable transplants. Scientia Horticulturae 100:309-322.
12. Hue, N.V. and C.E. Evans. 1986. Procedures Used for Soil and Plant Analysis by the Auburn University Soil Testing Laboratory. Dep. of Agronomy and Soils. Serial 106.
13. 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.
14. Mills, H.A. and J.B. Jones, Jr. 1997. Plant Analysis Handbook II. MicroMacro Publishing, Inc. Athens, GA.
15. Muro J.I. Irigoyen, P. Samitier, P. Mazuela, M.C. Salas, J. Soler, and M. Urrestarazu. 2005. Wood fiber as growing medium in hydroponic crop. Acta Hort. 697:179-185.
16. Pokorny, F.A.1975. A physical characterization of pine bark used in three commercial nurseries. Proc. Southern Nursery Assn. Res. Conf. 20:25-27.

17. Saunders, T., J.F. Browder, B.E. Jackson, and R.D. Wright. 2006. Particle size of a pine chips substrate affects plant growth. Proc. Southern Nursery Assn. Res. Conf. 51:46-48.
18. 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.
19. Wright, R.D. 1986. The pour-through nutrient extraction procedure. HortScience 21:227-229.
20. Wright, R.D. and J.F. Browder. 2005. Chipped pine logs: A potential substrate for greenhouse and nursery crops. HortScience 40:1513-1515.
21. 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.

Figure 1. Average temperature gradient inside and outside of bulk bags of WholeTree Substrate.

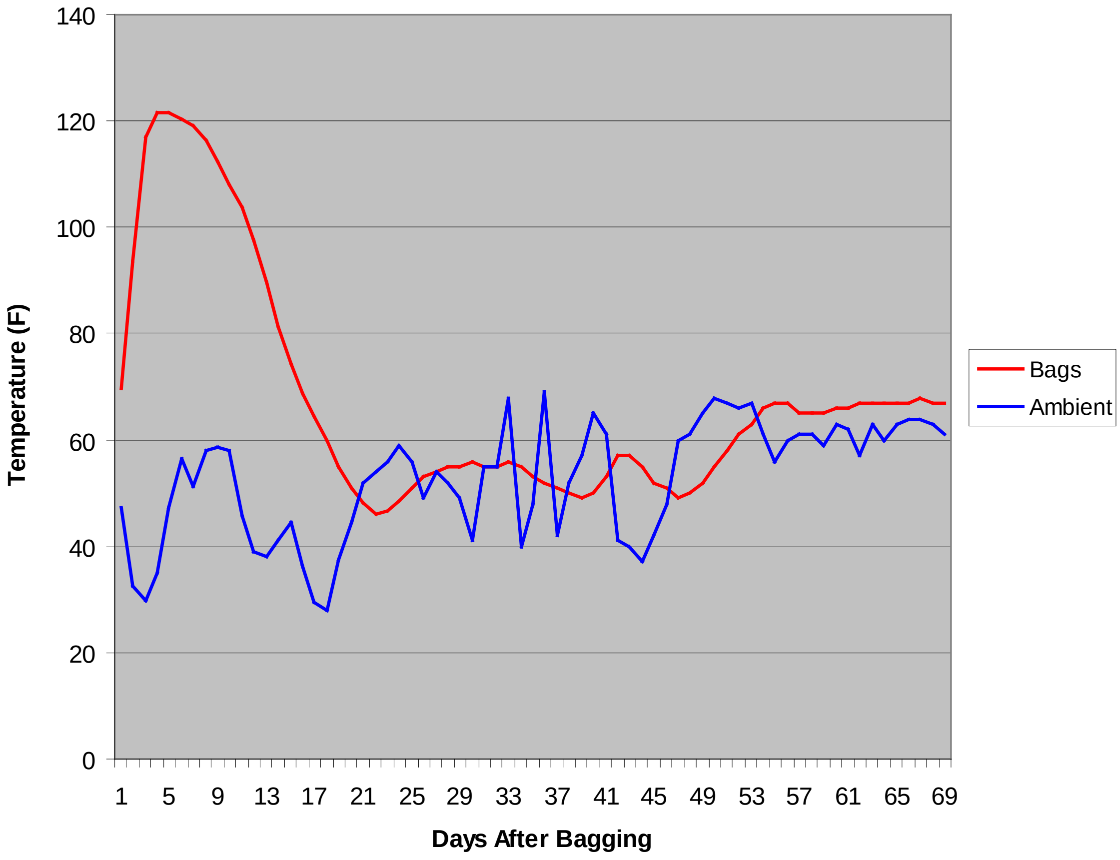

Table 1. Particle size distribution of Aged and Fresh *WholeTree* substrates amended with peat.

