EVALUATION OF CLEAN CHIP RESIDUAL AS AN ALTERNATIVE SUBSTRATE FOR CONTAINER-GROWN PLANTS

Except where reference is made to the work of others, the work described in this dissertation is my own or was done in collaboration with my advisory committee. This dissertation does not include proprietary or classified information.

Cheryl ReNee' Boyer

Certificate of Approval:

Charles H. Gilliam, Co-Chair Professor Horticulture	Glenn B. Fain, Co-Chair Assistant Professor Horticulture
Thomas V. Gallagher Assistant Professor Forestry and Wildlife Sciences	Jeff L. Sibley Alumni Professor Horticulture
H. Allen Torbert Director, National Soil Dynamics Laboratory USDA-ARS	Joe F. Pittman Interim Dean Graduate School

EVALUATION OF CLEAN CHIP RESIDUAL AS AN ALTERNATIVE SUBSTRATE FOR CONTAINER-GROWN PLANTS

Cheryl ReNee' Boyer

A Dissertation
Submitted to
the Graduate Faculty of
Auburn University
in Partial Fulfillment of the
Requirements for the
Degree of
Doctor of Philosophy

Auburn, Alabama
May 10, 2008

EVALUATION OF CLEAN CHIP RESIDUAL AS AN ALTERNATIVE SUBSTRATE FOR CONTAINER-GROWN PLANTS

Cheryl ReNee' Boyer

Signature of Author

Date of Graduation

VITA

Cheryl ReNee' (Mason) Boyer, daughter of Jimmy D. and Carolyn K. Mason and sister to Marsha, was born May 9, 1980, in Cushing, Oklahoma. She graduated from Stillwater High School as a valedictorian in 1998 and then entered Oklahoma State University in Stillwater, Oklahoma where she graduated *cum laude* with a Bachelor of Landscape Architecture degree in May 2003. Continuing her education, she earned a Master of Science degree in Horticulture with a specialization in Nursery Crop Production at Oklahoma State University, Stillwater, Oklahoma in May of 2005. In May of 2008 she completed the requirements for a Doctor of Philosophy degree in Horticulture (Nursery Crops) at Auburn University, Auburn, Alabama. She married Russell P. Boyer on June 10, 2000.

DISSERTATION ABSTRACT

EVALUATION OF CLEAN CHIP RESIDUAL AS AN ALTERNATIVE SUBSTRATE FOR CONTAINER-GROWN PLANTS

Cheryl ReNee' Boyer

Doctor of Philosophy, May 10, 2008
(M.S., Oklahoma State University, 2005)
(B.L.A., Oklahoma State University, 2003)

204 Typed Pages

Directed by Charles H. Gilliam and Glenn B. Fain

Clean chip residual (CCR), a forestry by-product, could become an important replacement for pine bark in containerized nursery and greenhouse crop production. Rising costs of pine bark (PB) due to reduced production, increased importation of logs (no bark) and increased shipping costs have placed a large financial burden on the nursery and greenhouse industries.

The objective of this work is to determine if nursery and greenhouse crops grown in CCR can be produced with similar growth to plants grown in traditional PB substrates. Additional objectives include surveying the forest industry to determine availability and potential supply of CCR. If CCR, a local (to the Southeast U.S.), sustainable, and economical forest by-product can be used to amend or replace PB and/or peat, the benefits to grower's bottom lines and the environment could be tremendous.

A variety of nursery and greenhouse crops were evaluated for growth in CCR over the course of this investigation. Chapter two evaluated the annual crops ageratum, salvia, and impatiens in a greenhouse setting. At the study termination two out of three annual species tested had similar growth when compared to standard PB substrates. Chapter three evaluated eight perennial species including buddleia, gaura, coreopsis, verbena, scabiosa, dianthus, rosmarinus, and salvia for growth in CCR on an outdoor container pad. There were few differences in growth at the conclusion of the study for most species. However, shoot dry weight tended to be greater in substrates containing peat. Peat amended treatments produced similar growth in five of seven species at Auburn, AL and two of eight species at Poplarville, MS. Chapter four evaluated growth of woody ornamental crops including crapemyrtle, loropetalum, buddleia and azalea. Data for all species indicated that plants grown in CCR had similar or greater growth than plants grown in PB.

Chapter five involved surveying loggers in order to characterize the potential supply of CCR to horticultural industries. Samples from this survey revealed the approximate composition of component particles (wood, bark, needles). Chapter six investigated the potential of CCR to immobilize nitrogen during a 60-day crop cycle. Results showed that CCR does not immobilize nitrogen differently than PB except at higher supplemental nitrogen rates.

In general, most plants grew as well as those grown in control treatments for annuals, perennials and woody ornamentals. These studies have demonstrated that CCR is a viable alternative substrate in nursery and greenhouse production of ornamental crops.

ACKNOWLEDGEMENTS

I would like to thank my heavenly Father for directing the path of my life and for sustaining me every day. Without His guidance and love I would surely not have completed the requirements for this Doctor of Philosophy degree. Second, my sounding board, best friend, and love, Rusty—I could not have done this without you, nor would I have wanted to. Thanks to Mom & Dad, Ken & Sherri, Robert & Marsha, and Ben & Becky for loving me and coming all the way across the country for visits.

I would also like to express appreciation to my graduate committee members for their direction and assistance, Drs. Charles Gilliam, Glenn Fain, Tom Gallagher, Allen Torbert and Jeff Sibley. Thank you to Diana Cochran, Adam Newby and Ben Richardson, fellow graduate students, for companionship and camaraderie during my time in Auburn and to Greg Creech, Michael Sanford, Wes Ezzell, Jesse Creech, and B.J. Haisten for assistance with taking data. Thank you, Charlie, Michelle and little Liam for your friendship. Thanks are also due to Dr. Janet Cole, former advisor, for support during the course of this investigation.

This work is dedicated to the memory of Ethel Cora Kuhlman (my grandmother), Paul & Waneta Haga (Rusty's grandparents), and Erma Berg (Rusty's great grandmother) who passed during the construction of this document. Their love and support were treasured. They are missed every day.

Styled after the following journal: *HortScience*

Computer software used:

Microsoft® Word, Excel and PowerPoint 2007, SAS® version 9.1

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

Introduction and Literature Review

Container substrate components have been the focus of much research since the 1950s when containerized nursery and greenhouse crop production began on a large scale (Davidson et al., 2000). Prior to the 1960s field soil and peat were the primary components of nursery and greenhouse substrates (Lunt and Kohl Jr., 1956). Field soil, however, has unfavorable physical properties for containerized crop production and, if not sterilized, harbors numerous pathogens (Scott and Bearce, 1972). Soon, bark began to be promoted as a useful material in substrate mixes, particularly bark:sand blends. Bark at that time was considered a waste product of the forest industry (Gartner et al., 1971). The presence of bark in many wood products was considered unfavorable due to discoloration of the final product. Therefore, bark was removed from trees prior to lumber processing and began to accumulate on site at lumber mills. When mills were no longer allowed to burn bark for disposal, a new problem arose as spontaneous fires from the bark piles began to damage lumber facilities resulting in a search for methods of bark disposal (Gartner et al., 1970). A study by Lunt and Clark (1959) revealed that, for horticultural uses, bark was inexpensive, readily available, largely inert, and generally pathogen-free. They also noted that growing plants in bark induced nitrogen deficiency.

In the 1970s pine bark (PB) began to be evaluated as a container substrate (Brown and Pokorny, 1975; Cotter and Gomez, 1977; Natarella, 1976; Pokorny and Delaney, 1976). Commercial nurseries found PB to be ideal once physical and chemical properties began to be understood (Airhart et al., 1978). Researchers began adding slow-release nitrogen fertilizer to combat nitrogen deficiencies which could not be eliminated by "normal" fertilizing practices (Gartner et al., 1971). Further studies resulted in the recommendation that bark be stockpiled (aged) for at least 30 days before use (Gartner et al., 1972).

In the 1980s researchers began to branch out and explore alternative substrates. A study by Regulski, Jr. (1982) demonstrated that gasifer residue was an acceptable substrate component when exchanged for PB in a peat-based substrate. Similar or greater growth was obtained with all three woody nursery crops evaluated. Pecan shells were evaluated as an organic component of container substrates, but were found to produce inferior crops, possibly due to phytotoxic substances associated with the shells (Wang and Pokorny, 1989). Also in the early 1980s, continued work on the physical properties of PB resulted in two definitive studies involving the development of PB substrates from component particles (Pokorny and Henny, 1984a, 1984b). Additionally, PB porosity, water availability and root penetration were explored (Pokorny and Wetzstein, 1984). Leaching of phosphorous was identified as an important issue in PB-based substrates (Yeager and Barrett, 1985).

In the 1990s and 2000s a large extent of substrate research revolved around the exploration and evaluation of alternative substrates. These substrates were generally composed of waste products or composts and were evaluated as amendments or substitutes for PB and/or peat. A need for alternative substrates in the nursery and greenhouse industries had become evident over time. Coupled with that need was an understanding that there were many waste products that could completely or partially fulfill the needs required for rooting substrates while reducing waste management problems.

Many compost products have been tested for use in plant production with varying success. Generally composts are only recommended as amendments (rather than substitutes for PB) at v:v rates of no more than 25-50%. Some compost products have characteristically high salt levels and are limited to 10-20% of the substrate volume. Reduced plant quality occurs when these amendments are present in higher amounts. Additionally, substrates that contain unstable/non-aged organic components may decompose rapidly resulting in "shrinkage" of the substrate up to ¾ of the container volume in a short time (Robbins, 2002).

Rice hulls are among the most studied alternative substrate components. Laiche (1989) reported favorable results in a study using up to 100% composted rice hulls as a container substrate. In that study four substrates were tested with varying amounts of fertilizer amendments: 4:1 PB:sand, 100% PB, 100% composted rice hulls and 100% pine wood shavings. Results indicated that the highest quality plants were obtained with composted rice hulls and poorest with pine shavings regardless of fertilizer treatment. Dueitt et al. (1993) concluded that the use of rice hulls, either fresh or composted, meets all the needs of a container growing substrate while being relatively inexpensive, readily available and free from diseases and insects. Later, in a bedding plant study, Dueitt and Newman (1994) analyzed the physical properties of fresh and aged rice hulls and reported that the addition of rice hulls did not modify the pore space and was a viable option for a growing substrate. Substrates containing fresh rice hulls initially had greater air space than aged rice hulls, however, the reverse was reported at the end of the study. They attributed the loss of air space to substrate shrinkage during the growing period. Additionally, they reported differences in water holding capacity among the fresh and aged rice hulls, but at the conclusion of the study the fresh rice hull substrates held more water than the aged.

Composted yard-debris (grass clippings, leaves, branches and other plant debris) has also been extensively studied as an alternative organic material component. Ticknor and Hemphill (1990) reported using yard-debris compost to grow a variety of herbaceous and woody crops with some success. All species tested were able to put on new growth in 100% yard-debris compost; however, growth was greater when compost was mixed with other growing substrates. McConnell and Harrell (1992) evaluated the use of yard-debris compost in commercial nursery production and reported that it could be used as a potting mix component under commercial management practices. However, some plants experienced chlorosis when grown in substrates containing more than 50% yard-debris.

Poultry litter has shown great promise in nursery production while at the same time helping to alleviate major waste management problems of the poultry industry. Tyler et al. (1993a, 1993b, 1993c) evaluated many aspects of poultry litter such as chemical, physical and thermal properties when used with a PB substrate and the effect of poultry litter on plant growth. Poultry litter study results indicated that substrates were generally favorable when composted poultry litter was incorporated at low volumes (Fulcher et al., 2002). Poultry litter provides most micronutrients and some macronutrients needed for plant growth which makes it an attractive option for substrate amendment. However, it has characteristically high soluble salt levels which can quickly damage horticultural crops (Allen et al., 1994). Each compost source must be tested prior to being used as a substrate amendment to ensure biologically stable compost (Midcap, 1995). Fresh poultry litter is not recommended due to high ammonia and salt levels.

Many other alternative substrates have been tested with varying results and include ground tea leaves (Tatum and Owings, 1992), cotton gin compost (Cole and Sibley, 2004; Jackson et al., 2005a, 2005b; Owings, 1993), rockwool (Verwer, 1975), peanut hulls (Bilderback et al., 1982), pecan shells (Wang and Porkorny, 1989), monolithic slag (Blythe et al., 2005), vermicompost (Bachman and Metzger, 1998), wulpak (Bilderback and Lorscheider, 2000), scrubber waste (Thomas and Bauerle, 2003) coir pith (Laiche, 1995), mushroom compost (Knox et al., 1995), dairy waste (Bradley et al., 1996), paper production waste (Chong and Lumis, 2000; Tripepi et al., 1996), crumb rubber (Johnson and Tatum, 1996), and bioconverted swine biosolids (Flinn et al., 1997).

Today, nursery and greenhouse substrates in the U.S. are composed primarily of aged PB and Canadian sphagnum peat moss (Fig. 1.1). These materials provide structural support as well as a nutrient and water reservoir for plant growth. Pine bark and peat moss are ideal because they are largely inert, pathogen-free, and have been readily available. However, a study by Lu, et al. (2006) showed a consistent decline in the availability (and subsequent rise in price) of PB due to reduced domestic forestry production, increased importation of logs (no bark), increased in-field harvesting (leaving bark on the forest floor rather than at the mill), and use of PB as a source of fuel. What was once a forestry production waste product is now a valuable commodity. Additionally, the recent rise in fuel prices has driven transportation costs up significantly, which may soon render peat a cost-prohibitive component of greenhouse substrates. In the case of Canadian peat moss, shipping to U.S. greenhouse producers can consume as much as half the cost of the growing material (Young's Plant Farm, personal communication).

Peat is a slowly-renewable resource and its use raises environmental sustainability issues. Some peat bogs in Europe are scheduled to be closed within the next decade as a result of over-harvesting (Carlile, 2004). Environmental lobbyists in the UK have pursued the protection, conservation, and restoration of peat bogs as well as the development of alternative substrates for horticultural uses since the late 1980s. Their attempts have been partially successful in that a number of alternative substrates have been evaluated by growers and many producers are currently implementing peat dilution plans into their practices. However, the general public of the UK (hobbyists) continues to prefer peat, accounting for 62% of peat use for horticultural purposes (33% is used commercially) (Carlile, 2004). A 2004 report on commercial horticulture in England and Wales described several alternative substrates being used including composted bark, green compost and loam, coir, perlite, fine bark and woodfibre (Holmes, 2004).

Adding to the increase in substrate cost is a trend in greenhouse production toward increased volume of substrate per container without a corresponding increase in sale price (Young's Plant Farm, personal communication). Many growers are increasingly moving toward producing crops in larger "finished" containers. These products generally have several species of plants growing in the same container in order to provide an "instant landscape" or "impact" for consumers. Large retail chain stores are ordering increasing quantities of these products with little concern for the cost involved in the increased substrate volume required for production. This has led to an increased need for economical, local, and sustainable growth substrates to fulfill greenhouse production requirements and reduce input costs.

Recent substrate research has identified CCR, a forest in-field harvesting residual material, as a potential substrate substitute for PB and peat moss (Boyer et al., 2008). Clean chip residual is derived from the forestry production process of thinning pine plantations using mobile equipment (Fig. 1.2 and 1.3). This process, first carried out when a plantation is about 10-15 years old, results in two products: clean chips (used for making paper products) (Fig. 1.4) and CCR (everything else, including wood, needles and bark) (Fig. 1.5, 1.6, 1.7, 1.8 and 1.9). The resulting CCR product is composed of approximately 50% wood, 40% bark, and 10% needles and is either sold for boiler fuel, or more commonly, left in the field and spread across the harvested area. When CCR is sold for fuel, the price is about \$18-24/ton (\$3 to 4 yard^3) when sold within a 40-mile radius (Castleberry Logging, Inc., personal communication). Growers across the Southeast U.S. have reported current prices of PB ranging from \$12 to 20/yard^3. The cost of peat can be as much as \$68/yard^3 (Nelson, 2003). Add to these figures the cost of shipping with recent rising fuel costs and it is clear that substrates represent a significant portion of production costs.

Forest residues are defined by the forest industry as the remaining woody biomass, usually considered un-merchantable, left on site after harvesting merchantable stand and tree components (Stokes et al., 1989). Residual materials in the stand or at the landing (machine area) are the limbs, tops, cull portions, and stumps of the merchantable and un-merchantable trees. In a more intensive integrated harvesting system that produces pulp chips, the only residues would be the limbs, tops and broken sections of the trees, the small trees too small for chipping, and stumps. In all cases, the residues are woody biomass components not recovered by the harvesting system (Stokes et al., 1989). When the trees or residual material are chipped, with limbs, tops, and bark attached, the chips have limited use for making paper pulp and composite panel products (Stokes and Watson, 1991). Usually material with such a high bark content is only suitable as energywood to produce electricity and steam. Clean chips for pulping can be produced in the woods by de-limbing and de-barking before chipping (Stokes and Sirois, 1986; Stokes et al., 1989).

In the 1970's a move toward in field harvesting began to occur. At that time logging residues were available at a free stumpage rate since such material must be destroyed or removed to regenerate the next stand (Watson, et al., 1987). Later, a study by Stokes and Watson (1988) stated that increasing the utilization of the woody biomass provided additional revenues from the site as well as reducing site preparation costs which make tree planting easier. The usual disposal of residual is an additional cost charged to the clean chips; processing the material turns the residues into a positive cash flow (Baughman et al., 1990). Increasing the use of residual reduces site preparation costs, which leads to lower regeneration costs and improved stocking and production from the forest land base (Stokes et al., 1989). If residues from flailing are recovered, over 84% of the total tree biomass can be recovered as pulp fiber and residual (Stokes and Watson, 1988).

Studies with in-woods flailing and chipping have revealed high chip quality and increased biomass recovery (Stokes and Watson, 1988; 1991). Three products result from the combined flail/chip process: flail residues, chipper rejects, and chips. The majority of the material is ‘clean chips’ for pulp (about 82.1%). The flail residues, characterized as limbs, tops, foliage, and bark, accounted for 14.7% of the whole-tree biomass in a study by Stokes and Watson (1988) utilizing slash pine (*Pinus elliottii*). Chipper rejects from the chipper separator accounted for 3.2% of the whole tree for a total residue harvest of 17.9%. A separate study by Baughman et al. (1990) indicated that residual yield as a percent of the total volume of chips and residual produced averaged 26.5% with a minimum of 24.8% and a maximum of 28.9%. Total residual recovery from a flail/chip process was 39.4% in a study by Stokes (1998) with Loblolly pine (*Pinus taeda*). The range of yield data can be attributed to the amount of biomass available in the stand in the form of green limbs and needles on the stems. This is, in turn, a function of age of the stand, site, stocking and previous silvicultural history (Baughman et al., 1990; Whalenberg, 1960; Burns and Honkala, 1990; Andrulot et al., 1972; and Brender, 1973). Trailer loads of processed residual ranged from 17.8 to 20.9 green tonnes (Baughman et al, 1990).

In-field tree harvesting operations are increasing across the Southeast (Johnson and Steppleton, 2007; Wear et. al, 2007). This process leaves about 25% of the total biomass (residual) in the field. In general, forest landowners are only paid for the “clean chips” that are harvested from their site. A horticultural use for CCR presents an additional income opportunity for landowners. This additional income would be a result of eliminating the cost of spreading residual back across the forest site and increasing the total biomass harvested from the site. Use of CCR has the potential to provide a sustainable substrate resource that is able to meet the continuing needs of the nursery and greenhouse industries and have a value-added benefit to forestry landowners.

Previous work in the U.S. on substrates containing wood fiber has centered on the use of industrial wood waste products which, generally, must be composted before use. Bell et al. (1973) explored the development of compost composed of softwood lumber mill wastes using different fertilizer sources. It was recommended that the material obtained when using broiler manure as the nitrogen source be used for horticultural purposes due to the excellent appearance of the compost. However, the composts were not evaluated for use as plant growth substrates. King (1979) evaluated waste wood fiber from the production of fiberboard as a soil amendment. Results indicated that waste fiber is a source of slowly available nitrogen and a beneficial soil amendment though application may be difficult without considerable loss by blowing (the material leaves the fiberboard mill in a dry, fluffy state).

Laiche and Nash (1986) were the first to evaluate PB with wood and pine tree chips as components of a container plant growing media. They determined at that time that PB was the best growth media tested followed by PB with wood and the poorest growth in pine tree chips. These differences were attributed to nitrogen immobilization, high leaching, lower nutrient retention and lower water holding capacity in pine chips. A later study by Laiche (1989) evaluated woody landscape plants (*Ilex crenata* 'Compacta' and *Ilex vomitoria* Straughn's selection) grown in single component substrates (either pine wood shavings, composted rice hulls or pine bark) with all fertilizer amendments surface-applied. The study did not state whether the pine wood shavings had been composted or used fresh. In general, highest quality was obtained with composted rice hulls and poorest with pine shavings. Differences in growth were attributed to the initial poor water-holding capacity of pine wood shavings.

A study by Lord et al. (1993) evaluated a wood waste compost substrate composed of ground particle board, plywood, pine dimensional lumber and swine lagoon effluent. Wood waste was composted for 18 months and was biologically stable at the time of the study. Two additional substrates were used for comparison: 5:1 PB:sand (v:v) and 70:15:15 (v:v:v) pine bark: turkey litter: rockwool. Physical properties between substrates were similar and did not contribute greatly to differences in chemical properties affected by drainage and water movement, or to plant growth differences. The major finding of this study was excessive electrical conductivity levels for all substrates initially. They concluded that frequent irrigation would be required to produce crops in the wood waste compost substrate.

Another wood-based waste product is pulp and paper sludge from newsprint mills. This material was composted for six weeks and evaluated as a substitute for peat moss in container substrates (Tripepi et al., 1996). All plants in compost-amended substrate grew as well or better than those in peat-amended substrate, regardless of the species grown (one-year-old seedlings of lilac *Syringa vulgaris*, maple *Acer tataricum* L. ssp. *ginnala*, and plum *Prunus* x *cistena*). The results of the study indicated that a thorough evaluation of potential products was necessary due to the variability in paper products produced (newsprint sludge is relatively benign; however, bleached Kraft paper sludge can have a high pH and salt content). The substrate materials tested were void of bark and needles and may have gone through a manufacturing process which could alter their physical and chemical characteristics (pH, salts, etc.).

Studies evaluating hardwood bark have also been conducted since the 1970s. In general, growing crops in hardwood bark requires a different set of production protocols due to increased nitrogen immobilization (Gartner et al., 1971). Klett et al. (1972) compared growth of forsythia (*Forsythia intermedia* Zabel 'Lynwood Gold') and juniper (*Juniperus chinensis Pfitzeriana* Spaeth) plants produced in hardwood bark substrates to those produced in a standard mix of soil, peat and perlite. They concluded that, based on dry weight, the most rapid growth of forsythia was obtained in a bark and fine sand substrate; whereas, the least growth was obtained in soil, peat and perlite. However, pfitzer juniper plants under two different fertility regimes grew most rapidly in a bark, soil, and peat substrate, slowest in a bark and sand substrate and at an intermediate growth rate in soil, peat and perlite. A study by Yates and Rogers (1981) developed hardwood bark composting standards (1-2 months adequate).

Kenna and Whitcomb (1985) evaluated hardwood chips from post oak (*Quercus stellata*) and Siberian elm (*Ulums pumila*) as an alternative substrate for container plant production. Substrates were obtained by grinding entire dormant trees, including dead leaves, twigs, bark and wood through a large chipper. Wood chips were processed further through a hammer mill with a 7.6 x 7.6 cm screen. Each type of wood chip was mixed in a 3:1:1 (v:v:v) with spaghnum peat and sand. Plants evaluated in the study (pyracantha, *Pyracantaha* x 'Mojave' and Formosan sweetgum, *Liquidambar formosana*) grown in elm and oak chip substrates showed no visible micronutrient deficiency or toxicity symptoms during the growing season. Results suggested that chips from elm and/or oak in Oklahoma can be used successfully as components in soilless substrates without composting. Growth of Formosan sweetgum trees and Mojave pyracantha in oak and elm chip substrate equaled that in a standard PB substrate. However, the decrease in the percentage of drainable pore space after one growing season suggested the oak and elm substrate may not be acceptable for long-term crops. Some nurseries in the U.S. are currently utilizing wood fiber components in their substrates. One nursery in Alabama (Martin's Nursery, Semmes, AL) has successfully used high percentage (up to 40%) pine shavings for 40 years in the production of azalea (*Rhododendron* sp.) which require an acidic substrate.

Wood fiber products have been used in Europe since 1995 to grow vegetable seedlings (Gruda and Schnitzler, 2001). Gruda and Schnitzler (2003) reported the use of wood-fiber substrates for vegetable transplant production. They did not detect any differences for the absolute and relative growth rate of tomato transplants cultivated in woof fiber substrates as compared to white peat. Additionally, plants grown in wood fiber substrate showed a well developed root system. Currently, there are two main European wood fiber materials used in horticultural practices: Toresa and Fibralur. Toresa (European patent no. 0472684) has four wood-based products for the horticultural industries. Toresa is composed of the wood chip remains from the production of boards and beams (pine and spruce trees). Some of the four products produced by Toresa have been impregnated with nitrogen during the production process to reduce initial nitrogen-immobilization during plant growth. Toresa is marketed as a peat alternative for nursery and greenhouse production (Gruda and Schnitzler, 2004). Fibralur is also a recently developed product. It is produced by treating wood chips with a thermal-mechanical process. Fibralur is primarily used for vegetable production and hydroponic crops (Muro et al., 2005). Currently there are no readily available wood fiber-based substrates commercially marketed in the U.S.

Recent studies in the U.S. evaluating the growth of crops in substrates composed of high percentages of wood and bark have showed promising results. Wright and Browder (2005) demonstrated that with proper nutrition and irrigation, ground pine logs (including bark) offer potential as a container substrate when compared to PB. Their study reported that pine wood chips provided acceptable container capacity, aeration and water drainage if the wood chips were ground finely (0.5 mm). Root growth of Japanese holly (*Ilex crenata* 'Chesapeake'), azalea (*Rhododendron obtusum* 'Karen') and marigold (*Tagetes erecta* 'Inca Gold') was more extensive in ground pine wood chips than in aged milled PB. In addition, substrate analysis indicated that there were no toxic nutrient levels associated with pine wood chips, pH (5.7) was acceptable for plant culture, and there was no apparent shrinkage due to decomposition over the course of the study. A subsequent study by Wright et al. (2006) evaluated a variety of woody species for growth in a pine wood chips (PC; 100% wood fiber) substrate compared to a PB substrate. Results indicated comparable growth in PC and PB for most species. Shoot dry weight of 13 of 18 species in the first planting was not different between PB and PC, with shoot dry weight of four species in this planting being higher when grown in PB and one being higher when grown in PC. Shoot dry weight for 6 of 10 species in the second planting was higher in PB compared to PC. A nutrition deficit in the PC substrates was noted for the species, *Rhododendron obtusum* 'Karen' and *Tagetes erecta* 'Inca Gold', exhibiting less growth than plants grown in PB.

Another potential substrate material is *WholeTree*. *WholeTree* is composed of the entire shoot portion of the tree and is therefore about 80% wood fiber depending on the age of the trees harvested. *WholeTree* can be obtained from low-value biomass acquired from forest thinning (making room for the remaining trees to grow larger) or salvage operations where young plantations have not been managed well and are harvested completely in order to replant (this material is then sold to pulpmills or sawmill operations for fuel). Fain and Gilliam (2006) reported that annual vinca (*Catharanthus roseus*) grown in *WholeTree* had similar growth to plants grown in PB. While shoot dry weights were 15% greater for plants grown in 100% PB 60 days after planting, there were no differences in plant growth indices. Fain et. al (2008) reported *WholeTree* composed of three species of pine could each be successfully used as a growth substrate for annual vinca.

Boyer et al. (2006) tested substrates composed of 50% to 100% whole pine trees (small caliper (2 to 10 cm) *Pinus taeda*; tops cut off) for the production of container-grown lantana (*Lantana camara*). In this study two substrates were tested alone and in combination with PB, peat (P) and composted poultry litter (PL). A 6:1 (v:v) PB:sand control treatment was also included. The two substrates were both composed whole pine trees processed in a chipper (including needles) (C) however, one substrate was additionally processed through a hammer mill with a 0.95 cm screen (HM). Treatments included were 100% C, 3:1 (v:v) C:PB, 3:1 (v:v) C:P, 3:1 (v:v) C:PL, 1:1 (v:v) C:PB, 1:1 (v:v) C:P, 1:1 (v:v) C:PL and the same treatments for the HM substrate. Chipped and HM treatments amended with either PL or P resulted in lantana with growth indices similar to PB:sand (6:1). In general, plants tended to be larger when amended on a 1:1 basis with either PL or P but were similar statistically to those amended 3:1. For example, plants grown with HM:P 1:1 or HM:PL 1:1 were 7.3 and 8.8% larger respectively than plants grown in the same medium at 3:1. The lowest growth indices occured with C and HM, either alone or amended with pine bark. Shoot dry weight followed a similar trend to growth indices. Lantana root growth followed a similar trend to growth indices in that greatest coverage of the rootball surface occurred with either C or HM amended with PL or P.

Another study by Fain et al. (2006) evaluating *WholeTree* in production of herbaceous greenhouse crops (marigold, *Tagetes patula* ‘Little Hero Yellow’; lantana, *Lantana camara* ‘Lucky Red Hot Improved’; and petunia, *Petunia* x *hybrida* ‘Dreams Pink’) indicated mixed results. Plants were grown in 100% *WholeTree* ground to three different screen sizes and mixed on a v:v basis with peat moss. At 34 DAP there were no differences in flower number for marigold; however, lantana grown in 100% *WholeTree* substrates had the fewest flowers. Petunias grown in an industry standard peat blend substrate had over twice the number of flowers than was observed on plants grown in other substrates. Leaf chlorophyll content was similar for petunia, but marigold and lantana plants had a general trend of an increase in chlorophyll content with an increase in substrate peat moss content. In general, plants grown in *WholeTree* substrates were smaller than plants in other blends, but plants increased in size with increasing peat moss percentage.

It appears, based on current research, that production of nursery and greenhouse crops in alternative substrates is a viable option. There may be some slight changes in production practices, but they should be minimal. These alternative substrates have the potential to provide a positive economic benefit to the green industry in that they are locally produced, sustainable, and economical.

Literature cited

Airhart, D.L., N.J. Natarella, and F.A. Pokorny. 1978. The structure of processed pine bark. J. Amer. Soc. Hort. Sci. 103:404-408.

Allen, V.T., B.K. Behe, and D.G. Himelrick. 1994. Broilder litter compost affects growth of annual and perennial plants. Proc. Southern Nur. Assn. Res. Conf. 39:89-91.

Andrulot, A.E., L.P. Blackwell, and P.Y. Burns. 1972. Effects of thinning on yield of loblolly pine in central Louisiana. Louisiana Tech. University, Bulletin 6. Ruston. 145 p.

Bachman, G.R., and J. Metzger. 1998. The use of vermicompost as a media amendment. Proc. Southern Nur. Assn. Res. Conf. 43:32-34.

Baughman, R. K., B.J. Stokes, and W.F. Watson. 1990. Utilizing residues from in-woods flail processing. In: Stokes, B.J., ed. Harvesting small trees and forest residues: Proceedings of the International Energy Agency, task 6, activity 3 workshop. Auburn, AL: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 21-30.

Bell, R.G., J.Pos., and R.J. Lyon. 1973. Production of composts from soft wood lumber mill wastes. Compost Science. March/April pp.5-7.

Bilderback, T.E., W.C. Fonteno, and D.R. Johnson. 1982. Physical properties of media composed of peanut hulls, pine bark, and peatmoss and their effects on Azalea growth. J. Amer. Soc. Hort. Sci. 107:522-525.

Bilderback, T. and M. Lorscheider. 2000. Use of wulpak as a mulch and amendment for nursery potting substrates. Proc. Southern Nur. Assn. Res. Conf. 45:73-76.

Blythe, E.K., J.L. Sibley, K.M. Tilt, and R. Zinner. 2005. Monolithic slag as a substrate for rooting and bare-rooting stem cuttings. J. Environ. Hort. 23:67-71.

Boyer, C.R., G.B. Fain, C.H. Gilliam, T.V. Gallagher, H.A. Torbert, and J.L. Sibley. 2006. Evaluation of freshly chipped pine tree substrate for container-grown *Lantana camara*. HortScience 41:1027. Abstr.

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 (In Press).

Bradley, G.J., M.H. Glass, and T.E. Bilderback. 1996. Dairy cow compost as a potting substrate for growing hybrid rhododendrons. Proc. Southern Nur. Assn. Res. Conf. 41:128-129.

Brender, E.V. 1973. Silviculture of loblolly pine in the Georgia Piedmont, Georgia Forest Research Council, Report 33. Macon. 74 p.

Brown, E.F. and F.A. Pokorny. 1975. Physical and chemical properties of media composed of milled pine bark and sand. J. Amer. Soc. Hort. Sci. 100:119-121.

Burns, R.M. and B.H. Honkala. 1990. Silvics of North America: 1. Conifers; 2. Hardwoods. Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, DC. 877 p.

Carlile, W.R. 2004. Growing media and the environment lobby in the UK 1997-2001. Acta Hort. 644:107-113.

Chong, C., and G.P. Lumis. 2000. Mixtures of paper mill sludge, wood chips, bark, and peat in substrates for pot-in-pot shade tree production. Plant Sci. 80:669-675.

Cole, D.M. and J.L. Sibley. 2004. Waste not, want not. Amer. Nurseryman 199:44-47.

Cotter, D.J. and R.E. Gomez. 1977. Bark as a growing media. HortScience 12:27. Abstr.

Davidson, H., R. Mecklenburg, and C. Peterson. 2000. Nursery management: Administration and culture. 4th ed. Prentice Hall, Upper Saddle River, N. J.

Dueitt, S.D., J. Howell, and S.E. Newman. 1993. Rice hulls as a vermiculite substitute in peat-based media for growing greenhouse bedding plants. Proc. Southern Nur. Assn. Res. Conf. 38:62-63.

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 Nur. Assn. Res. Conf. 39:81-85.

Fain, G.B and C.H. Gilliam. 2006. Physical properties of media composed of ground whole pine trees and their effects on vinca (*Catharanthus roseus*) growth. HortScience 40:510. Abstr.

Fain, G.B., C.H. Gilliam, J.L. Sibley, and C.R. Boyer. 2006. Evaluation of an alternative, sustainable substrate for use in greenhouse crops. Proc. Southern Nur. Assn. Res. Conf. 51:651-654.

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

Flinn, C.L., R. Campbell and T.E. Bilderback. 1997. The use of bioconverted swine biosolids as an amendment for potting media for commercial nursery production. Proc. Southern Nur. Assn. Res. Conf. 42:146-147.

Fulcher, A., C. Finneseth, and W.C. Dunwell. 2002. Use of pelletized poultry litter as a container substrate. Proc. Southern Nur. Assn. Res. Conf. 47:73-76.

Gartner, J.B., D.C. Saupe, J.E. Klett and T.R. Yocom. 1970. Hardwood bark as a medium for container growing. Amer. Nurseryman 131:11, 40-44.

Gartner, J.B., M.M. Meyer, Jr., and D.C. Saupe. 1971. Hardwood bark as a growing media for container-grown ornamentals. Forest Products J. 21:25-29.

Gartner, J.B., T.D. Hughes and J.E. Klett. 1972. Using hardwood bark in container growing mediums. Amer. Nurseryman 135:10-12, 77-79.

Gruda, N. and W.H. Schnitzler. 2001. Physical properties of wood fiber substrates and their effect on growth of lettuce seedlings (*Lactuca sativa* L. var. *capitata* L.). Acta Hort. 548:415-423.

