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Date July 31, 1986

THE INFLUENCE OF COMPOSTING ON BLENDED PINE AND HARDWOOD BARK GROWING MEDIA

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Sven Eric-Dale Svenson

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To my wife, Jennifer,

for her unending love, patience, and encouragement.

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ABSTRACT

This research consisted of a series of experiments designed to study the preparation and use of blended pine and hardwood bark as a container growing medium. The first experiment studied the influence of composting on the preparation of blended hardwood and pine bark media, and the succeeding experiments studied plant growth in the media prepared in the first experiment.

2.72 m^3 piles of hardwood bark, pine bark, and 75:25, 50:50, and 25:75 (percent by volume) blends of hardwood and pine bark were composted using a partitioned windrow. Differing amounts of fertilizer amendments including urea, potassium nitrate, superphosphate, iron sulfate, and sulfur were added before composting prorated on the amount of hardwood bark in the medium. Daily heat production during composting was measured and used to determine when stabilization was achieved. Changes in physical and chemical properties were recorded. For comparison with blends mixed before composting, three additional groups of 75:25, 50:50, and 25:75 blends were formed by mixing composted hardwood bark with composted pine bark, composted hardwood bark with noncomposted pine bark, or fresh hardwood bark with noncomposted pine bark. The two control media were a 50:50 (percent by volume) blend

of noncomposted pine bark and spent mushroom compost, and a 3:1:1 (by volume) blend of noncomposted pine bark:peat:river sand, which is a standard nursery medium. Physical and chemical properties were compared between blends mixed before or after composting, and between hardwood and pine bark media and control media.

Pine bark and hardwood bark amended with 50% or 75% pine bark stabilized before 100% hardwood bark. Based upon the time to stabilization in hardwood and pine bark, the 50:50 blend stabilized before expected. Based on the terminal volume of hardwood and pine bark, shrinkage in blended media was less than expected. Since the 50:50 blend stabilized sooner with comparatively less shrinkage, it appeared to be the most efficient blend of hardwood and pine bark for composting. All media had acceptable physical properties, except for the low air capacity of the 3:1:1 control. Physical and chemical properties did not differ between blends containing composted hardwood bark mixed before or after composting.

Euphorbia pulcherrima Willd. ex Klotzch 'Gutbier V-14 Glory', Pelargonium X hortorum L.H. Bailey 'Aurora', Chrysanthemum X morifolium Ramat. 'May Shoesmith', Ilex crenata Thunb. 'Hetzii', and Rhododendron hybrid 'Red Ruffles' were grown in the previously described media. Root rot, manganese

toxicity, and nitrogen, iron, copper, or boron deficiencies variously influenced the growth of these crops. Plants grew as well in treebark media as in the control media. Growth was the same in composted hardwood bark, composted pine bark, and noncomposted pine bark, showing that there is no need to compost pine bark, and that composted hardwood bark is a suitable substitute for pine bark. Growth did not differ between blended media mixed before or after composting. Several species grew better in 50:50 blends than in the control media. Azaleas grown in media containing fresh hardwood bark grew as well as control media, indicating that hardwood bark may not need to be composted before use as a container medium component. Since the 50:50 blend finished composting before expected with more volume than expected, and frequently produced better growth than control media, it appeared to be an excellent medium for container nursery production systems.

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CHAPTER I

INTRODUCTION

The production of quality ornamental plants in containers utilizes large quantities of organic matter as the major ingredient in the growing medium. Organic matter serves as a storehouse of moisture and nutrients, while improving aeration and drainage (126). Traditionally, peat moss has been the favored organic component in container growing media (29).

As interest in recycling waste products and awareness of environmental protection increased in the 1970's, horticultural use of treebark gained emphasis (31). A by-product of the lumbermill and papermill industries, waste-bark accumulated in monstrous quantities. To avoid unsightly piles, mills often incinerated the bark, or dumped it into rivers. Using treebark as a substrate provided a rational solution to the waste-bark disposal problem without polluting land, air, or water resources (88). Treebark has now replaced peat moss as the major organic media component in many areas of the United States (16, 127).

According to Gartner et al. (53), growers in the western and southeastern regions of the United States have found fir, redwood, or pine bark to be excellent

sources of organic media amendment for the production of ornamental plants in containers, with pine bark being the favored ingredient in the southeast (16, 127). Hardwood bark has been shown to be an excellent media component for growers in the northern and midwestern regions (41, 44, 55, 64, 74, 80, 137, 162, 176), though requiring different preparation than pine bark.

Recently, supplies of pine bark to many southeastern states have been erratic. Growers who find a suitable pine bark supply often find the purchase price and cost of transportation prohibitive (166). Reduced availability and higher costs have developed for several reasons.

First, as a fuel source, pine bark can supply up to 9000 BTU per pound of bark (87), depending upon the bark's moisture content (71). As the price of fossil fuel and electricity have increased, demand for pine bark as a fuel source has increased (166, 169), reducing the amount of bark available for use as a growing medium. Thus, growers must compete with the prevailing bark fuel value (16).

Second, demand for pine bark as packaged and bulk landscape mulch has increased (166). Since mulch commands a premium price, and costs less to produce, suppliers prefer to sell bark as mulch rather than as a less-profitable growing media component.

Finally, the amount of bark being produced by sawmills fluctuates according to demand for lumber by the building industry. As demand for lumber rises or falls, the number of trees being harvested and debarked increases or decreases accordingly.

Increasingly, composted (137, 176) and noncomposted (64, 65) hardwood bark is being used as a substitute for peat moss, and other expensive media components (176). With a plentiful supply of hardwood bark in Tennessee, Tilt (166) suggested that Tennessee growers could supplement inconsistent pine bark supplies by mixing them with readily available hardwood bark. He noted that hardwood bark should be composted before use as a media component.

Currently, almost all of the horticulturally used hardwood bark in Tennessee is processed for use as landscape mulch, and growers would have to purchase mulch in this form. Hardwood bark processed for mulch has a stringy texture, and may contain large pieces that make it unsuitable for use in small containers.

A two-part research project was designed to study the use of blended hardwood bark and pine bark media in Tennessee. Part one studied the influence of composting on the preparation of blended hardwood and pine bark media, and the second part studied the growth of several plants in the media prepared in part one.

This research had several objectives. First, this investigation studied the effect of mixing hardwood bark with pine bark on the pace of decomposition during composting, and the effect of composting on the physical and chemical properties of hardwood and pine bark when they were composted separately, or when they were blended together in varying ratios. A comparison was made among media mixed before or after composting. A second objective was to determine if Tennessee hardwood bark can be used as a container media ingredient, and if hardwood bark must be composted before it can be used as a container media component. Finally, this study compared the growth of several ornamental crops in growing media composed of composted or noncomposted pine bark and composted or noncomposted hardwood bark used separately, or blended together.

Style and abbreviations used in this report follow guidelines established for horticulturally related publications by the American Society For Horticultural Science.

CHAPTER II

LITERATURE REVIEW

The bark of softwood tree species is granular or platy after processing, while bark from hardwood tree species has a more fibrous texture. The two bark types also differ in chemical composition. Softwood bark is acidic, and contains large amounts of lignin. Hardwood bark becomes alkaline as it ages, and contains large amounts of cellulose. Thus, plant growth in a medium containing softwood bark may not be directly comparable with growth in the bark of hardwood tree species.

Anatomy of bark

As phloem layers are made each year, the outer layers become crushed and compressed. The crushed layer of cells no longer participates in physiological processes, and it isolates sections of periderm. These become transformed into the relatively inert outer bark (rhytidome) that comprises the bulk of the bark of most trees (71).

The function of the rhytidome layer is to prevent moisture loss and external damage. The suberized and waxy surfaces in the rhytidome result in a bark medium that is difficult to wet under certain conditions (4).

Sieve cells of softwood tree species, and sieve tube elements of hardwood species are food-conducting cells. Both cell types are found in the phloem, and both are thin-walled. Sieve cells and sieve tube elements are collapsed when they are sloughed into the rhytidome layer.

The thickest-walled cells in tree bark are lignified sclerenchyma cells of hardwood species called fibers and sclereids. Fibers are long, straight cells, while sclereids are short. Thin-walled cell layers surround the fibers and sclereids, which facilitates separation of these components during hammermilling. Hardwood species contain either fibers or sclereids, or both, while softwood bark of the genus Pinus contains neither.

Bark has a mixed physical and chemical structure of organic compounds such as lignin, cellulose, hemicellulose, and suberin. Nonstructural components include tannins, starches, and sugars (22).

Debarking, Grinding, and Screening

The procedure used to remove bark from logs can influence the quality of the bark medium, according to the amount of wood removed with the bark.

According to Hoitink and Poole (79), many types of debarkers are now used to remove bark from logs. Rosserhead debarkers remove large amounts of wood with

the bark. The quantity of wood in bark varies according to the season in which the bark is removed from the logs (79, 150), and according to the age of the trees at harvest (8, 150). Hosmerhead debarkers remove less wood than Rosserhead debarkers because they follow the contour of the log. Ring and drum debarkers remove very little wood from logs, creating a bark product containing less than 10% wood; therefore, ring and drum or hosmerhead debarkers are more suitable for harvesting bark for use in container growing media (79, 125). Other devices in use include rollers and knives (139).

Whole tree chippers have been introduced by the papermill industry (16, 79). Entire trees are chipped in the field, and a separation of wood from bark is attempted at the mill by screening. The screened bark contains up to 60% wood, which increases the length of time bark must be composted before it can be used in container media (16, 79).

Most treebark is hammermilled (ground) to pass through a given screen, or sieved through a shaker, to create a reproducibly uniform growing media. According to Pokorny and Delaney (129), milled pine bark makes a satisfactory container media component when screened through a 1.6 mm mesh sieve. This sieve size removes large particles which are often used for landscape mulch. Self (139) favors a 6.4 mm screen for production

media bark, and a 3.2 to 4.8 mm screen for propagation media bark. Vanlandingham (169) recommended using a 3.6 mm screen.

For hardwood bark, Gartner (50), and Hoitink and Poole (79), recommend using a 3.2 mm sieve. Yates and Rogers (176) used a 1.9 mm screen, while Koranski and Hamza (96) reported best results using a 1.6 mm screen.

Lumbermills and papermills often process a mixture of hardwood tree species from different locations at the same time. Gartner et al. (52) recognised over 20 hardwood species in one lot of bark. This lack of uniformity can create much chemical and physical variation among different lots of hardwood bark. Softwood bark is more consistent than hardwood bark, even among different species.

Hammermilling and screening insures proper moisture retention, aeration, and drainage when bark is used as a container media component.

Composting Bark To Remove Phytotoxic Compounds

Several researchers suggest that bark should be composted before use as a media component to remove compounds that are toxic to plants (29, 56, 99, 121, 142, 148, 177).

Plant growth inhibitors have been found in the bark of various tree species (97). Gartner et al. (56) and

Solbraa et al. (150) noted that bark harvested in winter was more toxic than bark harvested in other seasons.

Lamb (99) suggested phenolic compounds in freshly harvested pine bark inhibit plant growth. Research in Australia (177) showed stunting in several species of plants when grown in noncomposted Pinus radiata bark. There have been numerous studies concerning the phytotoxicity of hardwood bark (29, 56, 121, 142, 148, 150, 168, 176).

According to Solbraa et al. (150) and Aaron (2), potential growth-inhibiting components of bark must be water soluble to influence plant growth. Water extracts of bark predominantly contain carbohydrates or phenolic compounds, with the phenolic group being dominated by tannins.

Still et al. (163) determined phytotoxic effects of bark from four hardwood species on mung bean and cucumber growth using water extracts. Silver maple, hackberry, sycamore, and cottonwood bark extracts inhibited cucumber seed germination, with root elongation most severely reduced by fresh silver maple extracts. Mung bean adventitious rooting was similarly affected.

Bark toxicity has been chemically removed (29). In the study done by Still and coworkers (163), pretreatment of fresh silver maple bark with PVP (polyvinyl-

pyrrolidone) reduced the inhibition of root elongation of cucumber. Since PVP is known to complex phenolics with free aromatic hydroxyl groups, the inhibitors must be phenolic compounds such as scopoletin or rutin (10). Chromatograms of extracts produced by Still et al. (163) yielded spots with identical R_F values as tannic acid, apparently verifying the identification of phenolic compounds. In a similar study, Solbraa et al. (148) removed about two-thirds of tannin caused inhibition of spruce bark extracts using a pre-treatment of hide-powder.

Parker (121) identified phenolic compounds in black oak bark using paper and liquid chromotoagraphy, and ultraviolet spectoscopy. Phenolics identified by these three methods included scopoletin, quercitin, catechin, robinin, chlorogenic acid, quercitin 3-methyl ester, and hydrolyzable and condensed tannins. Variation of phenolic types among different black oak trees was no greater than variation among branches within a single tree.

Composting will also remove plant growth inhibitors from bark. Worrall (175) found composting hardwood sawdust for 44 days removed most of the phytotoxins, and steaming reduced phytotoxicity. Gartner et al. (52) stated that phytotoxic effects of hardwood bark can be overcome by 'stockpiling' the bark for 30 days. Solbraa

et al. (148) found that two weeks of composting reduced amounts of inhibitory organic compounds to non-toxic levels. Although composting reduced the overall levels of toxic compounds in bark, the percentage of tannins (50%) in the extracts from spruce bark remained constant.

It may be more advantageous to remove toxic substances by composting rather than treating the bark with chemicals such as PVP. Research in Norway (142, 144, 148) demonstrated that small concentrations of extracts from fresh bark reduced root growth, while medium concentrations of extracts from composted bark stimulated root growth. In one study (148), a phenolic compound inhibited root growth at 10 ppm, but the same compound stimulated growth at 2 to 3 ppm. Solbraa (142, 144) has demonstrated growth enhancement of plants growing in bark compared with plants growing in other media.

Patrick et al. (122) found lettuce seed germination was severely inhibited by phytotoxins of bark residues after 10 to 25 days of composting; however, after 30 days of composting, extracts stimulated seed growth. These findings agree with those of Solbraa (142, 144), and concur with the statement by Gartner et al. (52) that 30 days of stockpiling will overcome phytotoxic effects of bark.

While phenolic extracts from fresh bark reduced root growth, the same substances in composted bark stimulated growth (150); therefore, composting the bark to lower the toxic amounts of phenols to non-toxic levels may be better than losing growth stimulation when phenolic substances are chemically removed.