Sieve Opening	Experiment 1			Experiment 2		
	AWTP[z]	FWTP[y]	Significance[x]	AWTP	FWTP	Significance
(mm)	(% dry weight)			(% dry weight)		
>6.4	6.2	3.9	***	3.9	7.7	***
3.2-6.4	11.4	8.5	***	4.2	12.7	***
2.0-3.2	31.5	23.5	***	16.8	21.4	***
1.0-2.0	26.5	36.5	***	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	NS	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 $P \leq 0.001$. NS denotes no significance.

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

	(% volume)						$(g{\cdot}cm^{-3})$	
Substrate	Air Space		Container Capacity		Total Porosity		Bulk Density	
	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 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 $P \le 0.05$, 0.01, or 0.001, respectively. NS denotes no significance.

Table 3. Effects of Aged and Fresh *WholeTree* substrates amended with peat on pH and electrical conductivity in two greenhouse- grown annuals. (Experiment 1).

	Tagetes patula 'Little Hero Yellow'													
	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
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	**
	Petunia xhybrida 'Dreams White'													
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	*

^{z}Days after potting.

^{y} Electrical conductivity (dS-cm) of substrate solution using the pourthrough method (n = 12).

^{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.

Table 4. Aged and Fresh *WholeTree* substrate amended with peat N and P content 7 DAP.

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

[z] 1:1 *WholeTree* :peat.

[y] 1:1 Chpped Pine Logs:peat.

[x] **,*** represent significance when P≤ 0.01 or 0.001, respectively. NS denotes no significance.

Table 5.Effects of Aged and Fresh *WholeTree* substrates amended with peat on growth of two greenhouse- grown annuals (Experiment 1).

	Tagetes patula 'Little Hero Yellow'					
Substrate	Shrinkage (mm)[z]	GI[y]	Bloom Count[x]	Dry Weight (g)[w]	Root R[v]	Lg[u]
AWTP[t]	10.5	20.6	14.5	6.6	3.5	-
FWTP[s]	11.9	16.1	9.6	3.7	1.9	-
Significance[r]	*	***	***	***	***	-
	Petunia xhybrida 'Dreams White'					
AWTP	10.7	30.8	14	6.3	3.1	30.2
FWTP	10.5	23.2	8.2	3.5	3	27.5
Significance	NS	***	***	***	NS	**

[z] Shrinkage in millimeters measured from the top of the container to the top of the substrate surface (n = 12).

[y] Growth index in centimeters [(height + width + perpendicular width)/3] (n = 12).

[x] Bloom counts determined by counting all attached flowers and buds showing color (n = 12).

[w] Plant shoot dry weight in grams (n = 12).

[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 (n = 12) .

[u] Leaf greenness (chlorophyll content) quantified using a SPAD-502 Chlorophyll Meter (average of three leaves per plant) (n = 12).

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

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

[r] *,**,*** represent significance when P≤0.05, 0.01, or 0.001, respectively. NS denotes no significance.

Table 6. Effects of Aged and Fresh *WholeTree* substrates amended with peat on pH and electrical conductivity in two greenhouse- grown annuals (Experiment 2).

	Tagetes patula 'Little Hero Yellow'													
	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
AWTP[x]	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[w]	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[v]	NS	NS	***	**	**	**	**	**	**	**	NS	NS	NS	NS
	Petunia x*hybrida* 'Dreams White'													
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 (n = 12).

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

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

[v] **,*** represent significance when P≤0.01 or 0.001, respectively. NS denotes no significance.