Gruda, N. and W.H. Schnitzler. 2003. Suitability of wood fiber substrate for production of vegetable transplants II. The effect of wood fiber substrates and their volume weights on the growth of tomato transplants. Scientia Hort. 100:333-340.

Gruda, N. and W.H. Schnitzler. 2004. Suitability of wood fiber substrate for production of vegetable transplants I. Physical properties of wood fiber substrates. Scientia Hort. 100:309-322.

Holmes, S. 2004. Peat and peat alternatives: Their use in commercial horticulture in England and Wales in 2003. A report for Horticulture and Potatoes Division, Department for Environment, Food and Rural Affairs. ADAS Horticulture, Boxworth, England.

Jackson, B.E., A.N Wright, D.M. Cole and J.L. Sibley. 2005a. Cotton gin compost as a substrate component in container production of nursery crops. J. Environ. Hort. 23:118-122.

Jackson, B.E., A.N. Wright, J.L. Sibley, and J.M. Kemble. 2005b. Root growth of three horticultural crops grown in pine bark amended cotton gin compost. J. Environ. Hort. 23:133-137.

Johnson, P., and D. Tatum. 1996. The use of curmb rubber amendment in the production of poinsettias. Proc. Southern Nur. Assn. Res. Conf. 41:111-115.

Johnson, T.G. and C.D. Steppleton. 2007. Southern pulpwood production, 2005. USDA-Forest Service Southern Research Station. Bulletin SRS-116.

Kenna, S.W. and C.E. Whitcomb. 1985. Hardwood chips as an alternative medium for container plant production. HortScience 20:867-869.

King, L.D. 1979. Waste wood fiber as a soil amendment. J. Environ. Qual. 8:91-95.

Klett, J.E., J.B. Gartner, and T.D. Hughes. 1972. Utilization of hardwood bark in media for growing woody ornamental plants in containers. J. Amer. Soc. Hort. Sci. 97:448-450.

Knox, G., J. Norcini and D. Covan. 1995. Evaluation of waste products as peat substitutes in container substrates. Proc. Southern Nur. Assn. Res. Conf. 40:98-100.

Laiche, A.J. Jr. 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.

Laiche, A.J. Jr. 1989. Container-grown ornamentals produced in single-component plant growth medium. MAFES Research Report. 14:1-3.

Laiche, A.J. Jr. 1995. Pine bark growth media amended with coir pith. Proc. Southern Nur. Assn. Res. Conf. 40:125-128.

Lord, W.G., T.E. Bilderback, and L. Hight. 1993. Wood waste compost as a potting medium amendment. Proc. Southern Nur. Assn. Res. Conf. 38:75-77.

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.

Lunt, O.R. and H.C. Kohl, Jr. 1956. Influence of soil physical properties on the production and quality of bench grown carnations. J. Amer. Soc. Hort. Sci. 69:535-542.

McConnell, D.B. and R. Harrell. 1992. Commercial production of landscape plants using yard waste compost. Proc. Southern Nur. Assn. Res. Conf. 37:72-74.

Midcap, J.T. 1995. Preliminary evaluation of composted poultry litter as a potting mix component. Proc. Southern Nur. Assn. Res. Conf. 40:94-97.

Muro, J., I. Irigoyen, P. Samitier, P. Mazuela, M.C. Salas, J. Soler, and M. Urrestarazu. 2005. Wood fiber as a growing medium in hydroponic crop. Acta Hort. 697:179-185.

Natarella, N.J. 1976. Lime requirement determination for a milled pine bark substrate. HortScience 11:24. Abstr.

Nelson, P.V. 2003. Greenhouse operation and management. 6th ed. Prentice Hall, Upper Saddle River, N. J.

Owings, A.D. 1993. Cotton gin trash as a medium component in production of ‘Golden Bedder’ coleus. Proc. Southern Nur. Assn. Res. Conf. 38:65-66.

Pokorny, F.A. and S. Delaney. 1976. Preparation of a model pine bark substrate from component particles. Hortscience 11:24. Abstr.

Pokorny, F.A. and B.K. Henny. 1984a. Construction of a milled pine bark and sand potting medium from component particles I. Bulk density: A tool for predicting component volumes. J. Amer. Soc. Hort. Sci. 109:770-773.

Pokorny, F.A. and B.K. Henny. 1984b. Construction of a milled pine bark and sand potting medium from component particles II. Medium synthesis. J. Amer. Soc. Hort. Sci. 109:774-776.

Pokorny, F.A. and H.Y. Wetzstein. 1984. Internal prosoity, water availability, and root penetration of pine bark particles. HortScience 19:447-449.

Regulski Jr., F.J. 1982. Evaluation of a gasifer residue as a container medium for woody ornamentals. HortScience 17:209-210.

Robbins, J.A. 2002. Effect of media type on the growth of container-grown woody ornamentals. Proc. Southern Nur. Assn. Res. Conf. 47:67-72.

Scott, E.G. and B.C. Bearce. 1972. A hardwood-bark-sawdust compost for greenhouse pot flower production. 22:36-39.

Stokes, B.J. and D.L Sirois. 1986. Evaluation of chipper-forwarder biomass harvesting concept. In: Proceedings of the 1985 southern forest biomass workshop. Gainesville, FL: University of Florida: 62-67.

Stokes, B. J., D.L. Sirois, and W.F. Watson. 1989. Recovery of forest residues in the Southern United States. In: Stokes, B.J., ed. Harvesting small trees and forest residues: Proceedings of the 1989 International Energy Agency, task 6, activity 3 symposium. Auburn, AL: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 32-43.

Stokes, B. J. and W.F. Watson. 1991. Wood recovery with in-woods flailing and chipping. In: Proceedings of the 1990 TAPPI pulping conference. Atlanta, GA: TAPPI Press: 851-854.

Stokes, B. J. 1998. Harvesting systems for multiple products an update for the United States. In: Wood fuels from conventional forestry: Proceedings of the 3rd annual workshop of activity 1.2, task 7, International Energy Agency Bioenergy. Auburn, AL: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 49-56.

Tatum, D.H., and A.D. Owings. 1992. Ground tea leaves as a bedding plant medium amendment. Proc. Southern Nur. Assn. Res. Conf. 37:75-76.

Thomas, C.N. and W.L. Bauerle. 2003. Potential benefits of scrubber waste in nursery crop production. Proc. Southern Nur. Assn. Res. Conf. 48:114-116.

Ticknor, R.L., and D.D. Hemphill Jr. 1990. Yard-debris compost as a growing medium. American Nurseryman 172: 97-99.

Tripepi, R.R., M.W. George, A.G. Campbell, and B. Shafii. 1996. Evaluating pulp and paper sludge as a substitute for peat moss in container media. J. Environ. Hort. 14:91-96.

Tyler, H., K.B. Perry, and S.L. Warren. 1993a. Composted turkey litter: Effect on the thermal characteristics of an amended pine bark substrate. Proc. Southern Nur. Assn. Res. Conf. 38:92-95.

Tyler, H., S.L. Warren, T.E. Bilderback, and W.C. Fonteno. 1993b. Composted turkey litter: I. Effect on chemical and physical properties of a pine bark substrate. J. Environ. Hort. 11:131-136.

Tyler, H., S.L. Warren, T.E. Bilderback, and K.B. Perry. 1993c. Composted turkey litter: II. Effect on plant growth. J. Environ. Hort. 11:137-141.

Verwer, F.L.J.A.W. 1975. Cutting and cropping in artificial media. Acta Hort. 50:13-20.

Wahlenberg, W.G. 1960. Loblolly pine: Its use, ecology, regeneration, protection, growth, and management. Duke University, School of Forestry, Durham, NC. 603 p.

Wang, T., and F.A. Pokorny. 1989. Pecan shells as an organic component of container potting media. HortScience 24:75-78.

Watson, W.F., J.R. Ragan, T.J. Straka, and B.J. Stokes 1987. Economic analysis of potential fuel wood sources. In: Proceedings of the 1986 Society of American Foresters national convention. Bethesda, MD: Society of American Foresters: 339-342.

Wear, D.N., D.R. Carter, and J. Prestemon. 2007. The U.S. south’s timber sector in 2005:A prospective analysis of recent change. USDA-Forest Service Southern Research Station.

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

Wright, R.D., J.F. Browder, and B.E. Jackson. 2006. Ground pine chips as a substrate for container-grown woody nursery crops. J. Environ. Hort. 24:181-184.

Yates, N.L. and M.N. Rogers. 1981. Effects of time, temperature, and nitrogen source on the composting of hardwood bark for use as a plant growing medium. J. Amer. Soc. Hort. Sci. 106:589-593.

Yeager, T.H. and J.E. Barrett. 1985. Considerable leaching of phosphorus may occur with soilless media. Amer. Nurseryman 161:47-48.

Fig. 1.1. Common substrate components (clockwise): pine bark, vermiculite, perlite and peat.

Fig. 1.2. Total tree harvesting machine. Trees are fed into a flail which de-limbs and de-barks the trees before they are fed into a chipper which results in small, uniform 'clean chips' used for paper manufacturing. There is a less than 1% tolerance for the presence of pine bark in 'clean chips.'

Fig. 1.3. Total tree harvester with view of chipper.

Fig. 1.4. ‘Clean chips’ loaded into a van for transport to a pulp mill.

Fig. 1.5. Residual material resulting from in-field harvesting for ‘clean chips.’ This material is processed into clean chip residual.

Fig. 1.6. Clean chip residual is piled on site, awaiting further processing.

Fig. 1.7. Clean chip residual is processed in the field through a horizontal grinder before sale to a pulp mill as fuel.

Fig. 1.8. Clean chip residual obtained from a grinder can be used in horticultural industries.

Fig. 1.9. Clean chip residual obtained from a grinder can be further processed in a swinging hammer mill to pass any of several screen sizes in order to make the material more suitable for crop production.

CHAPTER II

Clean Chip Residual: A Substrate Component for Growing Annuals

Abstract

A study was conducted at Auburn University in Auburn, AL and the USDA-ARS (United States Department of Agriculture, Agricultural Research Service) Southern Horticultural Laboratory in Poplarville, MS to evaluate clean chip residual (CCR) as an alternative substrate component for annual bedding plant production. Clean chip residual used in this study was processed through a horizontal grinder with 4-inch screens at the site and then processed again through a swinging hammer mill to pass a ¾- or ½- inch screen. Two CCR particle sizes were used alone or blended with either 10% (9:1) or 20% (4:1) peat moss (PM) (by volume) and compared with control treatments, pine bark (PB) and PB blends (10 and 20% PM). Three annual species, 'Blue Hawaii' ageratum (*Ageratum houstonianum*), 'Vista Purple' salvia (*Salvia* x *superba*) and impatiens (*Impatiens walleriana* 'Coral' at Auburn and 'White' at Poplarville), were transplanted from 36-cell (12.0 inch^3) flats into 1-gal containers, placed on elevated benches in a greenhouse and hand watered as needed. Ageratum plants grown at Auburn had leaf chlorophyll content similar or greater than that of plants grown in PB. There were no differences in salvia, however impatiens plants grown in PB substrates at Auburn had less leaf chlorophyll content than those grown in CCR. There were no differences in ageratum, salvia or impatiens leaf chlorophyll content at Poplarville. There were no differences in growth indices (GI) or shoot dry weight (SDW) of ageratum while the largest salvia was in PB: PM and largest impatiens were in PB-based substrates at Auburn. Growth index of ageratum at Poplarville was similar among treatments but plants grown in 4:1 ¾-inch CCR: PM were the largest. Salvia was largest in 4:1 CCR: PM and PB: PM while there were no differences in GI for impatiens at Poplarville, the greatest SDW occurred with PB: PM. Foliar nutrient content analysis indicated elevated levels of manganese (Mn) and zinc (Zn) in treatments containing CCR at Auburn and PB at Poplarville. At the study termination two out of three annual species tested at both locations had very similar growth when compared to standard PB substrates. This study demonstrates that CCR is a viable alternative substrate in greenhouse production of ageratum, salvia and impatiens in large containers.

Introduction

In the southeastern U.S., many greenhouse growers have moved toward producing 1-gal or larger containers for the landscape market due to an interest in large finished containers for consumer “instant landscapes.” Substrates used in these large containers are composed primarily of aged PB and Canadian sphagnum PM blends. These materials provide support for plant growth structurally as well as providing a nutrient and water reservoir. Pine bark and PM are ideal substrates because they are largely inert, pathogen-free, and have been readily-available. However, Lu et al. (2006) showed a consistent decline in the availability (and subsequent rise in price) of PB due to reduced domestic forestry production, increased importation of logs (no bark), increased in-field harvesting (leaving bark on the forest floor rather than at the mill), and use of PB as fuel. The large containers require more substrate than has previously been needed for crop production.

Clean chip residual (CCR) is a potential substrate substitute for PB. Clean chip residual is derived from the forestry production process of thinning pine plantations using mobile equipment to harvest and process small trees directly in the field. This process, which is first carried out when the plantation is about 10-15 years old, results in two products: clean chips (used for making paper products) and CCR (everything else, including wood, needles and bark). The resulting CCR product is composed of approximately 50% wood, 40% bark, and 10% needles (data not shown) and is either sold for boiler fuel, or more commonly, left in the field and spread across the harvested area. Use of CCR may have the potential to provide a sustainable substrate resource that is able to meet the continuing needs of the greenhouse industry and have a value-added benefit to forestry landowners.

The objective of this work was to evaluate freshly processed CCR (two screen sizes) as a substrate component or a PB replacement for production of greenhouse-grown annual crops in large containers.

Materials and methods

Clean chip residual used in this study was obtained from a 10- to 12-year-old loblolly pine (*Pinus taeda* L.) plantation near Evergreen, AL, which was thinned and processed for clean chips using a total tree harvester (Peterson DDC-5000-G Portable Chip Plant, Peterson Pacific Corp., Eugene, OR), a horizontal grinder with 4-inch screens

(Peterson 4700B Heavy Duty Horizontal Grinder, Peterson Pacific Corp., Eugene, OR), and a swinging hammer mill (No. 30; C.S. Bell, Tifton, OH) with either a ¾- or ½-inch screen. These two CCR particle sizes were used alone or blended with either 9:1 (10%) or 4:1 (20%) PM (by volume) and compared with PB and PB blends (9:1 and 4:1 PM by volume) (Table 1). Pine bark used in this study was obtained from Pineywoods Mulch Co. (Alexander City, AL). Pine bark used at Poplarville was transported from Auburn to ensure PB source and consistency. Substrates were mixed at Poplarville before splitting material between Poplarville and Auburn for the study. Auburn substrates were then transported to Paterson Greenhouse Complex for study installation in Auburn.

This study was conducted at two locations: USDA-ARS Southern Horticultural Laboratory, Poplarville, MS (23 Feb. 2006) and at Paterson Greenhouse, Auburn University, Auburn, AL (12 Apr. 2006). These locations were chosen due to their location in the southeastern U.S. where the practice of growing annuals in large containers is becoming common. Auburn and Poplarville are located approximately 350 miles apart. Poplarville is approximately 60 miles from the Gulf of Mexico while Auburn is more than 200 miles from the Gulf. Plants at Poplarville were placed in a single layer corrugated polycarbonate greenhouse covered with a 30% shade cloth from 1000 to 1400 HR daily. Plants at Auburn were placed in a twin wall polycarbonate greenhouse with no additional shade for the duration of the study. Greenhouse facilities in Poplarville had a 12-ft gutter height and a crushed limestone floor while the Auburn greenhouse had a 16-ft gutter height and a concrete floor. Greenhouses were maintained at a 22 °C day and 17 °C night temperature in Poplarville and 29 °C day and 18 °C night in Auburn.

Each substrate blend was pre-plant incorporated with 12 lb/yard^3 15-9-12 (15N-3.9P-9.9K) Osmocote® (The Scotts Company, Marysville, OH) (3-4 month release), 5 lb/yard^3 dolomitic limestone and 1.5 lb/yard^3 Micromax® (The Scotts Company, Marysville, OH). Three annual species, ageratum, salvia and impatiens were transplanted from 36-cell (12.0 inch^3) flats into 1-gal containers. Plants at both locations were arranged by species in a randomized complete block with seven single plant replications on elevated benches in a greenhouse (described above), and hand-watered as needed when plants began to show signs of wilt.

Substrates were analyzed for particle size distribution (PSD) 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 (Ro-Tap RX-29, W.S. Tyler, Mentor, OH) sieve shaker (278 oscillations/min, 159 taps/min). Substrate air space (AS), container capacity (CC), and total porosity (TP) were determined following procedures described by Bilderback et al. (1982). Substrate bulk density (measured in grams per cubic centimeter) was determined from 347.5 cm^3 samples dried in a 105 °C forced air oven for 48 h. Substrate pH and electrical conductivity (EC) of ageratum were determined at 1, 15 and 30 d after planting (DAP) using the PourThru technique (Wright, 1986). Only one species was used to measure pH and EC in this study. Media shrinkage (centimeters below the top of the container) was measured at 7 and 41 DAP. Leaf chlorophyll content was quantified using a SPAD-502 Chlorophyll Meter (Minolta Camera Co., Ramsey, NJ) at 30 DAP. Growth indices (GI) [(height + width + perpendicular width) / three (cm)] were recorded at 30 DAP. A visual evaluation of the rootball (scale of 0% to 100% root coverage of the rootball surface) was conducted at the conclusion of the study. Shoot dry weights (SDW) were recorded at the conclusion of the study (41 DAP) by drying in a forced air oven at 70 °C for 48 h. Recently matured leaves (Mills and Jones, 1996) were sampled from four replications of ageratum and salvia at both locations. Samples from impatiens were not collected due to cost restrictions. Foliar samples (four replications per treatment) were analyzed for nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B), iron (Fe), manganese (Mn), copper (Cu) and zinc (Zn). Foliar N was determined by combustion analysis using a 1500 N analyzer (Carlo Erba, Milan, Italy). Remaining nutrients were determined by microwave digestion with inductively coupled plasma-emission spectrometry (Thermo Jarrel Ash, Offenbach, Germany). Data were analyzed using Waller-Duncan k ratio t tests ($P \leq 0.05$) using a statistical software package (SAS® Institute version 9.1, Cary, NC). Data were analyzed separately for each location.

Results and discussion

Since there are no universally accepted standards for physical properties of greenhouse substrates, several recommendations have been used to evaluate the substrates in this study. Jenkins and Jarrell (1989) suggested optimal ranges of 60-75% TP, 50-65% CC and 10-20% AS. Boertje (1984) recommended minimum of 85% TP and at least 45% CC. Recommended ranges for nursery crop substrates include: 50-85% TP, 10-30% AS, 45-65% CC and 0.19-0.70 $g \cdot cm^{-3}$ bulk density (Yeager et al., 2007). Air space was the greatest in both of the 100% CCR treatments, which was almost 10% more than 100% PB (Table 2.1). Treatments containing 20% PM had the greatest CC (53-56%)

while those containing 10% PM had slightly less CC (45-51%) and 100% CCR or PB had the least CC (38-49%). Substrates in this study all had between 84-87% TP, indicating adequate porosity, although these values are near the top of the suggested ranges (10% over the range suggested by Jenkins and Jarrell (1989)). Bulk density was acceptable (0.16-0.18 $g \cdot cm^{-3}$) for all treatments indicating that substrates were heavy enough to support plant growth yet not so heavy as to inhibit root growth as well as increase shipping costs for final product.

Recent studies in the U.S. on the effect of growing crops in substrates composed of high percentages of wood-fiber have indicated similar properties to CCR. Wright and Browder (2005) demonstrated that with proper nutrition and irrigation, ground pine logs (including bark) offer potential as a container substrate when compared to PB. Their study reported that pine wood chips provided acceptable CC (48.6%), AS (40%; high but could be reduced by inclusion of more small particles), and water drainage if the wood chips were ground finely (0.5 mm).

Substrate PSD data (Table 2.2) shows that substrates containing PB had more large particles (> 6.35 mm) than those containing CCR. The 4:1 substrate treatments had the lowest amount (65-67%) of medium sized particles (1.0 to 6.35 mm), while the other treatments had 70-76% medium sized particles. Small particles in the substrate contribute to water-holding capacity (Bilderback et al., 2005). Too many small particles will render the substrate water-logged and too few will result in the substrate needing frequent irrigation. The potential exists with CCR to manipulate these parameters for the needs of each crop by processing CCR at different screen sizes, mixing to enhance physical properties, and creating prescription substrates.

Auburn

Substrate EC measurements of ageratum were generally high (2.56 to 3.09 $mS.cm^{-1}$) 1 DAP (recommended range of 1.20 to 2.40 $mS.cm^{-1}$; Cavins et al., 2000) (Table 2.3). Substrate EC may have been high initially due to the substrate treatments being mixed in Poplarville 2 d before being planted in Auburn. The control release fertilizer may have begun to release salts in Auburn before the containers had been planted. At 15 DAP all substrate EC levels except 100% PB (low) were within recommended range. At 30 DAP most treatments had EC measurements within recommended ranges except for 100% PB, which was low (0.70 $mS.cm^{-1}$) and ½-inch CCR:PM (9:1 and 4:1) which had elevated EC levels (2.51 and 3.19 $mS.cm^{-1}$). All substrate pH levels were generally within the recommended pH range (5.5-6.0; Cavins et al., 2000) for the duration of the study.

Ageratum. Leaf chlorophyll content for plants grown in 100% PB, 9:1 PB: PM, and 4:1 CCR: PM were slightly lower than plants grown in 100% ¾-inch CCR (Table 2.4). While these differences were statistically significant, the visual difference was minimal. There were no differences among treatments for plant height, average width, GI or SDW at 30 DAP.

Ageratum tissue nutrient analysis (Table 2.5) revealed high levels of N, B, Fe, Cu, and Zn among all treatments when compared to average levels of ageratum tissue nutrient content (Mills and Jones, 1996). Concentrations of P, K, Ca, Mg, and S were near the survey average. Tissue content of Mn was high in treatments containing CCR and 4:1 PB: PM. No toxicity or deficiency symptoms were observed. Fain and Gilliam (2006) reported increased foliar Mn in vinca (*Catharanthus roseus*) grown in *WholeTree* substrate.

Salvia. There were no differences in leaf chlorophyll content (Table 2.6). Plant height at 30 DAP was greatest in PB treatments. There was no difference among treatments for average plant width at 30 DAP. Growth indices were greatest in 9:1 and 4:1 PB: PM. The lowest GI occurred with salvia grown in CCR: PM combinations. Salvia SDW was the greatest in 4:1 PB: PM (18.7 gm). Tissue nutrient content for salvia (Table 2.7) was within sufficiency ranges for all elements except S, Mn and Zn. Sulfur was low in all treatments. Manganese was high in treatments containing CCR. Zinc was high in all treatments. No toxicity or deficiency symptoms were observed.

Impatiens. Treatments containing PB had less leaf chlorophyll content than the other treatments (Table 2.8). Fain et al. (2006) evaluated *WholeTree* in production of herbaceous greenhouse crops. This study indicated mixed results with leaf chlorophyll content, which was similar for petunia, but marigold and lantana plants had a general trend of an increase in chlorophyll content with an increase in substrate PM content. Plant height was greatest in 4:1 PB: PM (11.4 cm). Average plant width, GI, and SDW followed a similar trend with PB treatments having the greatest growth.

Poplarville

Substrate electrical conductivity measurements were within recommended values of 1.20 to 2.40 $mS.cm^{-1}$ (Cavins et al., 2000) at 1 DAP. At 15 DAP EC in the substrates had fallen below the recommended range except for 9:1 PB: PM, 4:1 PB: PM and 4:1 ¾-inch CCR: PM. At 34 DAP all readings were low (0.26-0.86 $mS.cm^{-1}$).

Substrate leachate pH levels at Poplarville were acceptable 1 DAP (recommended range 5.5-6.0; Cavins et al., 2000), but began to rise slightly at 15 and 34 DAP (6.1 to 6.7). At 15 and 34 DAP treatments containing PB had lower pH levels (range 6.1-6.3) than other treatments (average 6.4-6.7).

Ageratum. No differences were detected in leaf chlorophyll content at 32 DAP (Table 2.4). Plant height, average width and GI were similar for all treatments at 32 DAP. Ageratum grown in 4:1 ¾-inch CCR: PM had greater SDW (19.0 g) than all the other treatments except 100% PB and 9:1 ¾-inch CCR: PM. Similar results were reported by Fain and Gilliam (2006) with annual vinca (*Catharanthus roseus*) grown in *WholeTree* (ground up entire shoot portion of the tree) having similar growth to plants grown in PB. While SDW were 15% greater for plants grown in 100% PB than those grown in *WholeTree* 60 DAP, there were no differences in plant GI.

Ageratum tissue nutrient analysis (Table 2.5) revealed high levels of N, B Cu, and Zn among all treatments (Mills and Jones, 1996). Concentrations of P and K were close to the survey average while Ca, Mg and S were slightly low. Treatments containing CCR had the lowest concentrations of Fe. Manganese concentration was almost double in 100% PB when compared to other treatments which were near the survey average published by Milles and Jones (1996). No toxicities or deficiencies were observed for the duration of the study.

Salvia. No differences in leaf chlorophyll content were detected (Table 2.6). Plants grown in 9:1 ½-inch CCR: PM had the greatest height (17.9 cm). Average plant width was similar in all treatments except 100% ¾-inch CCR which was slightly smaller. Growth indices showed the least growth in 100% ¾-inch CCR. Results for SDW showed the greatest SDW occurred in combinations of PB: PM. Both of the 100% CCR treatments had the least growth. Tissue nutrient content for salvia (Table 2.7) was within sufficiency ranges for all elements except S which was low. Treatments containing CCR: PM blends had low amounts of K. Manganese was high in 100% PB and 9:1 PB: PM. Zinc was only slightly above the sufficiency range for a few treatments. No toxicity or deficiency symptoms were observed.

Impatiens. No differences among treatments for leaf chlorophyll content were recorded (Table 2.8). Plant height was greatest for 4:1 PB: PM. There were no differences among impatiens plants for average plant width or GI. The treatment producing the highest SDW was 4:1 PB: PM.

Substrate shrinkage occurs when the substrate decomposes due to microbial activity in the root zone which compacts the remaining material (Kenna and Whitcomb, 1985; Robbins, 2002). Containers having reduced capacity for root growth are not as marketable as those with full containers. In this study, no differences among treatments were observed for substrate shrinkage at either location (data not shown). For each species, root ratings were similar among all treatments (data not shown). Root growth of all plants was uniform over the entire rootball. There were no odors or diseases observed with any of the substrate blends in this study. Wright and Browder (2005) reported that substrate analysis of pine wood chips indicated there were no toxic nutrient levels associated with the material and the pH (5.7) was acceptable for plant culture. Also in this study by Wright and Browder (2005), no apparent shrinkage due to decomposition over the course of the test was reported. Root growth was more extensive in ground pine wood chips than in aged milled PB (Wright and Browder, 2005).

Results of this study concur with results obtained by Wright and Browder (2005) and Fain et al. (2006) where annuals grown in wood-based substrates can have comparable growth to plants grown in traditional PB substrates. Ageratum and salvia plants had fewer detectable differences among treatments than impatiens which indicated that further studies with more species is warranted. Differences among impatiens were attributed to using different impatiens cultivars. Treatments composed of 100% CCR generally had excessive air space which lowered water holding capacity (Table 2.1), possibly explaining some of the reduced growth measurements (Tables 2.4, 2.6, and 2.8). A smaller screen-sized material may be more suitable for greenhouse production of annual plants if CCR is used alone. Blending CCR and PB with PM increased water holding capacity as the percentage of PM increased (Table 2.1). In general, when PM was a component, plant growth was similar regardless of PB or CCR rate. These results confirm that freshly processed CCR is a promising alternative substrate component or PB replacement for producing greenhouse-grown annuals in large containers.

Literature cited

Bilderback, T.E., W.C. Fonteno, and D.R. Johnson. 1982. Physical properties of media composed of peanut hulls, pine bark and peat moss and their effects on azalea growth. J. Amer. Soc. Hort. Sci. 107:522-525.

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

Boertje, G.A. 1984. Physical laboratory analysis of potting composts. Acta Hort. 150:47-50.

Cavins, T.J., B.E. Whipker, W.C. Fonteno, B. Harden, I. McCall, and J.L. Gibson. 2000. Monitoring and managing pH and EC using the PourThru extraction method. N.C. State Univ. Coop. Ext. Hort. Info. Leaflet 590.

Fain, G.B., C.H. Gilliam, J.L. Sibley, and C.R. Boyer. 2006. Evaluation of an alternative, sustainable substrate for use in greenhouse crops. Proc. Southern Nur. Assn. Res. Conf. 51:651-654.

Fain, G.B and C.H. Gilliam. 2006. Physical properties of media composed of ground whole pine trees and their effects on vinca (*Catharanthus roseus*) growth. HortScience 40:510. Abstr.

Jenkins, J.R. and W.M. Jarrell. 1989. Predicting physical and chemical properties of container mixtures. HortScience 24:292-295.

Kenna, S.W. and C.E. Whitcomb. 1985. Hardwood chips as an alternative medium for container plant production. HortScience 20:867-869.

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.

Mills, H.A. and J.B. Jones. 1996. Plant analysis handbook II. MicroMacro Publishing. Athens, Ga.

Robbins, J.A. 2002. Effect of media type on the growth of container-grown woody ornamentals. Proc. Southern Nurs. Assoc. Res. Conf. 47:67-72.

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

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

Yeager, T., T. Bilderback, D. Fare, C. Gilliam, J. Lea-Cox, A. Niemiera, J. Ruter, K. Tilt, S. Warren, T. Whitwell, and R. Wright. 2007. Best management practices: Guide for producing nursery crops. 2nd ed. Southern Nursery Assn., Atlanta, Ga.

Table 2.1. Physical properties of pine bark- and clean chip residual-based substrates[z].

Substrates[y]	Air space[x]	Container capacity[w]	Total porosity[v]	Bulk density ($g{\cdot}cm^{-3}$)[u]
		(% vol)		
100% PB	36 d[t]	49 c	85 bc	0.17 c
100% ¾-inch CCR	47 a	38 f	85 bc	0.18 b
100% ½-inch CCR	44 b	42 e	86 ab	0.18 b
9:1 PB:PM	34 de	51 b	85 bc	0.17 c
9:1 ¾-inch CCR:PM	39 c	45 d	84 c	0.19 a
9:1 ½-inch CCR:PM	39 c	46 d	85 ab	0.18 ab
4:1 PB:PM	31 e	56 a	87 a	0.16 d
4:1 ¾-inch CCR:PM	33 de	53 b	86 ab	0.18 b
4:1 ½-inch CCR:PM	31 e	55 a	86 ab	0.18 b

[z] Analysis performed using the North Carolina State University porometer.

[y] Treatments were: PB = pine bark, CCR = clean chip residual (1 inch = 2.54 cm), PM = sphagnum peat moss.

[x] Air space is volume of water drained from the sample / volume of the sample.

[w] Container capacity is (wet wt - oven dry wt) / volume of the sample.

[v] Total porosity is container capacity + air space.

[u] Bulk density after forced-air drying at 105°C (221.0 °F) for 48 h ($1\ g \cdot cm^{-3} = 62.4274\ lb/ft^3$).

[t] Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests ($\alpha = 0.05$, n = 3).

Table 2.2. Particle size analysis of pine bark (PB)- and clean chip residual (CCR)-based substrates.

U.S. standard sieve no.	Sieve opening (mm)[z]	100% PB[y]	100% 3/4-inch CCR	100% 1/2-inch CCR	9:1 PB:PM	9:1 ¾-inch CCR:PM	9:1 ½-inch CCR:PM	4:1 PB:PM	4:1 ¾-inch CCR:PM	4:1 ½-inch CCR:PM
1/2	12.50	1.7 b[x]	0.1 d	0.0 d	3.3 a	0.6 cd	0.0 d	1.4 bc	0.3 d	0.0 d
3/8	9.50	5.1 a	1.0 b	0.0 b	5.9 a	1.2 b	0.0 b	5.2 a	1.4 b	0.0 b
1/4	6.35	14.4 a	7.9 c	2.7 e	14.3 a	7.0 cd	3.7 e	12.2 b	5.5 d	2.9 e
6	3.35	25.7 a	25.3 a	23.6 abc	24.9 ab	24.4 abc	22.5 bcd	22.3 cd	24.4 abc	21.0 d
8	2.36	12.8 f	16.9 d	20.1 a	12.4 f	16.2 e	19.2 b	11.7 g	15.4 e	17.7 c
10	2.00	4.6 de	7.8 ab	8.2 a	4.2 e	6.1 bcd	7.4 abc	4.2 e	5.8 cde	7.3 abc
14	1.40	9.3 de	11.7 ab	12.4 a	8.7 de	10.1 bcd	11.9 a	8.3 e	10.0 cd	11.3 abc
18	1.00	7.2 ab	5.9 c	7.4 a	7.1 ab	6.0 c	6.8 b	7.1 ab	6.0 c	7.0 ab
35	0.50	11.0 bc	7.7 g	9.3 ef	11.6 b	8.9 f	10.0 d	15.0 a	9.9 de	10.8 c
60	0.25	4.9 f	6.3 e	7.2 d	4.8 f	8.1 c	8.3 bc	8.7 b	9.5 a	9.8 a
140	0.11	2.3 f	6.6 d	6.8 d	2.0 f	8.2 b	7.5 c	3.2 e	8.8 a	9.1 a
pan	0.00	1.0 d	2.8 abc	2.3 c	0.8 d	3.2 a	2.7 bc	0.7 d	3.0 ab	3.1 ab

[z] 1 mm = 0.0394 inch.

[y] Treatments were: PB = pine bark, CCR = clean chip residual (1 inch = 2.54 cm), PM = sphagnum peat moss.

[x] Percent weight of sample collected on each screen, means within row followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests ($\alpha = 0.05$, $n = 3$).

Table 2.3. Substrate electrical conductivity (EC) and pH for pine bark and clean chip residual-based substrates in a greenhouse container study (ageratum).

Substrate[z]	Auburn, AL						Poplarville, MS					
	1 DAP[y]		15 DAP		30 DAP		1 DAP		15 DAP		34 DAP	
	EC[x]	pH[w]	EC	pH	EC	pH	EC	pH	EC	pH	EC	pH
100% PB	2.96 abc[v]	5.0 b	1.08 e	6.1 ns[u]	0.70 c	6.2 a	2.04 ns	5.7 cd	1.08 c	6.2 ef	0.31 c	6.4 b
100% ¾-inch CCR	2.56 d	5.5 a	1.45 de	6.1	1.55 bc	5.9 abc	1.76	6.0 a	0.85 c	6.5 ab	0.32 bc	6.7 a
100% ½-inch CCR	2.71 cd	5.2 ab	1.87 cd	6.1	1.58 bc	6.0 ab	1.72	5.9 a	1.04 c	6.5 a	0.40 bc	6.7 a
9:1 PB:PM	3.06 ab	5.5 a	1.52 de	6.0	1.57 bc	5.7 bcd	2.22	5.6 de	1.42 b	6.1 f	0.55 b	6.3 b
9:1 ¾-inch CCR:PM	2.74 bcd	5.3 ab	2.16 bc	6.1	1.85 b	5.8 bc	1.62	5.9 ab	0.99 c	6.4 bc	0.26 c	6.7 a
9:1 ½-inch CCR:PM	2.86 abcd	5.2 ab	2.28 bc	6.0	2.51 ab	5.6 cde	1.71	5.8 bc	0.91 c	6.4 b	0.30 c	6.7 a
4:1 PB:PM	3.09 a	5.1 b	1.67 d	5.9	1.79 bc	5.6 bcde	2.20	5.4 e	1.77 a	6.0 g	0.86 a	6.1 c
4:1 ¾-inch CCR:PM	2.94 abc	5.3 ab	2.87 a	6.0	2.13 ab	5.4 de	2.00	5.9 abc	1.42 b	6.3 cd	0.32 bc	6.7 a
4:1 ½-inch CCR:PM	2.58 d	5.1 b	2.60 ab	5.8	3.19 a	5.3 e	2.00	5.7 cd	1.17 bc	6.3 de	0.37 bc	6.7 a

[z] Treatments were: PB = pine bark, CCR = clean chip residual (1 inch = 2.54 cm), PM = sphagnum peat moss.