According to Self (139), composting pine bark removed potentially toxic substances, but he noted that neither aging nor composting are necessary. Whitcomb and Appleton (172) grew several woody ornamentals in the bark of Pinus echinata and Pinus taeda. They compared fresh bark, aged bark, fresh bark amended with activated charcoal, and fresh bark amended with 'starter' nitrogen. There were no growth differences among the media treatments, indicating that plants grow equally fast in fresh bark as in aged bark. Cobb and Keever (39), Pokorny (127), Schusler (140), and Aaron (1) reported similar results. According to Aaron (1), "Pine bark has been clearly demonstrated to be non-toxic."

Klett et al. (94) reported that most growth suppression of plants in bark (hardwood) are due to lack of nitrogen, and not the presence of any toxic materials. Lunt and Clark (103) reported that lack of nitrogen is the cause of growth suppression in plants grown in hardwood bark, and not any toxic materials found in the bark. Apparently, the potential presence

of phytotoxic compounds does not predispose a need to compost bark.

Beside potential toxicity problems, researchers recommend composting bark for several reasons including the following: to reduce the carbon to nitrogen (C:N) ratio (31, 71, 161, 163), and to stabilize the substrate (16, 79).

Composting To Reduce The Carbon to Nitrogen Ratio

According to chemical analysis, bark contains from 100 to 450 parts carbon for each part nitrogen (8, 12, 22). C:N ratios can be as high as 435:1 in Black Oak bark (Quercus velutina Bartram) or as low as 115:1 in Hickory bark (Carya sp. Nutt) (8).

Microorganisms that infest harvested tree bark feed on one part N for every 35 parts of cellulose (carbon source) (6). Bunt (29) stated that composting micro-organisms require 1.0 part N, 0.5 part phosphorus (P), and 0.1 part sulfur (S) for every 50 parts of C. Fresh bark contains only 1.1% N by weight. Since microbes are more efficient scavengers of N than plant roots, the microbes 'tie-up' all available N in fresh hardwood bark media, leaving no N available for plant use (11, 150). Composting bark allows rapid release of excess carbon as CO_2 through decomposition of cellulose, narrowing the C:N ratio to levels where nitrogen becomes available for plant use.

According to Bunt (29), only cellulose and hemicellulose compounds need to be considered when determining the microbial need for nitrogen. Hardwood bark contains up to 40% readily degradeable cellulose, while pine bark is less than 5% cellulose (74, 128); therefore, microbial demand for nitrogen is much higher in hardwood bark than in softwood bark. In fact, the microbial demand for nitrogen in pine bark is low enough to permit use of fresh pine bark as a container media.

Since pine bark contains only small amounts of cellulose, it is a more stable material than hardwood bark. Allison and Murphy (8) found that fresh hardwood bark decomposes three times faster than fresh pine bark, because of the pine bark's resistance to microbial breakdown.

Whitcomb and Appleton (172), and others (39, 139), have proven there is no need to compost pine bark. Conversely, most researchers recommend that hardwood bark be composted to reduce the amount of cellulose to acceptable levels (15, 38, 94). Finished bark compost should have a C:N ratio from 10:1 to 12:1 of degradable carbon (125).

Bilderback (15) stated that attempting to offset the nitrogen draft of fresh hardwood bark by adding N creates soluble salts levels injurious to plant roots. Adding 0.15 Kg/m^3 N is required to satisfy the microbial

need of N in pine bark (128); however, Hoitink and Poole (79) found that a minimum of 2 Kg/m^3 N are needed in hardwood bark. Since hardwood bark is naturally high in soluble salts, this addition of N creates salt levels that inhibit plant growth. Even if soluble salts levels in fresh hardwood bark were tolerable, there would still be a need to compost to avoid shrinkage.

Composting To Stabilize The Bark

The term shrinkage refers to decomposition and resulting loss of volume of a growth medium in a container. According to Whitcomb (171), three complications arise from media shrinkage. First, N is tied-up during the decomposition. Second, the particle size, drainage, and aeration characteristics of the medium change quickly, increasing the water held while decreasing the aeration. Third, reduced depth of the medium in the container will further add to poor drainage. Whitcomb (171) noted: "It is not uncommon to see a container with such a mix only four inches deep (10 cm) after a few months when the initial depth in the container was six inches (15 cm) or more."

Bilderback (15) notes that failure to compost hardwood bark before using it as a container medium can cause up to 50% shrinkage of the medium in one growing season. Composting stabilizes the bark, preventing

problems of slower growth associated with shrinkage (15, 29, 32, 150).

Koranski and Hamza (96) found it was necessary to compost bark for longer time periods when adding increasing levels of hardwood bark to a hardwood bark:peat moss medium. To produce 'Bright Golden Anne' chrysanthemums that were equal in quality to control plants, bark had to be composted from 1 to 10 months, depending upon how much bark was present in the mix. Dunn (43) reported hardwood bark which was stockpiled for several years gave higher crop yields than bark fresh from the mill.

Using Noncomposted Hardwood Bark

According to Schusler et al. (140), when Euonymus kiautschovicus 'Manhattan' and Juniperus chinensis 'Pfitzeriana' grown in composted and noncomposted hardwood bark, and composted or noncomposted pine bark, were compared, it was found that there was no difference between the pine barks. Plants in the noncomposted hardwood bark were stunted. Composted hardwood bark had a higher N fertilization requirement than pine bark. It was necessary to lower the pH of hardwood bark and raise the pH of pine bark to maintain good plant growth. Not all researchers have had poor success with growing plants in noncomposted hardwood bark.

Matthews (109) stated that the growth of Antirrhinum majus and Begonia sempervirens seemed to be noticeable better in composted barks than in fresh barks, but not significantly better. Furthermore, he found no significant difference in the length of stems of Rosa hybrida 'Parfait' in either composted or noncomposted hardwood bark:sand media compared with those grown in a peat:vermiculite (1:1 by volume) control.

Guthrie (60) and Guthrie and Bearce (59) found 'Brilliant Diamond' poinsettias grew as well in noncomposted hardwood bark as in a Pro-mix (Premier Brands) control. They had amended the hardwood bark with a Osmocote 14-14-14 (Sierra Chemical Company, Milpitas, CA) and Magamp (W.R. Grace and Company, Fogelsville, PA), and they liquid fed plants every fourth watering with a 20-20-20 fertilizer (59). No problems with excessive salts were reported.

Guthrie (60) used noncomposted hardwood bark as a media component to grow hydrangea. Hydrangeas in a fresh hardwood bark:soil:sand medium grew as well as those in a peat:soil:sand commercially used hydrangea mix.

Further research with fresh hardwood bark will have to be successful before it will become an accepted container media ingredient.

Review Of Composting

The oldest solid waste disposal method known to humanity is composting. As a waste treatment process, composting converts all forms of organic waste into a smaller volume of stable and useful product (88).

Discussing the history of composting, Golueke (61) and Minnich et al. (114) stated that uses of compost were detailed in the Talmud and in the Bible. The first modern composting process was recorded in the 1930's when Albert Howard outlined a three month process now called the Indore Method. Contemporary windrow composting methods developed from Howard's process (125).

Composting Methods

Two processes can be used to compost large volumes of bark--windrow composting or high-rate composting (11). In windrow composting, the bark is piled in rows and turned periodically to provide air. High-rate composting uses machinery in continuous operation to bring about rapid composting. Because of energy costs for high-rate composting, windrow composting is used to compost tree bark. Several researchers have written guidelines on using windrows to compost tree bark (11, 61, 79, 125).

Windrow Composting

According to Bell (11), a windrow is made by piling bark in heaps six to eight feet high, ten feet wide, and often hundreds of feet long. Turning the pile periodically supplies air to the pile's center. A front-end loader, a grab crane, or a specially designed windrow composter can be used to turn the bark pile.

Golueke (61) suggested the pile shape should be a trapezoidal cross-section with a repose angle of 30 degrees for dry weather, or a semi-circle for wet weather to facilitate run off. Since windrows lose volume and height as decomposition proceeds, he suggested pile height be restored during the turning procedure.

The most favorable windrow, according to Poincelot (125), is trapezoidal-shaped with a base of seven feet, a top of five feet, and an angled side of five feet (yielding a height of approximately 4.8 ft.). Since heat loss is proportional to surface area while heat retention is proportional to volume, larger piles allow higher temperatures to develop closer to the pile's surface. When ambient temperature was 20^{o}F, Poincelot recorded a temperature of 140^{o}F at a six inch depth in a 5 X 10 ft windrow.

Minnich and Hunt (114) found that if a windrow is piled too high, it can compress itself. The smaller

pore space formed when a tall pile compresses itself favors growth of unwanted anaerobic microorganisms. However, a low pile is unfavorable because of rapid heat loss.

To avoid anaerobic conditions, Hoitink et al. (79, 84) described several precautions. First, the surface upon which the windrow is placed should provide adequate drainage to avoid anaerobic pockets in the base of the pile. Second, piles should not be covered with polyethylene plastic because the plastic cuts off the air supply. Windrows can be placed under a roof in areas of high rainfall. Finally, to avoid compaction of the bark and subsequent anaerobic conditions, heavy equipment must not be driven on the windrow.

The Composting Process

Composting bark is an aerobic decomposition process that converts easily degradable bark solids into stable humus material (12). Bollen (22) described the process in the following way:

> In the composting process, organic residues undergo sufficient decomposition to narrow the carbon to nitrogen ratio, much of the carbon passing off as carbon dioxide. The process should be allowed to proceed to near humification where some nitrogen becomes available as ammonium or nitrate.

According to McKinley et al. (111), the role of the microorganisms that make up composting materials has not received sufficient study. They describe composting as follows:

> Composting is the result of the actions of a microbial community which converts easily degradeable organic matter to more stable, humified forms and to organic products (e.g. carbon dioxide, water, ammonia, nitrate, and methane), giving off heat as a metabolic waste product.

This complex series of biological events removes cellulose (wood and cambium) and various toxins from the bark, leaving humic acid, lignin, and a host of microscopic organisms as end products (79). The process must proceed through three phases: 1) the mesophilic phase, 2) the thermophilic phase, and 3) stabilization (77, 79, 125).

Mesophilic Phase

In the mesophilic phase, bark hosts an assortment of fungi and bacteria that live when temperatures remain below 40°C. These microorganisms feed on sugars, starches, and other water soluble substrates (11, 125). Some feed on cellulose and hemicellulose, producing CO_2 and sugar as a by-product (6). This replenishes the

food supply for those microbes which are strictly sugar feeders.

After a "lag period" (51) of one or two days (74, 79), this feeding activity generates enough heat to raise the bark pile's temperature above 40°C (11, 125). Like insulation, the bark keeps the heat from dissipating (53). Mesophilic microbes die when temperatures reach 40°C (79), and the thermophilic phase begins.

Thermophilic Phase

Thermophilic fungi, bacteria, and actinomycetes live at temperatures from 40°C to 55°C or 60°C (92, 111, 125). One gram of "heating" bark compost contains one trillion microorganisms busily feeding on lipids, fats, cellulose, and lignin. These organisms perform the most rapid decomposition of the cellulose in bark, making a well-managed thermophilic phase essential for speedy completion of the composting process (92).

Although the thermophilic microbes' feeding activities generate enough heat to maintain their warm environment, they frequently produce too much heat. Since these microbes die when temperatures exceed 55°C (111), the bark piles should be cooled by turning them over as soon as this temperature occurs. Allowing the thermophilic microbes to die by failing to turn the pile causes composting to stop, and the process must start over.

The microorganism-heat combination results in the following conditions: 1) stabilizes the bark, 2) creates a substrate that suppresses or eliminates weed seeds and plant pathogens, 3) removes phytotoxic compounds and plant growth inhibitors from the bark, 4) reduces C:N ratio, 5) creates a substrate less likely to shrink, 6) increases bulk density of the bark, and 7) improves physical and chemical properties of the bark.

The length of the thermophilic phase is dictated by the cellulose content in the bark (74).

Stabilization

Stabilization begins as temperatures cool. When cellulose and other available food sources decrease, thermophilic microbial populations decrease causing temperatures to decline. When temperatures fall below 40^{o}C (79), decomposition products stabilize into humic acid materials composed mostly of lignins (125). According to Hoitink et al. (84), when temperatures fall below 40^{o}C, the mesophilic microbes recolonize the bark pile from the outside inward. Hoitink (74) noted these mesophilic microbes can be antagonistic to soil-borne plant pathogens.

Handling Composted Bark

Hoitink et al. (84) reported that excessive handling or mixing of composted bark exposes undigested

cellulose found under the surfaces of bark particles. This can cause a nitrogen draft that the composting process was performed to avoid. Therefore, amendments to bark should be made before the composting process is initiated.

Time Required To Complete Composting

Bell (11) reported the time period required for composting is influenced by climactic conditions, nature and texture of the waste being composted, and degree of stabilization desired. Table 1 lists the time requirements reported by various researchers.

While 30 days of composting eliminates toxic substances (29, 52, 150), 8-15 weeks are required to complete the composting process. When temperatures in the center of the pile remain below 30^{o}C after turning, the compost is called mature (150). Hoitink and Poole (79) noted mature bark compost has a top-soil odor, a pH of 6.4 to 7.2, and a low soluble salts concentration. Actinomycete and fungal microbial species produce the top-soil odor after they recolonize the bark at the end of the thermophilic phase (79).

Microorganisms

Three major groups of microorganisms live in composting tree bark. They are bacteria, actinomycetes, and fungi. Bacteria are most numerous under mesophilic

Table 1. Reported time period required to complete composting of hardwood bark.

year	Source	Weeks
1972	Klett, Gartner, and Hughes (94)	6
1973	Bell (11)	16-48
1973	Gartner, Still, and Klett (56)	6
1974	Solbraa (143)	16-24
1976	Hoitink and Poole (78)	10
1977	Sterrett and Fretz (157)	6
1978	Self (139)	8.5
1978	Ammon (9)	8.5
1978	Hoitink, Wilson, and Poole (84)	16-24
1980	Hoitink (74)	16
1980	Hoitink and Poole (79)	16-24
1983	Solbraa et al. (150)	10-15

conditions; however, fungi account for most of the total microbiological cell mass (6).