Table 7. Effects of Aged and Fresh WholeTree substrate amended with peat on growth of two greenhouse- grown annuals (Experiment 2).

Substrate	Shrinkage (mm)[z]	GI[y]	Bloom Count[x]	Dry Weight (g)[w]	Root R[v]	Lg[u]
			Tagetes patula 'Little Hero Yellow'			
AWTP[t]	11.6	22.3	19.2	18.2	-	-
FWTP[s]	13.7	17.4	11.1	8.5	-	-
Significance[r]	*NS*	***	***	***	-	-
			Petunia x*hybrida* 'Dreams White'			
AWTP	13.5	27.0	24.5	18.4	4.0	40.9
FWTP	10.9	21.3	11.5	9.6	2.8	39.2
Significance	NS	***	***	***	*	NS

[z] Shrinkage in millimeters measured from the top of the container to the top of the substrate surface (n = 12).

[y] Growth index in centimeters [(height + width + perpendicular width)/3] (n = 12).

[x] Bloom counts determined by counting all attached flowers and buds showing color (n = 12).

[w] Plant shoot dry weight in grams (n = 12).

[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 (n = 12).

[u] Leaf greenness (chlorophyll content) quantified using a SPAD-502 Chlorophyll Meter (average of three leaves per plant) (n = 12).

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

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

IV. FINAL DISCUSSION

A Comparison of *WholeTree* and Chipped Pine Log Substrates

Findings indicate that there is no difference in plant growth response in WholeTree (WT) versus Chipped Pine Log (CPL) substrates, and growers could use either as an extender or replacement for peat. While there were no growth differences in the two substrate components in either experiment, plants in Experiment 2 grew nearly twice as large as those in Experiment 1. The source of the WT and CPL were the same for both experiments, except that in Experiment 2 the material was aged 144 days versus 30 days in Experiment 1. Based on these findings and personal observation, a research proposal comparing aged and fresh WT was developed and the experiment was repeated twice.

Greenhouse Annuals Grown in Aged and Fresh *WholeTree*

Plants grown in aged WT were larger, had greener leaves, and had more blooms than those grown in fresh WT in both experiments. Plant and soil analyses carried out only 7 days after potting indicated far less soil N and P in fresh WT than in aged WT when analyzed using a saturated paste extract. Plants grown in fresh WT had less foliar N and P than those grown in aged WT. Literature suggests terpenes, chemical compounds common in *Pinus* species, may inhibit the nitrogen cycle until the chemicals are broken down. It was hypothesized that aging WT may allow time for these chemicals to decompose. These chemicals may be detrimental due to the direct contact of the plant. Phytotoxicity depends on the chemical composition of the substrate, and may be due to organic or inorganic substances (3), which cause salinity, nutritional disorders, and/or metabolic alterations (11). Methods such as composting, aging, washing, or fertilization have been used to reduce or eliminate these problems (4, 8).

Findings indicate plant growth response is superior in aged WT as compared to fresh WT substrate. One possible explanation is the presence or absence of some chemical compound in the substrate. The discovery of plant – plant interactions are becoming more frequent as scientific technology improves. Scientists currently acknowledge inhibitory relationships between black walnut (*Juglans nigra*) and turf species (18), crabgrass (*Digitaria sanguinalis*) and agronomic crops such as cotton and peanuts (15), and apple (*Malus spp.*) and turf species (12), to name a few. It is reasonable to hypothesize that reduced plant growth in fresh WT substrate may be due to some type of chemical interaction between the milled pine wood and young plants.

Professor Hans Molisch is considered the modern Father of Allelopathy, having coined the term in 1937 to refer to biochemical interactions between all types of plants including microorganisms (9). A more modern definition defines allelopathy as any direct or indirect harmful effect by one plant on another through production of chemical compounds that escape into the environment (13); however, in the more recent edition of his book, Rice refers back to Molisch’s original definition to allow the term allelopathy to include both harmful and beneficial interactions between plants and microorganisms (14).