[y] DAP = days after planting.

[x] EC = $mS.cm^{-1}$.

[w] pH = a measure of the activity of hydrogen ions (H+) in a solution and, therefore, its acidity or alkalinity. The pH value is a number without units, between 0 and 14, that indicates whether a solution is acidic (pH 0-7), alkaline (pH 7-14) or neutral (pH 7).

[v] Means within column followed bythe same letter are not significantly different based on Waller-Duncan k ratio t tests (α =0.05, n = 4).

[u] ns indicates that means are not significantly different.

Table 2.4. Effects of pine bark and clean chip residual-based substrates on growth of *Ageratum houstionianum* 'Blue Hawaii'.

			Plant growth							
	Leaf chlorophyll content[z]		Auburn, AL 30 DAP			Poplarville, MS 32 DAP			Shoot dry wt (g)	
Substrate[x]	Auburn, AL 30 DAP[w]	Poplarville, MS 32 DAP	Height	Average width (cm)	Growth indices[y]	Height	Average width (cm)	Growth indices	Auburn, AL 41 DAP	Poplarville, MS 42 DAP
100% PB	35.2 b[v]	36.4 ns[u]	12.4 ns	20.5 ns	17.8 ns	13.4 ns	25.7 ns	21.6 ns	10.4 ns	15.9 ab
100% ¾-inch CCR	39.6 a	34.6	12.0	18.9	16.5	12.6	24.9	21.0	7.9	14.1 b
100% ½-inch CCR	37.4 ab	33.6	12.3	19.5	17.1	13.1	24.9	21.0	8.8	12.5 b
9:1 PB:PM	34.9 b	37.9	11.1	19.9	17	13.4	25.2	21.3	9.2	13.5 b
9:1 ¾-inch CCR:PM	36.6 ab	38.1	11.1	18.5	16.1	15.3	26.1	22.5	8.4	15.3 ab
9:1 ½-inch CCR:PM	37.3 ab	38.5	12.0	20.3	17.5	13.8	26.2	22.0	9.7	14.0 b
4:1 PB:PM	36.5 ab	36.1	12.0	19.1	16.7	13.4	24.6	21.0	9.1	13.3 b
4:1 ¾-inch CCR:PM	35.4 b	33.5	11.7	19.1	16.7	14.1	27.4	23.0	8.7	19.0 a
4:1 ½-inch CCR:PM	36.1 b	34.9	11.6	18	15.8	14.0	25.9	21.9	7.8	13.7 b

[z] Leaf chlorophyll content quantified using a SPAD-502 Chlorophyll Meter (Minolta Camera Co., Ramsey, NJ) (average of five leaves per plant).

[y] Growth indices [(height + width1 + width2)/3] presented in centimeters (1 cm = 0.3937 inch) and shoot dry weight presented in grams (1 g = 0.0353 oz).

[x] Treatments were: PB = pine bark, CCR = clean chip residual (1 inch = 2.54 cm), PM = sphagnum peat moss.

[w] DAP = days after planting.

[v] Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests (α =0.05).

[u] ns indicates that means are not significantly different.

Table 2.5. Tissue nutrient content of *Ageratum houstonianum* 'Blue Hawaii' grown in pine bark and clean chip residual-based substrates.

	Tissue nutrient content[z]										
Substrates[x]	N[y] (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	B (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)
						Auburn, AL					
100% PB	3.5 d[w]	0.36 ns[u]	3.4 a	2.7 ns	1.9 d	0.71 ns	53 ns	1465 d	393 d	23 cd	228 ns
100% ¾-inch CCR	4.2 a	0.36	2.0 cd	3.3	2.2 bc	0.92	52	861 e	1094 b	36 a	243
100% ½-inch CCR	4.1 ab	0.29	2.5 bcd	3.1	2.1 cd	0.79	51	1100 e	814 c	29 bc	228
9:1 PB:PM	3.7 bcd	0.37	3.0 ab	3.1	2.2 bc	0.59	65	2062 bc	476 d	19 d	250
9:1 ¾-inch CCR:PM	4.0 abc	0.34	1.8 d	3.4	2.4 ab	0.84	59	1731 cd	1170 b	28 bc	256
9:1 ½-inch CCR:PM	4.0 abc	0.32	2.7 abc	3.2	2.2 bc	0.78	63	1864 c	1100 b	30 ab	270
4:1 PB:PEAT	3.5 cd	0.41	2.8 abc	3.1	2.3 bc	0.64	69	2426 a	725 c	23 cd	274
4:1 ¾-inch CCR:PM	3.6 bcd	0.33	2.3 bcd	3.3	2.4 ab	0.68	72	2560 a	1346 a	23 cd	257
4:1 ½-inch CCR:PM	3.6 cd	0.31	2.1 cd	3.4	2.6 a	0.78	64	2364 ab	1226 ab	30 ab	251
						Poplarville, MS					
100% PB	5.4 ns	0.41 ab	2.8 c	2.2 ns	1.2 a	0.52 ns	95 ns	862 ns	877 a	17 ns	154 ns
100% ¾-inch CCR	5.3	0.26 d	2.8 c	1.6	0.9 b	0.47	83	291	365 b	20	131
100% ½-inch CCR	5.8	0.37 bc	3.1 bc	2.2	1.2 a	0.61	94	263	354 b	18	127
9:1 PB:PM	5.5	0.42 ab	3.1 bc	2.3	1.3 a	0.57	93	640	440 b	15	167
9:1 ¾-inch CCR:PM	5.1	0.32 cd	3.9 a	2.0	1.1 a	0.53	90	532	382 b	16	149
9:1 ½-inch CCR:PM	5.2	0.37 bc	3.6 ab	1.9	1.1 a	0.53	92	357	391 b	17	156
4:1 PB:PM	5.9	0.45 a	3.2 abc	2.5	1.3 a	0.54	91	676	493 b	15	144
4:1 ¾-inch CCR:PM	5.1	0.27 d	3.4 abc	2.3	1.2 a	0.74	88	405	371 b	16	129
4:1 ½-inch CCR:PM	5.5	0.36 bc	3.4 abc	2.1	1.1 a	0.58	90	282	281 b	14	112
Survey average[v]	*2.82*	*0.42*	*2.10*	*3.61*	*2.19*	*0.73*	*33*	*428*	*474*	*6*	*107*

[z] Tissue analysis performed on 50 recently mature leaves per plant.

[y] Nutrients: N = nitrogen, P = phosphorus, K = potassium, Ca = calcium, Mg = magnesium, S = sulfur, B = boron, Fe = iron, Mn = manganese, Cu = copper, Zn = zinc. 1 ppm = $mg.kg^{-1}$.

[x] Treatments were: PB = pine bark, CCR = clean chip residual (1 inch = 2.54 cm), PM = sphagnum peat moss.

[w] Means within column and location followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests ($\alpha = 0.05$, n = 4).

[v] Survey average published by Mills and Jones (1996).

[u] ns indicates that means are not significantly different.

Table 2.6. Effects of pine bark and clean chip residual-based substrates on growth of *Salvia* x *superba* 'Vista Purple'.

			Plant growth							
	Leaf chlorophyll content[z]		Auburn, AL 30 DAP			Poplarville, MS 32 DAP			Shoot dry wt (g)	
Substrate[x]	**Auburn, AL 30 DAP[w]**	**Poplarville, MS 32 DAP**	**Height**	**Average width (cm)**	**Growth indices[y]**	**Height**	**Average width (cm)**	**Growth indices**	**Auburn, AL 41 DAP**	**Poplarville, MS 41 DAP**
100% PB	53.1 ns[vu]	50.9 ns	16.3 a	28.2 ns	24.2 ab	16.6 abcd	32.3 a	27.1 a	16.0 bcd	14.9 bc
100% ¾-inch CCR	54.0	48.0	14.0 bc	26.2	22.1 bc	15.1 d	28.4 b	24.0 b	13.7 d	11.7 d
100% ½-inch CCR	54.1	50.8	14.4 abc	26.8	22.7 abc	16.3 bcd	30.2 ab	25.5 ab	14.0 d	12.8 cd
9:1 PB:PM	55.3	51.5	15.4 ab	29.4	24.8 a	17.5 ab	33.6 a	28.2 a	17.6 ab	17.9 a
9:1 ¾-inch CCR:PM	54.9	49.8	13.0 c	25.3	21.2 c	17.6 ab	31.7 ab	27.0 a	14.0 d	14.7 bc
9:1 ½-inch CCR:PM	54.0	51.9	13.9 bc	25.6	21.7 bc	17.9 a	31.6 ab	27.0 a	14.7 cd	14.5 bc
4:1 PB:PM	54.6	48.6	16.3 a	29.4	25.0 a	15.8 cd	32.5 a	26.9 a	18.7 a	17.5 a
4:1 ¾-inch CCR:PM	54.3	49.2	13.9 bc	25.4	21.5 c	17.3 abc	33.8 a	28.3 a	16.9 abc	16.2 ab
4:1 ½-inch CCR:PM	53.7	48.4	14.3 abc	25.9	22.0 bc	16.7 abcd	31.5 ab	26.6 ab	16.9 abc	16.1 ab

[z] Leaf chlorophyll content quantified using a SPAD-502 Chlorophyll Meter (Minolta Camera Co., Ramsey, NJ) (average of five leaves per plant).

[y] Growth indices [(height + width1 + width2)/3] presented in centimeters (1 cm = 0.3937 inch) and shoot dry weight presented in grams (1 g = 0.0353 oz).

[x] Treatments were: PB = pine bark, CCR = clean chip residual (1 inch = 2.54 cm), PM = sphagnum peat moss.

[w] DAP = days after planting.

[v] Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests (α =0.05).

[u] ns indicates that means are not significantly different.

Table 2.7. Tissue nutrient content of *Salvia x superba* 'Vista Purple' grown in pine bark and clean chip residual-based substrates.

	Tissue nutrient content[z]										
Substrates[x]	N[y] (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	B (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)
						Auburn, AL					
100% PB	4.5 bc[w]	0.41 a	3.9 ns[u]	1.8 ns	0.67 c	0.45 ns	44 ns	109 abc	194 de	14 bc	192 ns
100% ¾-inch CCR	4.9 abc	0.30 c	4.1	1.8	0.70 c	0.39	41	93 cd	500 c	15 ab	181
100% ½-inch CCR	4.5 bc	0.31 c	4.3	1.8	0.72 c	0.37	43	91 cd	484 c	14 abc	178
9:1 PB:PM	4.3 c	0.42 a	3.6	1.9	0.77 bc	0.43	46	114 ab	130 e	12 c	198
9:1 ¾-inch CCR:PM	4.9 abc	0.34 bc	4.4	2.1	0.79 abc	0.37	49	92 cd	529 bc	15 ab	192
9:1 ½-inch CCR:PM	5.4 a	0.40 ab	4.3	2.2	0.89 a	0.42	48	108 abcd	721 a	17 a	213
4:1 PB:PM	4.6 bc	0.43 a	3.7	2.0	0.85 ab	0.46	50	126 a	253 d	15 abc	238
4:1 ¾-inch CCR:PM	5.2 ab	0.31 c	4.3	1.9	0.86 ab	0.37	43	101 bcd	552 bc	16 ab	213
4:1 ½-inch CCR:PM	4.8 abc	0.30 c	4.0	2.0	0.90 a	0.38	45	90 d	634 ab	14 abc	194
						Poplarville, MS					
100% PB	4.2 ab	0.42 a	3.1 ns	1.3 ns	0.59 c	0.33 ns	44 ns	96 ab	377 a	10 ns	117 ns
100% ¾-inch CCR	4.1 abc	0.34 b	3.3	1.3	0.61 bc	0.32	45	85 abcd	276 bc	10	111
100% ½-inch CCR	4.1 abc	0.35 b	3.5	1.4	0.69 ab	0.32	45	95 abc	255 bc	10	121
9:1 PB:PM	4.5 a	0.36 b	3.2	1.4	0.63 abc	0.33	42	96 ab	306 b	9.2	118
9:1 ¾-inch CCR:PM	3.6 cd	0.26 c	3.2	1.3	0.60 c	0.34	46	78 cd	239 c	9.0	120
9:1 ½-inch CCR:PM	3.4 d	0.24 c	3.0	1.3	0.57 c	0.30	44	72 d	221 c	8.4	105
4:1 PB:PM	4.5 a	0.35 b	3.1	1.5	0.70 a	0.30	42	97 a	283 bc	8.0	112
4:1 ¾-inch CCR:PM	3.8 bcd	0.27 c	3.1	1.3	0.63 abc	0.31	45	79 bcd	237 c	8.3	119
4:1 ½-inch CCR:PM	3.5 cd	0.23 c	2.9	1.3	0.59 c	0.31	39	78 cd	227 c	8.2	107
Sufficiency ranges[v]	*2.38-5.61*	*0.30-1.24*	*2.90-5.86*	*1.00-2.50*	*0.25-0.86*	*0.73*	*25-75*	*60-300*	*30-284*	*7-35*	*25-115*

[z] Tissue analysis performed on 50 recently mature leaves per plant.

[y] Nutrients: N = nitrogen, P = phosphorus, K = potassium, Ca = calcium, Mg = magnesium, S = sulfur, B = boron, Fe = iron, Mn = manganese, Cu = copper, Zn = zinc. 1 ppm = mg.kg-1.

[x] Treatments were: PB = pine bark, CCR = clean chip residual (1 inch = 2.54 cm), PM = sphagnum peat moss.

[w] Means within column and location followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests (α = 0.05, n = 4).

[v] Sufficency ranges for *Salvia splenden* published by Mills and Jones (1996).

[u] ns indicates that means are not significantly different.

Table 2.8. Effects of pine bark and clean chip residual-based substrates on growth of *Impatiens walleriana* 'Coral' (Auburn) and 'White' (Poplarville).

	Leaf chlorophyll content[z]		Plant growth						Shoot dry wt (g)	
			Auburn, AL 30 DAP			Poplarville, MS 32 DAP				
Substrate[x]	Auburn, AL 30 DAP[w]	Poplarville, MS 32 DAP	Height	Average width (cm)	Growth indices[y]	Height	Average width (cm)	Growth indices	Auburn, AL 41 DAP	Poplarville, MS 43 DAP
100% PB	52.5 c[v]	56.4 ns[u]	10.7 ab	26.6 a	21.3 a	10.0 b	29.1 ns	22.7 ns	8.2 a	8.9 cd
100% ¾-inch CCR	57.5 ab	54.2	8.4 c	17.1 d	14.2 c	9.9 b	30.5	23.6	3.8 bc	8.2 d
100% ½-inch CCR	55.4 bc	56.7	9.6 bc	21.9 bc	17.8 b	10.4 ab	30.2	23.6	5.3 c	10.4 bcd
9:1 PB:PM	52.4 c	54.6	11.0 ab	27.5 a	22.0 a	10.3 b	30.8	24.0	7.9 a	13.3 ab
9:1 ¾-inch CCR:PM	58.5 ab	58.0	8.9 c	20.1 cd	16.3 bc	10.3 b	29.6	23.1	4.9 bc	10.7 abcd
9:1 ½-inch CCR:PM	59.8 a	56.3	8.7 c	19.2 cd	15.7 bc	10.3 b	30.7	23.8	4.7 bc	10.4 bcd
4:1 PB:PM	52.8 c	52.7	11.4 a	26.1 ab	21.2 a	12.3 a	33.7	26.6	7.8 a	13.5 a
4:1 ¾-inch CCR:PM	59.4 ab	52.4	8.9 c	21.7 bc	17.4 b	11.1 ab	30.7	24.2	5.6 b	9.5 cd
4:1 ½-inch CCR:PM	60.1 a	57.2	9.0 c	20.9 cd	16.9 bc	11.3 ab	31.5	24.7	4.1 bc	11.6 abc

[z] Leaf chlorophyll content quantified using a SPAD-502 Chlorophyll Meter (Minolta Camera Co., Ramsey, NJ) (average of five leaves per plant).

[y] Growth indices [(height + width1 + width2)/3] presented in centimeters (1 cm = 0.3937 inch) and shoot dry weight presented in grams (1 g = 0.0353 oz).

[x] Treatments were: PB = pine bark, CCR = clean chip residual (1 inch = 2.54 cm), PM = sphagnum peat moss.

[w] DAP = days after planting.

[v] Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests ($\alpha = 0.05$).

[u] ns indicates that means are not significantly different.

CHAPTER III

Clean Chip Residual as a Substrate for Perennial Nursery Crop Production

Abstract

Pine bark (PB) for horticultural uses is becoming less available and as a result, there is a need to develop alternative substrates for continued profitability of the nursery industry. This study, conducted at Poplarville, MS and Auburn, AL, evaluated the growth of eight perennial species in a substrate composed of a pulpwood harvesting by-product called clean chip residual (CCR) which contains approximately 50% wood fiber. Two CCR particle sizes were used alone or amended with peat moss (PM) (4:1 by volume) and compared with control treatments PB and PB:PM. Substrates composed of 100% PB or 100% CCR had high air space (AS) and low container capacity (CC) which resulted in less available water to plants. Addition of PM lowered AS and increased CC. Leaf chlorophyll content was similar among all treatments for 3 of 4 species evaluated at 100 days after planting. Growth indices were similar at Poplarville for 6 of 8 species and for 3 of 7 species at Auburn. Shoot dry weight was greater in substrates amended with PM. Results of this study indicate that acceptable growth of perennial plants can be obtained in substrates composed of CCR when compared to PB and PB amended with PM.

Introduction

In recent years, pine bark (PB) supplies have begun to decline and the cost of shipping peat moss (PM) from Canada has increased rapidly. Pursuit of local/regional, sustainable substrate resources have become paramount. One substrate option is clean chip residual (CCR), a forest by-product of the pulp industry. Clean chip residual contains approximately 50% wood fiber, 40% bark and 10% needles. Research evaluating fresh CCR as a growth substrate for nursery production is ongoing. Clean chip residual can be used in a fresh state and is a regionally available resource in the Southeastern U.S. Currently, CCR is not being marketed to the horticultural industries, but instead is generally left on-site following timber harvest due to lack of a market. If CCR can be established as a container-grown plant substrate it could reduce substrate costs for growers and provide an alternative market for forestry loggers and landowners.

Aged PB used alone or amended with sand or PM has been the primary substrate used in container nurseries since the 1960's. Unfortunately, availability of PB is declining due to reduced domestic forestry production, an increase in in-field harvesting, increased importation of logs (no bark), and use of PB as a fuel source (Lu et al., 2006). It is important to explore alternatives to the rapidly declining resource of PB as a substrate. Potential options must be readily available, sustainable, economical, pest-free, and easily processed.

A new trend in harvesting pine trees is mobile in-field chipping operations. Whole tree in-field harvesting equipment is used to process trees into 'clean chips' to be sent to pulp mills. This process occurs throughout the pine plantation being harvested, leaving a by-product residual material composed of about 50% wood, 40% bark and 10% needles (about 25% of the site biomass). This by-product, ‘clean chip residual’ (CCR), is either sold for boiler fuel, or more commonly, spread back across the harvested area. If the processed product is sold for boiler fuel the approximate cost was $3-4 per cubic yard in Alabama in 2005 (Castleberry Logging, Inc., personal communication). In-field harvesting operations are increasing and are located across the Southeast U.S. where several million acres are currently in pine production. Clean chip residual has potential to provide a locally available, sustainable and economical substrate to meet the continuing needs of the nursery industry.

One concern among nursery producers about CCR is the increased wood content compared to the traditionally used PB substrate. A recent study by Wright and Browder (2005) reported that a predominantly wood-fiber substrate could be used successfully for nursery crop production with proper nutrition and irrigation. Studies by Fain et al. (2006a) and Boyer et al. (2006a) successfully used substrates composed of whole pine trees (*WholeTree*) to produce container-grown nursery crops. Wood percentage in *WholeTree* substrates ranges from 75-85%. Clean chip residual was previously tested as a growth substrate for greenhouse-grown annuals (Boyer et al., 2006b). Annuals produced in CCR were similar in size to those grown in PB alone. In addition, several 100% wood-fiber products have been used in Europe in vegetable production (Gruda and Schnitzler, 2001). Gruda and Schnitzler (2001) evaluated physical properties of wood fiber substrates and observed that the material had high amounts of air space, necessitating more frequent watering. A subsequent study by Gruda and Schnitzler (2003) reported wood fiber substrates had a similar volume weight and total pore space as PM substitutes, but lower water retention. Wood fiber substrates evaluated in the Gruda and Schnitzler studies (2001, 2003) were composed of pure, untreated spruce wood chipping with little bark which was a by-product of the woodworking industry. The chips were shredded under frictional pressure, and a nitrogen (N)-source was added in an attempt to avoid N-immobilization. These studies suggest that having a larger portion of wood in the substrate may be acceptable for producing horticultural crops.

Clean chip residual has been evaluated for use as a growth substrate for greenhouse-grown annuals (Boyer et al., 2006b), however, no studies have evaluated the potential of CCR for production of container-grown perennials. The objective of this work was to evaluate fresh CCR as a PB replacement substrate for outdoor cultivation of container-grown perennial crops.

Materials and methods

Clean chip residual used in this study was obtained from a 10-year-old pine plantation near Evergreen, AL on 1 December 2005. A Loblolly pine (*Pinus taeda* L.) plantation was being thinned and processed for clean chips using a total tree harvester (Peterson DDC-5000-G Portable Chip Plant, Peterson Pacific Corp., Eugene, OR). Further processing occurred through a horizontal grinder with 4-inch (10.2 cm) screens (Peterson 4700B heavy duty grinder, Peterson Pacific Corp., Eugene, OR), and then processed again through a swinging hammer mill (No. 30; C.S. Bell, Tifton, OH) to pass either a 1.9 cm (0.75 in) or 1.9 cm (0.50 in) screen on 29 March 2006. These two CCR particle sizes were used alone or blended 4:1 (v:v) with PM and compared to standard controls of PB or 4:1 PB:PM (Table 3.1).

These studies were initiated at two locations: USDA-ARS Southern Horticultural Laboratory, Poplarville, MS (30 March 2006) and at Paterson Greenhouse, Auburn University, Auburn, AL (2 June 2006). Each substrate was pre-plant incorporated with 8.3 kg/m^3 (14 lb/yd^3) 18N–2.6P–9.9K (18-6-12) Polyon® (Harrell's Fertilizer, Inc., Sylacauga, AL) control release fertilizer (9 month); 3.0 kg/m^3 (5 lb/yd^3) dolomitic limestone and 0.9 kg/m^3 (1.5 lb/yd^3) Micromax® (The Scotts Company, Marysville, OH). Nine perennial species, *Buddleia davidii* 'Pink Delight', *Gaura lindheimeri* 'Siskiyou Pink', *Coreopsis grandiflora* 'Early Sunrise' (Poplarville only), *Coreopsis rosea* 'Sweet Dreams' (Auburn only), *Verbena canadensis* 'Homestead Purple', *Scabiosa columbaria* 'Butterfly Blue', *Dianthus gratianopolitanus* 'Firewitch', *Rosemarinus officinalis* 'Irene', and *Salvia guaranitica* 'Black and Blue' (Poplarville only), were transplanted from 36-cell flats into #1 containers, placed outdoors on a gravel container pad and overhead irrigated twice daily (0.5 in total). Water quality between locations was similar. Irrigation water pH at Poplarville was 6.2, electrical conductivity (EC) (mmhos/cm) was 0.1 and alkalinity (HCO_3^- mg/L) was 41. Irrigation water pH at Auburn was 6.5 with an EC of 0.2 (mmhos/cm) and alkalinity (HCO_3^- mg/L) of 80. Plants were arranged by species in a randomized complete block with eight single plant replications.

Substrates were analyzed for particle size distribution (PSD) 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 (Ro-Tap RX-29, W.S. Tyler, Mentor, OH) sieve shaker (278 oscillations/min, 159 taps/min). Substrate air space (AS), container capacity (CC), and total porosity (TP) were determined following procedures described by Bilderback et al.

(1982). Substrate bulk density (measured in grams per cubic centimeter) was determined from 347.5 cm^3 samples dried in a 105 C (221 F) forced air oven for 48 h. Substrate pH and EC were determined at 1, 15, 30, 60 and 90 days after planting (DAP) using the PourThru technique (Wright, 1986). Media shrinkage (cm below the top of the container) was measured at 7 and 90 DAP. Leaf chlorophyll content was quantified using a SPAD-502 Chlorophyll Meter (Minolta Camera Co., Ramsey, N.J.) at 30, 60 and 90 DAP. Growth indices (GI) [(height + width + perpendicular width) / three (cm)] were recorded at 30, 60 and 90 DAP. Flower counts were conducted at 60 and 90 DAP. Root ratings (percent coverage of the rootball) were conducted at 98 DAP in Auburn. Shoot dry weights (SDW) were recorded at the conclusion of the study (100 DAP) by drying in a forced air oven at 70 C (158 F) for 48 h. Data were analyzed using Waller-Duncan k ratio t tests ($P \leq 0.05$) using a statistical software package (SAS® Institute version 9.1, Cary, NC). Data were analyzed separately for each location.

Results and discussion

Physical properties

Recommended range for container substrate AS is 10-30% (Yeager et al., 2007). All substrates in this study were well above this range including the industry standard 4:1 PB:PM control treatment (38%). Treatments composed of 100% substrate had the highest AS in general (Table 3.1). Container capacity corresponded to the AS numbers in that the 100% substrates had the lowest values (30-32%) while blends with PM had the highest (44-49%; recommended range: 45-65%). Total porosity was slightly high (81-93%) in all substrates (recommended range: 50-85%) though it was highest in the 4:1 CCR:PM substrate (92-93%) and lowest in 100% PB (81%). This is similar to results reported by Wright and Browder (2005) in that substrates composed of 100% PB had the lowest TP (70%) and substrates composed of 100% pine chips (predominantly wood fiber) or a75% pine chip:25% PB blend had greater TP (82-86%). Bulk density was low for all substrates (0.11-0.15 g/cm^3; recommended range is 0.19-0.70 g/cm^3), although no blow-over problems occurred during this test.

Particle size analysis indicated that substrates containing PB or 1.9 cm (0.75 in) CCR had more coarse particles (3.35-12.50 mm) than those substrates composed of 1.9 cm (0.50 in) CCR (Table 3.2). Coarse particles provide aeration to substrates. Medium sized particles (1.00-2.36 mm) were greatest in 100% 1.9 cm (0.50 in) CCR and least in 100% PB, 4:1 PB: PM and 4:1 1.9 cm (0.75 in) CCR:PM. Fine particles (0.00-0.50 mm) were greatest in 4:1 PB:PM, 4:1 1.9 cm (0.50 in) CCR:PM and 100% PB, though 100% PB was not different from 100% 1.9 cm (0.50 in) CCR or 4:1 1.9 cm (0.75 in) CCR:PM. Substrates composed of 100% 1.9 cm (0.75 in) CCR had the least amount of fine particles. Small particles in the substrate contribute to water-holding capacity (Bilderback et al., 2005). Too many small particles will render the substrate water-logged and too few will result in the substrate needing frequent irrigation. Potential exists with CCR to manipulate these parameters for the needs of each crop by processing CCR at different screen sizes, mixing to enhance physical properties, and creating prescription substrates. No differences in substrate shrinkage were detected at either site at the conclusion of the study (data not shown).

pH and EC

Substrate pH at both locations remained within recommended levels of 4.5-6.5 (11) for the duration of the study (Table 3.3). Substrates composed of 4:1 PB:PM tended to have the lowest pH at both locations across most sample dates. Substrates with 100% CCR tended to have highest pH at both locations and most sample dates, though they were acceptable for plant culture. EC levels at Poplarville were slightly high at 15 DAP (0.88-1.20 mS/cm; recommended range: 0.5-1.0 mS/cm). By 32 DAP and for the duration of the study EC levels were below recommended levels (0.09-0.32 mS/cm). At Auburn EC levels were at the high end of the recommended range (0.81-1.11 mS/cm) 1 DAP, but by 14 DAP and through 60 DAP were within acceptable levels. At 91 DAP EC levels had dropped below the recommended level (0.31-0.52 mS/cm). Wright and Browder (2005) reported that EC of a pine chip (predominantly wood fiber) substrate solution was generally lower than that of PB, possibly due to greater leaching with the more porous pine chip. Data presented in the current study differ in that EC was generally similar among treatments at both sites. This is most likely due to the presence of approximately 40% PB in CCR material.

Buddleia at Poplarville

Leaf chlorophyll content was similar at all rating dates (Table 3.4). At 32 DAP GI were smallest for plants in substrates composed of 100% 1.9 cm (0.50 in) and 1.9 cm (0.75 in) CCR, and 4:1 1.9 cm (0.50 in) CCR:PM. Plant growth indices were similar at 64 and 102 DAP among all treatments. At 64 DAP there were no differences in flower count. However, at 102 DAP treatments containing PB had more flowers than other treatments. The least flowering occurred in the 100% CCR treatments and 4:1 1.9 cm

(0.50 in) CCR:PM. Shoot dry weight was greatest with 4:1 PB:PM (58.1 g). Plants with the lowest SDW were in treatments of 100% CCR, though 4:1 CCR:PM treatments were similar. Results from a study by Fain et al. (2006a) reported no differences for flower number and leaf chlorophyll content of buddleia grown in either a 100% PB or 0.95 cm (0.375 in) *WholeTree* (approximately 80% wood fiber) substrate at 90 DAP, however SDW was greater in buddleia plants grown in pine bark than those grown in *WholeTree* substrate.

Buddleia at Auburn

Leaf chlorophyll content at 28 DAP was highest for plants grown in 4:1 CCR:PM, but at 60 and 97 DAP plants in all treatments had similar leaf chlorophyll content (Table 3.4). At 28 DAP plants grown in 4:1 CCR:PM had greater GI than plants grown in other substrates. By 61 DAP plants grown in 4:1 CCR:PM were still the largest. However, at 97 DAP only plants grown in 100% 1.9 cm (0.75 in) CCR were smaller than other treatments though plants grown in 100% PB and 1.9 cm (0.50 in) CCR were similar in GI. Plants grown in treatments containing 4:1 CCR:PM had the most flowers at 63 DAP (average of 9.2). By 97 DAP plants grown in 100% PB and 4:1 1.9 cm (0.50 in) CCR:PM had the most flowers while all other treatments had fewer flowers. The least flowering occurred for plants in the 100% CCR and 4:1 PB:PM treatments. Shoot dry weight at Auburn was greatest with 4:1 1.9 cm (0.50 in) CCR:PM. Plants with the lowest SDW were in 100% CCR treatments. Rootball coverage (percent) at Auburn (98 DAP) was greatest for plants grown in any substrate amended with PM.

Gaura at Poplarville

Growth indices at 64 DAP were greatest for plants in 4:1 PB: PM, though plants in 100% PB and 4:1 1.9 cm (0.75 in) CCR:PM were similar (Table 3.5). By 106 DAP plants grown in 4:1 PB:PM had the most growth. Flower numbers were greatest on plants grown 4:1 PB:PM though 100% PB was similar. Shoot dry weight at 111 DAP was greater for plants in 4:1 PB:PM than all other treatments, which were similar.

Gaura at Auburn

At 61 and 97 DAP GI of plants grown in 100% 1.9 cm (0.75 in) CCR were smaller than all other treatments (Table 3.5). Plants grown in substrates containing combinations of CCR:PM or PB had similar plant GI and SDW. Flower numbers were greatest in treatments containing PM. Plants in treatments with PM or 100% PB had the greatest SDW (29.0-31.8 g) while plants in 100% CCR treatments had the lowest SDW (13.3-18.5 g) at 112 DAP. Rootball coverage was greatest for plants in 4:1 PB:PM (51.3%) while 100% 1.9 cm (0.75 in) CCR had the least rootball coverage (28.1%).

Coreopsis at Poplarville

Coreopsis plants differed between sites due to availability of liners at the time of study initiation. *Coreopsis grandiflora* ‘Early Sunrise’ (Poplarville) had large leaves suitable for leaf chlorophyll content measurement while *Coreopsis rosea* ‘Sweet Dreams’ (Auburn) did not. Leaf chlorophyll content at 32 DAP was greatest for plants in treatments containing PB, however, by 64 and 103 DAP all plants had similar leaf chlorophyll content (Table 3.6). Slight differences in GI occurred at 32 DAP, but at 64 and 103 DAP all plants had similar GI. Flower counts at 64 DAP were least for 100% CCR treatments (2.9-3.0) and greatest for plants grown in 4:1 PB:PM though 100% PB and 4:1 1.9 cm (0.50 in) CCR:PM were similar. Shoot dry weights at 104 DAP were greatest for plants in treatments containing PB and 4:1 1.9 cm (0.50 in) CCR:PM.

Coreopsis at Auburn

Growth indices were greatest with 4:1 PB:PM at 28 DAP, but by 61 DAP most of the other treatments had caught up except 100% CCR treatments (Table 3.6). By 97 DAP there were no differences in GI among treatments. Coreopsis grown in 4:1 PB:PM had significantly more flowers than all other treatments at 63 DAP. Shoot dry weight at 112 DAP was greatest for plants grown in 4:1 PB:PM while all other treatments were similar. Root ratings were greatest for plants grown in PM amended substrates.

Verbena at Poplarville

Growth indices at 32 DAP were greatest in PB treatments (Table 3.7). By 64 DAP there were minor statistical differences (4:1 1.9 cm (0.50 in) CCR:PM being the largest), but at 103 DAP verbena in all treatments had similar GI. Flower counts were greatest in PB treatments at 64 DAP. By 103 DAP verbena plants grown in 4:1 PB:PM still had the greatest number of flowers, but was similar to verbena grown in 100% PB and 100% 1.9 cm (0.50 in) CCR. Shoot dry weight at 110 DAP was greatest for plants grown in 4:1 PB:PM (74.2 g), however 100% PB plants were similar to both 4:1 PB:PM and the remaining treatments.

Verbena at Auburn

Leaf chlorophyll content at 28 DAP was greatest for plants grown in substrates amended with PM, but at 60 DAP there were no differences among treatments (Table 3.7). At 97 DAP there were slight statistical differences among treatments for leaf chlorophyll content where plants grown in 100% 1.9 cm (0.75 in) CCR had the most leaf chlorophyll content (57.9), but were similar to all other treatments except 4:1 PB:PM (51.8). At 28 DAP the greatest GI occurred with plants in 4:1 PB:PM. This trend continued at 61 DAP with plants in the CCR:PM blends being similar to PB:PM. At 97 DAP all verbena had similar GI. Greatest flower numbers at 63 DAP occurred with CCR:PM, but by 97 DAP there were no differences among treatments. Shoot dry weight at 110 DAP was greatest for plants in treatments containing PM. There were no differences in percent rootball coverage at 98 DAP (data not shown).

Scabiosa at Poplarville

There were no differences in GI at 32, 64 or 109 DAP (Table 3.8). Flower counts at 64 DAP were greatest in PB treatments. Shoot dry weight at 110 DAP indicated slight statistical differences among treatments, with those containing 1.3 cm (0.50 in) CCR having less shoot dry weight.

Scabiosa at Auburn

There were no differences in GI at 28 DAP (Table 3.8). By 61 DAP 100% CCR treatments had less GI than plants in the remaining treatments. At 97 DAP the 100% CCR treatments still had smaller GI than plants in other treatments, but the growth gap was less than at 61 DAP. Flower numbers at 63 DAP were greatest for treatments containing PB and 4:1 1.9 cm (0.75 in) CCR:PM, though 4:1 1.9 cm (0.75 in) CCR:PM and 100% PB were similar to all other treatments. There were no differences in SDW at 112 DAP. Root ratings were greatest for plants in 100% 1.3 cm (0.50 in) CCR at 98 DAP (53.8%) and least with 4:1 PB:PM (29.4%).