Bacteria

Bacteria are rod-shaped, spherical, or spiral-shaped cellular organisms ranging in size from 0.5 to 10 micrometers long. In a cubic inch of bark, one billion of these organisms would account for only 0.01 percent of the volume (6). Bacteria feed on simple carbon compounds such as sugars, and some contain enough chlorophyll to produce their own food. Poincelot (125) isolated only one species of bacteria, Bacillus stearothermophilis, from a thermophilic compost pile.

Few bacteria possess the cellulase enzyme complex. According to Alexander (6), Cytophaga are important to aerobic decomposition of cellulose. Other bacterial genera possessing cellulase include Vibrio, Bacillus, and Pseudomonas.

Bacteria account for all biological activity in anaerobic (airless) composting bark piles. Anaerobic bacteria produce substances that are toxic to plants; therefore, an aerobic compost pile must be maintained if the bark is to be used as a growing medium. Bacillus stearothermophilis and other bacteria, and fungi account for most of the microbiological activity in a thermophilic composting bark pile (8).

Actinomycetes

Actinomycetes form a transitional group between bacteria and fungi. They produce hyphae similar to fungal hyphae, but with a diameter ranging from 0.5 to 1.0 micrometers (6). This size more easily compares to the size of bacteria than to fungal hyphae. Actinomycetes are less numerous than bacteria, and fungi occupy greater cell mass under mesopohilic conditions (125). Poincelot (125) isolated several actinomycete species from a thermophilic compost.

Although many actinomycetes posses the cellulase enzyme complex, they are much slower in attacking cellulose than most fungi and bacteria, and they may not be good competitors for the substrate.

Many actinomycetes excrete enzymes that destroy bacterial cells and fungal hyphae (49), a process that is extremely effective at eliminating plant disease fungi and bacteria from the bark pile. Actinomycetes also decompose toxic phenolic compounds and substances such as lignin, chitin, and other materials that resist attack by fungi or bacteria. The white or gray color seen on the surface of a composting bark pile is often the hyphal growth of actinomycetes such as Streptomyces and Thermoactinomyces (125).

Fungi

These colorless organisms produce the commonly recognised structures known as mushrooms. Fungi possess filamentous mycelium of individual or branched hyphal strands. Fungi are less numerous than other micro-organisms, but their size and longevity are phenomenal by comparison (6).

While bacteria and actinomycetes feed on a variety of substances, fungi feed exclusively on carbonaceous organic substrates such as sugar, starch, fat, pectin, cellulose, and lignin. Members of all fungal groups can feed on hemicellulose, cellulose, and other plant materials. While certain bacteria and actinomycetes do not require oxygen, fungi require an aerated environment in which to feed (6).

Since fresh tree bark typically has an acidic pH, it is dominated by fungal species instead of acid-inhibited bacteria or actinomycetes. Abundant in woodland soils, fungi invade the bark of trees while the logs lie on the ground after they have been harvested.

Microorganisms In A Composting Bark Pile

Since removal of cellulose stabilizes the bark, the most important microbes in a bark pile feed on cellulose.

The linear cellulose chain is composed of individual glucose units connected at the first and

fourth carbon of the six carbon glucose ring. To digest cellulose, an organism must possess the enzyme complex named cellulase, composed of beta-(1-4)glucanase, beta-glucosidase, and a third uncharacterized enzyme. Cellulase attacks the 1,4-beta linkages along the cellulose chain, producing glucose, carbon dioxide, and heat as waste products. This chemical reaction proceeds more vigorously as the bark's particle size decreases (22), and as the temperature increases (125).

Studies on thermophilic degradation of cellulose frequently include strains of Trichoderma viride, Chaetomium thermophile, and Sporotrichium pulverulentum (14, 92). According to Solbraa et al. (150), Coprinus sp. rapidly infest hardwood bark piles. Other genera isolated from compost piles include Aspergillus, Humicola, Mucor, Penecillium, Stilbella, and Thermoascus (125).

Under acid conditions, fungi feed on cellulose, being replaced by bacteria and actinomycetes if the pH rises above 6.5 (6). For several reasons, bacteria and actinomycete isolation from bark piles rarely occurs in large numbers. First, bark piles, especially pine bark piles, tend to be acidic. Second, fungal species establish themselves during the acid conditions of fresh tree bark. If the pH rises above pH 6.5, established fungi competitively prevent the invasion of other

microorganisms. Finally, few bacteria or actinomycete species possess the cellulase enzyme complex required to feed on cellulose. Thus, fungi predominate in composting bark piles (6). Thermophilic fungi grow at temperatures from 37°C to 65°C, and rarely reproduce at temperatures below 40°C.

Compost Starters

Attempts to initiate composting by inoculating fresh bark piles with the necessary populations of microorganisms have failed. Solbraa (149) reported no significant response from a spruce bark pile inoculated with any of the following commercially available "compost starters": Biorott, Actilex, Eokomit I, Eokomit II. Solbraa stated: "Failure of starters to have a detectable effect is probably that raw organic materials contain the necessary microbes." His conclusion that there is no benefit from artificially inoculating bark piles with microbial populations agrees with the results reported by Hoitink and Poole (79).

Although manipulating microbial populations has had no influence upon time required to complete the composting process, manipulating the environmental parameters that affect the microorganisms has hastened the overall process. According to Mckinley et al. (111), the physical and chemical environment surrounding the composting microbes changes constantly, primarily as

a result of their metabolic activity. Fluctuations in temperature, moisture, air supply, pH, and nutrient levels occur constantly. These factors greatly affect their ability to grow, to metabolize, and to survive.

Influence Of Minerals

The elemental composition of microorganisms differs little among the various microbe types found in a composting bark pile (6). The following minerals have been isolated from the protoplasm of fungi, bacteria, and actinomycetes:

nitrogen (N)	iron (Fe)
phosphorus (P)	manganese (Mn)
potassium (K)	zinc (Zn)
calcium (Ca)	copper (Cu)
magnesium (Mg)	cobalt (Co)
sulfur (S)	molybdenum (Mo)

Microorganisms form their cells from these minerals and carbon (C), hydrogen (H), and oxygen (O). With the exceptions of N, P, and K, most substrates contain amounts of minerals in excess of microbial need. Table 2 lists mineral amounts several researchers added to hardwood bark before composting.

The Need For Nitrogen

Most researchers state N is the most important mineral addition. Increased cellulose degradation rates after addition of mineral N proves the value of N to composting (6, 31, 147). The pace of decomposition is proportional to the concentration of added N; however,

Table 2. Fertilizer amendments added to a hardwood bark pile before composting.

year[1]	urea	ammonium nitrate	potassium nitrate	super phosphate	magnesium sulfate	iron sulfate	sulfur
1972	0	5.4	0	1.8	0	0.6	0.6
1973	0	3.6	0	3.0	0	0.6	0.6
1978	0	3.0	1.2	3.0	0.6	0.6	0
1978	0	4.2	0	1.8	0	0.6	0.6
1978	0	6.0	0	5.0	0	0	0
1979	0	3.0	0	3.0	0	0.6	0.6
1980	2.4	0	0	0.3	0	0	0.6
1981	1.8	0	0	3.0	0	0	0
1983	2.0	0	0	2.0	0	0	0
1984	0	3.0	1.2	3.0	0.6	0.6	0

[1] Sources of information are in the following order: 52, 56, 96, 9, 139, 50, 79, 175, 150, 166.

if addition of N brings the C:N ratio below 35:1, too much N has been added (6), and this slows the decomposition process (31). Table 2 lists the levels of N used by several researchers.

Influence of Nitrogen Source

Sterrett and Fretz (157) reported that the source of mineral N added before composting had no influence on the decomposition rate. Other researchers claim faster composting when using ammonium-nitrogen (NH_4-N) instead of nitrate-nitrogen (NO_3-N) sources (31, 74, 84, 113, 143). According to Yates and Rogers (175), $CO(NH_2)_2$ (urea) supports faster decomposition than NH_4-N sources.

The influence of NH_4-N or urea on the pH of the bark causes faster decomposition of cellulose (176). After adding these compounds, the pH of bark rises rapidly to 6.5 or 7.0. Microorganisms favored at this pH level decompose cellulose more rapidly than those in more acidic environments. Compared to NH_4-N or urea, NO_3-N sources do not cause pH to rise as quickly (31, 32, 33, 79, 84, 143, 150).

Gartner et al. (52) composted hardwood bark piles with five different nitrogen sources--urea, ammonium sulfate, ammonium nitrate, calcium nitrate, and sodium nitrate. NH_4NO_3 consistently produced the fastest decomposition. Gartner et al. (52) advised against

using only urea or ammonium sources because a balance between NH_4-N and NO_3-N supported the most rapid cellulose decomposition.

Bunt (29) and others (32, 84, 125, 143, 146) also advised against using only urea or NH_4-N sources when composting hardwood bark because ammonia gas can be released from urea or NH_4-N when the pH is above 7.0. Poincelot (125) stated C:N ratios below 26:1 result in N loss as ammonia, and ratios above 35:1 lead to progressively longer time periods required to complete the composting process. Release of ammonia gas must be avoided because it kills the composting microorganisms (6, 74).

When using urea, researchers frequently add NO_3-N in the form of potassium nitrate (KNO_3) to provide a readily-available source of nitrogen. As a source of NO_3-N and K, KNO_3 does not influence the pH of the bark.

Influence of Phosphorus

According to Alexander (6) and Cappaert et al. (32), adding P before composting is unnecessary. They stated that tree bark contains sufficient P to meet the needs of the composting microorganisms.

Several other researchers claimed increased decomposition rates when using P additions (12, 84, 89, 96, 143, 146, 147). According to Jeris and Regan (89),

a P:N ratio of 5:1 should be maintained. Solbraa (147) recommended 0.18 Kg/m^3 of superphosphate as sufficient for composting bark. Table 2 lists the amounts of superphosphate used by several researchers.

Influence of Sulfur

Researchers usually incorporate S in the form of iron sulfate or elemental S. Both sources have an acid reaction that helps keep the pH below 7.0; such pH controls the formation of unwanted ammonia gas. Iron sulfate supplies some Fe along with the needed S. Hoitink (79) advised against adding any S source before composting because the S creates an environment that is too acidic for rapid decomposition. Solbraa et al. (150) recommended avoiding alkaline conditions in bark piles when urea has been added because of the risk of generating ammonia gas.

Carrico (35) stated that addition of S to composts amended with NH_4NO_3 may promote the activity of certain microorganisms involved in making smaller pores in the bark particles, increasing the bark's water holding capacity. Logically, these microbes may competitively inhibit the microbes that make larger pores, reducing the bark's air capacity.

Table 2 lists the levels of S used by several researchers.

Influence of Calcium

Researchers generally use calcitic ($CaCO_3$) or dolomitic ($CaMgCO_3$) limestone when adding Ca. To guarantee availability of Mg, they favor dolomite over limestone. Both sources have a similar alkaline reaction, increasing the pH.

While Ca is added to pine bark, it is rarely added to hardwood bark because hardwood bark is 4% Ca by dry weight (16, 30). Adding Ca to hardwood bark creates dangerously high pH levels that risk the formation of ammonia gas and toxic nitrites (29).

Influence of Magnesium

Epsom salt ($MgSO_4$) supplies both Mg and S. It has little influence on pH of the bark because the Mg portion has an alkaline reaction that neutralizes the acid reaction of the sulfate. Epsom salt is not added to pine bark when dolomite has been added because dolomite supplies enough Mg to meet the needs of the composting microorganisms. If the inherent Mg supply in hardwood bark is small, epsom salt is added to hardwood bark either before or after composting is complete (79).

Table 2 lists the levels of Mg used by several researchers. According to Solbraa et al. (150), there is no need for addition of other micronutrients during composting of bark.

Influence Of pH

The hydrogen ion (H^+) concentration influences the composition and activity of the microorganisms in a composting bark pile. Because of the insensitivity of most fungi to high H^+ concentrations, and because of the narrow pH range for most bacteria and actinomycetes, fungi make up the largest percentage of the microbial community in a bark pile. As pH increases to 6.0 and above, actinomycetes and bacteria become more involved. The mixed composition of microorganisms present at pH values near neutral perform the most rapid decomposition (6). Table 3 lists the optimal pH levels suggested in several reports.

According to Jeris and Regan (89), microbial production of small amounts of acidic or basic materials causes the change in pH. Gartner (50), however, reported that pH change in composting hardwood bark from 5.2 to 7.2 or 8.0 could result from mineralization of the high Ca content of hardwood bark. The type of material being composted influences the magnitude of pH change during the composting process (32, 79, 150, 157). The pH change can also be influenced by certain minerals added to the bark pile before composting begins. The pH levels in hardwood bark will rise above 7.0 in six weeks if $CaCO_3$ is added to the bark (55, 94). Carey (34) suggested that gypsum ($CaSO_4$) as a Ca

Table 3. Recommended optimum pH levels during composting.

year	source	optimal pH
1973	Jeris and Regan (89)	7.8
1973	Jeris and Regan (90)	6.5-8.5
1976	Cappaert, Verdonck, and Deboodt (33)	6.5-8.5
1979	Minnich and Hunt (118)	6.0-7.4
1980	Hoitink and Poole (79)	6.5-8.5
1980	Hoitink (74)	6.5-8.5

addition to hardwood bark might help control pH, but later reported that the pH tends to increase regardless of this treatment.

Poincelot (125) stated that a slightly alkaline condition at the start of composting accelerates decomposition, but care must be taken to control high pH values to avoid generation of ammonia gas.

Influence Of Temperature

Heat accumulates in a composting bark pile for two reasons: 1) microbial metabolism of organic matter creates heat, and 2) bark acts as insulation, retaining much of the heat in the pile (125).

Once microbial activity begins, generation of heat is very rapid. Jeris and Regan (88) reported that temperatures of a compost pile increased from 15 to 70°C in nine days. They noted that temperatures remained high until all readily degradable materials such as cellulose were used. When composting bark with NH_4NO_3, Carey (34) noted that temperatures reached 54.4°C, and stayed at this level for 10 days. Microbes living at these high temperatures performed most of the decomposition (125).

McKinley et al. (111) found microbial activity in a composting sludge pile decreased dramatically when temperatures rose above 55°C, and fell to nearly no activity when temperatures exceeded 60°C. They

concluded that temperature is a dominant physical-chemical parameter controlling microbial activity and biomass during composting.