With the previous definition in mind, several investigators have reported on the allelopathic effects of *Pinus spp.* on other plants. Nektarios et al. (10) reported the allelopathic potential of *Pinus halepensis* Mill. needles is greatest with fresh needles, moderate in senesced needles, and low in decaying needles in a bioassay using fresh, senesced, and decaying pine needle leachate with *Avena sativa* as the biosensor plant. The dynamics of ponderosa pine stands in North Dakota were studied to determine the influence of plant-produced chemicals on nitrification (7). Low levels of nitrate-nitrogen relative to ammonium-nitrogen and low numbers of *Nitrosomas* and *Nitrobacter* in the soils suggested that nitrification rates were low. This could not have been pH related as the soils were alkaline. Evidence in the study suggested that the reduction in nitrate synthesis was due to the production and subsequent transfer of allelochemicals to the soil. Several compounds inhibitory to nitrification were found in extracts from ponderosa pine needles, bark, and A-horizon soils (7).

Work at the USDA Bureau of Soil demonstrated that various leachates of oak, pine, chestnut, tuliptree, dogwood, maple, and cherry were inhibitory to wheat seedling transpiration or growth (6, 17), but this work was never followed up.

Whittaker and Feeny (20) identified five major categories of plant-produced chemical inhibitors: phenylpropanes, acetogenins, terpenoids, steroids, and alkaloids. Terpenoids, or terpenes, consist of five-carbon isoprene units linked together in various ways and with different types of ring closures, functional groups, and degrees of saturation (16). Monoterpenes consist of C_{10} hydrocarbons and are the major constituents of many pine resin oils (21). Potential sources of monoterpenes include leaf litter, canopy, and roots exudates. Leachate from pine leaf litter is thought to be the largest source (21). As allelopathic agents, they are thought to inhibit plant growth and germination in several plant communities (21).

In 1986, White began research on monoterpene inhibition of the nitrogen cycle (19). He hypothesized that vegetation in ponderosa pine forests inhibited nitrification by releasing volatile terpenes that retarded the oxidation of ammonium. White used ‘trapped vapor’ experiments to assay they effects of vapors on nitrification in soils from burned plots. Soil from non-burned plots placed in sealed jars containing soil from burned plots reduced nitrification by 87%. A single water extraction of unburned forest floor reduced nitrification by 17%. Vapors from a mixture of five major monoterpenes found in the pine resin completely inhibited nitrification.

With new pine wood fiber alternative substrates (2, 5, 22) becoming more available to growers, concern for potential growth inhibition due to phytotoxins is rising. Because WT composition is approximately 80% wood, 15% bark, and 5% needles, it stands to reason that needles in the fresh WT could be releasing terpenes into the substrate solution, inhibiting the nitrogen cycle and negatively effecting plant growth. A research proposal for a bioassay of fresh and aged WT was developed.

A study was initiated on March 18, 2010. Fresh pine needles were collected directly from 12 year old loblolly pine trees (*Pinus taeda* L.) at the Mary Olive Thomas Forestry Research Plot in Auburn, Alabama. Aged pine needles were collected from the ground under the same pine trees. Procedures used in this bioassay followed the procedures outlined by Al Hamdi, et al. (1) and Nektarios et al. (10). Needles were immediately rinsed with distilled water. Two hundred needles each of fresh and aged were crushed with mortar and pestle and soaked in 600 mL of distilled water for 24 hours. On March 19, 2010 the samples were drained to obtain full-strength leachate for A and F. One germination sheet (Anchor Paper Company St. Paul, Minnesota) was placed in the bottom of a glass Petri dish. Five *Lectuca sativa* L. seeds were placed on each germination sheet, and another sheet placed on top of the seeds. Five mL of the appropriate solution was poured into each Petri dish. Each dish counted as one experimental unit. With two treatments and thirteen replications per treatment, there were a total of 26 experimental units. The Petri dishes were completely randomized, and placed in plastic zip bags and sealed to retain moisture. The bags were then placed in an incubator in the dark at 26C for five days. After the incubation period germination percentage and average radicle length for each Petri dish were calculated. Data were analyzed as a binomial in SAS 9.1 (SAS Institute Cary, North Carolina).