Dianthus at Poplarville

On all rating dates plants grown in PB had the greatest GI (Table 3.9). Flower numbers at 64 DAP were greater with PB treatments and 4:1 1.9 cm (0.75 in) CCR:PM. Shoot dry weight was greatest in treatments containing PB or 4:1 1.9 cm (0.75 in) CCR:PM.

Dianthus at Auburn

There were no differences in GI at 28 DAP, though by 61 and 97 DAP plants in treatments containing 100% CCR had less growth (Table 3.9). There were no differences in flower number. Shoot dry weight was the least in 100% CCR treatments; all other treatments were similar. Similarly, root ratings in 100% CCR treatments were less than in other treatments.

Rosmarinus at Poplarville

Growth indices at 32 DAP were greatest in PM blends, however by 64 and 109 DAP there were no growth differences (Table 3.10). Shoot dry weight at 111 DAP was greatest in 4:1 PB:PM (61.7 g) while 4:1 1.9 cm (0.75 in) CCR:PM (53.0 g), 4:1 1.3 cm (0.50 in) (0.50 in) (0.50 in) CCR:PM (55.6 g) and 100% PB (56.9 g) were similar.

Rosmarinus at Auburn

Growth indices at 28 DAP were greatest for plants grown in 4:1 1.9 cm (0.75 in) CCR:PM (Table 3.10). By 61 DAP only plants in 100% PB and 100% 1.9 cm (0.75 in) CCR had less growth than plants in other treatments, but by 97 DAP there were no differences among treatments for GI of rosmarinus. Shoot dry weight at 110 DAP was least in 100% 1.9 cm (0.75 in) CCR (21.7 g), however 100% PB (24.3 g) and 4:1 1.3 cm

(0.50 in) (0.50 in) (0.50 in) CCR:PM (28.0 g) were similar. There were no differences in rootball coverage at 98 DAP (data not shown).

Salvia at Poplarville

Salvia was only grown at Poplarville. At 32 DAP leaf chlorophyll content was greatest for salvia in PB treatments (Table 3.11). However, at 64 and 106 DAP there were no differences among treatments. Growth indices at 32 DAP were greatest for plants in PB treatments. By 64 DAP there were minor differences among treatments, but at 106 DAP all plants were similar in GI. There were no differences among treatments for flower number at 64 DAP. Shoot dry weight at 106 DAP was greater for treatments containing PB.

In most cases, plants grown in CCR lagged slightly behind other treatments at early rating dates (60 and 90 DAP) for GI and leaf chlorophyll content. This could potentially be due to early N tie-up in the wood fiber substrates (CCR). Fain et al. (2006b) suggested that an initial N sink in *WholeTree* substrates early in the crop cycle could explain differences in final growth of greenhouse-grown petunia. Data in the current study suggests an initial N tie-up in the crop, however, by mid crop cycle N had become available for plant uptake and before the end of the study had growth comparable to control treatments. Leaf chlorophyll content reflects N status in plant tissue. Data presented here suggests that early N-immobilization is reflected in leaf chlorophyll readings, however, plants overcame the early N barrier in a short time. A study by Wright et al. (2008) evaluated the growth of chrysanthemum under four N rates in order to overcome initial N-immobilization found in a pine tree substrate (100% wood fiber). Results indicated that the pine tree substrate required 100 mg/L^{-1} N more fertilizer than a commercial peat-lite substrate to obtain comparable growth. Future studies will need to evaluate supplemental fertilizer rates in substrates composed of CCR in order to determine whether or not they are required. The current study suggests that supplemental fertilizer may not be necessary as most plants were similar in GI at termination.

For Poplarville, 4:1 PB:PM produced the most plant SDW in 4 of 8 species tested (buddleia, gaura, dianthus and salvia). At Auburn, 4:1 PB:PM produced the most SDW in 2 of 7 species (gaura and coreopsis). At Auburn, PM amended treatments produced similar growth in 5 of 7 species indicating that CCR is an adequate replacement for PB (when combined with PM) for several species of perennial ornamental crops. While minor differences in plant growth were measured, most were not detectable to the human eye when the treatments were de-randomized. It is not likely that consumers would notice a difference among plants grown in any of the treatments evaluated in this study.

Concerns about high wood content substrates being detrimental to plant growth continue to be addressed by results of this study which concur with several other studies. Fain et al. (2008) postulated that N immobilization was not a limiting factor in production of annual vinca in *WholeTree* substrates when using slow release fertilizer. Instead, the differences in annual vinca growth between *WholeTree* and PB was more likely due to differences in substrate physical properties. Substrates composed of 100% PB or CCR had high AS and low CC which results in less available water to plants. Addition of PM lowered AS and increased CC. While the addition of PM may not be practical for outdoor container production of perennial crops due to high cost, it is promising that many species performed adequately in substrates composed of 100% PB or CCR. In this study, perennial crops produced in a traditional outdoor, overhead irrigated system performed well whether grown in PB or CCR-based substrates when mixed with PM. However, each grower should conduct their own trial with CCR to determine performance at their nursery. While the results of the perennial species tested are positive, more species must be evaluated for growth in alternative substrates in order to continue substantiation of plant growth in wood-based substrates.

Literature cited

Bilderback, T.E., W.C. Fonteno, and D.R. Johnson. 1982. Physical properties of media composed of peanut hulls, pine bark and peat moss and their effects on azalea growth. J. Amer. Soc. Hort. Sci. 107:522-525.

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

Boyer, C.R., G.B. Fain, C.H. Gilliam, T.V. Gallagher, H.A. Torbert, and J.L. Sibley. 2006a. Evaluation of freshly chipped pine tree substrate for container-grown *Lantana camara*. HortScience 41:1027. Abstr.

Boyer, C.R., G.B. Fain, C.H. Gilliam, T.V. Gallagher, H.A. Torbert, and J.L. Sibley. 2006b. Alternative substrates for bedding plants. Proc. Southern Nurs. Assoc. Res. Conf. 51:22-25.

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

Fain, G.B., C.H. Gilliam, J.L. Sibley, and C.R. Boyer. 2006b. Evaluation of an alternative, sustainable substrate for use in greenhouse crops. Proc. Southern Nurs. Assoc. Res. Conf. 51:651-654.

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

Gruda, N. and W.H. Schnitzler. 2001. Physical properties of wood fiber substrates and their effect on growth of lettuce seedlings (*Lactuca sativa* L. var. *capitata* L.) Acta Hort. 548:415-423.

Gruda, N. and W.H. Schnitzler. 2003. Suitability of wood fiber substrate for production of vegetable transplants II. The effect of wood fiber substrates and their volume weights on the growth of tomato transplants. Scientia Hort. 100:333-340.

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.

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

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

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.

Yeager, T., T. Bilderback, D. Fare, C. Gilliam, J. Lea-Cox, A. Niemiera, J. Ruter, K. Tilt, S. Warren, T. Whitwell, and R. Wright. 2007. Best management practices: Guide for producing nursery crops. 2nd ed. Southern Nursery Assn., Atlanta, Ga.

Table 3.1. Physical properties of pine bark-based and clean chip residual-based substrates (Auburn).[z]

Substrate[y]	Air space[x]	Container capacity[w]	Total porosity[v]	Bulk density $(g \cdot cm^{-3})$[u]
		(% Vol)		
100% PB	51 b[t]	30 c	81 e	0.15 a
100% 1.9 cm (0.75 in) CCR	60 a	30 c	90 c	0.13 c
100% 1.3 cm (0.50 in) CCR	60 a	32 c	92 b	0.12 cd
4:1 PB:PM	38 d	49 a	87 d	0.14 b
4:1 1.9 cm (0.75 in) CCR:PM	48 b	44 b	92 ab	0.11 e
4:1 1.3 cm (0.50 in) CCR:PM	44 c	49 a	93 a	0.11 de
Recommended range[s]	*10-30*	*45-65*	*50-85*	*0.19-0.70*

[z] Analysis performed using the North Carolina State University porometer.

[y] PB = pine bark, CCR = clean chip residual, PM = sphagnum peat moss, 1 cm = 0.394 inch.

[x] Air space is volume of water drained from the sample ÷ volume of the sample.

[w] Container capacity is (wet weight - oven dry weight) ÷ volume of the sample.

[v] Total porosity is container capacity + air space.

[u] Bulk density after forced-air drying at 105°C (221.0 °F) for 48 h; $1 \ g \cdot cm^{-3} = 62.4274 \ lb/ft^3$.

[t] Means within column follwed by the same letter are not significantly different based on Waller-Duncan k ratio *t* tests at $\alpha = 0.05$ (n = 3).

[s] Recommended ranges as reported by Yeager et al., 2007. Best Management Practices Guide for Producing Container-Grown Plants.

Table 3.2. Particle size analysis of pine bark-based and clean chip residual-based substrates (Auburn).

U.S. standard sieve no.	Sieve opening (mm)^{z}	Substrate^{y} 100% PB	100% 1.9 cm (0.75 in) CCR	100% 1.3 cm (0.50 in) CCR	4:1 PB:PM	4:1 1.9 cm (0.75 in) CCR:PM	4:1 1.3 cm (0.50 in) CCR:PM
1/2	12.50	0.7 a^{x}	0.4 a	0.0 a	0.0 a	0.5 a	0.1 a
3/8	9.50	0.3 b	1.4 a	0.2 b	0.0 b	1.1 a	0.4 b
1/4	6.35	8.9 ab	10.1 a	3.3 c	8.3 b	8.5 ab	2.9 c
6	3.35	32.4 a	32.2 a	29.6 ab	30.1 ab	31.8 a	27.0 b
8	2.36	16.1 d	20.6 b	22.1 a	15.1 d	18.7 c	20.2 b
10	2.00	5.7 e	7.6 c	8.8 a	5.3 e	6.9 d	8.1 b
14	1.40	11.8 bcd	11.3 cd	14.4 a	12.0 bc	10.8 d	12.8 b
18	1.00	7.9 a	6.4 b	8.3 a	8.7 a	6.8 b	8.0 a
35	0.50	9.8 b	5.9 c	7.8 bc	13.0 a	8.7 b	10.2 b
60	0.25	4.0 abc	2.4 c	3.2 bc	5.1 ab	4.0 abc	6.1 a
140	0.11	1.1 b	1.1 b	1.4 b	1.8 b	1.6 b	3.4 a
270	0.05	0.7 a	0.4 b	0.4 b	0.4 b	0.4 b	0.6 a
pan	0.00	0.6 a	0.2 a	0.5 a	0.2 a	0.2 a	0.2 a
Texture^{w}							
Coarse		42.4 ab	44.3 a	33.3 cd	38.3 bc	42.0 ab	30.4 d
Medium		41.5 d	45.8 c	53.5 a	41.1 d	43.1 d	49.1 b
Fine		16.1 ab	9.9 c	13.2 bc	20.6 a	14.9 b	20.5 a

[z] 1 mm = 0.0394 inch.

[y] PB = pine bark, CCR = clean chip residual, PM = sphagnum peat moss, 1 cm = 0.394 inch.

[x] Percent weight of sample collected on each screen, means within row followed by the same letter are not significantly different based on Waller-Duncan k ratio *t* tests at $\alpha = 0.05$ (n = 3).

[w] *Coarse* = 3.35-12.50 mm; *Medium* = 1.00-2.36 mm; *Fine* = 0.00-0.50 mm.

Table 3.3. Substrate electrical conductivity (EC) and pH for pine bark-based and clean chip residual-based substrates in a container-grown perennial study at two locations.

	Poplarville, MS					
	15 DAP^{y}		32 DAP		63 DAP	
Substrate^{z}	EC (mS·cm^{-1})^{x}	pH	EC (mS·cm^{-1})	pH	EC (mS·cm^{-1})	pH
100% PB	1.01 $^{w,\ ns}$	6.2 b	0.13 b	6.4 ^{ns}	0.15 ^{ns}	6.2 b
100% 1.9 cm (0.75 in) CCR	0.88	6.5 a	0.18 b	6.6	0.15	6.6 a
100% 1.3 cm (0.50 in) CCR	1.03	6.5 a	0.19 b	6.7	0.12	6.6 a
4:1 PB:PM	1.07	5.9 c	0.32 a	6.2	0.09	5.7 c
4:1 1.9 cm (0.75 in) CCR:PM	1.20	6.3 b	0.17 b	6.5	0.13	6.1 b
4:1 1.3 cm (0.50 in) CCR:PM	1.04	6.4 a	0.19 b	6.6	0.09	6.3 ab

	Auburn, AL									
	1 DAP		14 DAP		28 DAP		60 DAP		91 DAP	
	EC (mS·cm^{-1})	pH	EC (mS·cm^{-1})	pH	EC (mS·cm^{-1})	pH	EC (mS·cm^{-1})	pH	EC (mS·cm^{-1})	pH
100% PB	0.81 ^{ns}	5.4 abc	0.54 ^{ns}	5.9 b	0.25 c	5.9 c	0.71 ^{ns}	5.2 c	0.52 ^{ns}	6.0 a
100% 1.9 cm (0.75 in) CCR	0.89	5.7 ab	0.54	6.5 a	0.43 b	6.5 ab	0.67	5.8 ab	0.40	6.3 a
100% 1.3 cm (0.50 in) CCR	1.01	5.8 a	0.55	6.3 a	0.53 ab	6.6 a	0.81	6.1 a	0.33	5.9 a
4:1 PB:PM	0.88	5.1 c	0.55	5.6 c	0.66 a	6.2 bc	0.54	5.0 c	0.38	4.9 c
4:1 1.9 cm (0.75 in) CCR:PM	0.95	5.3 bc	0.52	6.3 a	0.53 ab	6.3 abc	0.48	5.2 bc	0.31	5.4 b
4:1 1.3 cm (0.50 in) CCR:PM	1.11	5.5 abc	0.58	6.2 a	0.50 ab	6.3 abc	0.63	4.9 c	0.34	5.3 b

[z] PB = pine bark, CCR = clean chip residual, PM = sphagnum peat moss, 1 cm = 0.394 inch.

[y] DAP = days after planting.

[x] 1 mS·cm^{-1} = 1 mmho/cm.

[w] Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio *t* tests at $\alpha = 0.05$ (n = 4).

[ns] Means not significantly different.

Table 3.4. Effects of pine bark-based and clean chip residual-based substrates on growth of *Buddleia davidii* 'Pink Delight' at two locations.

	Poplarville, MS								
	Leaf chlorophyll content^{y}			Growth index^{w}			Flower count		Shoot dry weight (g)^{v}
Substrate^{z}	32 DAP^{x}	64 DAP	102 DAP	32 DAP	64 DAP	102 DAP	64 DAP	102 DAP	105 DAP
100% PB	55.9 $^{u, ns}$	53.6 ^{ns}	49.5 ^{ns}	31.5 a	55.7 ^{ns}	66.4 ^{ns}	7.1 ^{ns}	14.3 a	49.6 b
100% 1.9 cm (0.75 in) CCR	54.0	53.7	47.7	24.5 b	57.4	65.1	7.5	8.6 d	42.7 c
100% 1.3 cm (0.50 in) CCR	52.1	55.7	49.7	24.6 b	60.0	68.3	9.1	9.6 cd	42.6 c
4:1 PB:PM	57.0	54.5	47.4	31.3 a	55.2	68.9	6.1	18.7 a	58.1 a
4:1 1.9 cm (0.75 in) CCR:PM	54.3	56.0	47.1	30.7 a	56.7	69.5	7.0	13.5 bc	47.7 bc
4:1 1.3 cm (0.50 in) CCR:PM	54.7	53.1	47.3	26.8 b	63.0	67.4	7.4	10.3 cd	45.0 bc

	Auburn, AL									
	Leaf chlorophyll content			Growth index			Flower count		Shoot dry weight (g)	Root rating (%)
	28 DAP	60 DAP	97 DAP	28 DAP	61 DAP	97 DAP	63 DAP	97 DAP	110 DAP	98 DAP
100% PB	28.7 c	39.0 ^{ns}	46.6 ^{ns}	10.4 b	17.8 b	49.6 ab	2.9 bc	12.4 ab	45.7 c	58.1 b
100% 1.9 cm (0.75 in) CCR	29.9 c	39.9	46.4	10.1 b	13.3 c	45.6 b	3.3 bc	8.1 cd	28.3 d	60.0 b
100% 1.3 cm (0.50 in) CCR	36.6 b	38.8	47.3	9.9 b	15.0 c	49.6 ab	1.9 c	7.1 d	31.2 d	62.5 b
4:1 PB:PM	40.3 b	39.8	48.3	11.3 b	19.1 b	53.2 a	4.5 b	10.1 bc	48.5 bc	71.3 a
4:1 1.9 cm (0.75 in) CCR:PM	53.3 a	40.8	45.9	14.0 a	24.4 a	53.1 a	9.4 a	11.4 b	53.0 b	72.5 a
4:1 1.3 cm (0.50 in) CCR:PM	54.4 a	41.0	46.8	14.2 a	23.8 a	55.0 a	8.9 a	14.6 a	59.6 a	71.3 a

[z] PB = pine bark, CCR = clean chip residual, PM = sphagnum peat moss, 1 cm = 0.394 inch.

[y] Leaf chlorophyll content quantified using a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ) (average of four leaves per plant).

[x] DAP = days after planting.

[w] Growth index = (height + width1 + width2) ÷ 3.

[v] 1 g = 0.0353 oz.

[u] Means within column followed by the same letter are not significantly different based onWaller-Duncan k ratio *t* tests at α =0.05 (n = 8 (growth), n = 6 (SDW) for Poplarville, n = 8 for Auburn).

[ns] Means not significantly different.

Table 3.5. Effects of pine bark-based and clean chip residual-based substrates on growth of *Gaura lindheimeri* 'Siskiyou Pink' at two locations.

	Poplarville, MS			
	Growth index[x]		**Flower count**	**Shoot dry weight (g)[w]**
Substrate[z]	**64 DAP[y]**	**106 DAP**	**64 DAP**	**111 DAP**
100% PB	28.2 ab[v]	24.8 b	13.1 ab	32.6 b
100% 1.9 cm (0.75 in) CCR	23.8 c	22.8 b	6.1 c	28.5 b
100% 1.3 cm (0.50 in) CCR	25.4 bc	22.8 b	8.4 bc	30.0 b
4:1 PB:PM	32.4 a	28.6 a	15.9 a	44.1 a
4:1 1.9 cm (0.75 in) CCR:PM	28.2 ab	24.1 b	9.9 bc	33.9 b
4:1 1.3 cm (0.50 in) CCR:PM	27.3 bc	24.6 b	8.9 bc	31.6 b

	Auburn, AL				
	Growth index		**Flower count**	**Shoot dry weight (g)**	**Root rating (%)**
	61 DAP	**97 DAP**	**63 DAP**	**112 DAP**	**98 DAP**
100% PB	27.9 a	25.6 a	9.6 bc	31.8 a	41.9 bc
100% 1.9 cm (0.75 in) CCR	21.1 b	20.1 b	5.6 c	13.3 b	28.1 d
100% 1.3 cm (0.50 in) CCR	25.4 ab	24.6 ab	5.9 c	18.5 b	37.5 c
4:1 PB:PM	28.2 a	26.8 a	11.1 ab	30.1 a	51.3 a
4:1 1.9 cm (0.75 in) CCR:PM	27.6 a	26.4 a	14.9 a	29.7 a	43.8 b
4:1 1.3 cm (0.50 in) CCR:PM	28.6 a	27.8 a	15.4 a	29.0 a	44.4 b

[z] PB = pine bark, CCR = clean chip residual, PM = sphagnum peat moss, 1 cm = 0.394 inch.

[y] DAP = days after planting.

[x] Growth index = (height + width1 + width2) ÷ 3.

[w] 1 g = 0.0353 oz.

[v] Means within column followed by the same letter are not significantly different based onWaller-Duncan k ratio *t* tests at $\alpha = 0.05$ (n = 8 (growth), n = 6 (SDW) for Poplarville, n = 8 for Auburn).

Table 3.6. Effects of pine bark-based and clean chip residual-based substrates on growth of *Coreopsis grandiflora* 'Early Sunrise' (Poplarville), *Coreopsis rosea* 'Sweet Dreams' (Auburn).

	Poplarville, MS							
	Leaf chlorophyll content[y]			Growth index[w]			Flower count	Shoot dry weight (g)[v]
Substrate[z]	32 DAP[x]	64 DAP	103 DAP	32 DAP	64 DAP	103 DAP	64 DAP	104 DAP
100% PB	61.0 ab[u]	61.7 [ns]	51.8 [ns]	21.4 ab	32.3 [ns]	37.4 [ns]	10.6 ab	52.2 a
100% 1.9 cm (0.75 in) CCR	55.3 c	61.8	49.5	19.5 c	31.3	34.9	2.9 c	40.4 b
100% 1.3 cm (0.50 in) CCR	56.8 bc	59.7	51.4	19.4 c	31.3	34.9	3.0 c	38.4 b
4:1 PB:PM	64.4 a	57.1	51.3	21.7 a	33.8	37.0	12.0 a	54.8 a
4:1 1.9 cm (0.75 in) CCR:PM	56.0 c	59.8	52.1	20.5 abc	31.6	34.8	8.1 b	42.8 b
4:1 1.3 cm (0.50 in) CCR:PM	57.8 bc	59.4	49.6	20.2 bc	32.2	37.8	8.8 ab	46.6 ab

	Auburn, AL					
	Growth index			Flower count	Shoot dry weight (g)	Root rating (%)
	28 DAP	61 DAP	97 DAP	63 DAP	112 DAP	98 DAP
100% PB	20.4 d	32.7 abc	38.4 [ns]	37.5 b	24.6 b	35.6 bc
100% 1.9 cm (0.75 in) CCR	21.9 cd	27.7 c	38.9	39.4 b	23.5 b	31.9 c
100% 1.3 cm (0.50 in) CCR	22.8 bcd	29.5 bc	40.3	47.0 b	25.4 b	35.0 c
4:1 PB:PM	30.5 a	35.1 a	41.1	69.5 a	34.9 a	46.3 ab
4:1 1.9 cm (0.75 in) CCR:PM	24.1 bc	32.0 abc	40.0	48.1 b	28.3 b	42.5 abc
4:1 1.3 cm (0.50 in) CCR:PM	25.5 b	32.9 ab	39.3	51.6 b	26.6 b	46.9 a

[z] PB = pine bark, CCR = clean chip residual, PM = sphagnum peat moss, 1 cm = 0.394 inch.

[y] Leaf chlorophyll content quantified using a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ) (average of four leaves per plant).

[x] DAP = days after planting.

[w] Growth index = (height + width1 + width2) ÷ 3.

[v] 1 g = 0.0353 oz.

[u] Means within column followed by the same letter are not significantly different based onWaller-Duncan k ratio *t* tests at α =0.05 (n = 8 (growth), n = 6 (SDW) for Poplarville, n = 8 for Auburn).

[ns] Means not significantly different.

Table 3.7. Effects of pine bark-based and clean chip residual-based substrates on growth of *Verbena canadensis* 'Homestead Purple' at two locations.

	Poplarville, MS					
	Growth index[x]			Flower count		Shoot dry weight (g)[w]
Substrate[z]	32 DAP[y]	64 DAP	103 DAP	64 DAP	103 DAP	110 DAP
100% PB	32.1 a[v]	45.7 ab	82.3 [ns]	20.8 a	19.5 ab	70.8 ab
100% 1.9 cm (0.75 in) CCR	24.0 b	45.8 ab	85.3	15.0 b	16.4 b	63.3 b
100% 1.3 cm (0.50 in) CCR	24.5 b	42.1 b	86.8	12.9 b	19.4 ab	63.7 b
4:1 PB:PM	33.2 a	46.3 ab	84.8	22.1 a	24.5 a	74.2 a
4:1 1.9 cm (0.75 in) CCR:PM	24.6 b	46.6 ab	84.1	13.4 b	15.5 b	64.7 b
4:1 1.3 cm (0.50 in) CCR:PM	26.1 b	49.1 a	86.8	12.5 b	16.9 b	64.8 b

	Auburn, AL								
	Leaf chlorophyll content[u]			Growth index			Flower count		Shoot dry weight (g)
	28 DAP	60 DAP	97 DAP	28 DAP	61 DAP	97 DAP	63 DAP	97 DAP	110 DAP
100% PB	39.9 c	54.0 [ns]	54.0 ab	11.9 d	51.8 b	58.6 [ns]	8.4 c	6.5 [ns]	55.1 d
100% 1.9 cm (0.75 in) CCR	42.6 bc	51.0	57.9 a	12.9 d	52.3 b	60.1	12.4 bc	7.8	61.4 cd
100% 1.3 cm (0.50 in) CCR	45.3 b	51.1	52.8 ab	13.0 d	52.6 b	59.6	10.8 bc	7.9	69.4 bc
4:1 PB:PM	53.4 a	50.7	51.8 b	22.0 a	59.3 a	64.6	13.1 bc	7.8	81.8 a
4:1 1.9 cm (0.75 in) CCR:PM	50.5 a	52.0	54.8 ab	15.9 c	56.0 ab	60.4	14.5 ab	7.0	74.7 ab
4:1 1.3 cm (0.50 in) CCR:PM	51.3 a	51.9	54.3 ab	17.7 b	56.1 ab	64.0	19.8 a	7.9	75.8 ab

[z] PB = pine bark, CCR = clean chip residual, PM = sphagnum peat moss, 1 cm = 0.394 inch.

[y] DAP = days after planting.

[x] Growth index = (height + width1 + width2) ÷ 3.

[w] 1 g = 0.0353 oz.

[v] Means within column followed by the same letter are not significantly different based onWaller-Duncan k ratio *t* tests at $\alpha = 0.05$ (n = 8 (growth), n = 6 (SDW) for Poplarville, n = 8 for Auburn).

[u] Leaf chlorophyll content quantified using a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ) (average of four leaves per plant).

[ns] Means not significantly different.

Table 3.8. Effects of pine bark-based and clean chip residual-based substrates on growth of *Scabiosa columbaria* 'Butterfly Blue' at two locations.

	Poplarville, MS					
	Growth index[x]			Flower count	Shoot dry weight (g)[w]	
Substrate[z]	32 DAP[y]	64 DAP	109 DAP	64 DAP	110 DAP	
100% PB	13.8 [v], [ns]	16.9 [ns]	21.8 [ns]	11.3 a	19.4 a	
100% 1.9 cm (0.75 in) CCR	13.3	16.0	22.0	5.5 c	15.2 ab	
100% 1.3 cm (0.50 in) CCR	13.3	15.8	20.8	6.4 bc	13.2 b	
4:1 PB:PM	13.7	18.5	21.5	11.6 a	16.4 ab	
4:1 1.9 cm (0.75 in) CCR:PM	13.3	16.4	23.2	8.4 b	16.7 ab	
4:1 1.3 cm (0.50 in) CCR:PM	13.1	17.6	21.7	6.1 bc	13.4 b	
	Auburn, AL					
	Growth index			Flower count	Shoot dry weight (g)	Root rating (%)
	28 DAP	61 DAP	97 DAP	63 DAP	112 DAP	98 DAP
100% PB	12.4 [ns]	22.3 ab	22.5 abc	4.1 ab	12.5 [ns]	43.8 b
100% 1.9 cm (0.75 in) CCR	15.4	20.2 bc	21.1 bc	3.0 b	12.0	41.3 b
100% 1.3 cm (0.50 in) CCR	12.1	17.8 c	20.4 c	1.8 b	10.3	53.8 a
4:1 PB:PM	13.7	23.5 a	23.9 a	7.4 a	14.4	29.4 c
4:1 1.9 cm (0.75 in) CCR:PM	14.4	23.6 a	23.4 ab	4.5 ab	14.6	42.5 b
4:1 1.3 cm (0.50 in) CCR:PM	11.3	21.9 ab	22.6 abc	3.3 b	12.7	40.6 b

[z] PB = pine bark, CCR = clean chip residual, PM = sphagnum peat moss, 1 cm = 0.394 inch.

[y] DAP = days after planting.

[x] Growth index = (height + width1 + width2) ÷ 3.

[w] 1 g = 0.0353 oz.

[v] Means within column followed by the same letter are not significantly different based onWaller-Duncan k ratio *t* tests at $\alpha = 0.05$ (n = 8 (growth), n = 6 (SDW) for Poplarville, n = 8 for Auburn).

[ns] Means not significantly different.

Table 3.9. Effects of pine bark-based and clean chip residual-based substrates on growth of *Dianthus gratianopolitanus* 'Firewitch' at two locations.

	Poplarville, MS					
	Growth index[x]			Flower count	Shoot dry weight (g)[w]	
Substrate[z]	32 DAP[y]	64 DAP	109 DAP	64 DAP	112 DAP	
100% PB	9.9 a[v]	14.4 a	18.2 a	18.4 a	24.8 a	
100% 1.9 cm (0.75 in) CCR	8.3 cd	13.4 b	16.6 cd	9.3 b	20.0 b	
100% 1.3 cm (0.50 in) CCR	8.1 d	13.4 b	16.1 d	9.5 b	19.7 b	
4:1 PB:PM	10.1 a	14.8 a	18.0 ab	18.0 a	25.1 a	
4:1 1.9 cm (0.75 in) CCR:PM	9.2 b	13.6 b	17.2 bc	14.5 a	22.1 ab	
4:1 1.3 cm (0.50 in) CCR:PM	8.8 bc	13.6 b	16.7 cd	8.9 b	20.3 b	
	Auburn, AL					
	Growth index			Flower count	Shoot dry weight (g)	Root rating (%)
	28 DAP	61 DAP	97 DAP	63 DAP	110 DAP	98 DAP
100% PB	8.4 [ns]	12.5 a	14.9 a	7.4 [ns]	11.2 a	41.3 a
100% 1.9 cm (0.75 in) CCR	8.2	10.5 c	13.3 bc	4.9	9.2 b	28.8 b
100% 1.3 cm (0.50 in) CCR	8.1	10.4 c	13.2 c	4.0	9.1 b	31.3 b
4:1 PB:PM	8.2	12.4 a	14.3 ab	8.9	10.9 a	42.5 a
4:1 1.9 cm (0.75 in) CCR:PM	8.2	11.5 b	14.1 abc	5.9	10.5 a	40.0 a
4:1 1.3 cm (0.50 in) CCR:PM	8.3	11.7 ab	14.5 a	7.3	10.8 a	41.3 a

[z] PB = pine bark, CCR = clean chip residual, PM = sphagnum peat moss, 1 cm = 0.394 inch.

[y] DAP = days after planting.

[x] Growth index = (height + width1 + width2) ÷ 3.

[w] 1 g = 0.0353 oz.

[v] Means within column followed by the same letter are not significantly different based onWaller-Duncan k ratio *t* tests at α =0.05 (n = 8 (growth), n = 6 (SDW) for Poplarville, n = 8 for Auburn).

[ns] Means not significantly different.

Table 3.10. Effects of pine bark-based and clean chip residual-based substrates on growth of *Rosmarinus officinalis* 'Irene' at two locations.

	Poplarville, MS			
	Growth index[x]			**Shoot dry weight (g)[w]**
Substrate[z]	**32 DAP[y]**	**64 DAP**	**109 DAP**	**111 DAP**
100% PB	20.2 bc[v]	34.5 [ns]	53.7 [ns]	56.9 ab
100% 1.9 cm (0.75 in) CCR	18.7 cd	32.1	51.1	45.3 c
100% 1.3 cm (0.50 in) CCR	17.7 d	31.8	52.8	48.7 bc
4:1 PB:PM	22.8 a	34.3	49.6	61.7 a
4:1 1.9 cm (0.75 in) CCR:PM	21.0 abc	33.6	54.1	53.0 abc
4:1 1.3 cm (0.50 in) CCR:PM	21.8 ab	33.7	50.3	55.6 abc
	Auburn, AL			
	Growth index			**Shoot dry weight (g)**
	28 DAP	**61 DAP**	**97 DAP**	**110 DAP**
100% PB	13.8 b	28.9 b	36.7 [ns]	24.3 bc
100% 1.9 cm (0.75 in) CCR	13.8 b	26.1 b	37.7	21.7 c
100% 1.3 cm (0.50 in) CCR	14.3 b	33.8 a	40.3	32.3 ab
4:1 PB:PM	13.8 b	32.9 a	41.3	33.7 a
4:1 1.9 cm (0.75 in) CCR:PM	17.5 a	34.0 a	39.7	35.7 a
4:1 1.3 cm (0.50 in) CCR:PM	15.6 b	32.1 a	37.7	28.0 abc

[z] PB = pine bark, CCR = clean chip residual, PM = sphagnum peat moss, 1 cm = 0.394 inch.

[y] DAP = days after planting.

[x] Growth index = (height + width1 + width2) ÷ 3.

[w] 1 g = 0.0353 oz.

[v] Means within column followed by the same letter are not significantly different based onWaller-Duncan k ratio *t* tests at α =0.05 (n = 8 (growth), n = 6 (SDW) for Poplarville, n = 8 for Auburn).

[ns] Means not significantly different.

Table 3.11. Effects of pine bark-based and clean chip residual-based substrates on growth of *Salvia guaranitica* 'Black and Blue' (Poplarville, MS).

	Leaf chlorophyll content[y]			Growth index[w]			Flower count	Shoot dry weight (g)[v]
Substrate[z]	**32 DAP[x]**	**64 DAP**	**106 DAP**	**32 DAP**	**64 DAP**	**106 DAP**	**64 DAP**	**106 DAP**
100% PB	49.1 a[u]	41.6 [ns]	39.9 [ns]	26.6 ab	36.4 ab	43.4 [ns]	11.5 [ns]	35.1 a
100% 1.9 cm (0.75 in) CCR	41.4 b	39.3	36.5	20.8 d	31.4 c	42.2	9.1	24.4 b
100% 1.3 cm (0.50 in) CCR	41.0 b	40.2	37.3	23.3 cd	34.3 abc	41.2	8.5	26.4 b
4:1 PB:PM	46.4 a	40.6	40.3	27.1 a	37.1 a	45.6	11.0	34.6 a
4:1 1.9 cm (0.75 in) CCR:PM	41.4 b	39.5	37.0	24.0 bc	34.0 abc	41.7	10.6	23.7 b
4:1 1.3 cm (0.50 in) CCR:PM	40.2 b	38.2	37.9	23.4 cd	33.7 bc	41.7	7.9	26.6 b

[z] PB = pine bark, CCR = clean chip residual, PM = sphagnum peat moss, 1 cm = 0.394 inch.

[y] Leaf chlorophyll content quantified using a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ) (average of four leaves per plant).

[x] DAP = days after planting.

[w] Growth index = (height + width1 + width2) ÷ 3.

[v] 1 g = 0.0353 oz.

[u] Means within column followed by the same letter are not significantly different based onWaller-Duncan k ratio *t* tests at α =0.05 (n = 8 (growth), n = 6 (SDW) for Poplarville, n = 8 for Auburn).

[ns] Means not significantly different.

CHAPTER IV

Performance of Woody Nursery Crops in Clean Chip Residual Substrate

Abstract

Clean chip residual (CCR) is a potential replacement for pine bark (PB) in nursery crop substrates. Clean chip residual is a by-product of in-field forestry harvesting practices and has been shown to produce annual plants and perennials similar in size to plants grown in PB. Studies were conducted in two locations, Auburn, AL and Poplarville, MS to evaluate growth of woody ornamentals grown in CCR or PB. Five species were tested; *Loropetalum chinensis* var. rubrum, *Buddleia davidii* 'Black Knight', *Lagerstroemia indica* 'Hopi', *Lagerstroemia* x *fauriei* 'Natchez', and *Rhododendron indicum* 'Mrs. G.G. Gerbing'. Data for all species show that plants grown in CCR had similar or greater growth than plants grown in PB. There were few differences in plant growth index, leaf chlorophyll content, and inflorescence number over the course of the year for all species at both sites. Percent rootball coverage was generally similar among treatments, though those grown in PB had the greatest percent rootball coverage for loropetalum, buddleia (at both sites) and azalea at Auburn. Shoot dry weight of loropetalum and crapemytrle grown in PB at Poplarville was greater than plants grown in CCR.