Hoitink, Wilson, and Poole (84) noted that reaching thermophilic conditions thoughout the windrow requires temperatures of 55 to 70°C in the center of the pile. Slower decomposition has been reported at temperatures above 55°C (88), because even thermophilic microbes die as temperatures approach 60°C (92). Prolonged high temperatures of 45 to 55°C can kill pathogenic micro-organisms and weed seeds (11, 12, 92, 125) while increasing the populations of desired thermophilic microbes.

Influence Of Pore Space And Particle Size

Open pore spaces exist between solid particles in a composting bark pile. These pores must be filled with either air, water, or a combination of both. Since the composting microorganisms require both air and water, Cappaert, Verdonck, and deBoodt (33) stated an equilibrium must be maintained between the amount of air and water in the pores.

Bunt (29) and Hoitink and Poole (79) noted the amount of pore space is a function of the bark's particle size distribution. Small particles produce the following conditions:

1. Increased surface area exposed to microbial activity.
2. Increased moisture retention.
3. Decreased air-filled pore space.

In contrast to the small particles, large particles produce the following conditions:

1. Decreased surface area exposed to microbial activity.
2. Increased moisture loss.
3. Increased air-filled pore space.

An even distribution of particles from large to small sustains rapid composting (29, 79). Table 4 lists particle size distribution of fresh and composted hardwood bark as reported by Cappaert et al. (30).

Influence Of Moisture

Since water is the principal constituent of cell protoplasm, an adequate moisture supply must be available for microbial growth (8). Moisture has thus been labeled the most important parameter of microbial activity (8, 89).

Moisture becomes a critical factor when the piles contain too much or too little water. Poincelot (125) reported that a composting pile will be invaded by anaerobic microorganisms when moisture levels exceed 60% of the bark's wet weight. By limiting gas exchange, an oversupply of water creates an oxygen-deprived environment that supports anaerobic microorganisms. Since anaerobic microbes produce toxic substances,

Table 4. Particle size distribution of fresh and composted hardwood bark. Reported by Cappaert, Verdonck, and DeBoodt (30).

particle diameter mm	fresh bark % by weight	composted bark % by weight
0-1	28.1	50.0
1-2	16.1	18.1
2-2.8	4.9	2.9
2.8-4.8	14.7	13.3
4.8-8.0	12.7	14.6
larger than 8.0	22.9	3.0

excessive moisture will sour the bark, destroying its usefulness as a horticultural substrate. When moisture levels fall below 40% (61), the pace of decomposition slows considerably. A small supply of moisture reduces microbial growth by limiting the amount of protoplasm that they can produce. Although this reduction does not limit the bark's use as a substrate, it lengthens the time period required to complete composting.

Discrepancies exist between the reports of optimal moisture levels. Bell (11), for example, reported that aerobic composting proceeds rapidly at levels as high as 75%, and as low as 25%, while most reports suggest that an optimal moisture range exists from 45 to 65%. Poincelot (125) warned that 60% moisture on a wet weight basis may not provide enough air space to prevent invasions of anaerobic microbes. Table 5 lists the optimal moisture levels reported by several researchers.

Influence Of Aeration

Microorganisms use oxygen in breaking down carbonaceous materials. Hydrogen atoms are broken off carbon chains and chemically bound to oxygen (O_2) producing water (H_2O). Without this reaction, the interior of the microbial cell would rapidly become too acidic for the cell's survival (6).

Table 5. Recommended optimal moisture levels for composting with windrows.

year	Source	% moisture by wet weight	% moisture by dry weight
1973	Bell (11)		45-55%
1973	Bell et al. (12)		50%
1973	Jeris and Regan (89)	50-60%	
1974	Poincelot (125)	50-60%	
1975	Cappaert et al. (31)	50-60%	
1976	Cappaert et al. (33)	50-60%	
1976	Starcher (153)	50-60%	
1979	Gartner (50)		60%
1980	Hoitink and Poole (79)	50-65%	
1980	Hoitink (74)	50-65%	
1983	Wilson (174)		55%

During respiration, microbes absorb O_2 and release CO_2. The CO_2 displaces O_2 and other gases occupying air-filled pore spaces in the bark pile. The pile must be porous enough to allow CO_2 and other gases to be replaced by O_2 from the outside air. If the CO_2 is not replaced by O_2 from outside of the pile, the composting microorganisms die, and the pile becomes populated with undesirable anaerobic bacteria. Slow carbon dioxide replacement causes slow microbial activity. With adequate pore space, neither the O_2 nor the CO_2 supply limit microbial activity.

As with moisture levels, reported optimal oxygen levels differ from one another. Poincelot (125) noted composting piles remain aerobic when oxygen levels remain above 0.5% of the air-filled pore volume. Hoitink and Poole (79) stated oxygen levels in air-filled pores must remain above 0.1%, and preferably above 5 to 12%. Solbraa (150) reported the minimum O_2 level to be 6%.

Turning a composting bark pile assures the availability of oxygen in its center. Poincelot (125) suggested the time to turn over a pile can be determined by monitoring oxygen levels in the pile. Solbraa (150) reported excellent composting when using CO_2 level to determine when to turn the piles. Temperature has also

been used to determine when to turn over a bark pile (50, 125).

Changes Caused By Composting

Table 4, Table 6, and Table 7 list typical physical and chemical changes caused by the composting process. Except for loss of air space and water buffer capacity, all physical changes appear to be beneficial. The safest conclusion possible from the changes in chemical composition of four hardwood species is that bark from individual species responded differently.

Wilson (174) noted that composting killed insect life, and destroyed pathogens such as honey fungus and aspergillus spores (aspergillus spores can cause Farmer's Lung in humans). He also found the composting process decomposed plant growth inhibitors such as tannins, volatile terpenes, alkaloids, and organic acids.

Solbraa et al. (150) stated most toxins and most of the initial cellulose, hemicellulose, and proteins should decompose during composting, leaving lignins and microbially produced compounds. They reported the amount of large particles decreased from 63% to 48% of the total bark weight, while the amount of small particles increased from 16% to 37%. (Large particles do not pass through a 6 mm sieve, while small particles will pass through a 2 mm sieve).

Table 6. Changes in physical properties of hardwood bark induced by the composting process. Reported by Cappaert, Verdonck, and DeBoodt (30).

physical property	fresh bark	composted bark
bulk density	0.22	0.26
volume percent total pore space	85.20	82.10
volume percent water at		
10 cm tension	47.40	71.20
50 cm tension	29.60	42.20
100 cm tension	27.10	40.50
volume percent air capacity	37.80	10.90
easily available water[1]	17.80	29.00
water buffer capacity[2]	2.50	1.70

[1] Quantity of water released when tension increased from 10 cm to 50 cm.
[2] Quantity of water released when tension increased from 50 cm to 100 cm.

Table 7. Changes in elemental composition determined with a direct reading spectrograph of several species of hardwood bark induced by composting. Reported by Still et al. (161).

	percent dry weight					
bark species	N	P	K	Ca	Mg	Fe
before composting						
hackbery	0.8	0.09	0.44	3.59	0.22	0.11
cottonwood	0.3	0.04	0.25	1.74	0.11	0.06
silver maple	0.5	0.04	0.25	0.97	0.06	0.07
sycamore	0.4	0.07	0.25	1.85	0.09	0.06
after composting						
hackberry	1.2	0.14	0.75	7.30	0.11	0.08
cottonwood	1.4	0.12	0.58	1.99	0.14	0.13
silver maple	1.6	0.08	0.31	1.33	0.11	0.10
sycamore	1.5	0.10	0.43	1.65	0.11	0.07

After composting hardwood bark, Bunt (29) reported an increase in bulk density from 0.21 to 0.26 g/ml, an increase in volume of water available between 10 and 100 cm tension, and an increase in cation exchange capacity (CEC) from 8 to 60 me/100 g.

Cappaert et al. (30) reported that composting influenced the transformation of mineral N to organic N. This resulting pool of organic N is not readily available, creating a need for additional N when the bark is used as a growth medium.

Bell (11) reported bark continued to decompose after composting. Post-composting decomposition proceeds slowly since materials remaining after composting resist decay.

Hoitink et al. (84) stated that excess mixing after composting may expose cellulose inside the larger particles, recreating the nitrogen draft upon potting. Thus, excessive mixing could defeat one of the purposes of composting.

Composting Blends Of Pine And Hardwood Bark

Self (139) stated it was necessary to compost the mixture of softwood and hardwood bark frequently produced by some sawmills, especially if problems associated with tannic acid, high pH, excess manganese, or other unknowns were to be avoided.

Bilderback (15) theorized that mixing pine bark with hardwood bark could reduce the time required to complete the composting process. Enhanced decomposition could occur because pine bark would provide greater aeration to the compost pile. Bilderback (15) noted that no scientific facts about composting blends of pine and hardwood bark were currently available.

Solbraa et al. (150) performed an experiment similar to the idea suggested by Bilderback (15). Solbraa and his colleagues composted hardwood bark that had been mixed with 10% or 20% spruce bark. Spruce and hardwood bark required 10 and 15 weeks to compost, respectively. The blended spruce and hardwood bark required between 9 and 12 weeks to compost, which tends to support Bilderback's hypothesis, as both spruce and pine are softwood species.

Solbraa and collegues (150) added 20 Kg urea and 20 Kg superphosphate (9% P) to 10 m^3 piles of 100%, 90%, and 80% hardwood bark piles. They concluded the 100% hardwood bark pile may have composted faster if the initial amount of supplied N had been higher.

According to the amount of softwood bark mixed with the hardwood bark, careful adjustment of the minerals added to start the composting process must be made to avoid problems associated with extreme pH conditions or excess nitrogen.

Treebark as a Container Medium

Traditional container and pot-plant growing media have been composed of mixtures of sphagnum peat, perlite, vermiculite, or sand (74, 77). More of the criteria desired for media components are met by sphagnum peat than by any other ingredient (29). Hoitink and Kuter (77) stated that treebark has significantly replaced sphagnum peat in nursery container mixes due to its pathogen suppression, lower cost, and easier preparation.

Perched Water Table

One of the most important aspects of container growing media is the principle of "Richard's Outflow Law" (67, 151). The law defines the total water potential of a containerized substrate as being a function of the matric, gravitational, pressure, osmotic, and overburden potentials, with the matric and gravitation potentials being the most important considerations. After drainage, when soil water is not moving, gravitational and matric potentials are equally strong, but opposite in sign throughout the soil profile (one exhibits positive potential while the other exhibits negative potential). Since a container medium is exposed to the atmosphere at both end of its profile, the drainage level matric potential is zero. This

causes a perched water table to form, and media at this level is saturated. The extent to which saturation extends upward in the container is a function of the container's dimensions and the moisture-holding capacity of the medium in the container.

If a medium contains few coarse particles, pore size will be very small. Predictably, capillary action (adhesion) will cause a higher water table in that container. Such a medium will provide little air-space; in fact, a large portion of the root system of a plant in a shallow container could be mostly under water until the plant's transpiration reduces the amount of water in the container (123). This is why coarse amendments are added to container media (73).

Particle Size Distribution

To standardize large-scale use of container media amendments, the particle size distribution (PSD) is usually described using screen analysis, which has previously been discussed. PSD influences the medium's physical properties such as percolation rate of water, water-holding capacity, and air-space after drainage (27, 108). Brown and Pokorny (27) stressed the importance of knowing an amendment's PSD.

According to Conover (40) and Love (101), distribution of particle sizes in any medium should be rather uniform. They indicate that a cementing or

packing effect results when a medium contains only very large and very small particles.

Hanan et al. (70) found the distance that oxygen must travel to a root increases as particle size decreases. Capillary forces hold more water in fine textured soils, increasing the thickness of the water film around a root through which oxygen must diffuse.

Pokorny and Delany (129), stated the best particle size distribution for pine bark was 70% to 80% of the particles ranging from 1.6 mm to 2.4 mm, with remaining particles smaller in size. Gartner et al. (53) stated good results can be obtained using hardwood bark with particles from 0.4 mm to 0.8 mm, but they stated that a distribution of 35% less than 0.2 mm, and 55% between 0.2 mm and 0.8 mm, and 10% larger than 0.8 mm was best for hardwood bark media.

Researchers working with hardwood bark agree that extremes in particle size distribution should be avoided (52, 56, 93). Koranski and Hamza (93) found fresh hardwood bark had a particle size distribution of 35% to 40% less than 0.01 mm, while 23% were greater than 0.25 mm. After 10 months of composting, 56% were less than 0.01 mm, and 13% were larger than 0.25 mm.

Table 8 shows that particle size distributions of pine bark obtained by Pokorny (127) from six different sources were quite different.

Table 8. Particle size distribution (% by weight) of pine bark obtained from six commercial nursery sources. Adapted from Pokorny (127).

NBS sieve	mm screen size	pine bark source A	B	C	D	E	F
4	4.76	13.6	9.8	8.5	4.4	23.3	26.4
8	2.38	20.4	17.2	51.2	18.2	11.8	25.6
10	2.00	7.6	7.1	10.1	9.2	3.8	7.4
18	1.00	18.7	19.3	19.9	23.7	11.1	15.6
20	0.84	4.8	5.7	3.7	6.5	3.2	3.2
30	0.59	8.7	10.2	5.0	10.7	5.8	5.3
40	0.42	7.7	9.3	3.5	9.3	5.6	3.7
pan	----	18.6	21.4	7.9	17.8	35.0	12.4

Wettability

An initial delay in plant growth has been reported when plants were grown in pine bark (59). Research at the University of Georgia (127) indicates this problem is not nutritional in nature, but is moisture related.

Since availability of water at potting is critical to the growth cycle of plants (127), it is important that the bark be thoroughly moistened before use as a growing medium. An initial difficulty in wetting treebark has been reported (4, 53, 54, 127, 152, 169). This hydrophobicity has several causes.

Airhart et al. (4) stated the natural purpose of rhytidome (outer bark) is to prevent water loss and external damage; thus, when the bark is used as a growing substrate, the suberized and waxy surfaces, and other organic chemicals, repel water molecules. Physically, the rough particle surfaces of bark create and interfacial water tension that resists infiltration of moisture. If the quantity and size of pores is too small, water entry is difficult (4, 27).