There were no differences (p=1.00) in germination percentage for lettuce (*Lactuca sativa* L.) seeds between treatments (Figure 1). The radicle length of seeds germinated in aged needle leachate was greater (P=0.0062) than the radicle length of seeds germinated in fresh needle leachate (Figure 2). Results indicate that monoterpenes present in fresh pine needles may negatively affect plant growth by inhibiting the nitrogen cycle in fresh WT substrate. A comprehensive chemical analysis of fresh and aged pine needles should be executed in order to quantify the types and concentrations of compounds present in the needles. If terpenes are confirmed to be present in fresh loblolly pine needles, protocol can be developed so growers can manipulate *WholeTree* in order to obtain the best possible plant growth.

Literature Cited

1. Al Hamdi, B., J. Olofsdotter, Inderjit Corporation, J.C. 2001. Streibig. Laboratory bioassay for phytotoxicity: an example from wheat straw. Agron. J. 93:43-48
2. 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
3. Bunt, A.C. 1988. Media and mixes for container-grown plants. A manual on the preparation and use of growing media for pot plants. Unwin Hyman, London.

4. Estaun, V., C. Calvet, and J.M. Grases. 1985. Chemical determination of fatty acids, organic acids, and phenols during olive marc composting process. Acta Horticulturae 172:263-270
5. Fain, G.B., C.H. Gilliam, and J.L. Sibley. 2006. Processed whole pine trees as a substrate for container-grown plants. SNA Res. Conf. Proc. 51: 59-61
6. Livingston, B.C., C.A. Jensen, J.F. Breazeale, F.R. Pember, and J.J. Skinner. 1907. Further studies on the properties of unproductive soils. U.S. Department of Agriculture, Bureau of Soils Bulletin 36:1-71
7. Lodhi, M.A.K. and K.T. Killingbeck. 1980. Allelopathic inhibition of nitrification and nitrifying bacteria in a ponderosa pine (*Pinus ponderosa* Dougl.) community. Amer. J. Bot. 67:1423-1429
8. Mickler, K.D. and D.B. Williams. 1994. Allelopathic influences of fresh and composted yard waste on seed germination. SNA Research Conference 39:16-20
9. Molisch, H. 1937. "Der Einfluss einer Pflanze auf die andere-Allelopathie." Fischer, Jena.
10. Nektarios, P.A., G. Economou, and C. Avgoulas. 2005. Allelopathic effects of *Pinus halepensis* needles on turfgrasses and biosensor plants. HortScience 40:246-250
11. Ortega, M.C., M.T. Moreno, J. Ordovas, M.T. Aguado. 1996. Behavior of different horticultural species in phytotoxicity bioassays of bark substrates. Scientia Horticulturae 66:125-132
12. Pickering, S.V. 1919. The action of one crop on another. J. R. Hort. Soc. 43:372-380
13. Rice, E.L. 1974. Allelopathy. Academic Press, New York.

14. Rice, E.L. 1984. Allelopathy: Second Edition. Academic Press, New York.

15. Robinson, E.L. 1976. Effect of weed species and placement on seed cotton yields. Weed Sci. 24:353-355

16. Robinson, T. 1983. The organic constituents of higher plants. 5th Ed. Cordus -ress, North Amherst, Massachusetts.

17. Schreiner, O. and J.J. Skinner. 1911. Lawn soils. U.S. Department of Agriculture, Bureau of Soils Bulletin 75:1-55

18. Stickney, J.S., and P.R. Hoy. 1881. Toxic action of black walnut. Trans. Wis. State Hort. Soc. 11:166-167

19. White, C.S. 1986. Volatile and water-soluble inhibitors of nitrogen mineralization and nitrification in a ponderosa pine ecosystem. Biology and Fertility of Soils. 2:97-104

20. Whittaker, R.H. and P.P. Feeney. 1971. Allelochemics: chemical interactions between species. Science 171:757-770

21. Wood, S.E. 1996. Loss of foliar monoterpenes from *Umbellularia californica* leaf litter and their influence on nitrification potential in soil beneath the trees. University of California, Davis. 151 pages.