Introduction

As the expense of growing nursery crops continues to rise along with labor shortages and higher material prices, it has become increasingly important to search for production practices that will lower input costs for growers. With recent and continued trends in the reduced availability of pine bark (PB) (Lu et al., 2006) a promising avenue for reducing production costs has been the evaluation of alternative substrates. One potential substrate resource is forest residual materials which result from in-field harvesting operations, leaving bark and other miscellaneous plant material on the forest floor after timber harvest.

Clean chip residual (CCR) is a forest residual material, a by-product of in-field harvesting of small-caliper (10-30 cm diameter) pine trees for ‘clean chips’ used in paper manufacturing. Residual materials from this process are sometimes sold as boiler fuel to pulp mills, but, more often, are spread back across the harvested area as there is no other forest industry market for the material. Utilizing CCR as a nursery crop substrate could potentially lower costs to growers and provide a sustainable, local/regional substrate resource in the Southeast U.S.

Safe, effective, and economical growth substrates are an important part of nursery crop culture. Growers have been searching for innovative ways to meet this need since the inception of container-grown crops on a large scale in the 1950’s. The first container substrates were composed primarily of field soil which had poor physical properties and many soil-borne pathogens (Davidson et al., 2000). For the last 30 years PB has been the primary component of nursery crop substrates. Unfortunately, PB is becoming increasingly expensive and less available due to in-field harvesting practices, alternative fuel uses, decreased domestic forestry production and increased foreign importation of logs (Lu, et al., 2006).

Recent substrate research has identified CCR, a forest in-field harvesting residual material, as a possible replacement for PB-based substrates (Boyer et al., 2008). Clean chip residual is composed of a high percentage of wood-fiber (about 50%) though it also contains about 40% bark and approximately 10% foliage and other material (pine cones, etc.). Pine trees are passed though a total tree harvesting machine which de-limbs and de-barks the trees before sending remaining material through a chipper and into a chip truck/van. Residual material from this process (limbs, bark, needles, and chipper rejects) is then either sold for boiler fuel at the pulp mill or spread back across the harvested area. The high wood-fiber content material of CCR can then be further processed into a substrate material similar to traditional PB substrates, although PB substrates normally contain less than 5% wood-fiber.

To date, several studies have been conducted to evaluate the growth of nursery crops in high wood-fiber content substrates. Laiche (1986) was the first to evaluate plants grown in PB with wood chips or pine tree chips. He concluded that the best growth was obtained with PB and the poorest growth with pine tree chips. Gruda and Schnitzler (2003) reported the use of wood-fiber substrates for vegetable transplant production in Europe. They did not detect any differences for the absolute and relative growth rate of tomato transplants cultivated in woof fiber substrates as compared to white peat. Additionally, plants grown in wood fiber substrate showed a well developed root system. In the U.S. Wright and Browder (2005) conducted a short-term greenhouse study with 100% wood-fiber which showed that marigold (*Tagetes erecta*) could be grown successfully with a note that substrate fertility needed to be further evaluated. Fain and Gilliam (2006) reported *WholeTree* could be successfully used as a growth substrate for annual vinca producing plants similar in size to those grown in PB. *WholeTree* is composed of the entire shoot portion of trees, but has a higher (about 80%) wood-fiber content than CCR. Boyer et al. (2006a) demonstrated that ageratum and salvia grown in CCR or combinations of CCR and peat were similar in size to plants grown in traditional pine bark substrates. Later, Boyer et al. (2006b) evaluated perennials (buddleia and verbena) in CCR and reported similar results among all treatments. A further study indicated that use of supplemental nitrogen was not necessary for growth of perennial ‘Pink Delight’ buddleia (Boyer et al., 2007). No tests have evaluated long-term container-grown woody crops with CCR. The objective of this work was to evaluate fresh CCR, processed to several screen sizes, as a substrate for production of container-grown woody crops over the course of one year.

Materials and methods

CCR used in this study was obtained from a 10-year-old pine plantation near Evergreen, AL on 1 December 2005. A Loblolly pine (*Pinus taeda* L.) plantation was being thinned and processed for clean chips using a total tree harvester (Peterson DDC-5000-G Portable Chip Plant, Peterson Pacific Corp., Eugene, OR). Further processing occurred through a horizontal grinder with 4-inch (10.2 cm) screens (Peterson 4700B heavy duty grinder, Peterson Pacific Corp.) before the material was sold to a pulp mill for boiler fuel. Clean chip residual material left behind was then further processed through a swinging hammer mill (No. 30; C.S. Bell, Tifton, OH) to pass either a 3.2 cm (1.25 in), 1.9 cm (0.75 in), 1.3 cm (0.50 in), or 1.0 cm (0.38 in) screen on 29 March 2006. For our study these four CCR particle sizes were used alone and compared with a standard control, PB (Table 4.1).

This study was conducted at two locations: Paterson Greenhouse, Auburn University, Auburn, AL (6 June 2006) and at USDA-ARS Southern Horticultural Laboratory, Poplarville, MS (14 June 2006). Each substrate blend was pre-plant incorporated with 8.3 kg/m^3 (14 lb/yd^3) 18-6-12 Polyon® (Harrell's Fertilizer, Inc., Sylacauga, AL) control release fertilizer (9 month); 3.0 kg/m^3 (5 lb/yd^3) dolomitic limestone and 0.9 kg/m^3 (1.5 lb/yd^3) Micromax® (The Scotts Company, Marysville, OH). Five woody ornamental species, *Loropetalum chinensis* var. rubrum, *Buddleia davidii* 'Black Knight', *Lagerstroemia indica* 'Hopi' (Auburn) and *Lagerstroemia* x *fauriei* 'Natchez' (Poplarville), and *Rhododendron indicum* 'Mrs. G.G. Gerbing' were transplanted from standard 72-cell flats into #1 containers, placed outdoors on a gravel container pad and overhead irrigated twice daily (0.50 in total). Water quality between locations was similar. Irrigation water pH at Poplarville was 6.2, electrical conductivity (EC) (mmhos/cm) was 0.1 and alkalinity (HCO_3^- mg/L) was 41. Irrigation water pH at Auburn was 6.5 with an EC of 0.2 (mmhos/cm) and alkalinity (HCO_3^- mg/L) of 80. Azalea plants at Auburn were grown under 30% shade cloth. Plants were arranged by species in a randomized complete block with eight single plant replications. Containers were top-dressed with 7 lb per yd^3 19-6-12 Polyon® (Harrell's Fertilizer, Inc., Sylacauga, AL) control release fertilizer (6 month) on 23 February 2007. The study was terminated on 18 June 2007 at Auburn and on 22 June 2007 at Poplarville.

Substrates were analyzed for particle size distribution (PSD) 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 (Ro-Tap RX-29, W.S. Tyler, Mentor, OH) sieve shaker (278 oscillations/min, 159 taps/min). Substrate air space (AS), container capacity (CC), and total porosity (TP) were determined following procedures described by Bilderback et al. (1982). Substrate bulk density ($gm \cdot cm^{-3}$) was determined from 347.5 cm^3 samples dried in a 105 C forced air oven for 48 h.

Substrate pH and electrical conductivity (EC) were determined at 16, 30, 60, 90, 120, 240 and 365 days after planting (DAP) using the PourThru technique (Wright, 1986). Media shrinkage (cm below the top of the container) was measured at 7 and 365 DAP. Leaf chlorophyll content was quantified using a SPAD-502 Chlorophyll Meter (Minolta Camera Co., Ramsey, NJ) at 60, 90, 120 and 365 DAP. Growth indices (GI) ([height + width + perpendicular width] / three (cm)) were recorded at 60, 90, 120 and 365 DAP. Flower counts were conducted at 60 and 90 DAP for buddleia. Root ratings (percent coverage of the rootball) were conducted at 365 DAP. Shoot dry weights (SDW) were recorded at the conclusion of the study (365 DAP) by drying in a forced air oven at 70 C for 48 h.

Recently matured, current season terminal shoots (5.1 to 7.6 cm (2-3 in)) (Mills and Jones, 1996) were sampled from loropetalum at both locations. Foliar samples (four replications per treatment) were analyzed for nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B), iron (Fe), manganese (Mn), copper (Cu) and zinc (Zn). Foliar N was determined by combustion analysis using a 1500

N analyzer (Carlo Erba, Milan, Italy). Remaining nutrients were determined by microwave digestion with inductively coupled plasma-emission spectrometry (Thermo Jarrel Ash, Offenbach, Germany). Data were analyzed using Waller-Duncan k ratio t tests ($P \leq 0.05$) using a statistical software package (SAS® Institute version 9.1, Cary, NC). Data were analyzed separately for each location.

Results and discussion

Air space in all substrates was high (47-65%; recommended 10-30%) (Table 4.1). Air space tended to increase with increasing particle size. Container capacity (CC) was low for all substrates (27-38%; recommended 45-65% (Yeager et. al, 2007)); however, 1.3 cm (0.50 in) and 1.0 cm (0.38 in) CCR had similar CC to PB. Total porosity was slightly above (90-92%) recommended ranges (50-85%) except for PB (84%). This is similar to results reported by Wright and Browder (2005) in that substrates composed of 100% PB had the lowest TP (70%) and substrates composed of 100% pine chips (100% wood fiber) or a75% pine chip:25% PB blend had greater TP (82-86%). Bulk density was low for all substrates (0.11-0.15 g/cm^3; recommended 0.19-0.70 g/cm^3).

As expected, 3.2 cm (1.25 in) CCR and 1.9 cm (0.75 in) CCR had a higher component of large particles and fewer medium and small particles (Table 4.2). Substrates composed of 1.3 cm (0.50 in) CCR or 1.0 cm (0.38 in) CCR were similar to PB with the exception of more extra fine particles in the PB.

Substrate pH and EC remained relatively constant over the course of the year (Table 4.3). At Auburn, pH of PB was consistently lower than that of CCR substrates by about a half a point. In general, the pH was around 6.5 at both sites, which is acceptable for plant growth. The trend of lower pH for PB at Auburn did not occur at Poplarville. All pH levels were similar at all rating dates at Poplarville except 238 DAP where the larger sizes of CCR had a slightly higher pH level. Electrical conductivity (EC) also remained relatively constant over the course of the year. A steady EC decline from 0.36 mmhos/cm at 16 DAP to a low of about 0.13 mmhos/cm at 258 DAP existed at Auburn possibly due to depletion of the fertilizer. EC went back up to 16 DAP levels at 377 DAP after topdressing in February of 2007. A similar trend occurred at Poplarville except that the spike in EC levels occurred at 238 DAP instead of 374 DAP.

Loropetalum at Auburn

There were no differences in GI of loropetalum at 55 DAP (Table 4.4); however, by 92 DAP plants grown in 1.9 cm (0.75 in) CCR were the largest (31.4 cm), but were not different from plants grown in 1.3 cm (0.50 in) CCR (29.3 cm) or 1.0 cm (0.38 in) CCR (28.2 cm). At 141 DAP plants grown in 3.2 cm (1.25 in) CCR were the smallest (33.2 cm) along with PB (35.8 cm). At the conclusion of the study (373 DAP), plants grown in PB were the smallest (57.1 cm), but were similar to plants grown in 3.2 cm (1.25 in) CCR (58.0 cm) and 1.3 cm (0.50 in) CCR (62.4 cm). While plants grown in PB may have exhibited less shoot growth, root growth was excellent (85.0% rootball coverage) as was the root growth of plants grown in 1.3 cm (0.50 in) CCR (77.5%) and 1.0 cm (0.38 in) CCR (83.1%). Plants grown in 3.2 cm (1.25 in) CCR had the least rootball coverage (57.5%). Shoot dry weight at 377 DAP indicated that plants grown in 1.0 cm (0.38 in) CCR had the greatest shoot growth (99.7g) while plants grown in 1.9 cm (0.75 in) CCR and 1.3 cm (0.50 in) CCR were similar (81.7g, 88.5g). Plants grown in PB had the least SDW (76.4 g), but were similar to all other treatments except 1.0 cm (0.38 in) CCR.

Tissue nutrient content of loropetalum was similar among treatments for N, P, Mg, S, B, Fe, Mn, Cu, and Zn (Table 4.5). Foliar K content (0.70-0.86%) among all treatments was higher than the sufficiency range (0.40-0.52%) (Mills and Jones, 1996), but foliage from all CCR treatments were similar to PB. Calcium content was less in the tissue from plants grown in larger CCR particle sizes, however, overall calcium content was similar for 1.0 cm (0.38 in) CCR and PB.

Loropetalum at Poplarville

There were no differences in GI of loropetalum at any rating date during the study or in percent rootball coverage at 373 DAP (Table 4.4). However, SDW revealed that plants grown in PB had significantly more shoot growth (160.8 g) than plants grown in any CCR treatment. There was a trend for SDW to increase at Poplarville with decreasing screen size.

Tissue nutrient content analysis showed that N was acceptable for CCR treatments (1.4%), but was low for PB (1.1%) (Table 4.5). Phosphorus content was slightly high overall (0.16%; range is 0.10-0.13), but PB was lower than CCR treatments (0.13%). There were no differences among treatments for K, but the values (0.67-0.75%) were above the sufficiency range (0.40-0.52%). Calcium values were similar among treatments (1.0-1.2%), but below the sufficiency range (2.0-2.9%). Magnesium was slightly high among all treatments (0.17-0.19%, range is 0.13-0.15%), however 1¼-inch CCR had less Mg (0.17%) than other treatments, though 1.3 cm (0.50 in) CCR and PB were similar. Sulfur was similar among treatments (0.15%), though slightly high (sufficiency range 0.12-0.14%). Boron (15-18 ppm) was similar among treatments, but lower than sufficiency ranges (55-126 ppm). Iron (41-53 ppm) was lower than sufficiency ranges (58-69 ppm) however, 3.2 cm (1.25 in) CCR (41 ppm) was lower than other treatments except PB (44 ppm). There were no differences for Mn, though values were slightly high (29-39 ppm; range is 15-35 ppm). Copper was low in PB (3ppm), but 1.3 cm (0.50 in) CCR and 1.0 cm (0.38 in) CCR (5ppm) were similar. Zinc was highest in 1.9 cm (0.75 in) CCR (23 ppm) and all treatments were above the sufficiency range (7-10 ppm).

Buddleia at Auburn

Growth indices of buddleia at Auburn were similar among treatments for all rating dates except 92 DAP (Table 4.6). At 92 DAP plants grown in PB were larger than all other treatments (80.8 cm), though plants grown in 1.3 cm (0.50 in) CCR and 1.0 cm (0.38 in) CCR were similar. At 141 and 373 DAP GI were similar among all treatments. Leaf chlorophyll content and number of inflorescences was similar among all treatments at all rating dates. Percent rootball coverage at 373 DAP was greatest in PB (93.1%) and 1.0 cm (0.38 in) CCR (90.0%), though 1.3 cm (0.50 in) CCR was similar (85.0%). There were no differences in SDW at 377 DAP.

Buddleia at Poplarville

At 62 DAP in Poplarville GI of buddleia was smallest in PB (39.0 cm) and 1.9 cm (0.75 in) CCR (36.0 cm) while 1.0 cm (0.35 in) CCR had the greatest GI (45.6 cm) (Table 4.6). At 98 DAP there were no differences in GI. However, at 128 DAP the greatest growth occurred with 3.2 cm (1.25 in) CCR (66.6 cm) and the least with 1.9 cm (0.75 in) CCR (56.6 cm). All other treatments were similar to both 3.2 cm (1.25 in) and

1.9 cm (0.75 in) CCR. At the conclusion of the study (372 DAP) there were no differences in GI. Leaf chlorophyll content was similar among all treatments at 62, 98 and 372 DAP. At 128 DAP plants grown in 3.2 cm (1.25 in) CCR (59.5) and 1.3 cm (0.50 in) CCR (59.7) had greater leaf chlorophyll content than other treatments (54.9-57.0). Those differences were not present at 372 DAP. There were no differences in number of inflorescences at 62 or 98 DAP. Percent rootball coverage and SDW were similar among plants in all treatments for buddleia at Poplarville.

These data concur with previous work (Boyer et al. 2006) with ‘Pink Delight’ buddleia grown in 100% PB, 100% 1.9 cm (0.75 in) CCR, 100% 1.3 cm (0.50 in) CCR or these mixed 4:1 (v:v) with peat. Initial growth differences occurred; however, all buddleia had similar in growth indices, flower counts and leaf color in the 100% substrates.

Crapemyrtle at Auburn

At Auburn there were no differences for crapemyrtle for GI, leaf chlorophyll content, percent rootball coverage or SDW at any rating date (Table 4.7).

Crapemyrtle at Poplarville

For crapemyrtle at Poplarville there were no differences for GI, leaf chlorophyll content or percent rootball coverage at any rating date (Table 4.7). Shoot dry weight for was greatest for plants grown in PB (247.4 g). All other treatments were similar to each other for SDW (185.7-204.3 g).

Azalea at Auburn

Azalea plants at Auburn had similar GI and leaf chlorophyll content at all rating dates (Table 4.8). At the conclusion of the study (373 DAP) plants grown in PB had greater percent rootball coverage (93.8%) than all other treatments (66.3-71.3%). There were no differences in azalea SDW at 377 DAP.

Azalea at Poparville

Growth indices of azalea at Poplarville were similar at 62 DAP, however, by 97 and 128 DAP 3.2 cm (1.25 in) CCR had the greatest GI (23.6 cm and 23.8 cm) though 1.3 cm (0.50 in) CCR was similar (21.7 cm and 21.8 cm) (Table 4.8). There were no differences in GI of azalea at Poplarville by 373 DAP. Leaf chlorophyll content was similar among all treatments at all rating dates. There were no differences in percent rootball coverage or SDW of azalea at Poplarville.

Substrate Shrinkage at Auburn

Substrate shrinkage is an important indicator of substrate degradation due to microbial activity, particularly competition for N. A study by Kenna and Whitcomb (1985) reported large differences in drainable pore space for newly prepared media (composed of freshly chipped hardwood trees), compared to those after one growing season, suggesting that substantial decomposition of elm and oak chips did occur; however volume shrinkage of the media in the container was minimal and plant growth over the course of the study was acceptable. In the current study, there were no differences in substrate shrinkage (cm below the top of the container) at 7 DAP for Auburn (Table 4.9). At the conclusion of the study (365 days) loropetalum grown in substrates composed of 3.2 cm (1.25 in) CCR had more substrate shrinkage (2.9 cm) than all other substrates (1.9-2.1 cm), most likely due to settling of the substrate with such a large initial amount of air space due to the large particle sizes. Buddleia grown in 3.2 cm (1.25 in) CCR had the most substrate shrinkage (1.4 cm), though 1.9 cm (0.75 in) CCR

(1.1 cm) and 1.3 cm (0.50 in) CCR (1.1 cm) were similar. Crapemyrtle plants grown in 3.2 cm (1.25 in) CCR had the greatest shrinkage (2.3 cm) though 1.9 cm (0.75 in) CCR (1.8 cm) and 1.0 cm (0.38 in) CCR (1.9 cm) were similar. All CCR treatments had greater substrate shrinkage (4.3-3.8 cm) than PB (2.3 cm) for azalea.

Substrate Shrinkage at Poplarville

At 15 DAP in Poplarville there were slight differences in substrate shrinkage (Table 9). Pine bark had the least shrinkage (1.9 cm) though 1.0 cm (0.38 in) CCR was similar (2.2 cm). There were no differences in substrate shrinkage at the conclusion of the study for loropetalum or azalea. Buddleia and crapemyrtle plants had the least substrate shrinkage in PB. Substrate shrinkage measurements varied by species and location; however none of the shrinkage values at one year after potting negatively affected crop growth or salability.

Conclusions

In general, plants grown in CCR had comparable growth to plants grown in PB. The 3.2 cm (1.25 in) CCR and 1.9 cm (0.75 in) CCR had much larger amounts of substrate air space, and consequently less ability to hold water than other substrates. These substrates were also slightly lighter (low bulk density) than other substrates which resulted in more frequent blow-over in the small containers. Root growth of loropetalum and buddleia at Auburn was less in 3.2 cm (1.25 in) CCR and 1.9 cm (0.75 in) CCR substrates than in other treatments. These two screen sizes may be more appropriate for crops grown in larger containers such as large-caliper trees. The smaller screen sized material, 1.3 cm (0.50 in) CCR and 1.0 cm (0.38 in) CCR, works well in #1 containers for outdoor nursery crops.

Loropetalum, buddleia, crapemyrtle, and azalea plants grown in this study showed few differences among CCR and PB treatments. Larger particle size CCR (Coarse = > 3.35 mm; Medium = > 1.00- < 3.35 mm; Fine = < 1.0 mm) tended to have more substrate shrinkage and, in some cases, less growth than other treatments indicating they may not be the best option for #1 containers. There was also a tendency for plants in the smaller particle size media to have the best root growth. Consistency among pH and EC levels suggest that CCR will be a dependable substrate comparable to PB. Similarly, nutrient analysis shows that plant response was similar whether plants were grown in PB or CCR. Plant growth among the four woody species was generally similar at both locations with CCR and PB.

Comparatively, a study by Wright et al. (2006) evaluated the growth of 28 woody species in substrates composed of either 100% ground 0.64 cm (0.25 in) *Pinus taeda* logs or 100% PB. These plants were potted into #1 containers in either April or May and grown until August. In this study, 13 of the 18 species planted in April did not have significantly different SDW among treatments. Of the remaining plants, 4 had higher SDW when grown in PB and 1 had higher SDW when grown in pine chips. At the May planting 6 of the 10 species had higher SDW when grown in PB.

Our study had similar results in that most plants grew similarly to PB. Where differences occurred they appeared to be more related substrate physical properties from large screen sizes, with larger screen sized material being less suitable for use in production of plants in small containers. Fain et al. (2006) evaluated *WholeTree* in production of herbaceous greenhouse crops indicated mixed results. At 34 DAP there were no differences in flower number for marigold; however, lantana grown in 100%

WholeTree substrates had the fewest flowers. Petunias grown in an industry standard peat blend substrate had over twice the number of flowers than was observed on plants grown in other substrates. In general, plants grown in *WholeTree* substrates were smaller than plants in other blends, but plants increased in size with increasing peat moss percentage.

Literature cited

Bilderback, T.E., W.C. Fonteno, and D.R. Johnson. 1982. Physical properties of media composed of peanut hulls, pine bark and peat moss and their effects on azalea growth. J. Amer. Soc. Hort. Sci. 107:522-525.

Boyer, C.R., G.B. Fain, C.H. Gilliam, T.V. Gallagher, H.A. Torbert, and J.L. Sibley. 2006a. Alternative substrates for bedding plants. Proc. Southern Nurs. Assoc. Res. Conf. 51:22-25.

Boyer, C.R., G.B. Fain, C.H. Gilliam, T.V. Gallagher, H.A. Torbert, and J.L. Sibley. 2006b. A new substrate for container-grown plants: Clean Chip Residual. Proc. Intl. Plant Prop. Soc. 56:553-559.

Boyer, C.R., G.B. Fain, C.H. Gilliam, T.V. Gallagher, H.A. Torbert, and J.L. Sibley. 2007. Clean chip residual (CCR) substrate for container-grown perennials: Effect of supplemental nitrogen rates. HortScience 42:439. Abstr.

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 (In Press).

Davidson, H., R. Mecklenburg, and C. Peterson. 2000. Nursery management: Administration and culture. 4th ed. Prentice Hall, Upper Saddle River, N. J.

Fain, G.B. and C.H. Gilliam. 2006. Physical properties of media composed of ground whole pine trees and their effects on vinca (*Catharanthus roseus*) growth. HortScience 40:510. Abstr.

Fain, G.B., C.H. Gilliam, J.L. Sibley, and C.R. Boyer. 2006. Evaluation of an alternative, sustainable substrate for use in greenhouse crops. Proc. Southern Nurs. Assoc. Res. Conf. 51:651-654.

Gruda, N. and W.H. Schnitzler. 2003. Suitability of wood fiber substrate for production of vegetable transplants II. The effect of wood fiber substrates and their volume weights on the growth of tomato transplants. Scientia Hort. 100:333-340.

Kenna, S.W. and C.E. Whitcomb. 1985. Hardwood chips as an alternative medium for container plant production. HortScience 20:867-869.

Laiche, A.J. Jr. 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.

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.

Mills, H.A. and J.B. Jones. 1996. Plant analysis handbook II. MicroMacro Publishing. Athens, Ga.

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

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

Wright, R.D., J.F. Browder, and B.E. Jackson. 2006. Ground pine chips as a substrate for container-grown woody nursery crops. J. Environ. Hort. 24:181-184.

Yeager, T., T. Bilderback, D. Fare, C. Gilliam, J. Lea-Cox, A. Niemiera, J. Ruter, K. Tilt, S. Warren, T. Whitwell, and R. Wright. 2007. Best management practices: Guide for producing nursery crops. 2nd ed. Southern Nursery Assn., Atlanta, Ga.

Table 4.1. Physical properties of pine bark-based and clean chip residual-based substrates (Auburn)[z].

Substrates[y]	Air space[x] (% Vol)	Container capacity[w] (% Vol)	Total porosity[v] (% Vol)	Bulk density ($g \cdot cm^{-3}$)[u]
3.2 cm (1.25 in) CCR	65 a[t]	27 c	92 a	0.11 d
1.9 cm (0.75 in) CCR	62 a	29 b	91 a	0.12 c
1.3 cm (0.50 in) CCR	52 b	37 a	89 b	0.13 b
1.0 cm (0.38 in) CCR	52 b	38 a	90 b	0.13 b
PB	47 c	37 a	84 c	0.15 a
Recommended range[s]	*10-30*	*45-65*	*50-85*	*0.19-0.70*

[z] Analysis performed using the North Carolina State University porometer.

[y] PB = pine bark, CCR = clean chip residual, 1 cm = 0.394 inch.

[x] Air space is volume of water drained from the sample ÷ volume of the sample.

[w] Container capacity is (wet weight - oven dry weight) ÷ volume of the sample.

[v] Total porosity is container capacity + air space.

[u] Bulk density after forced-air drying at 105°C (221.0 °F) for 48 h; 1 $g \cdot cm^{-3} = 62.4274\ lb/ft^3$.

[t] Means within column follwed by the same letter are not significantly different based on Waller-Duncan k ratio *t* tests at $\alpha = 0.05$ (n = 3).

[s] Recommended ranges as reported by Yeager et al., 2007. Best Management Practices Guide for Producing Container-Grown Plants.

Table 4.2. Particle size analysis of pine bark-based and clean chip residual-based substrates (Auburn).

		Substrate^{y}				
U.S. standard sieve no.	**Sieve opening (mm)**^{z}	**3.2 cm (1.25 in) CCR**	**1.9 cm (0.75 in) CCR**	**1.3 cm (0.50 in) CCR**	**1.0 cm (0.38 in) CCR**	**PB**
1/2	12.50	3.2 a^{z}	0.4 b	0.1 b	0.0 b	0.0 b
3/8	9.50	8.5 a	2.2 b	0.1 b	0.0 b	0.1 b
1/4	6.35	17.9 a	10.3 b	3.4 d	1.3 d	6.5 c
6	3.35	25.5 a	33.4 a	29.9 a	25.5 a	26.2 a
8	2.36	17.9 b	19.6 b	23.4 a	23.1 a	14.7 c
10	2.00	6.2 c	7.5 b	9.6 a	9.7 a	5.6 c
14	1.40	9.2 d	11.5 c	14.1 ab	15.4 a	12.9 bc
18	1.00	4.7 d	6.4 c	8.1 b	9.3 ab	9.6 a
35	0.50	4.1 d	5.5 cd	7.2 c	9.1 b	14.2 a
60	0.25	1.6 d	1.7 cd	2.6 c	4.1 b	6.1 a
140	0.11	0.8 c	0.8 c	1.1 c	1.9 b	2.6 a
270	0.05	0.3 c	0.3 c	0.3 c	0.5 b	0.9 a
pan	0.00	0.1 a	0.4 a	0.1 a	0.1 a	0.6 a
Texture^{w}						
Coarse		55.1 a	46.3 b	33.6 c	26.8 d	32.7 cd
Medium		37.9 c	45.0 b	55.1 a	57.5 a	42.9 b
Fine		7.0 d	8.7 cd	11.3 c	15.7 b	24.4 a

[z] 1 mm = 0.0394 inch.

[y] PB = pine bark, CCR = clean chip residual, 1 cm = 0.394 inch.

[x] Percent weight of sample collected on each screen, means within row followed by the same letter are not significantly different based on Waller-Duncan k ratio *t* tests at $\alpha = 0.05$ (n = 3).

[w] *Coarse* = > 3.35 mm; *Medium* = > 1.00- < 3.35 mm; *Fine* = < 1.0 mm.

Table 4.3. Substrate electrical conductivity (EC) and pH for pine bark-based and clean chip residual-based substrates in a container-grown perennial study at two locations.

Substrate^{z}	EC (mS·cm^{-1})^{x}	pH	EC (mS·cm^{-1})	pH	EC (mS·cm^{-1})	pH	EC (mS·cm^{-1})	pH	EC (mS·cm^{-1})	pH	EC (mS·cm^{-1})	pH	EC (mS·cm^{-1})	pH
Auburn, AL	**16 DAP^{y}**		**31 DAP**		**59 DAP**		**92 DAP**		**141 DAP**		**258 DAP**		**377 DAP**	
3.2 cm (1.25 in) CCR	0.31 ^{ns}	6.4 a^{w}	0.42 ns	6.3 a	0.47 ^{ns}	6.0 a	0.41 ^{ns}	6.3 b	0.23 ^{ns}	6.4 ab	0.15 a	6.4 a	0.34 ^{ns}	6.3 a
1.9 cm (0.75 in) CCR	0.39	6.4 a	0.38	6.4 a	0.48	5.8 a	0.31	6.5 a	0.22	6.4 a	0.14 a	6.4 a	0.31	6.3 a
1.3 cm (0.50 in) CCR	0.44	6.4 a	0.52	6.3 a	0.44	5.9 a	0.33	6.4 a	0.21	6.3 b	0.11 b	6.3 a	0.34	6.1 a
1.0 cm (0.38 in) CCR	0.36	6.4 a	0.45	6.4 a	0.43	5.3 b	0.32	6.4 a	0.20	6.3 ab	0.11 b	6.3 a	0.46	6.0 ab
PB	0.38	5.9 b	0.52	5.0 b	0.55	4.8 c	0.34	6.0 c	0.18	5.9 c	0.11 b	5.8 b	0.28	5.7 b
Poplarville, MS	**16 DAP**		**30 DAP**		**61 DAP**		**98 DAP**		**128 DAP**		**238 DAP**		**374 DAP**	
3.2 cm (1.25 in) CCR	0.35 ^{ns}	6.9 ^{ns}	0.38 ^{ns}	6.9 ^{ns}	0.41 ^{ns}	6.5 ^{ns}	0.13 ^{ns}	6.6 ^{ns}	0.10 ^{ns}	6.5 ^{ns}	0.10 ^{ns}	6.5 ab	0.11 ^{ns}	5.7 ^{ns}
1.9 cm (0.75 in) CCR	0.39	6.9	0.35	6.8	0.67	6.3	0.14	6.7	0.36	6.5	0.08	6.7 a	0.14	5.0
1.3 cm (0.50 in) CCR	0.34	6.9	0.42	6.9	0.55	6.3	0.14	6.6	0.12	6.5	0.10	6.4 bc	0.20	5.2
1.0 cm (0.38 in) CCR	0.50	6.9	0.43	7.0	0.83	6.3	0.14	6.6	0.17	6.4	0.10	6.2 c	0.23	4.1
PB	0.42	6.9	0.47	6.9	0.68	6.2	0.16	6.4	0.13	6.1	0.08	6.2 c	0.18	4.5

[z] PB = pine bark, CCR = clean chip residual, 1 cm = 0.394 inch.

[y] DAP = days after planting. Auburn plants were planted on 6 June 2006, Poplarville plants were planted on 14 June 2006. All plants were topdressed with 7 lb per yd^{3} 19-6-12 Polyon control release fertilizer on 23 February 2007.

[x] 1 mS·cm^{-1} = 1 mmho/cm.

[w] Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio *t* tests at α = 0.05 (n = 4).

[ns] Means not significantly different.

Table 4.4. Effects of pine bark-based and clean chip residual-based substrates on growth of *Loropetalum chinensis* var. rubrum at two locations.

Substrate[z]	Growth index[x]				Percent rootball coverage[w]	Shoot dry weight (g)[v]
Auburn, AL	**55 DAP[y]**	**92 DAP**	**141 DAP**	**373 DAP**	**373 DAP**	**377 DAP**
3.2 cm (1.25 in) CCR	20.4 [ns]	25.2 b[u]	33.2 c	58.0 bc	57.5 c	60.3 c
1.9 cm (0.75 in) CCR	22.9	31.4 a	41.2 a	66.6 a	71.9 b	81.7 abc
1.3 cm (0.50 in) CCR	21.3	29.3 ab	40.3 ab	62.4 abc	77.5 ab	88.5 ab
1.0 cm (0.38 in) CCR	20.0	28.2 ab	42.1 a	63.3 ab	83.1 ab	99.7 a
PB	20.0	25.0 b	35.8 bc	57.1 c	85.0 a	76.4 bc
Poplarville, MS	**62 DAP**	**97 DAP**	**128 DAP**	**373 DAP**	**373 DAP**	**373 DAP**
3.2 cm (1.25 in) CCR	24.4 [ns]	35.9 [ns]	41.6 [ns]	60.2 [ns]	55.0 [ns]	124.1 b
1.9 cm (0.75 in) CCR	22.5	30.8	37.2	59.8	46.7	130.1 b
1.3 cm (0.50 in) CCR	24.5	32.2	38.2	62.8	46.7	131.0 b
1.0 cm (0.38 in) CCR	25.7	34.8	40.8	65.6	60.0	134.1 b
PB	24.4	34.2	40.6	64.1	48.3	160.8 a

[z] PB = pine bark, CCR = clean chip residual, 1 cm = 0.394 inch.

[y] DAP = days after planting.

[x] Growth index = (height + width1 + width2) / 3.

[w] Percent rootball coverage was rated on a scale of 0-100% coverage of the rootball by roots.

[v] 1 g = 0.0353 oz.

[u] Means within column followed by the same letter are not significantly different based onWaller-Duncan k ratio *t* tests at α =0.05 (n = 8).

[ns] Means not significantly different.

Table 4.5. Tissue nutrient content of *Loropetalum chinensis var. rubrum* grown in pine bark-based and clean chip residual-based substrates at two locations.