In another study , Airhart et al. (3) found the initial percent moisture of pine bark influences infiltration and absorption of water. With initial moisture content below 34% (on a wet weight basis), milled pine bark resists water infiltration, and holds insufficient

moisture to support plant growth. Therefore, pine bark should be thoroughly wetted before potting.

Pokorny (127) noted that milled pine bark is often hot-air dried to facilitate processing, storage, and shipping. The drying process lowers the initial moisture content below 34%, making the bark difficult to wet.

One way to increase initial moisture content of bark is to treat it with surfactant (wetting agent). Pokorny (127) tested 24 different wetting agents on pine bark, and found nine were effective at achieving "threshold wetting" of 35% moisture (wet weight basis). Tilt (167) tested several wetting agents on pine and hardwood bark. Successful agents identified by Pokorny (127) and Tilt (167) are listed in Table 9 and Table 10, respectively.

Bark media are known to dry out faster than peat amended media (44). This problem can be managed by using frequent watering with smaller amounts (syringing) (44, 127). Bark with finer particle size distribution will not dry out as fast as a coarser medium.

Water retention can also be improved by incorporating certain hydrophilic substances, such as Hydrogel or Viterra II (Union Carbide Corporation, Research Triangle Park, NC), into the bark medium. These

Table 9. Minimum concentration of surfactants that effectively wet pine bark. Reported by Pokorny (127).

	minimum concentration				
surfactant	0.1%	0.2%	0.4%	0.5%	1.0%
Neutronyx 600	---	XXX	---	---	---
Aquagro	---	---	XXX	---	---
Gafac PE510	---	---	---	XXX	---
Hydrowet	---	---	---	---	XXX
Firechem	XXX	---	---	---	---
Triton CF-54	XXX	---	---	---	---
Triton DF-16	---	XXX	---	---	---
Triton X-100	---	XXX	---	---	---
Triton X-1145B	---	XXX	---	---	---

Table 10. Concentration of surfactants that effectively wetted hardwood and pine bark. Reported by Tilt (167).

	concentration		
surfactant	0.1%	0.3%	0.5%
Triton CF-54	P[1]	H P	H P
Triton X-100	---	H P	H P
Triton DF-16	H P	H P	H P

[1] Hardwood bark was not sufficiently wetted at this concentration of this surfactant; H = hardwood bark, P = pine bark.

products have been shown to lengthen the shelf-life of many horticultural crops (159).

Shrinkage

The term shrinkage has three meanings as it relates to container media (16). Shrinkage can refer to loss of volume of a medium in a container due to microbial decomposition of organic amendments, it can refer to loss of volume of a media upon mixing two or more components of dissimilar particle size distribution (space-volume shrinkage), or it can refer to moisture related contraction of a medium upon drying in a container.

The worst type of shrinkage is caused by microbial breakdown of organic components. Bilderback (16) stated: "Uncomposted components may reduce the volume of a full container at potting to half a container of medium six months later." Decomposition increases the amount of small particles in the medium, changing the medium's porosity, and resulting in poor drainage and possible overwatering problems (127).

Composting hardwood bark before use as a container substrate prevented microbial-caused shrinkage (32, 33, 150). Pokorny (127) noted fresh pine bark shrinks very little (5.8%). The relative decomposition of pine and hardwood bark has been previously described.

Raker and Hoitink (133) compared growth of three species of ericaceous plants in composted hardwood bark, peat:sand, and haydite:peat:sand media. After two growing seasons, air capacity was 18%, 13%, and 14% of container capacity, respectively. They postulated this reflected the composted bark's stability and resistence to decay (shrinkage).

Space-volume shrinkage occurs when small particles of one media amendment occupy large pore space created by another media amendment of larger size. Bilderback (16) noted that mixing 1 ft^3 of pine bark with 1 ft^3 of sand will not make 2 ft^3 of medium. Whitcomb (171) noted that mixing 3 yd^3 of pine bark, 1 yd^3 of peat, and 1 yd^3 of sand yields 4.2 yd^3 of medium instead of 5 yd^3.

Moisture related shrinkage is common in media components such as peat moss which expand when wet, and "shrink" as they dry-out. Bilderback (16), observed peat moss actually pulls away from the sides of a container if it becomes too dry. Then, when irrigated, water runs between the shrunken medium and the container side rather than infiltrating the substrate.

Porosity

Havis and Hamilton (73) described container media as having dry material and pores which are filled with either air or water. The medium is saturated when all

pores are filled with water. Water drains from large pores by the force of gravity, being replaced with air. This condition is called container capacity, and the water held in the medium at container capacity is called percent water-holding capacity (percent by volume). The volume of air-filled pores at container capacity is called percent air capacity, or drainable pore space (171). Medium sized pores contain water held under tensions stronger than a plant's ability to obtain it without the expense of energy. The amount of water held in small pores is called moisture buffer capacity because this water provides a buffer zone before wilting. Smaller pores contain water that is not available for plant use, and, if this is the only water in the medium, the plant will be severely wilted.

Deboodt and Verdonck (42) established the gravity-drained large pores (percent air capacity) in container media should be from 20% to 30% of the total pore space (%TPS). Bunt (29) noted that air capacity (%AC) is influenced by size of the container, with %AC increasing linearly as container size increases geometrically.

Water Holding Capacity

Several researchers have noted the importance of water-holding capacity (%WHC). Mastalerz (108) stated that water deficiency limits plant growth more than all other environmental factors. Bunt (29) noted water

stress controls plant growth, and Puustjarvi (132) indicated water availability is the greatest limiting factor of plant growth. Whitcomb (171) indicated the greatest loss of plants in containers is due to over-watering.

Traditionally, peat moss has been added to container growing media to increase %WHC, because it retains large volumes of water, but dry peat can be difficult to wet. Like peat moss, pine bark possesses inner surfaces that increase its ability to hold water (3, 4). Airhart et al. (3) reported the saturated moisture content for a peat-vermiculite mix was 612% of dry weight, while pine bark was 460%.

After studying moisture availability of several hardwood species, Spomer (152) found saturated hardwood bark contained 40% moisture by volume, but only 25% of the total absorbed water was "plant available."

Cappaert, Verdonck, and Deboodt (30) reported a %WHC of 29.6% for a fresh hardwood bark medium, and a %WHC of 42.2% for a composted hardwood bark medium. Pokorny and Henny (130) reported a %WHC of 29.8% for a pine bark:sand (1:1 by volume) medium.

Air Capacity

The final %AC of a medium is governed by factors such as PSD and particle geometry (topography), which, in turn, influence plant growth. According to Grable

(63), the technology used to measure %AC greatly exceeds the understanding of how AC influences plant growth. Additionally, %AC is influenced by many independent factors; therefore, attempts to use aeration as an independent influence on plant growth can lead to erroneous conclusions.

Although conclusions based upon %AC may be erroneous, several attempts at describing optimum values for %AC have been made, and a discussion of %AC can be important. Some of the confusion about %AC could be due to the differing methods used to calculate %AC (57, 73, 171).

Both softwood and hardwood bark can improve the aeration of container media if a suitable PSD is used. Szopa et al. (164) and others (138, 157) used treebark alone or in combination with other ingredients to provide excellent %AC for container media.

The data on a composted hardwood bark medium indicates that %AC may be limiting, especially after larger particles are eliminated by composting (30). Hoitink (74) noted that growers found inadequate aeration when the mills had screened out the 12 mm to 18 mm particles from a hardwood bark medium. Conversely, pine bark has a higher %AC than hardwood bark (30, 74).

Since pine bark particles are platy or granular, and hardwood bark particles are fibrous, these two

materials pack differently. This would create different types of pore space, even if the %AC were identical. The different types of pore space influence the thickness of water film surrounding plant roots, which affects the length of the diffusion-path an O_2 molecule must traverse to reach a plant root. Thus, while two different media may have equal air capacities, the particle size distribution, and subsequent air-pore distribution and configuration, may be different, causing different plant growth responses (123).

It was previously mentioned that the ideal %AC has been estimated at 20% to 30% (42). Several researchers have reported different optimal levels. Bunt (28) studied the influence of %AC on growth of tomato plants, and concluded that 25% air capacity results in optimal vegetative growth. %AC above 25% reduced growth due to water stress problems. Paul and Lee (123) recommended 10% to 15%.

Researchers commonly blame poor plant growth on poor %AC. Hanan et al. (70) explained that growth inhibition does not occur as long as O_2 concentrations are greater than 10%, and CO_2 concentrations less than 5%. Accordingly, as long as a container is at least 18 cm tall, and nothing impedes drainage, extremes in O_2 or CO_2 supplies seldom directly cause symptoms attributed to deficient %AC.

Exchange Capacity

Plants obtain nutrients as ions such as Ca^{2+}, Mg^{2+}, K^{+}, NH_4^{+}, Na^{+}, NO_3^{-}, Cl^{-}, SO_4^{2-}, and $H_2PO_4^{-}$. The ability of a medium to hold these ions and prevent them from leaching is called exchange capacity (EC), or cation exchange capacity (CEC) when referring only to positively charged ions. EC is measured in milli-equivalents per 100 grams of medium (meq/100g). Whitcomb (171) stated that for container production, using milliequivalents per 100 cc of medium makes more sense because of limited volume in a container, and varying bulk densities of different media.

EC is important because it provides a buffer against rapid change in nutrient availability. Treebark provides excellent EC (184).

Bollen (22) reported that CEC of douglas fir bark varied with the particle size distribution from 44.8 to 60.5 meq/100g, which was 2 to 3 times the CEC of a silt loam soil. He attributed this high CEC to uronic acid substances in the bark. Other reports of treebark CEC are lower (32, 150). Aaron (2) reported the CEC of pine bark to be 30 meq/100g. Scott (137) reported the CEC of hardwood bark, sawdust, and peat moss to be 44, 18, and 73, respectively. Dyke (44) reported the CEC of hardwood bark to be 43 meq/100g, while Bunt (29) found

that fresh bark has a CEC of 8 meq/100g which rises rapidly with aging or composting.

Airhart et al. (88) found that interior bark surfaces could be of significance in providing exchange sites. Brown and Pokorny (27) obtained similar results. Generally, the CEC of bark is more than adequate to meet plant needs, and it is frequently noted that CEC of hardwood bark increases with age, eventually surpassing the CEC of peat moss (22, 52, 56, 80).

Treebark pH

Certain aspects of treebark pH have previously been discussed.

The pH of container media does not directly influence plant growth (72), and Whitcomb (171) noted that pH is often used as a scapegoat for problems with plant nutrition. Tilt (167) tested the influence of media pH on the rooting response of five woody ornamental species thought to have different pH preferences. Comparing a 100% pine bark medium with a peat:perlite (1:1 by volume) medium, both mediums were adjusted to a range of pH values from 3.4 to 7.8. They concluded that pH influences rooting of some species, but not others. Buxus sempervirens, and Cotoneaster microphyllus rooted differently at differing pH levels, while Juniperus conferta, Cytisus scoparius, and Ilex X

'Nellie R. Stevens' rooted equally well at all pH levels.

The pH is generally considered important only as it influences the availability of plant nutrients (72). Lucas and Davis (102) stated that highly organic media should not have high pH levels because these media are poor in component nutrients whose availability is suppressed by high pH conditions. Optimal medium pH values have been identified based upon nutrient availability.

Matkin, Chandler, and Baker (110) stated the desired pH range is from 5.5 to 6.5 for container growing media. Furuta (48) and Hartmann and Kester (72) recommended 5.5 to 7.0.

When a media component contains a certain nutrient in its composition, like hardwood bark contains 4% calcium by dry weight, pH has little influence on availability of the nutrient. The nutrient is released as the medium decomposes; therefore, pH is important as it influences the activity of the microorganisms decomposing the media amendment (112, 171).

Pine bark is typically acidic, ranging in pH from 3.9 to 5.4 (16). Self (139) reported that pine bark has a pH from 4.1 to 4.2, increasing to 4.5 with composting. Aaron (2) reported that pine bark has a pH of 5.5, and Pokorny (127) reported a pH of 4.1.

Hardwood bark pH values are initially around 5.2 to 5.5, but increase with aging or composting to 7.0 or more (74). Klett et al. (94) stated that the initial acidity of hardwood bark is due to the presence of polyphenols, and this acidity begins to subside four or five months after potting. Morris and Milbocker (115) found that the leachate pH of a red oak bark medium from Kentucky was 7.0 only 15 days after potting and fertilization with a complete nutrient solution, while 50 days later, the leachate pH was 8.0 while the pH of the water used had decreased from 6.8 to 6.2. Scott (137) reported that a bark medium of a mixture of hardwood species from West Virginia was 7.2. Table 11 lists the pH values of several hardwood species.

While pine bark tends to be overly acidic for good nutrient availability, composted hardwood bark tends to become too alkaline for good plant growth. Consequently, pine bark is limed to increase pH, and hardwood bark requires sulfur to lower the pH (16, 56). Schusler (140) stated it was necessary to raise the pH of pine bark and lower the pH of hardwood bark in order to maintain good plant growth.

Treebark Nutrient Composition

The component nutrients in organic media components are firmly bound in particle structure, and are released upon the microbial decomposition of the

Table 11. Bark pH of various hardwood species. Reported by Murphy et al. (117).

species	pH
white ash (*Fraxinus americana* L.)	6.0
beech (*Fagus* sp. L.)	5.9
american elm (*Ulmus americana* L.)	6.0
red maple (*Acer rubrum* L.)	4.9
sugar maple (*Acer saccharum* March)	5.5
white oak (*Quercus alba* L.)	5.5
black walnut (*Juglans nigra* L.)	5.5

component. This is why raising or lowering the pH within the range of 4.0 to 7.0 has little influence on nutrient availability, except for how the pH influences the activity of the microbes (112, 171). Thus, pH is more important to the EC of nutrients adsorbed to charged surfaces of media components.

Black (20) and Cappaert et al. (30) reported on the chemical composition of a hardwood bark medium (see Table 12). Like Gartner et al. (52, 53), Black (20) found Ca in hardwood bark to be very high (around 4%). This helps explain why increasing pH values are associated with hardwood bark media. Hardwood bark also has a plentiful supply of micronutrients when compared to pine bark (16, 29).

Bollen (22) noted that mineral content in bark is influenced by availability of nutrients in the soil in which the tree was growing rather than by the nutritional needs of the tree. Therefore, the component nutrients in tree bark will vary according to the geographic location in which the trees were growing; however, this does not explained differences in chemical composition among hardwood species from the same location.