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

Figure 1. Germination percentage of *Lactuca sativa* when germinated in aged and fresh pine needle leachate.

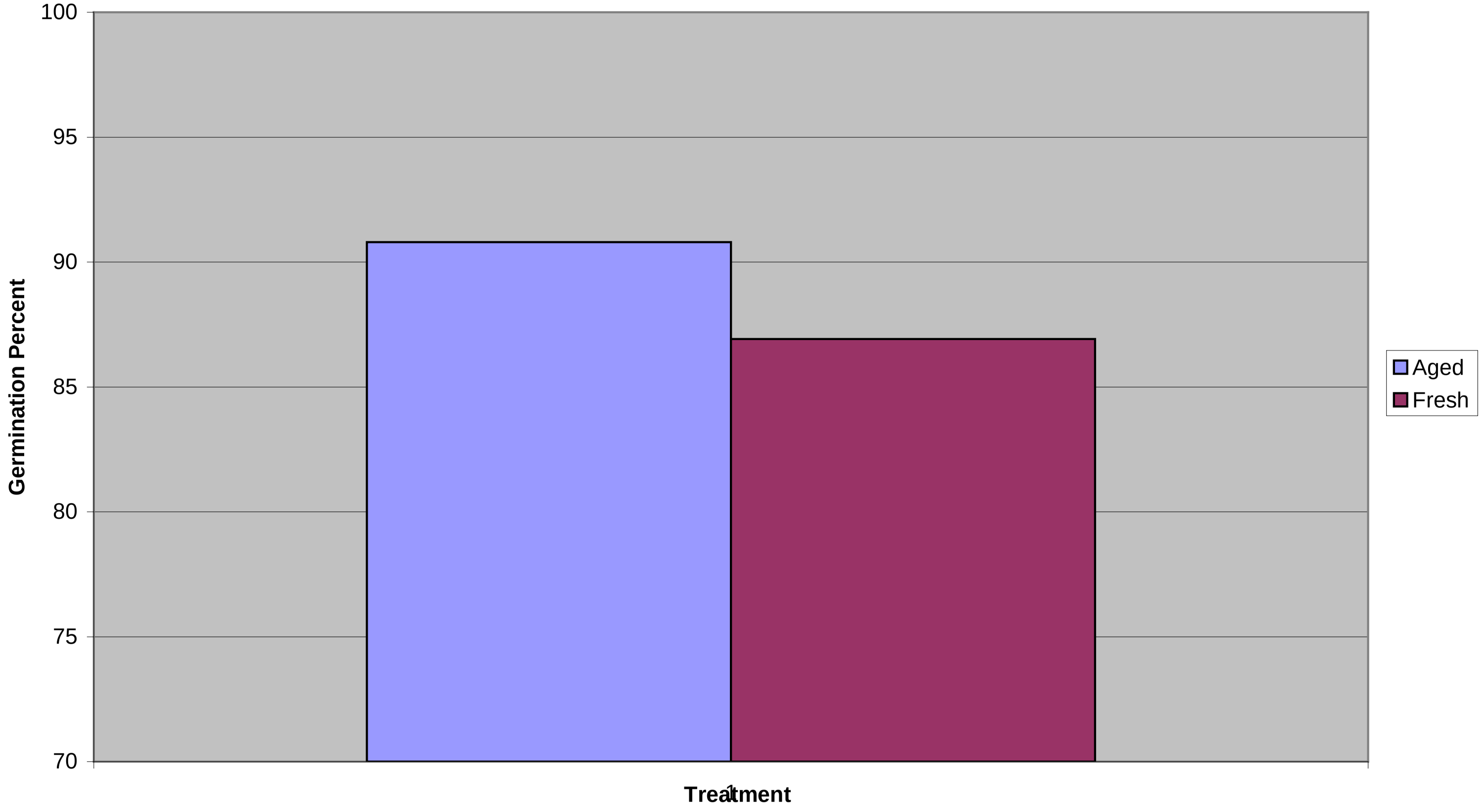

Figure 2. Radicle length of Lactuca sativa when germinated in aged and fresh pine needle leachate.