Substrate^z	**Tissue Nutrient Content**^{y}										
Auburn, AL	**N (%)**	**P (%)**	**K (%)**	**Ca (%)**	**Mg (%)**	**S (%)**	**B (ppm)**	**Fe (ppm)**	**Mn (ppm)**	**Cu (ppm)**	**Zn (ppm)**
3.2 cm (1.25 in) CCR	1.4 ^{ns}	0.13 ^{ns}	0.86 a^x	1.4 b	0.20 ^{ns}	0.16 ^{ns}	18 ^{ns}	50 ^{ns}	45 ^{ns}	7 ^{ns}	27 ^{ns}
1.9 cm (0.75 in) CCR	1.4	0.13	0.82 ab	1.4 b	0.20	0.15	19	49	40	10	33
1.3 cm (0.50 in) CCR	1.3	0.12	0.70 c	1.4 b	0.19	0.14	19	48	35	10	33
1.0 cm (0.38 in) CCR	1.3	0.13	0.74 bc	1.6 ab	0.21	0.14	20	59	33	10	31
PB	1.3	0.12	0.75 abc	1.7 a	0.20	0.15	17	48	38	7	31
Poplarville, MS											
3.2 cm (1.25 in) CCR	1.4 a	0.17 a	0.74 ^{ns}	1.0 ^{ns}	0.17 b	0.15 ^{ns}	15 ^{ns}	41 c	37 ^{ns}	6 a	13 b
1.9 cm (0.75 in) CCR	1.4 a	0.16 a	0.74	1.1	0.19 a	0.15	18	53 a	38	6 a	23 a
1.3 cm (0.50 in) CCR	1.4 a	0.15 a	0.71	1.0	0.18 ab	0.15	16	48 ab	37	5 ab	15 b
1.0 cm (0.38 in) CCR	1.4 a	0.15 a	0.75	1.1	0.19 a	0.15	18	47 b	39	5 ab	17 ab
PB	1.1 b	0.13 b	0.67	1.2	0.18 ab	0.13	17	44 bc	29	3 b	14 b
Suffiencieny range ^{w}	*1.43-1.90*	*0.10-0.13*	*0.40-0.52*	*2.0-2.9*	*0.13-0.15*	*0.12-0.14*	*55-126*	*58-69*	*15-35*	*4-6*	*7-10*

^{z}PB = pine bark, CCR = clean chip residual, 1 inch = 2.54 cm.

^{y}Tissue analysis performed on 20 terminal shoots (5.1 cm-7.6 cm or 2-3 in of most recently mature leaves) per plant on 15 June 2007; N = nitrogen, P = phosphorous, K = potassium, Ca = calcium, Mg = magnesium, S = sulfur, B = boron, Fe = iron, Mn = manganese, Cu = copper, Zn = zinc, 1 ppm = 1 mg·kg^{-1}.

^{x}Means within column and location followed by the same letter are not signicantly different based on Waller-Duncan k ratio t tests (α =0.05, n = 4).

^{w}Sufficiency range published by Mills and Jones (1996).

^{ns}Means not significantly different.

Table 4.6. Effects of pine bark-based and clean chip residual-based substrates on growth of *Buddleia davidii* 'Black Knight' at two locations.

Substrate[z]	Growth index[x]				Leaf chlorophyll content[w]				Number of inflorescences		Percent rootball coverage[v]	Shoot dry weight (g)[u]
Auburn, AL	**55 DAP[y]**	**92 DAP**	**141 DAP**	**373 DAP**	**63 DAP**	**92 DAP**	**141 DAP**	**373 DAP**	**62 DAP**	**92 DAP**	**373 DAP**	**377 DAP**
3.2 cm (1.25 in) CCR	43.8 [ns]	68.9 b[t]	83.6 [ns]	101.8 [ns]	53.6 [ns]	49.1 [ns]	53.1 [ns]	54.8 [ns]	6.3 [ns]	10.8 [ns]	72.5 c	145.4 [ns]
1.9 cm (0.75 in) CCR	44.3	68.3 b	79.8	96.5	54.4	47.9	53.8	55.4	5.1	9.8	75.0 bc	136.6
1.3 cm (0.50 in) CCR	43.5	74.5 ab	78.7	85.9	53.2	48.3	50.5	56.2	8.0	8.3	85.0 ab	128.2
1.0 cm (0.38 in) CCR	42.9	77.6 ab	88.0	97.6	52.2	50.4	52.1	54.9	7.5	12.4	90.0 a	152.4
PB	45.1	80.8 a	87.2	98.4	52.2	49.6	52.8	54.8	8.3	14.5	93.1 a	162.4
Poplarville, MS	**62 DAP**	**98 DAP**	**128 DAP**	**372 DAP**	**62 DAP**	**98 DAP**	**128 DAP**	**372 DAP**	**62 DAP**	**98 DAP**	**372 DAP**	**372 DAP**
3.2 cm (1.25 in) CCR	39.3 ab	58.4 [ns]	66.6 a	94.0 [ns]	53.3 [ns]	59.3 [ns]	59.5 a	51.3 [ns]	5.4 [ns]	6.8 [ns]	18.3 [ns]	138.1 [ns]
1.9 cm (0.75 in) CCR	36.0 b	51.6	56.6 b	96.3	52.7	56.8	55.8 b	51.6	4.5	3.9	20.0	140.4
1.3 cm (0.50 in) CCR	41.6 ab	55.4	61.4 ab	99.8	54.5	54.5	59.7 a	49.4	5.1	7.0	23.3	148.7
1.0 cm (0.38 in) CCR	45.6 a	60.3	62.1 ab	98.1	57.1	56.8	57.0 b	49.7	7.6	6.5	25.0	155.0
PB	39.0 b	57.4	62.3 ab	96.5	54.4	56.3	54.9 b	50.2	5.8	6.0	35.0	153.6

[z] PB = pine bark, CCR = clean chip residual, 1 cm = 0.394 inch.

[y] DAP = days after planting. Auburn plants were potted on 6 June 2006, Poplarville plants were potted on 14 June 2006.

[x] Growth index = (height + width1 + width2) / 3.

[w] Leaf chlorophyll content quantified using a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ) (average of 4 leaves per plant).

[v] Percent rootball coverage was rated on a scale of 0-100% coverage of the rootball by roots.

[u] 1 g = 0.0353 oz.

[t] Means within column followed by the same letter are not significantly different based onWaller-Duncan k ratio *t* tests at $\alpha = 0.05$ (n = 8).

[ns] Means not significantly different.

Table 4.7. Effects of pine bark-based and clean chip residual-based substrates on growth of *Lagerstroemia indica* 'Hopi' (Auburn) and *Lagerstroemia* x *fauriei* 'Natchez' (Poplarville)'.

Substrate^{z}	**Growth index^{x}**				**Leaf chlorophyll content^{w}**				**Percent rootball coverage^{v}**	**Shoot dry weight (g)^{u}**
Auburn, AL	**55 DAP^{y}**	**92 DAP**	**141 DAP**	**373 DAP**	**63 DAP**	**93 DAP**	**141 DAP**	**373 DAP**	**373 DAP**	**377 DAP**
3.2 cm (1.25 in) CCR	49.8 ^{ns}	46.3 ^{ns}	54.5 ^{ns}	64.0 ^{ns}	60.0 ^{ns}	66.2 ^{ns}	63.6 ^{ns}	49.4 ^{ns}	86.9 ^{ns}	81.2 ^{ns}
1.9 cm (0.75 in) CCR	46.9	45.5	51.5	64.5	56.5	60.4	60.6	49.4	76.3	83.0
1.3 cm (0.50 in) CCR	44.9	45.9	51.7	68.6	57.6	62.6	61.6	48.9	90.0	94.3
1.0 cm (0.38 in) CCR	41.0	40.6	45.8	65.4	58.2	61.6	62.2	48.1	81.9	87.7
PB	42.6	42.9	48.2	67.1	58.3	61.9	64.1	49.4	88.1	89.3
Poplarville, MS	**62 DAP**	**97 DAP**	**128 DAP**	**371 DAP**	**62 DAP**	**97 DAP**	**128 DAP**	**371 DAP**	**371 DAP**	**371 DAP**
3.2 cm (1.25 in) CCR	59.5 ^{ns}	74.4 ^{ns}	74.2 ^{ns}	101.9 ^{ns}	52.6 ^{ns}	51.3 ^{ns}	47.3 ^{ns}	51.0 ^{ns}	85.0 ^{ns}	185.7 b^{t}
1.9 cm (0.75 in) CCR	56.0	71.8	72.7	99.6	51.3	51.7	48.5	51.6	86.7	186.2 b
1.3 cm (0.50 in) CCR	55.7	72.7	69.4	101.9	53.3	54.7	50.6	50.4	86.7	203.4 b
1.0 cm (0.38 in) CCR	59.1	75.3	75.6	96.9	53.1	52.4	49.9	49.4	81.7	204.3 b
PB	56.0	73.6	74.6	104.5	49.8	52.6	48.9	49.1	86.7	247.4 a

[z] PB = pine bark, CCR = clean chip residual, 1 cm = 0.394 inch.

[y] DAP = days after planting. Auburn plants were potted on 6 June 2006, Poplarville plants were potted on 14 June 2006.

[x] Growth index = (height + width1 + width2) / 3.

[w] Leaf chlorophyll content quantified using a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ) (average of 4 leaves per plant).

[v] Percent rootball coverage was rated on a scale of 0-100% coverage of the rootball by roots.

[u] 1 g = 0.0353 oz.

[t] Means within column followed by the same letter are not significantly different based onWaller-Duncan k ratio *t* tests at α =0.05 (n = 8).

[ns] Means not significantly different.

Table 4.8. Effects of pine bark-based and clean chip residual-based substrates on growth of azalea (*Rhododendron indicum* 'Mrs. G.G. Gerbing') at two locations.

Substrate[z]	**Growth index**[x]				**Leaf chlorophyll content**[w]			**Percent rootball coverage**[v]	**Shoot dry weight (g)**[u]
Auburn, AL	**63 DAP**[y]	**89 DAP**	**144 DAP**	**373 DAP**	**89 DAP**	**144 DAP**	**373 DAP**	**373 DAP**	**377 DAP**
3.2 cm (1.25 in) CCR	15.1 [ns]	15.1 [ns]	16.8 [ns]	33.9 [ns]	49.1 [ns]	54.4 [ns]	51.9 [ns]	66.3 b[t]	26.3 [ns]
1.9 cm (0.75 in) CCR	15.6	16.0	16.5	33.2	46.2	55.8	53.5	69.4 b	21.1
1.3 cm (0.50 in) CCR	13.8	14.4	14.8	33.8	52.5	56.8	53.3	70.6 b	24.8
1.0 cm (0.38 in) CCR	15.1	15.2	16.3	34.4	48.7	50.1	56.1	71.3 b	22.4
PB	15.2	15.1	16.5	38.2	53.7	59.1	53.1	93.8 a	30.5
Poplarville, MS	**62 DAP**	**97 DAP**	**128 DAP**	**373 DAP**	**97 DAP**	**128 DAP**	**373 DAP**	**373 DAP**	**373 DAP**
3.2 cm (1.25 in) CCR	20.4 [ns]	23.6 a	23.8 a	38.0 [ns]	55.7 [ns]	56.7 [ns]	51.2 [ns]	33.3 [ns]	37.8 [ns]
1.9 cm (0.75 in) CCR	18.5	20.2 b	20.5 b	39.0	52.8	56.2	50.1	35.0	38.1
1.3 cm (0.50 in) CCR	19.6	21.7 ab	21.8 ab	37.6	52.3	54.6	50.3	40.0	35.2
1.0 cm (0.38 in) CCR	18.6	20.4 b	20.4 b	37.6	48.9	49.2	49.6	33.2	27.9
PB	19.3	20.7 b	20.9 b	37.8	51.7	52.7	49.7	50.0	40.5

[z] PB = pine bark, CCR = clean chip residual, 1 cm = 0.394 inch.

[y] DAP = days after planting. Auburn plants were potted on 6 June 2006, Poplarville plants were potted on 14 June 2006.

[x] Growth index = (height + width1 + width2) / 3.

[w] Leaf chlorophyll content quantified using a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ) (average of 4 leaves per plant).

[v] Percent rootball coverage was rated on a scale of 0-100% coverage of the rootball by roots.

[u] 1 g = 0.0353 oz.

[t] Means within column followed by the same letter are not significantly different based onWaller-Duncan k ratio *t* tests at α =0.05 (n = 8).

[ns] Means not significantly different.

Table 4.9. Effects of pine bark-based and clean chip residual-based substrates on substrate shrinkage in container.

Substrate[z]	**Substrate shrinkage (cm)** [y]				
		Loropetalum	**Buddleia**	**Crapemyrtle**	**Azalea**
Auburn, AL	**7 DAP**[x]	**373 DAP**	**373 DAP**	**373 DAP**	**373 DAP**
3.2 cm (1.25 in) CCR	0.5 [ns]	2.9 a[w]	1.4 a	2.3 a	4.3 a
1.9 cm (0.75 in) CCR	0.3	2.1 b	1.1 ab	1.8 ab	3.8 a
1.3 cm (0.50 in) CCR	0.3	1.9 b	1.1 ab	1.4 bc	3.9 a
1.0 cm (0.38 in) CCR	0.2	2.1 b	0.9 b	1.9 ab	4.1 a
PB	0.3	1.9 b	0.8 b	1.3 c	2.3 b
Poplarville, MS	**15 DAP**	**372 DAP**	**373 DAP**	**371 DAP**	**373 DAP**
3.2 cm (1.25 in) CCR	2.4 ab	3.7 [ns]	2.1 ab	1.8 a	4.6 [ns]
1.9 cm (0.75 in) CCR	2.7 a	3.4	2.3 a	1.7 a	4.2
1.3 cm (0.50 in) CCR	2.6 ab	3.6	2.0 b	1.7 a	4.4
1.0 cm (0.38 in) CCR	2.2 bc	3.4	2.1 ab	1.8 a	4.3
PB	1.9 c	2.8	1.4 c	0.9 b	4.5

[z] PB = pine bark, CCR = clean chip residual.

[y] Measured from the top of the container to the surface of the substrate.

[x] DAP = days after planting. Auburn plants were potted on 6 June 2006, Poplarville plants were potted on 14 June 2006.

[w] Means within column followed by the same letter are not significantly different based onWaller-Duncan k ratio *t* tests at α =0.05 (n = 8).

[ns] Means not significantly different.

CHAPTER V

Characterization of Clean Chip Residual in the Southeast U.S.

Abstract

A survey was conducted in the Southeast U.S. among individuals and companies conducting chipping operations on pine plantations for the production of pulpwood in the forest industry. Fourteen operators in four states (AL, MS, GA, FL) were visited or interviewed over the phone in order to evaluate the status of residual material on site. Residual chipping material (also called clean chip residual or CCR) has potential use as a growth substrate in the nursery and greenhouse horticultural industries. Samples analysis of CCR was performed which revealed that CCR is composed of 37.7% wood, 36.6% bark, 8.8% needles, and 16.9% indistinguishable (fine) particles. Survey participants estimated that approximately 27.5% of the site biomass is composed of CCR. Some growers were able to sell CCR as fuelwood to pulp mills while others did not recover the residual material, leaving it on the forest floor (44.3%). Many different operations were included in this survey including typical chipping and grinding operations, woodyards and pine plantations burned by wildfire. Several loggers were interested in making CCR available to horticultural industries if a profit could be made from the material.

Introduction

Production of plants in a nursery or greenhouse environment is an essential component of the green industry in the Southeast U.S. Plants grown in this region of the country are shipped throughout the continental U.S., contributing to the economy and the green industry as a whole.

Plants grown for the landscape market are either harvested from the field with partial rootballs intact or produced in a container with a self-contained root environment (Davidson et al., 2000). Plants produced in the latter fashion are grown, shipped, and planted in the same substrate material. Thus the substrate is sold with the plant and further production needs must be replenished with each new container. Substrates for the nursery and greenhouse industries are an important part of production costs.

Nursery substrates are composed primarily of pine bark (PB), a once plentiful waste by-product of the forest industry (Davidson et al., 2000). In recent years, however, forest product production has moved from debarking logs at the mill (thus the surplus bark) to processing trees in the field (and leaving waste material on the forest floor). Additionally, PB is increasingly being used as a source of clean fuel in many markets (Lu et al., 2006). Competition for PB coupled with a decrease in collection of waste PB has led to a steady decline in the availability of PB for horticultural uses. Many growers have been informed by their PB suppliers that they will not be able to fill orders in the coming years. Thus, decreased availability is resulting in price increases for PB that many growers cannot sustain.

Greenhouse substrates are composed primarily of Canadian-based sphagnum peat moss, a slowly renewable resource (Nelson, 2003). Prices for peat moss have also been increasing every year, in part due to increased fuel costs. A local, sustainable and economical substrate could potentially alleviate concerns about substrate costs for many growers.

Loblolly pine plantations, primarily in the southeast U.S. (Fig. 5.1), provide a variety of wood products to the consumer market (Little, 1971). Sawtimber, utility poles, and paper are just some of the finished products available (Whalenberg, 1960). While the most valuable product collected is ‘clean chips’ for paper products, the remainder material is generally left on site and sometimes spread back across the harvested area. Some loggers are able to sell this ‘clean chip residual’ (CCR, energywood or fuelwood) material as boiler fuel for pulp mills if the site is within a 40-mile radius. Sites further away from the pulp mill generally do not provide enough income for loggers to haul to the mill and continue to make a profit.

Forest residues are defined by the forest industry as the remaining woody biomass, usually considered un-merchantable, left on site after harvesting merchantable stand and tree components (Stokes et al., 1989). Residual materials in the stand or at the landing (machine area) are the limbs, tops, and cull portions of the merchantable and un-merchantable trees. In a more intensive integrated harvesting system that produces pulp chips, the only residues would be the limbs, tops and broken sections of the trees and the small trees too small for chipping. In all cases, the residues are woody biomass components not recovered by the harvesting system (Stokes et al., 1989). When the trees or residual material are chipped, with limbs, tops, and bark attached, the chips have limited use for making paper pulp and composite panel products (Stokes and Watson, 1991). Usually material with such a high bark content is only suitable as energywood to produce electricity and steam. Clean chips for pulping can be produced in the woods by de-limbing and de-barking before chipping (Stokes and Sirois, 1986; Stokes et al., 1989).

In the 1970's a move toward in field harvesting began to occur. At that time logging residues were available at a free stumpage rate since such material must be destroyed or removed to regenerate the next stand (Watson, et al., 1987). Later, a study by Stokes and Watson (1988) stated that increasing the utilization of the woody biomass provided additional revenues from the site as well as reducing site preparation costs which makes tree planting easier. The usual disposal of residual is an additional cost charged to the clean chips; processing the material turns the residues into a positive cash flow (Baughman et al., 1990). Increasing the use of residual reduces site preparation costs, which leads to lower regeneration costs and improved stocking and production from the forest land base (Stokes et al., 1989). If residues from flailing are recovered, over 84% of the total tree biomass can be recovered as pulp fiber and residual (Stokes and Watson, 1988).

Studies with in-woods flailing and chipping have revealed high chip quality and increased biomass recovery (Stokes and Watson, 1988; 1991). Three products result from the combined flail/chip process: flail residues, chipper rejects, and chips. The majority of the material is 'clean chips' for pulp (about 82.1%). The flail residues, characterized as limbs, tops, foliage, and bark, accounted for 14.7% of the whole-tree biomass in a study by Stokes and Watson (1988) utilizing slash pine (*Pinus elliottii*). Chipper rejects from the chipper separator accounted for 3.2% of the whole tree for a total residue harvest of 17.9%. A separate study by Baughman et al. (1990) indicated that residual yield as a percent of the total volume of chips and residual produced averaged 26.5% with a minimum of 24.8% and a maximum of 28.9%. Total CCR recovery from a flail/chip process was 39.4% in a study by Stokes (1998) with Loblolly pine, which compares favorably with site residue biomass estimate data of 27.5% in the current study with Loblolly pine. The range of yield data can be attributed to the amount of biomass available in the stand in the form of green limbs and needles on the stems. This is, in turn, a function of age of the stand, site, stocking and previous silvicultural history (Baughman et al., 1990; Whalenberg, 1960; Burns and Honkala, 1990; Andrulot et al., 1972; and Brender, 1973). Trailer loads of processed residual ranged from 17.8 to 20.9 green tonnes (Baughman et al, 1990).

Clean chip residual is a potential alternative to PB and peat moss for nursery and greenhouse substrates. This material is currently a by-product of the chipping industry yet it contains a high bark content rendering it suitable for plant growth. Loblolly pine is ideal as a plant production substrate in the Southeast. The range of loblolly extends through 14 states from southern New Jersey south to central Florida and west to eastern Texas (Fig. 5.1). Loblolly pine is used extensively in forest plantations due to responsiveness to management practices, adaptability, and good wood quality (Burns and Honkala, 1990). Loblolly pine has also been shown to have lower levels of polyphenolics (which may be toxic to tender seedlings) than other pine species (Rau et al., 2006).

Clean chip residual has been evaluated as a growth substrate for annuals, perennials and woody crops. A study by Boyer et al. (2006a) demonstrated that *Ageratum* and *Salvia* grown in CCR or combinations of CCR and peat produced similarly sized plants when compared to a traditional pine bark substrate. Later, Boyer et al. (2006b) evaluated perennials (buddleia and verbena) in CCR and reported similar results among all treatments. A further study indicated that use of supplemental nitrogen was not necessary for growth of buddleia (Boyer et al., 2007b). A woody crop, *Loropetalum chinensis* ‘Ruby’ was evaluated for growth in CCR over the course of one year (Boyer et al., 2007a). Results for woody species were similar to growth responses of annual and perennial crops. Since the use of CCR as a nursery and greenhouse substrate is currently being evaluated for plant growth response, it is prudent to characterize the availability and properties of CCR.

Materials and methods

Fourteen chipping operations were surveyed in person or by phone in the summer of 2007. Potential survey participants were identified by contacting sales representatives of companies which manufacture forest harvesting equipment (Peterson-Pacific and Morbark) as well as foresters in Alabama, Mississippi, Georgia and Florida. Since few companies manufacture and service this equipment, which requires a significant capital investment, it is reasonable to assume that they are aware of most of the chipping operations in the Southeast U.S. Since chipping operations generally move locations daily, it was challenging to interview every company identified in the search. While 14 operations were available for interview, it is believed that there may be up to 30 such roving operations in the Southeast U.S.

Conversations were conducted with individual loggers in an effort to answer the 14 questions in a survey. Samples, if available and usable (ground a second time as CCR) were obtained by filling two 5-gallon buckets with fresh material, weighing, and evaluating the age and height of the stand. Samples were further evaluated by sending subsamples to Brookside Laboratories, Inc. (New Knoxville, Ohio) for soil-less media nutrient analysis. Substrate N was determined by combustion analysis using a 1500 N analyzer (Carlo Erba, Milan, Italy). Remaining nutrients were determined by microwave digestion with inductively coupled plasma-emission spectrometry (ICP) (Thermo Jarrel Ash, Offenbach, Germany). Three subsamples from each location were dried in a 105 °C forced air oven for 48 h before being separated into components (bark, wood, needles and indistinguishable). Indistinguishable material was particles too fine to determine whether they were bark, wood or needles. Data were analyzed using Waller-Duncan k ratio t tests ($P \leq 0.05$) using a statistical software package (SAS® Institute, Cary, N.C.).

Results and discussion

We visited the following locations in order to survey the availability and characteristics of CCR in the Southeast U.S. Most sites were in the forest, but one was a woodyard and another was a landfill recovery operation. Every attempt was made to obtain an accurate sample and to define production at each site.

Cuthbert, GA

This chipping operation had a very favorable wquipment layout for the production of CCR. They were chipping a stand of 14 year-old (average diameter at breast height, DBH, of 6 inches and approximately 50 feet-tall) loblolly pine with a Morbark Model 23 Flail Total Chip Harvester with an attached Morbark tub grinder. The grinder was blowing residual material into the back of a truck/van for direct shipping to the mill for use as fuel; no material was left on the ground for any length of time. The resulting residual contained 44.7% wood, 35.7% bark, 12.1% needles and 7.5% indistinguishable

(Table 5.1). All of their residual was sold for fuel and they estimated that 25% of the site biomass was residual. Screens on the grinder were 3 by 5-inches and they were rarely changed. Preference was to use as large a screen as possible in order to minimize diesel fuel costs and still make an acceptable material for the market.

Dothan, GA

The Dothan company operated separate operations for chipping and grinding. One grinding crew (Peterson 4700B) followed two chipping crews and two longwood crews so some residual material sat on-site for 2-3 months before grinding. The grinding crew could produce 12-15 truck/van loads per day of biomass to be sold as fuel. A sample could not be obtained at this site due to machine malfunction. Also, at the time of interview, the crew was cleaning up a site with old, mixed vegetation (hardwood, pine, etc.), not representative of substrates previously used in plant growth studies.

Cottondale, FL

Cottondale was a woodyard operation. Longwood (no needles, limbs or tops) were stored on site for 2-3 weeks before chipping directly into railcars. Residual from the chipping process was sold for fuel to the mill; however, while hardwood and pine wood were separated for chipping, the residual material (15% of total volume generated) was mixed (80% pine, 20% hardwood). Four-inch screens were on the grinder (Morbark horizontal grinder model 5600), but could be changed from 2- to 6-inch screens. The woodyard produced 25-40 railcars of bark (residual) per week (1 railcar holds almost 4 truck/van loads). A sample obtained from Cottondale was composed of 38.9% wood, 48.8% bark, 0.10% needles, and 12.2% indistinguishable (Table 5.1).

Waycross, GA

The Waycross site was a pine plantation (40-foot tall Loblolly) that had been subjected to an uncontrolled forest fire in the summer of 2007. Loggers at this site reported that the chip quality was good in spite of the fire. The trees were processed with a Peterson 4800 flail and a Peterson 6623 Precision chipper with a Morbark 23 grinder. No grinder was used at this site and all residual at both sites was left in the field due to a lack of market. Component analysis revealed a wood content of 14.2%, bark 68.5%, needle 8.7% and indistinguishable 8.7% (Table 5.1). It is not known whether burned wood recovery residual is suitable for plant growth.

Greenville, GA

Loggers at this site (15 year-old Loblolly plantation, DBH 6-7 inches and 40 feet-tall) were running a Peterson flail 4800 chipper and a TreeLan 23 DC chipper to produce pulpwood. Trees were de-limbed with a loader before being chipped. All residual was left on site except for the occasional fuel sale if the operation was close enough to a mill. The residual material was large due to the absence of a grinder, but a sample near the chipper revealed a wood content of 31.4%, bark 59.7%, needle 0.96% and 8.0% indistinguishable (Table 5.1).

Barnett Crossroads, AL

This 12 year-old loblolly pine stand was about 40 feet-tall and 6-inches DBH. The loggers at this site owned two chipping opertaions; one reclaimed the residual for fuel and one left residual in the field. Wood content at this site was 35.7%, bark 28.0%, needles 5.3%, and 31.0% was so fine that it was indistinguishable (Table 5.1).

Lucedale, MS

The logger at this site was performing a ‘residential cut’ (clear cut before construction) to the pine plantation. The site was young (9 years, 30-foot tall, 4-inch DBH), but revealed a wood content of 49.2%, bark 22.9%, needles 12.0% and indistinguishable of 15.9% (Table 5.1). The owner operated two identical systems with Morbark model 24 chippers and The Beast model 2680 grinders. The screens on the machines were 5- by 7-inches. The screens were rarely swapped out, but switching screens was not difficult (30 minutes to an hour labor). This logger was able to sell all residual for fuel and was able to make a profit due to close proximity to two mills. They were interested in selling residual to the horticultural industries.

Hattiesburg, MS

There were two sites where this logger was producing CCR. The first was a large landfill composed of plants and other material lost due to Hurricane Katrina. The material was mixed hardwood, pine and residential material and had been stockpiled for up to two years. The material was separated by size and sold as topsoil or as fuel. A sample obtained from this site was of unknown origins and mixed components.

A second site ran three chippers, Morbark models 27, 30, and 22 with a tub grinder for residual. Residual was either placed directly in a truck/van for sale as fuel or sat for up to six months waiting to be ground and sold for fuel. No sample was obtained at this site due to unfavorable weather conditions restricting access to the site.

Atmore, AL and Evergreen, AL

Two chippers (both Peterson Pacific DDC5000) were followed by one grinding crew (Peterson 7400) in separate operations. Residual was generally left on the ground for one to three months before grinding and sale as fuel. This logger reported that the largest profit of his operation was obtained with fuel/residual due to close proximity to several mills. Both sites were approximately 10 years old with a height of 35 feet and average DBH of 5 to 6-inches. Residual from Atmore contained 50.4% wood, 18.8% bark, 14.2% needles and 16.6% indistinguishable (Table 5.1). Residual from Evergreen contained 50.5% wood, 16.1% bark, 4.7% needles and 28.7% indistinguishable. Material obtained at Evergreen was three months older than material obtained at Atmore thus more decomposition had occurred resulting in a lower percentage of needles and higher percentage of indistinguishable (fine) particles. This logger was interested in selling residual material to the horticultural industry.

Clanton, AL

A Morbark 2438 chipper was on this site owned by an individual. A thinning operation was occurring in a 35-foot tall, 9-10 year old, 6-inch DBH loblolly pine plantation. No sample was obtained as no grinding occurred and the residual was dragged back into the forest and left on-site.

Jasper, GA

This logging company ran five crews, but only two were chipping operations. Both chippers were Petersons and no grinding was conducted as 100% of the CCR was spread back across the site. The site was young (8-9 years, 25-feet tall, average DBH of 4-inches) as it had not grown well and the site was being prepared to replant. The sample obtained from this site contained 35.4% wood, 31.3% bark, 19.2% needles and 14.1% indistinguishable (Table 5.1). The logger estimated that up to 50% of the site biomass was residual due to the young age of the plantation.

Summerville, GA

No sample was obtained from this site as the crew was working in hardwood. An interview with the owner revealed that a Peterson 5000 was the chipper (no grinder) and all of the residual was left in the woods. The owner estimated that 20% of the site biomass was residual (Table 5.1).

Adairsville, GA

The plantation at Adairsville was approximately 35-feet tall, 12 years old, and average DBH of 6-inches. The logger had two chippers, though one was down at the time; both were Petersons. This particular site was loblolly mixed with virginia pine which is not marketable. The material obtained for a sample had less wood (26.5%) than other sites as there was no grinder and the residual material was very coarse. The remainder of the sample was composed of 36.2% bark, 10.6% needles and 26.7% indistinguishable (Table 5.1). All of the residual was left on site.

Conclusions

As you can see from the previous descriptions, sites and operations varied greatly in this survey. Most were 'traditional' chipping operations and many were willing to expand their market to the horticultural industries. Residual varies depending on the plantation age, species composition, site quality, and natural actions such as fire or flood (Burns and Honkala, 1990). Overall, the composition of CCR evaluated in this study was 37.7% wood, 36.6% bark, 8.8% needles, and 16.9% indistinguishable (Table 5.1). Of the operations we interviewed, 44.3% stated that residual is left in the field (Table 5.1).

All of the residual samples were returned to the lab for analysis. Average pH for all the samples ranged from 4.3 to 5.5 which are near the recommended range (4.5 to 6.5) for plant growth (Yeager et al., 2007) (Table 5.2). Electrical conductivity (salts) was low in all samples (0.16-0.41 mmhos/cm; recommended range 0.8 to 1.5 mmhos/cm; Yeager et al., 2007). Clean chip residual can be amended similarly to traditional pine bark substrates to raise pH and EC to levels suitable for plant growth. Samples from the woodyard operation (Cottondale, FL) had high concentrations of P, Ca, Mg, and Zn when compared to other locations, but were within ranges suggested by Brookside Laboratories, Inc. (Tables 5.2 and 5.3). Other macronutrients were similar among locations and/or within suggested ranges for media and plant growth. Iron and Mn were high at several locations: Fe at Barnett Crossroads, AL, Atmore, AL, and Adairsville, GA. (Table 5.3). Manganese was high at Cottondale, FL, Lucedale, MS, Jasper, GA, and Adairsville, GA. Aluminum was high at Atmore, AL and Adairsville, GA. Other locations maintained levels of micronutrients within suggested ranges.

Two other high wood content substrates have been evaluated in the U.S. Wright and Browder (2005) conducted a short-term greenhouse study with 100% wood-fiber which showed that marigold (*Tagetes erecta*) could be grown successfully with a note that substrate fertility needed to be further evaluated. Fain et. al (2006, 2008) reported *WholeTree* could be successfully used as a growth substrate for annual vinca. *WholeTree* is composed of the entire shoot portion of trees, but has a higher (about 80%) wood-fiber content than CCR. Fain also reported that annual vinca grown in *WholeTree* were similar in size to those grown in a pine bark substrate. Clean chip residual has the potential to replace pine bark and possibly peat moss as primary nursery and greenhouse crop substrates with few changes in crop production strategies due to high wood content.

In order to make CCR available to growers, several issues will need to be worked out. Most loggers deliver chips and CCR to the mill where the entire truck is lifted off a platform and the cargo is dumped into a holding area. Nursery growers would require live bottom trailers to unload CCR. Whether the logger or the nursery grower needs to provide the trailer will have to be worked out between the two. Hiring a truck to deliver CCR in a live bottom trailer to a nursery will add costs to the material. Also, most loggers produce far more CCR than the horticultural industry can use at this point. An agreement between loggers and nursery/suppliers as to how much is needed and when would be needed. For example, if the screens on the grinder need to be changed out and a nursery/supplier only needs a few truck/van loads, it may be that the logger chooses one day a week or less to harvest for horticultural uses. If a supplier elects to carry CCR (in a similar manner to PB), they may want to provide hammer-milling services as well. Conversely, growers may want to process their own CCR to best meet immediate crop needs. In any case, CCR is a promising alternative substrate for the horticultural industries. Logistics for growers to obtain CCR will need to be worked out in the future.

Literature cited

Andrulot, A.E., L.P. Blackwell, and P.Y. Burns. 1972. Effects of thinning on yield of loblolly pine in central Louisiana. Louisiana Tech. University, Bulletin 6. Ruston. 145 p.

Baughman, R. K., B.J. Stokes, and W.F. Watson. 1990. Utilizing residues from in-woods flail processing. In: Stokes, B.J., ed. Harvesting small trees and forest residues: Proceedings of the International Energy Agency, task 6, activity 3 workshop. Auburn, AL: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 21-30.

Boyer, C.R., G.B. Fain, C.H. Gilliam, T.V. Gallagher, H.A. Torbert, and J.L. Sibley. 2006a. Alternative substrates for bedding plants. Proc. Southern Nurs. Assoc. Res. Conf. 51:22-25.

Boyer, C.R., G.B. Fain, C.H. Gilliam, T.V. Gallagher, H.A. Torbert, and J.L. Sibley. 2006b. A new substrate for container-grown plants: Clean Chip Residual. Proc. Intl. Plant Prop. Soc. 56:553-559.

Boyer, C.R., G.B. Fain, C.H. Gilliam, J.L. Sibley, T.V. Gallagher, and H.A. Torbert. 2007a. Performance of container-grown *Loropetalum* grown in clean chip residual substrate. Proc. Intl. Plant Prop. Soc. (In Press).

Boyer, C.R., G.B. Fain, C.H. Gilliam, T.V. Gallagher, H.A. Torbert, and J.L. Sibley. 2007b. Clean chip residual (CCR) substrate for container-grown perennials: Effect of supplemental nitrogen rates. HortScience 42:439. Abstr.

Brender, E.V. 1973. Silviculture of loblolly pine in the Georgia Piedmont, Georgia Forest Research Council, Report 33. Macon. 74 p.

Burns, R.M. and B.H. Honkala. 1990. Silvics of North America: 1. Conifers; 2. Hardwoods. Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, DC. 877 p.

Davidson, H., R. Mecklenburg, and C. Peterson. 2000. Nursery management: Administration and culture. 4th ed. Prentice Hall, Upper Saddle River, N. J.

Fain, G.B., C.H. Gilliam, J.L. Sibley, and C.R. Boyer. 2006. Evaluation of an alternative, sustainable substrate for use in greenhouse crops. Proc. Southern Nurs. Assoc. Res. Conf. 51:651-654.

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

Little, E.L., Jr. 1971. Atlas of United States trees. Vol. 1. Conifers and important hardwoods. U.S. Department of Agriculture, Miscellaneous Publication 1146. Washington, DC. 9 p., 313 maps.

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.

Rau, B.J., J.F. Browder, B.E. Jackson, and R.D. Wright. 2006. Wood substrates derived from a variety of tree species affect plant growth. Proc. Sou. Nurs. Assoc. 51:43-45.

Stokes, B.J. and D.L Sirois. 1986. Evaluation of chipper-forwarder biomass harvesting concept. In: Proceedings of the 1985 southern forest biomass workshop. Gainesville, FL: University of Florida: 62-67.