Toxic Factors In Treebark

The possibility of Mn toxicity from hardwood bark has been noted (44, 115, 136). Morris and Milbocker

Table 12. Chemical composition of a hardwood bark medium of mixed species. Reported by Black (20) and Cappaert, Verdonck, and DeBoodt (30).

nutrient	ppm (20)	ppm (30)
nitrate	47.92	----
phosphorus	143.00	570
potassium	156.30	2200
calcium	3740.00	4100
magnesium	251.30	500
iron	42.83	----
manganese	130.70	----

(115) reported Mn toxicity on Ilex crenata Thunb. growing in a 1:1 (by volume) mix of red oak (Quercus rubra L.) bark and sand. Growth was less in this medium than in sand culture. Leaf chlorosis which appeared in bark:sand grown plants was at first believed to be caused by iron deficiency. Similarly, Black (20) reported iron deficiency on Ilex crenata 'Hetzii' growing in a 1:1 mix of hardwood bark and sand. However, Morris and Milbocker (115) found that Mn levels in leachates from their bark: sand medium were several times higher than the levels of Fe, indicating that Fe deficiency was probably induced by Mn toxicity.

Dyke (44) found high levels of Mn present in a hardwood bark medium that could have caused the iron chlorosis observed on 'Red Ruffles' azalea growing in this medium.

Sant et al. (136) reported that total Mn in spruce and hardwood bark media was high, but soluble Mn was kept below 200 mg/l (a Norwegian standard) because the pH was higher than 6.2. They stated that Mn levels above 500 mg/l are commonly thought to induce toxicity.

Hoyle (86) reported that a foliage Mn level of 441 ppm was optimal for growth of Betula alleghaniensis, with good growth ranging from 66 to 1328 ppm. Optimal soil concentration was 5.0 ppm, with good growth ranging from 0.0005 ppm to 25 ppm.

Pathogen Suppression In Bark

According to Hoitink (74), observing nurseries during the late 1960's, Phytophthora root rot of rhododendron was less frequently identified in media amended with composted treebark than in media amended with peat-moss. The first reported suppression of a soil-borne disease by incorporation of treebark into growing medium was from the University of Georgia in 1973 (49, 66, 74), even though the phenomenon of suppressiveness had been known as early as 1922 (49). Gugino, Pokorny, and Hendrix (66) found root fresh weights of Ilex crenata 'Helleri' increased as percentage of pine bark in the growing medium increased. The fresh weight increase occurred even in the presence of high populations of Pythium irregulare. Since then, there have been many reports of pathogen suppression in treebark media (16, 23, 29, 52, 56, 74, 77, 78, 79, 81, 82, 97, 101, 105, 106, 119).

Hoitink and Poole (79) noted that fir and pine bark can suppress many plant pathogens, but pine bark has little influence on Rhizoctonia solani. Love (101) observed that growers using pine bark media had fewer incidences of root rot. Solbraa (145) reported that development of damping-off in conifer seedlings was higher in spruce bark than in mineral soil. Comparatively, hardwood bark has fungicidal properties

(29, 77), and has suppressed all soil-borne pathogens examined (74, 76, 83), including nematodes (80, 105).

Hoitink et al. (76, 83) reported that Rhizoctonia and Pythium crown and root rots of Poinsettia 'Annette Hegg Dark Red' were suppressed in composted hardwood bark amended with sphagnum peat moss, but these diseases were not suppressed in peat. To match the suppression of hardwood bark, the peat medium had to be steam sterilized and drenched twice with fenaminosulf and quintozene. High levels of inoculum overcame the suppressive effect (41). Thielaviopsis basicola was also suppressed in hardwood bark (74).

Several factors are thought to be involved in the suppression of pathogens in bark media.

Suppression Through Processing

Initial populations of pathogens are reduced by the milling of bark. Bunt (29) found that rhizomorphs of the fungus Armillaria mellea Vahl. cannot survive more than a few weeks when broken into fragments. Shredding and hammermilling procedures used by most mills processing bark for market can fragment fungal rhizomorphs.

Suppression By Physical Properties

Compared to other media, improved aeration of treebark media has been considered a factor in

suppression of soil-borne pathogens. Hoitink (75) stated that with more than 25% air capacity in a typical nursery container medium, Phytophthora root rot of rhododendron will be suppressed by the medium's physical properties alone. Hoitink, Van Doren, and Schmitthenner (83) studied the effect of aeration on rhododendron root rot. Using hammermilled and screened hardwood bark amended with sand before composting, they obtained a medium with physical properties similar to a peat:sand medium. Four inoculum levels of Phytophthora cinnamomi were added to each medium. 'Sweet Frost' lupine seedlings were killed more often in the peat:sand medium than in the hardwood bark:sand medium. Benson (13) reported that optimal water potentials for plant growth (42) were also the optimal water potentials for sporangia production of Phytophthora cinnamomi. Therefore, either the biological or chemical characteristics of bark may be more influential than physical properties in the suppression of Phytopthora cinnamomi.

Suppression by Chemical Composition

Gill (58) found better seedlings grew in Pythium infested media that had been treated with gypsum compared to seedlings in untreated soil. High calcium levels from the gypsum either provided direct inhibition of pathogens, or imparted extra resistance to the

plant. Gill (58) theorized that the high calcium content of hardwood bark, 4% by weight, could be responsible for some of the substrate's pathogen inhibition.

Suppression by Composting

The thermophilic stage of composting produces temperatures in excess of 40°C for several weeks, effectively eliminating plant pathogens and weed seeds (74, 84, 143). Hoitink (74) reported heat resistant viruses, such as tobacco mosaic virus, frequently survive thermophilic conditions.

Hoitink et al. (76) found that infection plugs of the pathogens Phytophthora cinnamomi, Pythium irregulare, Rhizoctonia solani, Botrytis cinerea, and Erwinia carotovora var. chrysanthemi did not survive high composting temperatures. These same organisms persisted in a bark pile that never heated above 25°C. Clearly, composting drastically reduces initial populations present in the media, effectively pasteurizing the substrate. A bark composting procedure reviewed by Hoitink and Poole (79) produced a treebark medium free of pathogens and toxic substances, and suppressive to soil-borne diseases.

Suppression by Release of Organic Compounds

Many researchers have noted that fresh bark contains compounds which suppress root and crown rot pathogens (18, 21, 78, 97, 145), including diseases caused by Rhizoctonia, Phytophthora, and Pythium. Krogstad and Solbraa (97), and others (82, 145) found these compounds are destroyed by composting, and removed by leaching with water. Since hardwood bark is composted before use as a substrate, and since container media are watered frequently, these compounds can function in suppression of pathogens only prior to the use of hardwood bark as a medium. Still, these compounds may be of significance when fresh pine bark is used as a medium (75).

Hoitink et al. (82) reported that water extracts from composted hardwood bark media inhibit zoospore release by Phytophthora, a response not obtained from extracts of peat moss or soil. Fusarium oxysporum was similarly suppressed (76). Hoitink and Kuter (77) stated that some composts released "natural product fungicides" into the liquid phase of the medium. They found red oak bark released ethyl esters of hydroxylated oleic acids that effectively inhibited Phytophthora. Hoitink (75) stated that while fresh pine barks released chemical inhibitors for a short time period, hardwood bark composts may release these chemicals for up to a

year after potting. He also noted these chemicals do not suppress pathogens other than Phytophthora. Further, Hoitink and Kuter (77) stated that after suppressive compounds are no longer being released, composted hardwood bark continues to suppress plant pathogens, indicating other biological factors may also be involved.

Suppression By Antagonists

Solbraa (145) described how the decomposition of organic materials is performed by microorganisms which produced biocides, placing them in an antagonistic role toward pathogens. For example, Nelson and Hoitink (118) found that microbial activity induced the pathogen suppression of a hardwood bark medium. The Penicillium, Streptomyces, Trichoderma, Aspergillus, Pseudomonas, and Pachybasium genera contain species or varieties of species possessing the capacity to antagonize pathogenic organisms.

Hong and Ueyama (85) showed microbes isolated from composted bark reduced the growth of many soil-borne plant pathogens, including the following: Fusarium oxysporum, Rhizoctonia solani, Pythium aphanidermatum, and Corticum rolfsii. A bark compost inoculated with an antagonist of the Pachybasium genus reduced disease attack on cucumber seedlings as much as 66%. This report suggested that controlled additions of specific

antagonists can increase the degree of suppression of a bark medium.

It has been shown that mesophilic microbes that recolonise bark piles upon completion of the composting process are often antagonistic toward plant pathogens (74), and that the age of a composted medium influences the activity of the antagonists (77, 139). Burnt (pyrolized) bark does not support antagonistic microflora.

Reyes and Dirks (134) reported that most antagonists disintegrate the hyphae of pathogens without physically penetrating the organism, suggesting that secreted chemicals may be responsible for pathogen suppression. Wilson (174) found that actinomycetes producing antibiotics such as actinomycin and musarin, and Trichoderma viride which produces gliotoxin and viridin, are very effective at controlling Fusarium oxysporum.

In 1981, Stephans et al. (155) compared the suppressive effects of three media including peat:vermiculite (1:1 by volume), 60% peat:10% sterile soil:15% vermiculite:15% perlite, and 50% hardwood bark:20% peat:20% perlite:10% sand, with all three media adjusted to a pH of 6.4. Celosia argentea L. 'Red Fox' seedlings showed greater damping off caused by Rhizoctonia solani in the 60% peat medium and in the

peat:vermiculite than in the medium containing hardwood bark. This agreed with the report by Nelson and Hoitink (118) that pine bark is less suppressive than hardwood bark, and that peat moss is conducive to damping off.

Nelson and Hoitink (119) used radiation and heat to kill the microbes in a bark substrate, removing all anti-pathogen influence. When suppressive organisms were introduced into a pathogen-infested bark media, suppression was restored. Hoitink and Kuter (77) performed a similar study in 1984. Re-addition of organisms isolated from the bark medium before radiation and heat treatment re-established pathogen suppression. They remarked that controlled additions of antagonists, such as specific strains of Trichoderma for control of Rhizoctonia solani, may soon be an integral part of container media preparation. Ohio State University currently has a patent pending on a media that is predictably suppressive to Rhizoctonia solani infestations (77).

Kuter et al. (98) stated suppressiveness is not associated with single taxon, and found high populations of Trichoderma hamatum and T. harzianum in suppressive media. Chet and Baker (37) stated that the suppressive capabilities of Trichoderma spp. are well known.

Chet and Baker (37) stated the mechanism of antagonism of Trichoderma spp. against R. solani is

parasitism followed by lysis, rather than antibiosis. Garibaldi (49) suggested that T. hamatum has potential as biological control of Pythium, Rhizoctonia, and other causal agents of damping off.

Nelson et al. (120) found that many species of Trichoderma including T. hamatum, T. harzianum, T. koningii, and T. viride show suppressive characteristics. Of these species, T. hamatum exhibited the strongest suppression when the medium was inoculated with antagonists, and when the medium environment favored antagonistic activity.

Chef et al. (36) reported that green bark (not composted of incompletely composted) was less suppressive than composted bark against Fusarium wilt of chrysanthemum and flax. Conversely, Kuter et al. (98) found Trichoderma isolates from a green and composted hardwood bark pile were equally effective at inducing suppression.

Stephans and Stebbins (156) studied suppression of Pythium ultimum and Rhizoctonia solani on impatiens 'Dwarf Baby Mix' by pine bark, hardwood bark, and various fungicides. Control of damping-off was least effective in pine bark, while undrenched hardwood bark provided significantly better control than both pine peat mediums. Use of metalaxyl drenches on hardwood

bark provided the best control of damping-off without any loss of suppressive microbial populations.

In 1985, Marios and Locke (106) used a benomyl-tolerant strain of Trichoderma viride (T-1-R9) as an amendment to a freshly pasteurized media. The organism established itself within twelve days, and incidence of Fusarium oxysporum var. chrysanthemi induced disease was reduced.

Hoitink and colleagues working at the Ohio State University have cultured over 600 fungal, bacterial, or actinomycete antagonists of Pythium ultimum from composted hardwood bark, or from tissue of plants growing in composted bark (74). They isolated Trichoderma from the outer 10 cm of a composted bark pile, while antagonistic actinomycetes could be isolated from all locations in the pile. Antagonistic Pseudomonas were isolated from all locations of a bark pile after the temperatures in the composting pile declined below 40^{o}C. These three types of antagonists were isolated from growing media prepared from a stabilized bark compost (74).

Malek and Gartner (105) noted definite supppression of Meloidogyne hapla Chitwood and M. incognita Kofoid and White nematodes on the roots of 'Rutgers' tomato when grown in composted hardwood bark. Also suppressed

were M. incognita, Pratylenchus penetrans Cobb., and Trichodorus chistiei Allen on Forsythia X intermedia.

The following mechanisms allow hardwood bark to suppress soil-borne plant pathogens: 1) reduction of inoculum during physical processing of bark, 2) thermal destruction during composting, 3) by physical and chemical properties of bark, 4) suppression by organic chemicals released into the liquid phase of bark media, and 5) suppression by antagonistic microbial species. Although pine bark possesses some of these mechanisms, it lacks the last mechanism. Since hardwood bark possesses all five mechanisms, it is the superior media for control and prevention of soil-related diseases.

Sources of Nitrogen For Treebark Media

Cappaert, Verdonck, and Deboodt (30) reported the pool of organic nitrogen built up during composting was not mineralized, or was very resistent to mineralization. They found no extractable NO_3-N, and very little NH_4-N, in finished bark compost. This would explain the conclusion of Sterrett and Fretz (157) that, under optimum fertilization conditions, nitrogen source added to bark before composting had no influence on nutrient composition of cotoneaster plants. Therefore, preplant nitrogen additions at the rate of 1-2 Kg/m^3 would be beneficial for plant growth.

Aaron (1) recommended using NO_3-N, not NH_4-N, in pine bark media because NH_4^+ is taken into "firm chemical union" with pine bark particles to form products that are at least as resistant to breakdown as the bark itself. Sant et al. (136) reported that peat moss and pine bark contain five times more NH_4-N than hardwood or spruce bark media.

According to Pokorny (127), if NH_4-N is supplied as more than 50% of the total nitrogen source in pine bark media, plant growth is suppressed. He noted this lack of available nitrogen is not related to microbial 'tie-up' of nitrogen. When compared with Nitroform (Nor-Am Chemical Company, Wilmington, DE) or Osmocote (Sierra Chemical Company, Milpitas, CA) amended pine bark, plants growing in NH_4-N amended pine bark grew slower (139). Others have noted growth suppression when NH_4-N was used with pine bark (101, 113).

Foster et al. (47) reported that pine bark absorbed more NH_4^+ as the pH increased from 3.8 to 5.8. Since pine bark typically absorbed 1.5 mg N/g of bark, they recommended a pre-plant addition to pine bark of NH_4^+ to avoid low nitrogen levels at potting.

No problems with NH_4-N have been reported when hardwood bark is used in the medium. Gartner et al. (52) and Klett and Gartner (93) observed the best plant

growth in hardwood bark media when NH_4NO_3 was used as the N source instead of urea or NO_3-N sources.

Bark Media Preparation

Before use as a media, pine bark is usually limed to raise the pH to the optimal range of 5.0 to 5.5 (102). Lucas and Davis (102) advised against liming to a pH above 6.5 because of additional cost, and possible problems with the availability of nutrients such as Mn, B, Zn, and P. Bilderback (16) suggested using 6 to 15 lbs. of dolomite per yd^3 of pine bark, allowing 60 to 90 days for this preplant addition to influence the pH. Self (139) stated that if the media contains 50% pine bark, 15 lbs. of dolomite per yd^3 of medium will be required to produce a pH of 6.0.

Osmocote (Sierra Chemical Company, Milpitas, CA), or a similar slow release fertilizer, is usually incorporated and/or top-dressed to pine bark media at 3 to 6 Kg/m^3 (127), depending upon plant needs. Smith (141) reported that 4-1-2 and 3-1-2 (N-P-K ratio) fertilizers were better than fertilizers with an even ratio. Self (139) recommended preplant additions (per cubic meter of bark) of 9 Kg dolomite, 1.2 Kg super phosphate (0-20-0), 1.2 Kg gypsum, 0.15 Kg Nu-iron, 0.15 Kg micronutrients, 0.7 Kg FTE 187, 1.2 Kg FTE potash, 2.1 Kg nitroform, and 6 Kg Osmocote 18-5-11. Addition

of micronutrients is considered essential when using pine bark-based media in containers.

Sulfur is usually added to hardwood bark to help control increasing pH levels (84). Hoitink (76, 79) suggested that S should not be added until after composting since low pH values slow the decomposition process. Sterrett and Fretz (157) reported that 0.59 Kg/m^3 of iron sulfate and 0.59 Kg/m^3 of elemental S may have overcompensated for the increasing pH tendencies of hardwood bark. Evans and Wagner (46) reported that 1.2 Kg/m^3 of powdered sulfur added to a 2:1 hardwood bark: sand medium maintained a fairly constant pH. This same study showed that increasing S levels increased the dry weight and growth index of marigolds.

Black (20), Scott (137), Gartner et al. (54, 55), and others (21, 94) have reported N deficiency problems when using hardwood bark-based media. Cappaert et al. (30) stated that higher N doses can be used on hardwood bark media without risking leaf-burn from excessive salts if slow release fertilizers are used. Required N amounts would create excessive soluble salt levels if the nutrient was applied using soluble liquid fertilizers.

Klett et al. (94) stated that hardwood bark contains enough Ca and Mg to justify elimination of these nutrients from the fertilizer program. However,

Sterrett and Fretz (157) found foliar analysis of cotoneaster 'Coral Beauty' showed levels of Mg that were below minimum levels set for woody ornamental crops. Since levels of Mg in hardwood bark apparently vary (16, 74), addition of $MgSO_4$, either before or after composting, may improve plant growth.

Because hardwood bark includes a plentiful supply of micronutrients, addition of micronutrientamendments to hardwood bark is considered unnecessary. In the case of Mn, addition of micronutrients to hardwood bark could produce toxic Mn levels detrimental to plant growth.

Bilderback (17) suggested using 2.4 Kg gypsum ($CaSO_4$), 1.2 Kg epsom salts ($MgSO_4$), 4.2 Kg super phosphate (0-20-0), and 6 Kg Prostart (Sta-Green Plant Food Company, Sylacauga, AL) for every m^3 of hardwood bark media. Black (20) used 2.4 Kg Osmocote 18-9-9 (Sierra Chemical Company, Milpitas, CA), 2.4 Kg super phosphate (0-20-0), 3 Kg gypsum, 0.6 Kg epsom salts, and 0.15 Kg FTE per m^3 of hardwood bark.

Treebark Media

Pine bark mixed with sand in varying ratios is a commonly used medium (129). As the percentage of sand increases, bulk density increases and air capacity decreases (16). Peat moss is frequently added to increase %WHC of pine bark:sand media (18). A common

container growing media in Tennessee is 3 pine:1 peat:1 sand by volume.

Self (139) reported 100% pine bark is a good medium when a complete fertilization program is applied. Pokorny (127) noted that while pine bark retains less water than peat moss, more of the water in pine bark is available for plant use. Therefore, it may not be necessary to add peat moss to the mix if a fine enough PSD of pine bark is used. Common media used in Georgia include soil:bark:sand (1:1:1 v:v:v), bark:sand (1:1 v:v), and bark:perlite (1:1 v:v).

Hardwood bark mixed with sand in varying ratios is also a popular container growing medium (16). Gartner (50) obtained excellent results using a 4:1 hardwood bark:sand mix. Bilderback (15) noted that hardwood bark:sand mixtures are characteristically heavy, poorly drained, and have inadequate pore space for frequent irrigation. Mixes containing peat moss (33, 143), and hardwood bark alone (16) have been used successfully. However, Black (20) reported that 100% hardwood bark produced less growth than a 1:1 hardwood bark:sand medium as measured by the fresh weights, dry weights, and stem diameters of Ilex crenata 'Hetzii'.

Gartner et al. (54) reported successful crops of geraniums, chrysanthemums, lilies, poinsettias, forsythia, taxus, junipers, barberry, cotoneaster, and

pyracantha in hardwood bark media. Matthews (131) reported hardwood bark was an acceptable germination medium for begonias and snapdragons. In another study, lettuce, marigolds, zinnias, and annual ryegrass germinated better in hardwood bark that in a peat:vermiculite control medium (62).

Dyke (44) observed that hardwood bark is an unsatisfactory rooting medium for 'Red Ruffles' azalea. Maleike et al. (104) used hardwood bark to root geraniums, poinsettias, carnations, chrysanthemums, dogwoods, Burford holly, spirea, forsythia, juniper, and magnolia. Geraniums rooted well in all media including the peat:perlite (1:1 by volume) control, while chrysanthemums rooted best in hardwood bark medium. All other plants rooted better in the control than in bark media.

Blended Pine and Hardwood Bark Media

In 1981, Bilderback (15) wrote about combining pine and hardwood bark to produce a growing medium. Preliminary studies with 3:1, 1:1, and 1:3 blends of pine bark: hardwood bark media showed the 1:1 blend gave best results with one inch of daily irrigation.

Bilderback (15) listed these possible advantages of blending pine bark with hardwood bark:

1. The blend could possess fungicidal properties of hardwood bark, reducing disease problems.

2. Hardwood bark may be available at a lower cost than pine bark, reducing overall cost of the medium.
3. If the two components were mixed before composting, the medium would be pasteurized, and the wood content of both the pine and hardwood bark would be removed, reducing the possibility of shrinkage. The increased airspace provided by the pine bark may allow the mix to compost more quickily.
4. The blend might have a bulk density high enough to prevent container-grown nursery plants from toppling-over in the wind; thus, sand would not have to be added to the growing medium.
5. The blend might possess increased WHC from hardwood bark, and increased AC from pine bark, producing a medium with better physical properties than either component used separately.
6. The acidic tendency of the pine bark, and the basic tendency of the hardwood bark offset each other, creating a medium with a pH of 5.6 to 6.2; thus, eliminating the need to adjust pH with lime or sulfur.

Bilderback (15) recommended the addition of Mg (epsom salts) and micronutrients, along with a complete NPK fertilizer, to the pine:hardwood bark medium.

In 1983, Solbraa et al. (150) added 10% and 20% spruce bark to a hardwood bark medium, and found that increased AC reduced the time-period required to complecomplete the composting process.

Also in 1983, Tilt et al. (167, 168) reported on the growth of three woody ornamentals in three different container sizes containing different particle size distributions of a 1:1 (by volume) blend of pine and hardwood bark. The 1:1 blended (pine:hardwood) medium required no adjustment of pH, although pH tended to increase with time. The extent of composting of hardwood bark would influence the stability of the medium's pH. The 1:1 blended medium used in this study had been amended with 1 Kg Micromax (Sierra Chemical Company, Milpitas, CA), 3.7 Kg Osmocote 18-6-12 (Sierra Chemical Company, Milpitas, CA), and 0.3 Kg treble superphosphate (0-46-0) per m^3 of medium.

Tilt (167) reported the 1:1 pine:hardwood bark medium had air capacities ranging from 33.3% to 43.1%, which far exceeds the suggested optimal range for AC (18, 30). These physical properties were higher than either pine or hardwood bark produced alone, suggesting that interaction between the different geometric shapes

of pine and hardwood bark particles creates pore spaces beneficial for plant growth.

In 1985, Bilderback (18) reported on growth of X Cupressocyparis leylandii 'Haggerston Grey' in three container sizes filled with either pine bark:sand (4:1 by volume), a hardwood bark:sand (4:1 by volume), or a pinebark:hardwood bark:sand (2:2:1 by volume) medium. Four different NH_4NO_3 levels (from 200 ppm N to 800 ppm N) were used as a weekly liquid feed. Results showed the pine bark:hardwood bark:sand medium required no adjustment of pH, and it produced the largest plants as container size and N application increased.

Also in 1985, Bilderback (19) reported on growth of Ilex X 'Nellie R. Stevens' in pine bark-based media amended with composted hardwood bark in 25% increments (by volume). Incremental increase in the amount of hardwood bark did not increase total porosity of the medium. Bulk density, however, increased steadily as percentage of hardwood bark in the medium increased. When pine and hardwood barks were in equal volumes (1:1), %WHC was slightly increased, and more %AC was created, indicating the 1:1 blend has better physical properties than either component used separately. The pH of the 1:1 blend eventually stabilized at 6.2.

The following aspects of blended pine and hardwood bark media have yet to be reported:

1. Whether or not the composting process is hastened by amending hardwood bark with pine bark.
2. Whether or not there is a difference between blended pine and hardwood bark media when mixed before or after the hardwood bark has been composted.
3. Whether or not blended pine and hardwood bark media possess the fungicidal properties associated with the hardwood bark.

These aspects of blended pine and hardwood bark media need to be evaluated before a complete assessment of the value of this medium can made.

Spent Mushroom Compost

Spent Mushroom Compost (SMC) was shown to be a useful media component after composting (100). Lohr et al. (100) showed that the bulk density, %TPS, %WHC, and %AC were acceptable for plant growth. Initially high soluble salts levels were readily leachable. With a large supply of micronutrients, SMC could be a useful amendment for pine bark-based container growing media.

CHAPTER III

COMPOSTING HARDWOOD BARK AND PINE BARK BLENDS

Introduction

While non-composted pine bark can be used as a media component (1, 39, 127, 139, 140, 150), researchers recommend composting hardwood bark before using it in container growing media (29, 74, 79, 99, 122, 142, 148, 176). A few researchers have reported successful growth of plants in noncomposted hardwood bark media (64, 65, 108). Blended hardwood and pine bark compost has recently been shown to be and excellent container growing medium (18, 19). Bilderback (15) suggested that blending hardwood bark with pine bark would significantly reduce the length of time required to complete the composting process. Currently, there is no information available comparing blended hardwood and pine bark media when the two bark types are mixed before or after composting.

To obtain information about composting hardwood bark and pine bark blends, a composting experiment was designed using hardwood bark, pine bark, and 75:25, 50:50, and 25:75 (by volume) blends of hardwood and pine bark. Main objectives were: 1) to compare the length of time required to compost pine bark, hardwood bark, and 75:25, 50:50, and 25:75 blends of hardwood bark and

pine bark; 2) to compare the amount of shrinkage due to composting in hardwood bark, pine bark, and 75:25, 50:50, and 25:75 blends of hardwood bark and pine bark; 3) to compare physical and chemical properties, before and after composting, of hardwood bark, pine bark, and 75:25, 50:50, and 25:75 blends of hardwood bark and pine bark; 4) to compare the physical and chemical properties of 75:25, 50:50, and 25:75 blends of hardwood bark and pine bark when the media were mixed before or after composting; 5) to compare the physical and chemical properties of composted and non-composted pine bark, composted and non-composted hardwood bark, and 75:25, 50:50, and 25:75 blends of composted and non-composted hardwood bark, and pine bark with the physical and chemical properties of a standard nursery industry growing medium.

Materials and Methods

Freshly milled pine bark was obtained from Joe K. Smith Trucking (Cummings, GA), and freshly milled hardwood bark (unknown species mix) was obtained from Posey Lawn and Garden Center (Knoxville, TN).

To compost hardwood bark, pine bark, and blends of hardwood and pine bark under comparable conditions, a partitioned windrow composting facility 16 by 60 ft long was constructed. Land with a slight grade was leveled with a tractor-pulled box scraper. A non-woven

synthetic fiber weed mat was laid over the leveled site, then a two inch layer of river sand was spread with a very slight crown in the center to facilitate water run off. Four by eight by sixteen inch solid concrete blocks were placed in a running bond pattern on top of the packed, smoothed sand. Sand was brushed over the surface of the blocks to fill joint cracks.

Pairs of posts eight feet apart were placed every six feet along the axis of the paved area. Marine plywood sheets (1/2 in by 4 ft by 8 ft) were nailed up which created a row of 10 equal size bins with open sides. The plywood partitions kept different bark piles separated while allowing for a continuous windrow; thus, minimizing exposed surface area and heat loss compared to isolated small piles.