Stokes, B. J. and W.F. Watson. 1988. Recovery efficiency of whole-tree harvesting. In: Proceedings of the 1988 International Energy Agency Biomass Energy Agreement, A-1 technical group meeting. Rotorua, New Zealand: Forest Research Institute, Forest Management and Resources Division: 186-200.

Stokes, B. J., D.L. Sirois, and W.F. Watson. 1989. Recovery of forest residues in the Southern United States. In: Stokes, B.J., ed. Harvesting small trees and forest residues: Proceedings of the 1989 International Energy Agency, task 6, activity 3 symposium. Auburn, AL: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 32-43.

Stokes, B. J. and W.F. Watson. 1991. Wood recovery with in-woods flailing and chipping. In: Proceedings of the 1990 TAPPI pulping conference. Atlanta, GA: TAPPI Press: 851-854.

Stokes, B. J. 1998. Harvesting systems for multiple products an update for the United States. In: Wood fuels from conventional forestry: Proceedings of the 3rd annual workshop of activity 1.2, task 7, International Energy Agency Bioenergy. Auburn, AL: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 49-56.

Wahlenberg, W.G. 1960. Loblolly pine: Its use, ecology, regeneration, protection, growth, and management. Duke University, School of Forestry, Durham, NC. 603 p.

Watson, W.F., J.R. Ragan, T.J. Straka, and B.J. Stokes 1987. Economic analysis of potential fuel wood sources. In: Proceedings of the 1986 Society of American Foresters national convention. Bethesda, MD: Society of American Foresters: 339-342.

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

Yeager, T., T. Bilderback, D. Fare, C. Gilliam, J. Lea-Cox, A. Niemiera, J. Ruter, K. Tilt, S. Warren, T. Whitwell, and R. Wright. 2007. Best management practices: Guide for producing nursery crops. 2nd ed. Southern Nursery Assn., Atlanta, Ga.

Figure 5.1. Native range of *Pinus taeda* L. in the United States. Image courtesy of Little (1971) and the U.S. Forest Service.

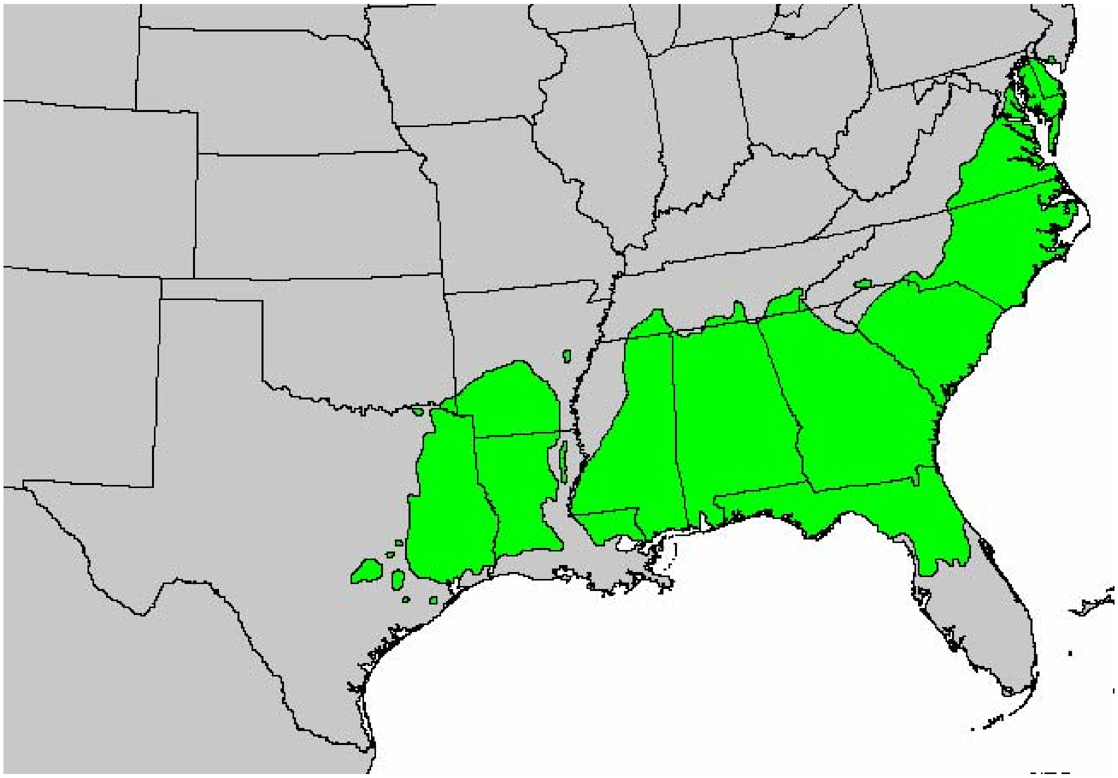


Table 5.1. Distribution of components and site biomass of CCR at several chipping sites.

Location	**Wood (%)**	**Bark (%)**	**Needle (%)**	**Indistinguishable (%)**	**Site biomass composed of CCR (%)[z]**	**CCR left in field (%)[z]**
Cuthbert, GA	44.7 a[y]	35.7 bcd	12.1 b	7.5 a	25	0
Dothan, GA	--[x]	--	--	--	--	0
Cottondale, FL	38.9 a	48.8 abc	0.10 e	12.2 a	15	0
Waycross, GA	14.2 a	68.5 a	8.7 bcd	8.7 a	--	100
Greenville, GA	31.4 a	59.7 ab	0.96 e	8.0 a	20	100
Barnett Crossroads, AL	35.7 a	28.0 cd	5.3 cde	31.0 a	35	20
Lucedale, MS	49.2 a	22.9 cd	12.0 b	15.9 a	25	0
Hattiesburg, MS	--	--	--	--	35	0
Atmore, AL	50.4 a	18.8 d	14.2 ab	16.6 a	25	0
Clanton, AL	--	--	--	--	--	100
Jasper, GA	35.4 a	31.3 cd	19.2 a	14.1 a	50	100
Summerville, GA	--	--	--	--	20	100
Adairsville, GA	26.5 a	36.2 bcd	10.6 bc	26.7 a	--	100
Evergreen, AL	50.5 a	16.1 d	4.7 de	28.7 a	25	0
Total	*37.7*	*36.6*	*8.8*	*16.9*	*27.5*	*44.3*

[z] Estimate reported by loggers conducting chipping operation at each site.

[y] Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests (α=0.05, n=3).

[x] No sample obtained, interview only.

Table 5.2. Soil-less media macro-nutrient content, pH and salt content.

Location	pH[z]	Salt (mmhos/cm)	NO_3-N (ppm)	NH_4-N (ppm)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	SO_4 (ppm)
Cuthbert, Ga.	5.5 a[y]	0.24 ns[x]	0.20 ns	0.27 ns	5 de	86 ab	6 cde	5 de	15 e
Cottondale, Fla.	4.3 f	0.41	0.10	1.6	9 a	71 cd	59 a	42 a	28 b
Waycross, Ga.	4.8 de	0.16	0.10	0.13	7 b	26 f	6 cde	7 cde	22 c
Greenville, Ga.	4.3 f	0.20	0.10	0.33	7 bc	75 bc	8 cd	10 cd	16 e
Barnett Crossroads, Ala.	4.9 bcd	0.22	0.20	0.23	4 e	40 e	4 de	3 e	20 cd
Lucedale, Miss.	4.5 ef	0.25	0.17	0.57	5 d	78 bc	16 b	18 b	22 c
Atmore, Ala.	5.2 b	0.24	0.17	0.23	5 d	61 d	6 cde	5 de	18 de
Jasper, Ga.	4.8 de	0.23	0.17	0.60	6 c	93 a	9 c	11 c	37 a
Adairsville, Ga.	4.8 cd	0.21	0.13	0.43	6 f	74 c	6 cde	7 cde	23 c
Evergreen, Ala.	5.1 bc	0.26	0.17	0.10	2 f	33 ef	3 e	2 e	9 f
Suggested range[w]	*5.5-6.5*	*0.60-2.0*	*70-200*	*3-20*	*6-11*	*80-250*	*80-230*	*40-120*	*30-150*

[z] pH = a measure of the activity of hydrogen ions (H+) in a solution and, therefore, its acidity or alkalinity. The pH value is a number without units, between 0 and 14, that indicates whether a solution is acidic (pH 0-7), alkaline (pH 7-14) or neutral (pH 7).

[y] Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests ($\alpha = 0.05$, $n = 3$).

[x] ns indicates that means are not significantly different.

[w] Suggested range for most media and plants (as stated by Brookside Laboratories, Inc., New Knoxville, Ohio).

Table 5.3. Soil-less media micro-nutrient and other beneficial mineral nutrient content.

Location	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)	Mo (ppm)	B (ppm)	Na (ppm)	Al (ppm)
Cuthbert, Ga.	0.51 c[z]	0.62 c	0.03 cd	0.06 d	0.05 ns[y]	0.15 d	5 cd	3 d
Cottondale, Fla.	1.00 c	3.70 ab	0.03 cd	0.36 a	0.05	0.25 a	9 b	7 c
Waycross, Ga.	0.19 c	0.18 c	0.03 cd	0.10 cd	0.05	0.24 a	19 a	2 d
Greenville, Ga.	1.00 c	0.87 c	0.04 bc	0.17 b	0.05	0.20 b	6 c	5 cd
Barnett Crossroads, Ala.	3.30 b	0.99 c	0.06 a	0.06 d	0.05	0.16 cd	8 b	6 cd
Lucedale, Miss.	0.88 c	5.00 a	0.04 bc	0.17 b	0.05	0.18 bc	8 b	8 bc
Atmore, Ala.	4.60 ab	0.95 c	0.04 bc	0.06 d	0.05	0.20 b	5 d	13 b
Jasper, Ga.	0.69 c	4.20 ab	0.03 d	0.14 bc	0.05	0.25 a	4 e	5 cd
Adairsville, Ga.	5.90 a	3.20 b	0.04 b	0.18 b	0.05	0.27 a	4 e	21 a
Evergreen, Ala.	0.61 c	0.52 c	0.04 bc	0.04 d	0.05	0.15 cd	4 e	3 d
Suggested range[x]	*0.5-2.5*	*0.05-2.0*	*0.003-0.35*	*0.25-2.0*	*0.03-0.1*	*0.08-0.4*	*0-40*	*0-5*

[z] Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests ($\alpha = 0.05$, $n = 3$).

[y] ns indicates that means are not significantly different.

[x] Suggested range for most media and plants (as stated by Brookside Laboratories, Inc., New Knoxville, Ohio).

CHAPTER VI

Nitrogen Immobilization in Plant Growth Substrates: Clean Chip Residual, Pine Bark and Peat Moss

Abstract

A study was undertaken to determine the extent of nitrogen (N) immobilization and microbial respiration in a high wood-fiber content substrate (clean chip residual (CCR)). Control treatments of pine bark (PB) and peat moss (PM) were compared to two screen sizes (0.95 cm (0.375 in) and 0.48 cm (0.187 in)) of CCR for microbial activity and N availability in a 60 day incubation experiment. Four rates of supplemental N (0, 1, 2, and 3 mg N) were added to each of the four substrates in the study. Samples were adjusted to similar moisture contents, treated with fertilizer and placed in a jar containing 10 ml water to maintain humidity. The jars were placed in a dark incubation chamber at 25° C for 60 days. Four samples of each treatment were removed at 7, 15, 30 and 60 days after treatment and evaluated for microbial activity and N content. In general, PM had very little microbial respiration over the course of the study, regardless of supplemental N rate. The smallest sized CCR (0.48 cm) had the most respiration, followed by the larger CCR size (0.95 cm) and PB. Respiration generally increased with increasing N rate. Total inorganic N (plant available N) was greatest with PM. With both screen sizes of CCR and PB, the total inorganic N was generally similar within the 0, 1, and 2 mg supplemental N

treatments. A significant increase occurred with the highest rate of supplemental N. Clean chip residual and PB were also generally similar in available N when compared to PM. This study suggests that N-immobilization in substrates composed of CCR is similar to that of PB and can be treated similarly with fertilizer amendments in a nursery setting.

Introduction

Pine bark (PB) and peat moss (PM) have traditionally been used as nursery and greenhouse substrates in the U.S. These materials are becoming more costly to use in horticultural industry due to increasing fuel costs, reduced availability of PB (Lu et al., 2006) and environmental concerns over the use of PM for growing crops (Carlile 2004; Holmes, 2004). Finding alternative substrates as a way to reduce costs has become an important issue for growers.

One promising alternative substrate is CCR, a forest by-product of the ‘clean chip’ industry. The ‘clean chip’ industry processes small caliper pine trees into uniform, bark-free material for making paper products. This procedure is conducted on-site at pine plantations with in-field harvesting equipment. This equipment de-limbs, de-barks, and chips the material into the back of chip van/truck for shipment to a pulp mill. The remaining material, composed of approximately 40% wood, 35% bark, 10% needles, and 15% indistinguishable fine material, is either spread back across the harvested area or processed once more through a grinder with 10.2 to 15.2 cm (4 to 6 in) screens and sold to the pulp mills for boiler fuel. Currently, this leftover material composes around 25% of the site biomass and represents an income loss for the forest landowners.

Clean chip residual has been evaluated, in a fresh state, for the production of several types of horticultural crops (Boyer et al., 2006, 2007b, 2008). The residual material is obtained from loggers and further processed through a swinging hammer mill in order to produce material with reasonable particle sizes for horticultural use. Since this material is processed before use, it can be hammer milled to pass several different screen sizes, producing substrates that are suitable for a variety of crop types and container sizes. Boyer et al. (2006) evaluated perennials (buddleia and verbena) in CCR and reported similar results among all treatments. A further study indicated that use of supplemental N (beyond a standard control release fertilizer) was not necessary for growth of buddleia as compared to PB (Boyer et al., 2007a). Woody plants such as loropetalum were also shown to have adequate growth in several screen-sizes of CCR (compared to PB) over the course of one year (Boyer et al., 2007b). Later, Boyer et al. (2008) demonstrated that annual plants, ageratum and salvia grown in CCR or combinations of CCR and PM produced similarly sized plants when compared to a traditional PB substrate.

While growth of crops in CCR has been shown to be equal to that of plants in traditional substrates, questions remain regarding the high wood-content of forest residuals (especially among growers). Since PB has a high lignin content, it is slow to decompose and producing crops over a short-term growing season (and some long-term seasons) has not caused problems due to decomposition (and thus shrinkage of the substrate due to microbial activity; Kenna and Whitcomb, 1985).

Gruda et al. (2000) reported significant N -immobilization and less tomato (*Lycopersion lycopersicum* (L.) Karst. Ex Farw.) plant growth in substrates composed of a 100% wood fiber product. N-immobilization was calculated on the basis of N-balance including N-uptake by plants and residual mineral N in the substrates. Higher N-immobilization was found by increasing N-application rates. They determined that it is necessary to supply wood fiber substrates with nutrient solutions or fertilizer from the beginning of plant culture. Also, substrates without plants in this study (wood fiber and white PM) exposed to the same environmental conditions showed the same tendencies in N-immobilization as substrates with plants.

Concern has arisen over whether the high wood-content of CCR will immobilize N to an extent that plants experience a reduction in growth early in the crop cycle. This is especially important in greenhouse crops where the first few days and weeks are critical to the long term growth of the crops. The objective of this study was to determine the extent of N immobilization in CCR, PB and PM in order to make recommendations regarding how to overcome such a production problem.

Materials and methods

Clean chip residual used in this study was obtained from a 10- to 12-year-old loblolly pine (*Pinus taeda*) plantation near Atmore, AL, which was thinned and processed for clean chips using a total tree harvester (Peterson DDC-5000-G Portable Chip Plant, Peterson Pacific Corp., Eugene, OR), a horizontal grinder with 10.2 cm (4 in) screens (Peterson 4700B Heavy Duty Horizontal Grinder, Peterson Pacific Corp., Eugene, OR). The material was further processed through a swinging hammer mill (No. 30; C.S. Bell, Tifton, OH) with either a 0.95 cm (0.375 in) or 0.48 cm (0.187 in) screen to produce two

CCR products for testing. These two CCR particle sizes were compared with PB and PM (Table 6.1). Pine bark used in this study was obtained from Pineywoods Mulch Company (Alexander City, AL). Peat moss was obtained from Premier Horticulture, Inc. (Quakertown, PA) and was tested to confirm that no supplemental N had been added prior to use in this study.

Substrate air space (AS), container capacity (CC), and total porosity (TP) were determined following procedures described by Bilderback et al. (1982). Substrate bulk density (measured in g·cm^3) was determined from 347.5 cm^3 samples dried in a 105 °C forced air oven for 48 h. Substrates were analyzed for particle size distribution (PSD) 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 (Ro-Tap RX-29, W.S. Tyler, Mentor, OH) sieve shaker (278 oscillations/min, 159 taps/min). Substrate samples (four reps per treatment) were analyzed for pH, electrical conductivity (EC), N, phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B), iron (Fe), manganese (Mn), copper (Cu) and zinc (Zn). Substrate N was determined by combustion analysis using a 1500 N analyzer (Carlo Erba, Milan, Italy). Remaining nutrients were determined by microwave digestion with inductively coupled plasma-emission spectrometry (Thermo Jarrel Ash, Offenbach, Germany).

An incubation study was conducted at the USDA-ARS National Soil Dynamics Laboratory in Auburn, AL to determine N mineralization/immobilization and microbial activity of each of four substrate materials. The incubation procedure consisted of weighing 20 g (dry weight basis) of substrate into plastic containers. De-ionized water was added to adjust samples to consistent moisture content. Moisture content was determined by saturating 20 g of each substrate with de-ionized water and recording wet weight (after draining to simulate CC) and dry weight (after drying in an oven at 105° C for 48 h). The change in weight (wet minus dry) divided by the wet weight multiplied by 100 = percent (%) moisture content (average of three subsamples). Each substrate had different percent moisture contents and subsequently an appropriate amount of de-ionized water was added to each sample in order to bring the moisture of the substrate up to CC. Container capacity is the amount of water in a just-drained container substrate. Four rates of supplemental N (0, 1, 2, and 3 mg N added by the addition of 0, 0.5, 1.0 or 1.5 ml of 2000 ppm stock solution of NH_4NO_3) were added to each of the four substrates in the study. The containers were placed in sealed glass jars with 10 ml of water for humidity control, and a vial containing 10 ml of 1 M NaOH as a CO_2 trap. The jars were incubated in the dark at 25° C and removed after 7, 15, 30 and 60 days. Carbon mineralization, which is a direct measurement of microbial respiration, was measured in this study. Carbon dioxide in the NaOH traps was determined by titrating the excess base with 1 M HCl in the presence of $BaCl_2$. All traps were measured at each sampling date. At each sampling date, a set of samples were measured for inorganic N concentration. Samples were extracted with a 2N KCl solution and measured for NH_4-N and NO_3-N using a Model 680 Microplate Reader (Bio-Rad Laboratories Inc., Hercules, CA). Inorganic N was calculated as the sum of NH_4 and NO_3. Potential N mineralization was the difference between final and initial inorganic N contents.

Data were analyzed using Waller-Duncan k ratio t tests ($P \leq 0.05$) using a statistical software package (SAS® Institute, Cary, NC). Data were analyzed separately for each sampling date.

Results and discussion

Physical properties of the four substrates tested varied (Table 6.1). Each substrate had significantly different air space (AS): 0.95 cm CCR having the greatest (48%) and PM having the least (11%). Container capacity (CC) was also different for each substrate, however PM had the greatest CC (87%), as expected, and PB had the least CC (48%). Both CCR treatments were similar in total porosity (TP), but were between the high of 98% for PM and 79% for PB. Bulk density (BD) was greatest for 0.48 cm CCR (0.22 g/cm^3) and least for PM (0.11 g/cm^3).

Particle size analysis revealed that 0.48 cm CCR had the least amount of coarse particles (0.8%) while PM had the greatest amount of coarse particles (38.3%) (Table 6.2). Pine bark and 0.95 cm CCR were similar (30.0% and 26.6%) for coarse particles. Both CCR substrates had the highest amount of medium sized particles (48.0% for 0.48 cm and 49.5% for 0.95 cm). Pine bark had 38.0% medium sized particles and PM had 31.0%. The greatest percentage of fine particles was found in 0.48 cm CCR (51.2%), followed by PM (30.7%), PB (32.0%) and 0.95 cm CCR (23.9%).

Substrate pH was significantly different for each substrate (Table 6.3). Clean chip residual screened at 0.95 cm had the highest pH (5.5) while 0.48 cm had a pH of 5.0. Peat moss had the next highest pH (4.8) while PB had the lowest pH (4.1). Peat moss and PB generally have lime added to the mix in order to bring up the pH for plant culture. This may not be required for substrates composed of CCR as their pH is already in an acceptable range for plant growth. Electrical conductivity was in the typical range for plant production, though each substrate was different (0.15-0.29 $mS \cdot cm^{-1}$).

Chemical analysis of the substrates revealed that PM had a significantly higher amount of NO_3-N (39.0 ppm) than all other treatments (0.1-0.2 ppm) (Table 6.3). Values for NH_4-N were all low (0.1-0.4 ppm). Potassium was high in all substrates except PM (48.2-84.6 ppm vs. 6.9 ppm). Calcium was greatest in PM (27.7 ppm) and least in the CCR treatments (5.3-9.1 ppm). Magnesium was also greatest in PM (28.3 ppm) and least in CCR (2.6-7.0 ppm).Sulfur was high in PB (50.9 ppm) and low in 0.95 cm (0.375 in) CCR (7.7%). Iron, Mn and Zn were higher in 0.48 cm CCR than all other treatments.

Microbial Respiration

Microbial respiration was evaluated at each rating date (Table 6.4). Peat moss consistently had the least microbial respiration regardless of rating date or supplemental N rate. The greatest microbial respiration occurred with the CCR treatments. As particle size decreased (0.48 cm), microbial respiration increased. Also, as N rate increased, microbial respiration increased in CCR and PB.

Microbial respiration at 7 DAT (days after treatment) showed that at each N rate, 0.48 cm CCR had the greatest microbial respiration, followed by 0.95 cm CCR, PB and PM (Table 6.4). For 0.48 cm and 0.95 cm CCR, microbial respiration was highest with 2 mg N and decreased significantly as N rate decreased. Pine bark had significantly higher microbial respiration at 2 mg N than at 0 and 1 mg N (each were different from each other).

At 15 DAT, 0 and 1 mg N rates, 0.48 cm CCR had the greatest microbial respiration, followed by 0.95 cm CCR, PB and PM (Table 6.4). At 2 and 3 mg N the CCR treatments switched with 0.95 cm CCR having more microbial respiration than 0.48 cm. For 0.48 cm and 0.95 cm CCR, MR was highest with 2 mg N and decreased significantly as N rate decreased. Pine bark microbial respiration was similar at the three highest N-rates, though 0 and 1 mg N had less microbial respiration, they were similar to each other. There were no differences in microbial respiration for PM at any N rate.

The greatest microbial respiration at 30 DAT for 0 mg N was with 0.48 cm CCR, followed by 0.95 cm CCR, PB and PM (Table 6.4). At 1 and 2 mg N both CCR treatments were similar, but PB followed by PM had less microbial respiration. At the highest N rate, 0.95 cm CCR had the greatest microbial respiration followed (significantly different from each other) by 0.48 cm CCR, PB and PM. For 0.48 cm CCR the greatest microbial respiration was with 1 and 2 mg N while 0 and 3 mg N had less microbial respiration. For 0.95 cm CCR and PB only 0 mg N was significantly less than other N rates. There were no differences in microbial respiration for PM at any N rate.

Microbial respiration at 60 DAT showed that at 0 and 3 mg N rate, both CCR treatments had the highest microbial respiration, followed by PB and PM (Table 6.4). At 1 and 2 mg N rates, 0.95 cm CCR had the greatest microbial respiration, followed by 0.48 cm CCR, PB, and PM. For 0.48 cm CCR and PM there were no differences across N rates. For 0.95 cm CCR the only the highest rate of N had less microbial respiration than other rates, though the values was similar to 0 and 2 mg N.

Clean chip residual consistently had the greatest amount of microbial respiration among the substrates over the course of the incubation (0-60 DAT) (Table 6.4). At 0 mg N rate, 0.48 cm CCR had greater microbial respiration than 0.95 cm, but at 1 and 2 mg N they were similar (Fig 6.1). At 3 mg N 0.95 cm CCR had greater microbial respiration than 0.48 cm CCR. Pine bark and PM were different from each other and less than CCR treatments for microbial respiration. Across the N rates for 0.48 cm CCR, microbial respiration increased with increasing N rate. For 0.95 cm CCR, microbial respiration increased with increasing N rate, though 2 and 3 mg N were similar. Pine bark was similar at 1, 2 and 3 mg N rates, only 0 mg N had less microbial respiration. There was no difference in microbial respiration across N rates for PM.

Total inorganic N (plant available N)

At 7 DAT, 0 and 0.5 ml NH_4NO_3, PM had more N than all other treatments; and all other treatments were similar (Table 6.5). At 2 and 3 mg N, PM had the most N, followed by PB and the CCR treatments which were similar to each other. Across N rates for 0.48 cm CCR and PB, 3 mg N had more N than other rates which were similar to each other. For 0.95 cm CCR, N increased with increasing N rate, though 0 and 2 mg N were similar. Peat moss had increasingly available N as N rate increased.

Total inorganic N at 15 DAT showed that 0 and 1 mg N, PM had the greatest amount of available N, followed by PB and CCR treatments which were all similar to each other (Table 6.5). At 2 and 3 mg N, PM had the highest N, followed by PB and the two CCR treatments which were similar to each other. There was no significant difference in available N for 0.48 cm CCR across N rates. For 0.95 cm CCR and PB, the greatest amount of available N was with 3 mg N, all other N rates had less N and similar to each other. Peat moss had increasingly available N as N rate increased.

At 30 DAT, all results for total available N were similar to 15 DAT with the exception among substrates at 2 mg N that PM had the greatest amount of N and all other treatments were similar to each other (Table 6.5). Also for PM, 1 and 2 mg N were similar, though the trend continued for having more available N as N rate increased.

Peat moss had the most available N at all N rates among substrates at 60 DAT (Table 6.5). At 0 mg N 0.95 cm CCR had greater N than PB (Fig. 6.2). For all other N-rates, CCR and PB had similar available N, though less than PM. Across N-rates there were no differences for 0.48 cm CCR. For the remainder of the substrates, available N increased with increasing N rates.

Conclusions

Incubation studies have previously been used to evaluate N-immobilization for horticultural purposes. A study by Hartz and Giannini (1998) reported short-term net N-immobilization (in a 2-week aerobic incubation) in samples of composted municipal yard and landscape wastes from three locations. There was an overall trend toward decreased immobilization with increased compost age. At least 9 to 12 weeks of composting were required to minimize the undesirable characteristics of immature compost. Compost materials generally provide enough N to negate the use of supplemental fertilizer, however, materials such as PB, PM and CCR do not contain adequate amounts of N to support plant growth and require fertilization before use in plant production.

A subsequent study by Hartz et al. (2000) determined the N and C mineralization rates of 19 manure and compost samples for use as soil amendments in vegetable production in 1996 and 12 samples in 1997. Net N mineralization was measured at 4- or 8-week intervals, C mineralization at 4-week intervals. An average of 16%, 7%, and 1% of organic N was mineralized in 12 weeks of incubation in 1996, and an average of 15%, 6%, and 2% in 24 weeks of incubation in 1997, in manure, manure compost, and plant residue compost, respectively. Mineralization of manure C averaged 35% of initial C content in 24 weeks, while compost C mineralization averaged only 14%. Within 4 (compost) or 16 weeks (manure), the rate of mineralization of amendment C had declined to a level similar to that of soil organic C.

Waste paper as a substitute for PM has significant N-immobilization and high pH (Molitor and Brűckner, 1997). An incubation study was conducted to define the N status of the paper medium. Initial results indicated diminished plant growth in the pure paper substrate. The amount of additional N needed was difficult to predict during cultivation. A composting processed was determined to be necessary in order to overcome N-immobilization, lower pH and improve the water conducting properties.

When compost of manure is used the N-immobilization will eventually stop and N-mineralization will begin. In the previous cases, N is provided to the plant instead of being removed which results in plants competing with microbes for N. There is an indication that some N became available from 0.95 cm CCR during the study, but the change was small relative to the loss of N from PM.

While CCR does have high amounts of microbial respiration, particularly with smaller particle sizes, microbial activity and N-immobilization were generally similar to PB. Clean chip residual screened to 0.48 cm was more microbially active, most likely due to increased surface area resulting from smaller particle size, though differences between the substrates were due to the presence of PM. Since CCR inherently has a high percentage of PB (35%) it tends to perform similarly. The addition of 40% wood fiber does not seem to inhibit plant growth or require amendment changes in nursery crops. This study indicated that almost no differences could be expected for managing CCR compared to PB.

Peat moss is an inert material and had no microbial activity as measured by respiration in this study. However, unlike PB and CCR it was not due to N limitation because there was no indication that respiration was impacted at all from the addition of N. Since PM had no microbial response it can be taken as the base N level. It is clear that all of the other materials produced significant immobilization of the fertilizer N. However, relative to each other, there was little or no difference (PB vs. CCR). While at the highest rate of N application PB did have increased N levels, compared to PM it was miniscule and this change would not reflect an expectation of differences in management needed. In fact, over time PB decreased the level of N as compared to CCR which was slowly increasing the level of N. For example at 2 mg N, PB had 400 mg/kg available N at 7 DAT, but this was reduced to 58 by day 60. Clean chip residual, on the other hand, had 37 mg/kg at 7 DAT, but was increased to 91 by 60 DAT. This indicates that not only was the immobilization of N similar in PB and CCR, but it may have increased in PB. Respiration also reflects this point. Initially, there was much lower microbial respiration in PB, but by 31-60 DAT, the respiration rate was almost the same as CCR and much more response to changes in N rate. This indicates that PB became more inclined toward microbial N-immobilization as time progressed.

Electrical conductivity and pH of CCR are acceptable for plant culture, in particular CCR may not require a limestone amendment to raise pH. Since 0.95 cm CCR and PB had such similar particle size distributions we recommend this screen size for 1-gal. containers on outdoor beds. The smaller screen size CCR (0.48 cm) is more suitable for greenhouse production. Since many PM suppliers pre-mix amendments into shipped products, it will be essential to determine the fertilization amendments so that substrates composed of CCR can perform similarly to PM. The results of this study should alleviate grower concerns that N-immobilization in CCR (when compared to PB) will negatively affect their crops during a short-term growing cycle.

Literature cited

Bilderback, T.E., W.C. Fonteno, and D.R. Johnson. 1982. Physical properties of media composed of peanut hulls, pine bark and peat moss and their effects on azalea growth. J. Amer. Soc. Hort. Sci. 107:522-525.

Boyer, C.R., G.B. Fain, C.H. Gilliam, T.V. Gallagher, H.A. Torbert, and J.L. Sibley. 2006. A new substrate for container-grown plants: Clean Chip Residual. Proc. Intl. Plant Prop. Soc. 56:553-559.

Boyer, C.R., G.B. Fain, C.H. Gilliam, T.V. Gallagher, H.A. Torbert, and J.L. Sibley. 2007a. Clean chip residual (CCR) substrate for container-grown perennials: Effect of supplemental nitrogen rates. HortScience 42:439. Abstr.

Boyer, C.R., G.B. Fain, C.H. Gilliam, J.L. Sibley, T.V. Gallagher, and H.A. Torbert. 2007b. Performance of container-grown Loropetalum grown in clean chip residual substrate. Proc. Intl. Plant Prop. Soc. (In Press).

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 (In Press).

Carlile, W.R. 2004. Growing media and the environment lobby in the UK 1997-2001. Acta Hort. 644:107-113.

Gruda, N., S.V. Tucher, and W.H. Schnitzler. 2000. N-immobilization of wood fiber substrates in the production of tomato transplants. J. of Applied Botany 74: 32-37.

Hartz, T.K. and C. Giannini. 1998. Duration of composting of yard wastes affects both physical and chemical characteristics of compost and plant growth. HortScience 33:1192-1196.

Hartz, T.K., J.P. Mitchell, and C. Giannini. 2000. Nitrogen and carbon mineralization dynamics of manures and composts. HortScience 35:209-212..

Holmes, S. 2004. Peat and peat alternatives: Their use in commercial horticulture in England and Wales in 2003. A report for Horticulture and Potatoes Division, Department for Environment, Food and Rural Affairs. ADAS Horticulture, Boxworth, England.

Kenna, S.W. and C.E. Whitcomb. 1985. Hardwood chips as an alternative medium for container plant production. HortScience 20:867-869.

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.

Molitor, H.-D. and U. Brűckner. 1997. Waste paper – a substitute for peat in horticulture. Acta Hort. 450:47-55.

Table 6.1. Physical properties of clean chip residual, pine bark and peat moss substrates.[z]

Substrates[y]	Air space[x]	Container capacity[w]	Total porosity[v]	Bulk density (g·cm^{-3})[u]
		(% Vol)		
0.48 cm CCR	28 b[t]	57 b	85 b	0.22 a
0.95 cm CCR	48 a	42 d	90 b	0.19 b
PB	31 b	48 c	79 c	0.18 b
PM	11 c	87 a	98 a	0.11 c

[z] Analysis performed using the North Carolina State University porometer.

[y] CCR = clean chip residual, PB = pine bark, PM = sphagnum peat moss, 1 cm = 0.394 inch.

[x] Air space is volume of water drained from the sample ÷ volume of the sample.

[w] Container capacity is (wet weight - oven dry weight) ÷ volume of the sample.

[v] Total porosity is container capacity + air space.

[u] Bulk density after forced-air drying at 105°C (221.0 °F) for 48 h; 1 g·cm^{-3} = 62.4274 lb/ft^3.

[t] Means within column follwed by the same letter are not significantly different based on Waller-Duncan k ratio *t* tests at $\alpha = 0.05$ (n = 3).

Table 6.2. Particle size analysis of clean chip residual, pine bark and peat moss substrates.

U.S. standard sieve no.	Sieve opening (mm)[z]	Substrate[y] 0.48 cm CCR	0.95 cm CCR	PB	PM
1/2	12.50	0.0 a[x]	0.0 a	0.0 a	2.2 a
3/8	9.50	0.0 b	0.0 b	0.1 b	8.2 a
1/4	6.35	0.0 d	2.7 c	6.0 b	11.0 a
6	3.35	0.8 c	23.9 a	24.0 a	17.0 b
8	2.36	8.8 c	20.0 a	12.6 b	9.1 c
10	2.00	7.9 a	8.1 a	5.0 b	3.5 c
14	1.40	19.0 a	13.2 b	11.3 c	9.0 d
18	1.00	12.4 a	8.2 b	9.1 b	9.0 b
35	0.50	13.0 b	7.7 c	13.8 ab	15.1 a
60	0.25	12.1 a	7.8 b	8.4 b	9.4 b
140	0.11	15.1 a	7.0 b	5.1 b	5.0 b
270	0.05	5.8 a	0.9 c	2.5 b	1.1 c
pan	0.00	5.1 a	0.5 c	2.1 b	0.4 c
Texture[w]					
Coarse		0.8 c	26.6 b	30.0 b	38.3 a
Medium		48.0 a	49.5 a	38.0 b	31.0 c
Fine		51.2 a	23.9 c	32.0 b	30.7 b

[z] 1 mm = 0.0394 inch.

[y] CCR = clean chip residual, PB = pine bark, PM = sphagnum peat moss, 1 cm = 0.394 inch.

[x] Percent weight of sample collected on each screen, means within row followed by the same letter are not significantly different based on Waller-Duncan k ratio *t* tests at $\alpha = 0.05$ (n = 3).

[w] *Coarse* = > 3.35 mm; *Medium* = > 1.00- < 3.35 mm; *Fine* = < 1.0 mm.

Table 6.3. Chemical properties of clean chip residual, pine bark and peat moss substrates.

			Substrate micro-nutrient content[x]				
Substrate[z]	pH	EC (mS·cm^{-1})[y]	B (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)
0.48 cm CCR	5.0 b[w]	0.21 b	0.23 a	3.7 a	2.3 a	0.01 b	0.28 a
0.95 cm CCR	5.5 a	0.15 c	0.17 b	2.1 b	0.6 b	0.02 ab	0.06 c
PB	4.1 d	0.23 b	0.16 b	1.3 c	1.0 b	0.03 a	0.16 b
PM	4.8 c	0.29 a	0.13 c	0.2 d	0.2 c	0.01 b	0.05 c
	Substrate macro-nutrient content						
	NO_3-N (ppm)	NH_4-N (ppm)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	SO_4 (ppm)
0.48 cm CCR	0.1 b	0.2 b	4.1 a	84.6 a	9.1 c	7.0 c	15.8 c
0.95 cm CCR	0.2 b	0.4 a	1.4 b	48.2 b	5.3 d	2.6 d	7.7 d
PB	0.1 b	0.1 b	4.0 a	52.5 b	16.2 b	11.5 b	50.9 a
PM	39.0 a	0.1 a	1.6 b	6.9 c	27.7 a	28.3 a	29.5 b

[z] CCR = clean chip residual, PB = pine bark, PM = sphagnum peat moss, 1 cm = 0.394 inch.

[y] 1 mS·cm^{-1} = 1 mmho/cm.

[x] Substrate analysis performed on non-amended samples; N = nitrogen, P = phosphorous, K = potassium, Ca = calcium, Mg = magnesium, S = sulfur, B = boron, Fe = iron, Mn =

[w] Means within column followed by the same letter are not signicantly different based on Waller-Duncan k ratio t tests ($\alpha = 0.05$, n = 3).

Table 6.4. Microbial respiration in clean chip residual, pine bark and peat moss substrates.

	Carbon mineralization (mg/kg)				
	0 mg N	**1 mg N**	**2 mg N**	**3 mg N**	*MSD N-rate*[x]
Substrate[z]		**0-7 Days**			
0.48 cm CCR	2370	3236	3584	3882	*113*
0.95 cm CCR	1757	2593	2987	3414	*154*
PB	1918	2311	2367	2478	*111*
PM	143	94	614	258	*335*
MSD Substrate	*84*	*121*	*284*	*170*	
		8-15 Days			
0.48 cm CCR	2615	2827	2888	3358	*183*
0.95 cm CCR	2200	2620	3105	3706	*209*
PB	1625	1986	1944	2021	*329*
PM	356	384	353	371	*117*
MSD Substrate	*283*	*140*	*172*	*149*	
		16-30 Days			
0.48 cm CCR	3479	3615	3631	3436	*134*
0.95 cm CCR	3229	3556	3728	3714	*225*
PB	2254	2485	2585	2586	*129*
PM	751	591	578	641	*166*
MSD Substrate	*195*	*139*	*123*	*126*	
		31-60 Days			
0.48 cm CCR	4133	3812	3721	3837	*459*
0.95 cm CCR	4082	4211	4041	3767	*324*
PB	2950	3173	3356	3417	*190*
PM	1723	1682	1581	1582	*258*
MSD Substrate	*355*	*166*	*238*	*248*	
		Total: 0-60 Days			
0.48 cm CCR	12360	13414	13778	14108	*609*
0.95 cm CCR	11016	13110	14377	14624	*799*
PB	8954	10097	10313	10484	*422*
PM	2989	2922	2762	2781	*440*
MSD Substrate	*668*	*405*	*662*	*409*	

[z] CCR = clean chip residual, PB = pine bark, PM = sphagnum peat moss, 1 cm = 0.394 inch.

[y] 2000 ppm stock solution of NH_4NO_3 (0, 0.5, 1.0, 1.5 ml).

[x] MSD based on Waller-Duncan k ratio t tests ($\alpha = 0.05$).

Fig. 6.1. Total microbial respiration in clean chip residual, pine bark and peat moss (0-60 days).

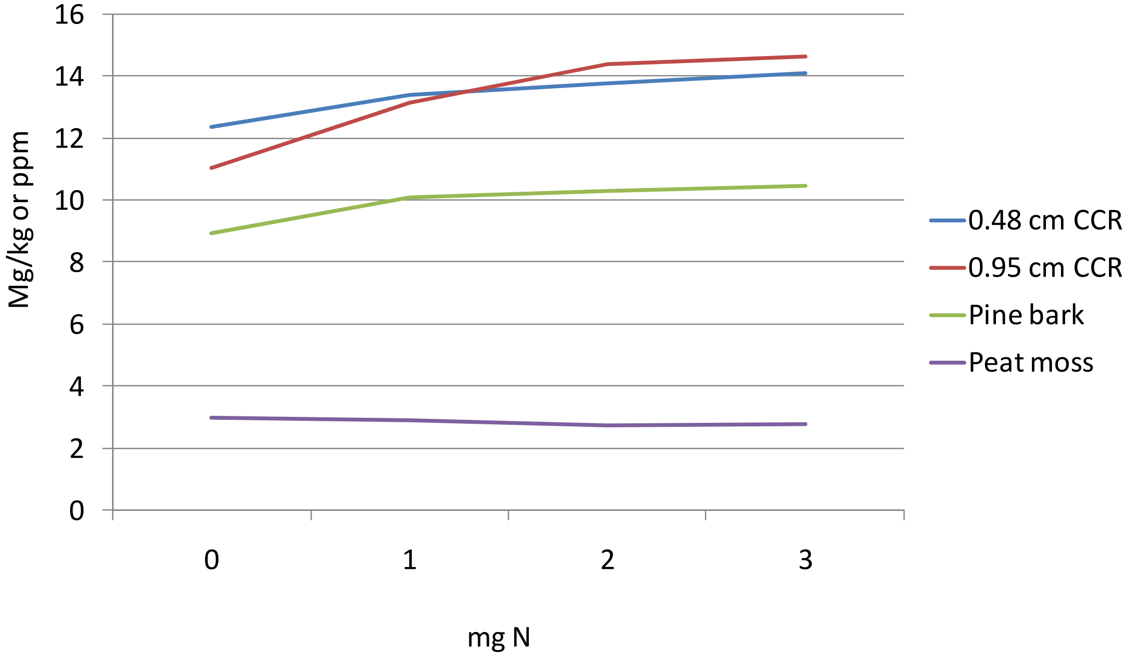
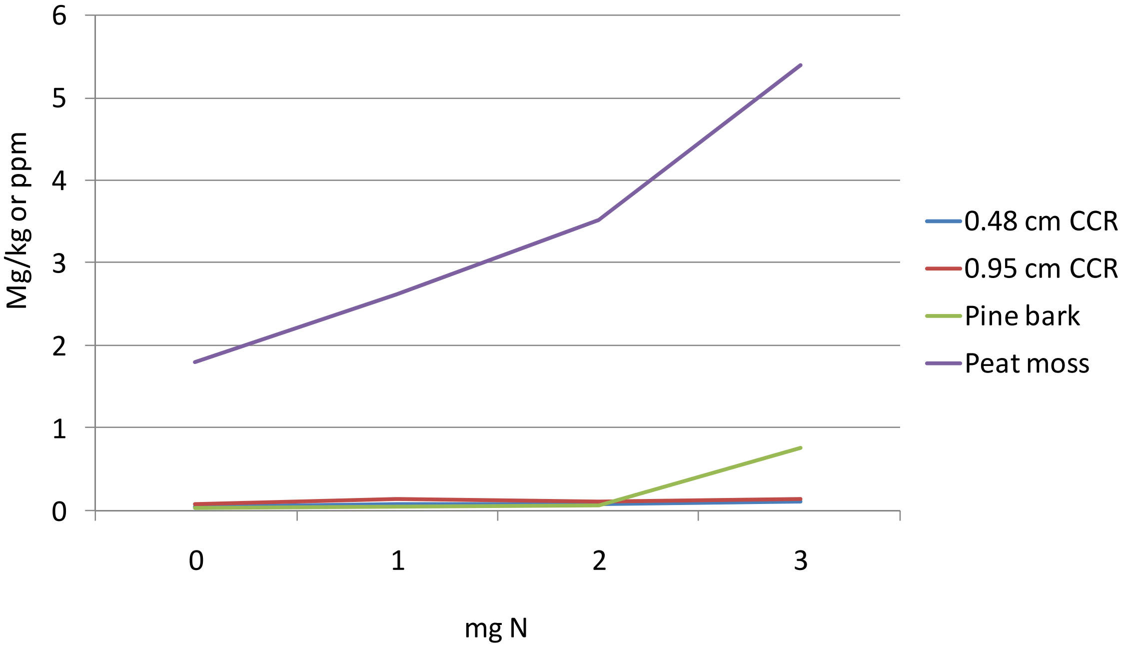


Table 6.5. Total inorganic nitrogen (NH_4 and NO_3) mineralization in clean chip residual, pine bark and peat moss substrates.

	Nitrogen mineralization (mg/kg)				
	0 mg N	**1 mg N**	**2 mg N**	**3 mg N**	*MSD N-rate*[x]
Substrate[z]			**0-7 Days**		
0.48 cm CCR	31	28	37	128	*16*
0.95 cm CCR	44	77	262	515	*174*
PB	44	56	440	1458	*459*
PM	1753	2549	3359	5264	*790*
MSD Substrate	*130*	*174*	*250*	*850*	
			0-15 Days		
0.48 cm CCR	58	61	42	50	*55*
0.95 cm CCR	53	52	64	168	*79*
PB	5	88	293	1572	*442*
PM	1619	2937	3610	5869	*588*
MSD Substrate	*169*	*281*	*169*	*630*	
			0-30 Days		
0.48 cm CCR	101	148	99	80	*67*
0.95 cm CCR	114	116	102	310	*119*
PB	75	108	152	1061	*82*
PM	2530	3591	4043	6149	*768*
MSD Substrate	*342*	*429*	*356*	*402*	
			0-60 Days		
0.48 cm CCR	63	87	91	117	*44*
0.95 cm CCR	91	142	121	142	*34*
PB	33	39	58	761	*94*
PM	1806	2632	3533	5404	*783*
MSD Substrate	*44*	*150*	*205*	*734*	

[z] CCR = clean chip residual, PB = pine bark, PM = sphagnum peat moss, 1 cm = 0.394 inch.
[y] 2000 ppm stock solution of NH_4NO_3 (0, 0.5, 1.0, 1.5 ml).
[x] MSD based on Waller-Duncan k ratio t tests ($\alpha = 0.05$).

Fig. 6.2. Total inorganic nitrogen (NH_4 and NO_3) mineralization in clean chip residual, pine bark and peat moss (0-60 days).



CHAPTER VII

Conclusion

The purpose of these studies was to evaluate clean chip residual (CCR) as an alternative substrate for nursery and greenhouse production. Since costs are rising daily for growers it is important to look for ways to offset increased expenses. Pine bark (PB) is becoming less available and fuel charges for peat are steadily increasing. If CCR, a local (to the Southeast U.S.), sustainable, economical forest by-product can be used to amend or replace PB and/or peat, the benefits to grower's bottom lines and the environment could be tremendous.

In Chapter 2 we began evaluating CCR by producing greenhouse-grown annuals in 1-gallon containers. This study was conducted at Auburn University in Auburn, AL and the USDA-ARS (United States Department of Agriculture, Agricultural Research Service) Southern Horticultural Laboratory in Poplarville, MS to evaluate clean chip residual (CCR) as an alternative substrate component for annual bedding plant production. Clean chip residual used in this study was processed through a horizontal grinder with 4-inch screens at the site and then processed again through a swinging hammer mill to pass a ¾- or ½- inch screen. Two CCR particle sizes were used alone or blended with either 10% (9:1) or 20% (4:1) peat moss (PM) (by volume) and compared with control treatments, pine bark (PB) and PB blends (10 and 20% PM). Three annual species, ‘Blue Hawaii’ ageratum (*Ageratum houstonianum*), ‘Vista Purple’ salvia (*Salvia* x *superba*) and impatiens (*Impatiens walleriana* ‘Coral’ at Auburn and ‘White’ at Poplarville), were transplanted from 36-cell (12.0 inch^3) flats into 1-gal containers, placed on elevated benches in a greenhouse and hand watered as needed. Ageratum plants grown at Auburn had leaf chlorophyll content similar or greater than that of plants grown in PB. There were no differences in salvia, however impatiens plants grown in PB substrates at Auburn had less leaf chlorophyll content than those grown in CCR. There were no differences in ageratum, salvia or impatiens leaf chlorophyll content at Poplarville. There were no differences in growth indices (GI) or shoot dry weight (SDW) of ageratum while the largest salvia was in PB: PM and largest impatiens were in PB-based substrates at Auburn. Growth index of ageratum at Poplarville was similar among treatments but plants grown in 4:1 ¾-inch CCR: PM were the largest. Salvia was largest in 4:1 CCR: PM and PB: PM while there were no differences in GI for impatiens at Poplarville, the greatest SDW occurred with PB: PM. Foliar nutrient content analysis indicated elevated levels of manganese (Mn) and zinc (Zn) in treatments containing CCR at Auburn and PB at Poplarville. At the study termination two out of three annual species tested at both locations had very similar growth when compared to standard PB substrates. This study demonstrates that CCR is a viable alternative substrate in greenhouse production of ageratum, salvia and impatiens in large containers.

In Chapter 3 we continued our evaluation by growing perennial crops outdoors in a nursery setting. This study, conducted at Poplarville, MS and Auburn, AL, evaluated the growth of eight perennial species in a substrate composed of a pulpwood harvesting by-product called clean chip residual (CCR) which contains approximately 50% wood fiber. Two CCR particle sizes were used alone or amended with peat moss (PM) (4:1 by volume) and compared with control treatments PB and PB:PM. Substrates composed of 100% PB or 100% CCR had high air space (AS) and low container capacity (CC) which resulted in less available water to plants. Addition of PM lowered AS and increased CC. Leaf chlorophyll content was similar among all treatments for 3 of 4 species evaluated at 100 days after planting. Growth indices were similar at Poplarville for 6 of 8 species and for 3 of 7 species at Auburn. Shoot dry weight was greater in substrates amended with PM. Results of this study indicate that acceptable growth of perennial plants can be obtained in substrates composed of CCR when compared to PB and PB amended with PM.

In Chapter 4 woody ornamental plants were grown for one year in CCR and PB. This study was conducted in two locations, Auburn, AL and Poplarville, MS to evaluate growth of woody ornamentals grown in CCR or PB. Five species were tested; *Loropetalum chinensis* var. rubrum, *Buddleia davidii* ‘Black Knight’, *Lagerstroemia indica* ‘Hopi’, *Lagerstroemia* x *fauriei* ‘Natchez’, and *Rhododendron indicum* ‘Mrs. G.G. Gerbing’. Data for all species show that plants grown in CCR had similar or greater growth than plants grown in PB. There were few differences in plant growth index, leaf chlorophyll content, and inflorescence number over the course of the year for all species at both sites. Percent rootball coverage was generally similar among treatments, though those grown in PB had the greatest percent rootball coverage for loropetalum, buddleia (at both sites) and azalea at Auburn. Shoot dry weight of loropetalum and crapemytrle grown in PB at Poplarville was greater than plants grown in CCR.

Chapter 5 brought about a survey of loggers in order to characterize the potential supply of CCR to horticultural industries. The survey was conducted in the Southeast U.S. among individuals and companies conducting chipping operations on pine plantations for the production of pulpwood in the forest industry. Fourteen operators in four states (AL, MS, GA, FL) were visited or interviewed over the phone in order to evaluate the status of residual material on site. Residual chipping material (also called clean chip residual or CCR) has potential use as a growth substrate in the nursery and greenhouse horticultural industries. Samples analysis of CCR was performed which revealed that CCR is composed of 37.7% wood, 36.6% bark, 8.8% needles, and 16.9% indistinguishable (fine) particles. Survey participants estimated that approximately 27.5% of the site biomass is composed of CCR. Some growers were able to sell CCR as fuelwood to pulp mills while others did not recover the residual material, leaving it on the forest floor (44.3%). Many different operations were included in this survey including typical chipping and grinding operations, woodyards and pine plantations burned by wildfire. Several loggers were interested in making CCR available to horticultural industries if a profit could be made from the material.

A significant concern of many growers has been whether or not CCR, with such a high wood content, will immobilize nitrogen at any point during a production cycle. Pine bark is currently preferred due to its high lignin content and tendency to remain stable over the course of a growing season. In chapter 6, a study was undertaken to determine the extent of nitrogen (N) immobilization and microbial respiration in a high wood-fiber content substrate (clean chip residual (CCR)). Control treatments of pine bark (PB) and peat moss (PM) were compared to two screen sizes (0.95 cm (0.375 in) and 0.48 cm

(0.187 in)) of CCR for microbial activity and N availability in a 60 day incubation experiment. Four rates of supplemental N (0, 1, 2, and 3 mg N) were added to each of the four substrates in the study. Samples were adjusted to similar moisture contents, treated with fertilizer and placed in a jar containing 10 ml water to maintain humidity. The jars were placed in a dark incubation chamber at 25° C for 60 days. Four samples of each treatment were removed at 7, 15, 30 and 60 days after treatment and evaluated for microbial activity and N content. In general, PM had very little microbial respiration over the course of the study, regardless of supplemental N rate. The smallest sized CCR (0.48 cm) had the most respiration, followed by the larger CCR size (0.95 cm) and PB. Respiration generally increased with increasing N rate. Total inorganic N (plant available N) was greatest with PM. With both screen sizes of CCR and PB, the total inorganic N was generally similar within the 0, 1, and 2 mg supplemental N treatments. A significant increase occurred with the highest rate of supplemental N. Clean chip residual and PB were also generally similar in available N when compared to PM. This study suggests that N-immobilization in substrates composed of CCR is similar to that of PB and can be treated similarly with fertilizer amendments in a nursery setting.

In summary, the potential of CCR to replace PB and/or peat is remarkable. In general, plants grew as well as plants grown in control treatments for annuals, perennials and woody ornamentals. A major concern of growers has been answered: nitrogen immobilization will not cause a problem during short production cycles. In addition, the supply of CCR for horticultural industries seems to be sufficient. The challenge will be connecting loggers with growers to supply the material. Currently, several growers have contacted us with strong interest in testing CCR at their nursery or greenhouse. It seems that we cannot get the data or the substrate to the growers fast enough. A shift from PB and peat to CCR could fundamentally change the nursery and greenhouse industries for the better in the near future.

BIBLIOGRAPHY

Airhart, D.L., N.J. Natarella, and F.A. Pokorny. 1978. The structure of processed pine bark. J. Amer. Soc. Hort. Sci. 103:404-408.

Allen, V.T., B.K. Behe, and D.G. Himelrick. 1994. Broilder litter compost affects growth of annual and perennial plants. Proc. Southern Nur. Assn. Res. Conf. 39:89-91.

Andrulot, A.E., L.P. Blackwell, and P.Y. Burns. 1972. Effects of thinning on yield of loblolly pine in central Louisiana. Louisiana Tech. University, Bulletin 6. Ruston. 145 p.

Bachman, G.R., and J. Metzger. 1998. The use of vermicompost as a media amendment. Proc. Southern Nur. Assn. Res. Conf. 43:32-34.

Baughman, R. K., B.J. Stokes, and W.F. Watson. 1990. Utilizing residues from in-woods flail processing. In: Stokes, B.J., ed. Harvesting small trees and forest residues: Proceedings of the International Energy Agency, task 6, activity 3 workshop. Auburn, AL: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 21-30.

Bell, R.G., J.Pos., and R.J. Lyon. 1973. Production of composts from soft wood lumber mill wastes. Compost Science. March/April pp.5-7.

Bilderback, T.E., W.C. Fonteno, and D.R. Johnson. 1982. Physical properties of media composed of peanut hulls, pine bark, and peatmoss and their effects on Azalea growth. J. Amer. Soc. Hort. Sci. 107:522-525.

Bilderback, T. and M. Lorscheider. 2000. Use of wulpak as a mulch and amendment for nursery potting substrates. Proc. Southern Nur. Assn. Res. Conf. 45:73-76.

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

Blythe, E.K., J.L. Sibley, K.M. Tilt, and R. Zinner. 2005. Monolithic slag as a substrate for rooting and bare-rooting stem cuttings. J. Environ. Hort. 23:67-71.

Boertje, G.A. 1984. Physical laboratory analysis of potting composts. Acta Hort. 150:47-50.

Boyer, C.R., G.B. Fain, C.H. Gilliam, T.V. Gallagher, H.A. Torbert, and J.L. Sibley. 2006. Evaluation of freshly chipped pine tree substrate for container-grown *Lantana camara*. HortScience 41:1027. Abstr.

Boyer, C.R., G.B. Fain, C.H. Gilliam, T.V. Gallagher, H.A. Torbert, and J.L. Sibley. 2006. Alternative substrates for bedding plants. Proc. Southern Nurs. Assoc. Res. Conf. 51:22-25.

Boyer, C.R., G.B. Fain, C.H. Gilliam, T.V. Gallagher, H.A. Torbert, and J.L. Sibley. 2006. A new substrate for container-grown plants: Clean Chip Residual. Proc. Intl. Plant Prop. Soc. 56:553-559.

Boyer, C.R., G.B. Fain, C.H. Gilliam, J.L. Sibley, T.V. Gallagher, and H.A. Torbert. 2007. Performance of container-grown *Loropetalum* grown in clean chip residual substrate. Proc. Intl. Plant Prop. Soc. (In Press).

Boyer, C.R., G.B. Fain, C.H. Gilliam, T.V. Gallagher, H.A. Torbert, and J.L. Sibley. 2007. Clean chip residual (CCR) substrate for container-grown perennials: Effect of supplemental nitrogen rates. HortScience 42:439. Abstr.

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 (In Press).

Bradley, G.J., M.H. Glass, and T.E. Bilderback. 1996. Dairy cow compost as a potting substrate for growing hybrid rhododendrons. Proc. Southern Nur. Assn. Res. Conf. 41:128-129.

Brender, E.V. 1973. Silviculture of loblolly pine in the Georgia Piedmont, Georgia Forest Research Council, Report 33. Macon. 74 p.

Brown, E.F. and F.A. Pokorny. 1975. Physical and chemical properties of media composed of milled pine bark and sand. J. Amer. Soc. Hort. Sci. 100:119-121.

Burns, R.M. and B.H. Honkala. 1990. Silvics of North America: 1. Conifers; 2. Hardwoods. Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, DC. 877 p.

Carlile, W.R. 2004. Growing media and the environment lobby in the UK 1997-2001. Acta Hort. 644:107-113.

Cavins, T.J., B.E. Whipker, W.C. Fonteno, B. Harden, I. McCall, and J.L. Gibson. 2000. Monitoring and managing pH and EC using the PourThru extraction method. N.C. State Univ. Coop. Ext. Hort. Info. Leaflet 590.

Chong, C., and G.P. Lumis. 2000. Mixtures of paper mill sludge, wood chips, bark, and peat in substrates for pot-in-pot shade tree production. Plant Sci. 80:669-675.

Cole, D.M. and J.L. Sibley. 2004. Waste not, want not. Amer. Nurseryman 199:44-47.

Cotter, D.J. and R.E. Gomez. 1977. Bark as a growing media. HortScience 12:27. Abstr.

Davidson, H., R. Mecklenburg, and C. Peterson. 2000. Nursery management: Administration and culture. 4th ed. Prentice Hall, Upper Saddle River, N. J.

Dueitt, S.D., J. Howell, and S.E. Newman. 1993. Rice hulls as a vermiculite substitute in peat-based media for growing greenhouse bedding plants. Proc. Southern Nur. Assn. Res. Conf. 38:62-63.

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 Nur. Assn. Res. Conf. 39:81-85.

Fain, G.B. and C.H. Gilliam. 2006. Physical properties of media composed of ground whole pine trees and their effects on vinca (*Catharanthus roseus*) growth. HortScience 40:510. Abstr.

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

Fain, G.B., C.H. Gilliam, J.L. Sibley, and C.R. Boyer. 2006. Evaluation of an alternative, sustainable substrate for use in greenhouse crops. Proc. Southern Nur. Assn. Res. Conf. 51:651-654.

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

Flinn, C.L., R. Campbell and T.E. Bilderback. 1997. The use of bioconverted swine biosolids as an amendment for potting media for commercial nursery production. Proc. Southern Nur. Assn. Res. Conf. 42:146-147.

Fulcher, A., C. Finneseth, and W.C. Dunwell. 2002. Use of pelletized poultry litter as a container substrate. Proc. Southern Nur. Assn. Res. Conf. 47:73-76.

Gartner, J.B., D.C. Saupe, J.E. Klett and T.R. Yocom. 1970. Hardwood bark as a medium for container growing. Amer. Nurseryman 131:11, 40-44.

Gartner, J.B., M.M. Meyer, Jr., and D.C. Saupe. 1971. Hardwood bark as a growing media for container-grown ornamentals. Forest Products J. 21:25-29.

Gartner, J.B., T.D. Hughes and J.E. Klett. 1972. Using hardwood bark in container growing mediums. Amer. Nurseryman 135:10-12, 77-79.

Gruda, N., S.V. Tucher, and W.H. Schnitzler. 2000. N-immobilization of wood fiber substrates in the production of tomato transplants. J. of Applied Botany 74: 32-37.

Gruda, N. and W.H. Schnitzler. 2001. Physical properties of wood fiber substrates and their effect on growth of lettuce seedlings (*Lactuca sativa* L. var. *capitata* L.) Acta Hort. 548:415-423.

Gruda, N. and W.H. Schnitzler. 2003. Suitability of wood fiber substrate for production of vegetable transplants II. The effect of wood fiber substrates and their volume weights on the growth of tomato transplants. Scientia Hort. 100:333-340.

Gruda, N. and W.H. Schnitzler. 2004. Suitability of wood fiber substrate for production of vegetable transplants I. Physical properties of wood fiber substrates. Scientia Hort. 100:309-322.

Hartz, T.K. and C. Giannini. 1998. Duration of composting of yard wastes affects both physical and chemical characteristics of compost and plant growth. HortScience 33:1192-1196.

Hartz, T.K., J.P. Mitchell, and C. Giannini. 2000. Nitrogen and carbon mineralization dynamics of manures and composts. HortScience 35:209-212..

Holmes, S. 2004. Peat and peat alternatives: Their use in commercial horticulture in England and Wales in 2003. A report for Horticulture and Potatoes Division, Department for Environment, Food and Rural Affairs. ADAS Horticulture, Boxworth, England.

Jackson, B.E., A.N Wright, D.M. Cole and J.L. Sibley. 2005. Cotton gin compost as a substrate component in container production of nursery crops. J. Environ. Hort. 23:118-122.

Jackson, B.E., A.N. Wright, J.L. Sibley, and J.M. Kemble. 2005. Root growth of three horticultural crops grown in pine bark amended cotton gin compost. J. Environ. Hort. 23:133-137.

Jenkins, J.R. and W.M. Jarrell. 1989. Predicting physical and chemical properties of container mixtures. HortScience 24:292-295.

Johnson, P., and D. Tatum. 1996. The use of curmb rubber amendment in the production of poinsettias. Proc. Southern Nur. Assn. Res. Conf. 41:111-115.

Johnson, T.G. and C.D. Steppleton. 2007. Southern pulpwood production, 2005. USDA-Forest Service Southern Research Station. Bulletin SRS-116.

Kenna, S.W. and C.E. Whitcomb. 1985. Hardwood chips as an alternative medium for container plant production. HortScience 20:867-869.

King, L.D. 1979. Waste wood fiber as a soil amendment. J. Environ. Qual. 8:91-95.

Klett, J.E., J.B. Gartner, and T.D. Hughes. 1972. Utilization of hardwood bark in media for growing woody ornamental plants in containers. J. Amer. Soc. Hort. Sci. 97:448-450.

Knox, G., J. Norcini and D. Covan. 1995. Evaluation of waste products as peat substitutes in container substrates. Proc. Southern Nur. Assn. Res. Conf. 40:98-100.

Laiche, A.J. Jr. 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.

Laiche, A.J. Jr. 1989. Container-grown ornamentals produced in single-component plant growth medium. MAFES Research Report. 14:1-3.

Laiche, A.J. Jr. 1995. Pine bark growth media amended with coir pith. Proc. Southern Nur. Assn. Res. Conf. 40:125-128.

Little, E.L., Jr. 1971. Atlas of United States trees. Vol. 1. Conifers and important hardwoods. U.S. Department of Agriculture, Miscellaneous Publication 1146. Washington, DC. 9 p., 313 maps.

Lord, W.G., T.E. Bilderback, and L. Hight. 1993. Wood waste compost as a potting medium amendment. Proc. Southern Nur. Assn. Res. Conf. 38:75-77.

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.

Lunt, O.R. and H.C. Kohl, Jr. 1956. Influence of soil physical properties on the production and quality of bench grown carnations. J. Amer. Soc. Hort. Sci. 69:535-542.

McConnell, D.B. and R. Harrell. 1992. Commercial production of landscape plants using yard waste compost. Proc. Southern Nur. Assn. Res. Conf. 37:72-74.

Midcap, J.T. 1995. Preliminary evaluation of composted poultry litter as a potting mix component. Proc. Southern Nur. Assn. Res. Conf. 40:94-97.

Mills, H.A. and J.B. Jones. 1996. Plant analysis handbook II. MicroMacro Publishing. Athens, Ga.

Molitor, H.-D. and U. Brűckner. 1997. Waste paper – a substitute for peat in horticulture. Acta Hort. 450:47-55.

Muro, J., I. Irigoyen, P. Samitier, P. Mazuela, M.C. Salas, J. Soler, and M. Urrestarazu. 2005. Wood fiber as a growing medium in hydroponic crop. Acta Hort. 697:179-185.

Natarella, N.J. 1976. Lime requirement determination for a milled pine bark substrate. HortScience 11:24. Abstr.

Nelson, P.V. 2003. Greenhouse operation and management. 6th ed. Prentice Hall, Upper Saddle River, N. J.

Owings, A.D. 1993. Cotton gin trash as a medium component in production of 'Golden Bedder' coleus. Proc. Southern Nur. Assn. Res. Conf. 38:65-66.

Pokorny, F.A. and S. Delaney. 1976. Preparation of a model pine bark substrate from component particles. Hortscience 11:24. Abstr.

Pokorny, F.A. and B.K. Henny. 1984. Construction of a milled pine bark and sand potting medium from component particles I. Bulk density: A tool for predicting component volumes. J. Amer. Soc. Hort. Sci. 109:770-773.

Pokorny, F.A. and B.K. Henny. 1984. Construction of a milled pine bark and sand potting medium from component particles II. Medium synthesis. J. Amer. Soc. Hort. Sci. 109:774-776.

Pokorny, F.A. and H.Y. Wetzstein. 1984. Internal prosoity, water availability, and root penetration of pine bark particles. HortScience 19:447-449.

Rau, B.J., J.F. Browder, B.E. Jackson, and R.D. Wright. 2006. Wood substrates derived from a variety of tree species affect plant growth. Proc. Sou. Nurs. Assoc. 51:43-45.

Regulski Jr., F.J. 1982. Evaluation of a gasifer residue as a container medium for woody ornamentals. HortScience 17:209-210.

Robbins, J.A. 2002. Effect of media type on the growth of container-grown woody ornamentals. Proc. Southern Nur. Assn. Res. Conf. 47:67-72.

Scott, E.G. and B.C. Bearce. 1972. A hardwood-bark-sawdust compost for greenhouse pot flower production. 22:36-39.

Stokes, B.J. and D.L Sirois. 1986. Evaluation of chipper-forwarder biomass harvesting concept. In: Proceedings of the 1985 southern forest biomass workshop. Gainesville, FL: University of Florida: 62-67.

Stokes, B. J. and W.F. Watson. 1988. Recovery efficiency of whole-tree harvesting. In: Proceedings of the 1988 International Energy Agency Biomass Energy Agreement, A-1 technical group meeting. Rotorua, New Zealand: Forest Research Institute, Forest Management and Resources Division: 186-200.

Stokes, B. J., D.L. Sirois, and W.F. Watson. 1989. Recovery of forest residues in the Southern United States. In: Stokes, B.J., ed. Harvesting small trees and forest residues: Proceedings of the 1989 International Energy Agency, task 6, activity 3 symposium. Auburn, AL: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 32-43.

Stokes, B. J. and W.F. Watson. 1991. Wood recovery with in-woods flailing and chipping. In: Proceedings of the 1990 TAPPI pulping conference. Atlanta, GA: TAPPI Press: 851-854.

Stokes, B. J. 1998. Harvesting systems for multiple products an update for the United States. In: Wood fuels from conventional forestry: Proceedings of the 3rd annual workshop of activity 1.2, task 7, International Energy Agency Bioenergy. Auburn, AL: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 49-56.

Tatum, D.H., and A.D. Owings. 1992. Ground tea leaves as a bedding plant medium amendment. Proc. Southern Nur. Assn. Res. Conf. 37:75-76.

Thomas, C.N. and W.L. Bauerle. 2003. Potential benefits of scrubber waste in nursery crop production. Proc. Southern Nur. Assn. Res. Conf. 48:114-116.

Ticknor, R.L., and D.D. Hemphill Jr. 1990. Yard-debris compost as a growing medium. American Nurseryman 172: 97-99.

Tripepi, R.R., M.W. George, A.G. Campbell, and B. Shafii. 1996. Evaluating pulp and paper sludge as a substitute for peat moss in container media. J. Environ. Hort. 14:91-96.

Tyler, H., K.B. Perry, and S.L. Warren. 1993. Composted turkey litter: Effect on the thermal characteristics of an amended pine bark substrate. Proc. Southern Nur. Assn. Res. Conf. 38:92-95.

Tyler, H., S.L. Warren, T.E. Bilderback, and W.C. Fonteno. 1993. Composted turkey litter: I. Effect on chemical and physical properties of a pine bark substrate. J. Environ. Hort. 11:131-136.

Tyler, H., S.L. Warren, T.E. Bilderback, and K.B. Perry. 1993. Composted turkey litter: II. Effect on plant growth. J. Environ. Hort. 11:137-141.

Verwer, F.L.J.A.W. 1975. Cutting and cropping in artificial media. Acta Hort. 50:13-20.

Wahlenberg, W.G. 1960. Loblolly pine: Its use, ecology, regeneration, protection, growth, and management. Duke University, School of Forestry, Durham, NC. 603 p.

Wang, T., and F.A. Pokorny. 1989. Pecan shells as an organic component of container potting media. HortScience 24:75-78.

Watson, W.F., J.R. Ragan, T.J. Straka, and B.J. Stokes 1987. Economic analysis of potential fuel wood sources. In: Proceedings of the 1986 Society of American Foresters national convention. Bethesda, MD: Society of American Foresters: 339-342.

Wear, D.N., D.R. Carter, and J. Prestemon. 2007. The U.S. south's timber sector in 2005:A prospective analysis of recent change. USDA-Forest Service Southern Research Station.

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

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

Wright, R.D., J.F. Browder, and B.E. Jackson. 2006. Ground pine chips as a substrate for container-grown woody nursery crops. J. Environ. Hort. 24:181-184.

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.

Yates, N.L. and M.N. Rogers. 1981. Effects of time, temperature, and nitrogen source on the composting of hardwood bark for use as a plant growing medium. J. Amer. Soc. Hort. Sci. 106:589-593.

Yeager, T.H. and J.E. Barrett. 1985. Considerable leaching of phosphorus may occur with soilless media. Amer. Nurseryman 161:47-48.

Yeager, T., T. Bilderback, D. Fare, C. Gilliam, J. Lea-Cox, A. Niemiera, J. Ruter, K. Tilt, S. Warren, T. Whitwell, and R. Wright. 2007. Best management practices: Guide for producing nursery crops. 2nd ed. Southern Nursery Assn., Atlanta, Ga.