On May 29, 1985, two replications of 2.7 m^3 piles of hardwood bark, pine bark, and 75:25, 50:50, and 25:75 blends of hardwood and pine bark were randomly placed into the partitioned windrow bins. Using a Kubota B8200D tractor (Kubota LTD, Osaka, Japan) with a BF300A front mounted loader, all piles were thoroughly mixed. Within each bin, the bark was lifted and turned toward one side of the composting slab, then lifted and turned again toward the opposite side. Finally, the bark was lifted and turned back to the center of the bin to form a rounded pile about one meter high and two meters wide

at the base. A 3.5 l sample taken from each pile was oven dried and frozen for future analysis of physical and chemical properties. A smaller sample of bark was removed from each pile and oven dried at 80°C for 24 hours to determine percent moisture.

On May 30, 1985, each pile was flattened and water added to bring moisture to 70% of dry weight. Fertilizer amendments prorated to the volume of hardwood bark (Table 13), were spread over each pile and mixed using the front mounted loader as described above. Bark piles were sampled every 7 to 10 days for moisture, pH, and soluble salt analysis, and each pile watered enough to readjust the moisture level to 70% (dry weight basis).

Beginning May 31, 1985, daily heat production of each pile was measured at 0.3, 0.6, and 0.9 meters inward from the surface using a Keithley 865 Digital Thermometer with a 8662 Thermistor General Purpose/ Immersion Probe (Keithley Instruments, Inc., Cleveland, OH) mounted on the end of a fiberglass rod. A hole was poked into each bark pile with a broom stick, the probe was inserted into the pile for one minute, and then the temperature was recorded. Each hole was covered after the probe was removed.

Whenever the temperature in one of the piles dropped 7 to 10°C below the most recent peak temperature, all piles were turned as previously described.

Table 13. Fertilizer amendments added before composting to hardwood and pine bark media.

%HB:%PB[1]	urea	potassium nitrate	Kg/m^3 super phosphate	iron sulfate	sulfur
100:0	2.67	1.33	3.33	0.67	0.67
75:25	2.17	1.00	2.67	0.50	0.50
50:50	1.67	0.67	2.00	0.33	0.33
25:75	1.17	0.33	1.33	0.17	0.17
0:100	0.67	0.00	0.67	0.00	0.00

[1] Percentage ratio of hardwood bark to pine bark by volume.

Piles were first turned June 13, and 15 times thereafter at intervals of 6 to 10 days.

Days to stabilization was recorded from the date when temperature in a pile remained below 40°C, even after aeration from turning. After all piles were stabilized, the volume remaining in each pile was recorded, and amount of shrinkage resulting from composting calculated.

On October 10, 1985, 3.5 l samples were collected from each pile, oven dried at 80°C for 24 hours, and placed in freezer storage for future physical and chemical analysis.

Two additional groups of 75:25, 50:50, and 25:75 blends were formed by mixing composted hardwood bark with composted pine bark, and by mixing composted hardwood bark with noncomposted pine bark. These groups were developed for comparison with blends mixed before composting. A second lot of fresh hardwood bark was obtained from Posey Lawn and Garden Center (Knoxville, TN), and a fourth group of blends were mixed using noncomposted hardwood bark and noncomposted pine bark.

The following two control media were developed: a 50:50 (percent by volume) blend of non-composted pine bark and aged spent mushroom compost (SMC), and a 3:1:1 (by volume) blend of non-composted pine bark:peat:river sand, which is a standard nursery media (SNM). Media

codes and descriptions are listed in Appendix A. Samples of all media mixed after composting were dried and frozen as previously described.

A 500 ml aliquot of each frozen sample was sent to the Georgia Soil and Plant Tissue Analysis Laboratory (Athens, GA) for analysis of extractable mineral nutrients. Analysis procedure was a saturated medium extraction method developed by Michigan State University (124, 170).

A 250 ml aliquot of each sample was used for analysis of particle size distribution (PSD). PSD was obtained by screening a 250 ml oven-dry sample through U.S. Standard Sieves with openings of 12.7, 7.9, 5.7, 4.0, 2.8, 2.0, 1.4, 1.0, 0.7, and 0.5 mm. Samples were agitated for 5 minutes using a Tyler Model RX-24 Portable Sieve Shaker (W.S. Tyler Incorporated, Mentor, OH). Percent total weight remaining on each screen was recorded.

A 2.25 l aliquot of each frozen sample was used for analysis of total pore space (%TPS), water holding capacity (%WHC), air capacity (%AC), and bulk density (BD). %TPS, %WHC, and %AC were determined using the following volume-loss method adapted from Gessert (57) and Whitcomb (171).

Plastic freezer (2 mil) bags were placed in 2.5 l nursery containers. Containers were then filled with

2.25 l of each medium firmly packed as though a plant was being potted. Tare weight of individual bags and containers was recorded, and each filled container was weighed on a Terralion Monostat Gram Balance. Tare weight was subtracted to obtain the initial weight of the medium. BD was calculated by dividing weight of medium by volume of the medium (2.25 l).

A known volume of water containing 0.2% Triton AG98 surfactant (Rohm and Haas Company, Philadelphia, PA) was slowly poured into each container until the media appeared fully saturated (a water film became visible at the surface of the medium). Plastic bags were sealed tightly, and the media were allowed to soak 24 hours. Bags were opened and an additional known volume of water was added to again bring the media to saturation. The total volume of water added was recorded, and divided by 1% of the initial volume of the medium to obtain %TPS as a percent by volume.

Each container with saturated media was set on an upsidedown container in a level stainless steel pan. Holes were poked by inserting a pencil through the container's drain holes. The volume of water that drained into the pan after two hours was recorded, and divided by 1% of the initial volume of the medium to obtain %AC as a percent by volume. %WHC was then calculated by subtracting %AC from %TPS.

Analysis of Variance (ANOVA) was performed on all data using Statistical Analysis Software (SAS Institute, Inc., Cary, NC) on IBM 4381 computer facilities through the University of Tennessee Computing Center. The 5% significance level was chosen as acceptable error for this experiment. Mean separations were performed using Duncan's New Multiple Range Test.

Results and Discussion

Temperatures recorded at 60 cm in the piles were consistently higher than those recorded at 30 cm or 90 cm. At 90 cm, the microorganisms probably did not obtain enough oxygen for maximum activity, resulting in less heat produced. At 30 cm, heat probably escaped through the surface. Although the 30 cm level was not the hottest, it was probably the location where most of the microbial decomposition of bark took place because of the plentiful supply of air.

Because temperatures recorded at the 60 cm depth were consistently highest, they were used for analysis. Mean temperature profiles for pine bark, for 25:75, 50:50, and 75:25 blends of pine and hardwood bark, and for hardwood bark are shown in Figures 1, 2, 3, 4, and 5, respectively.

In all piles, temperatures of at least 50^{o}C were recorded within 2 days after turning. Extremely large drops in temperature indicate days when piles were

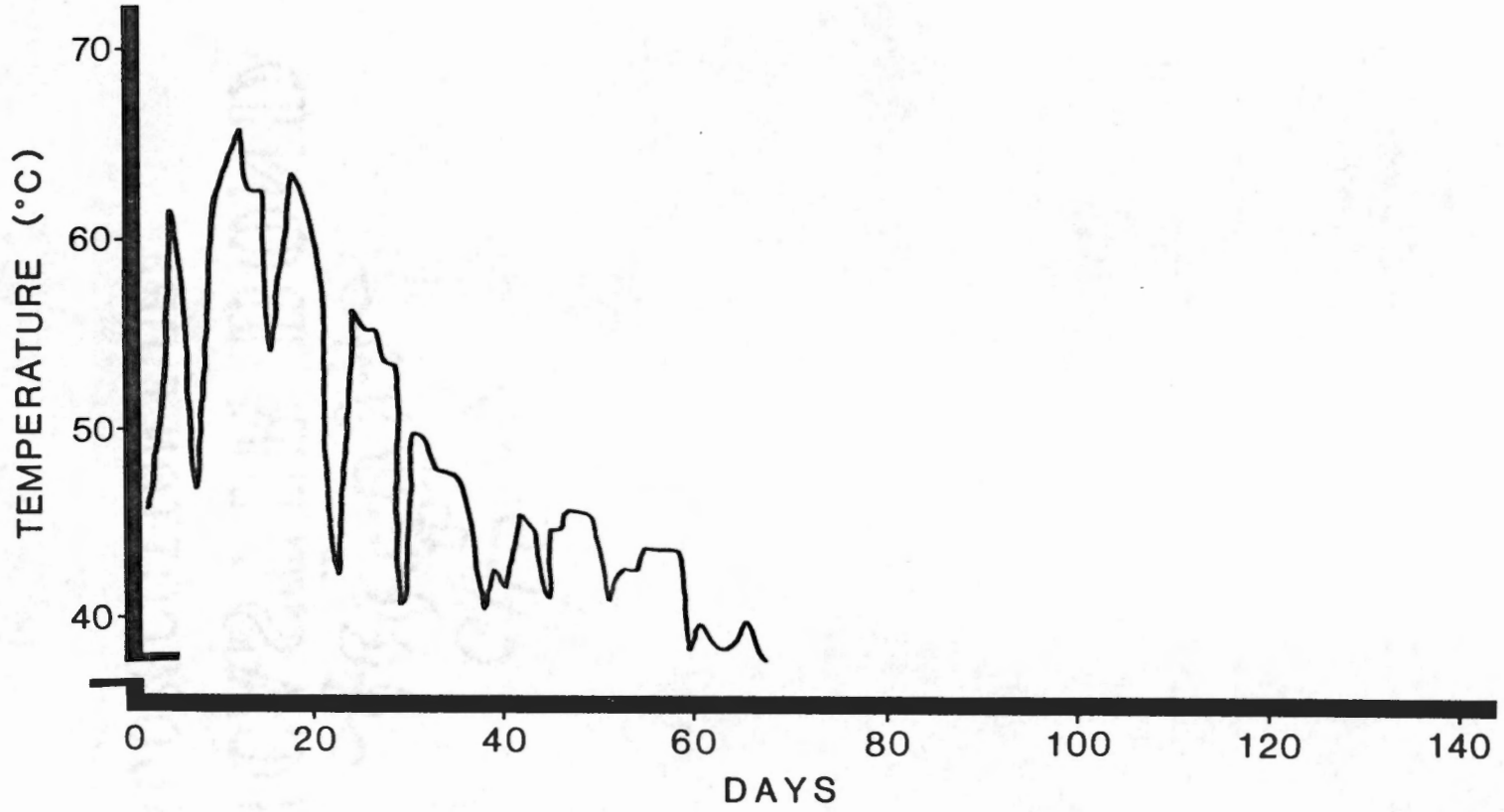


Figure 1. Daily temperature profile of pine bark compost piles.

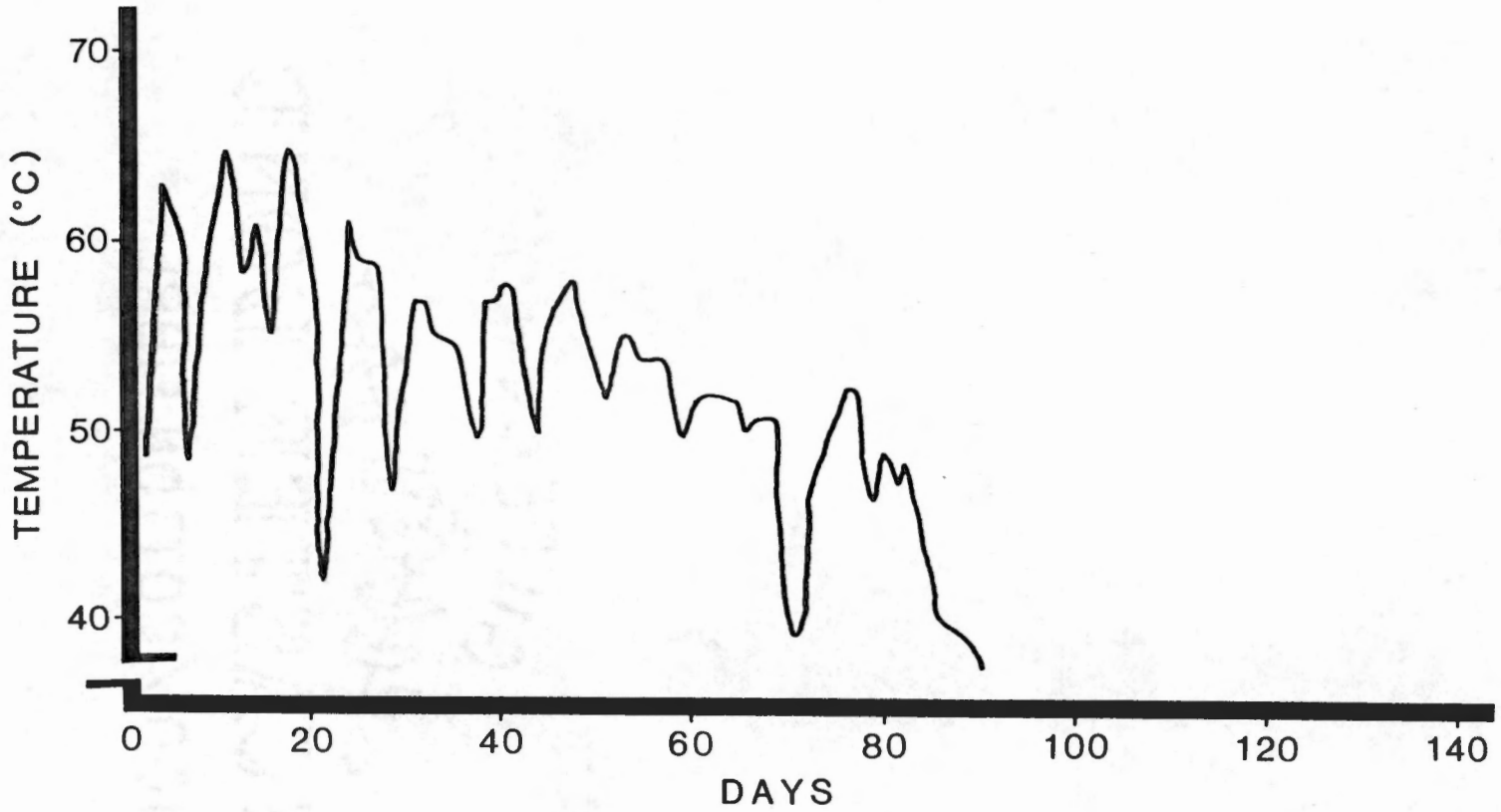


Figure 2. Daily temperature profile of blended hardwood:pine bark (25%:75% by volume) compost piles.

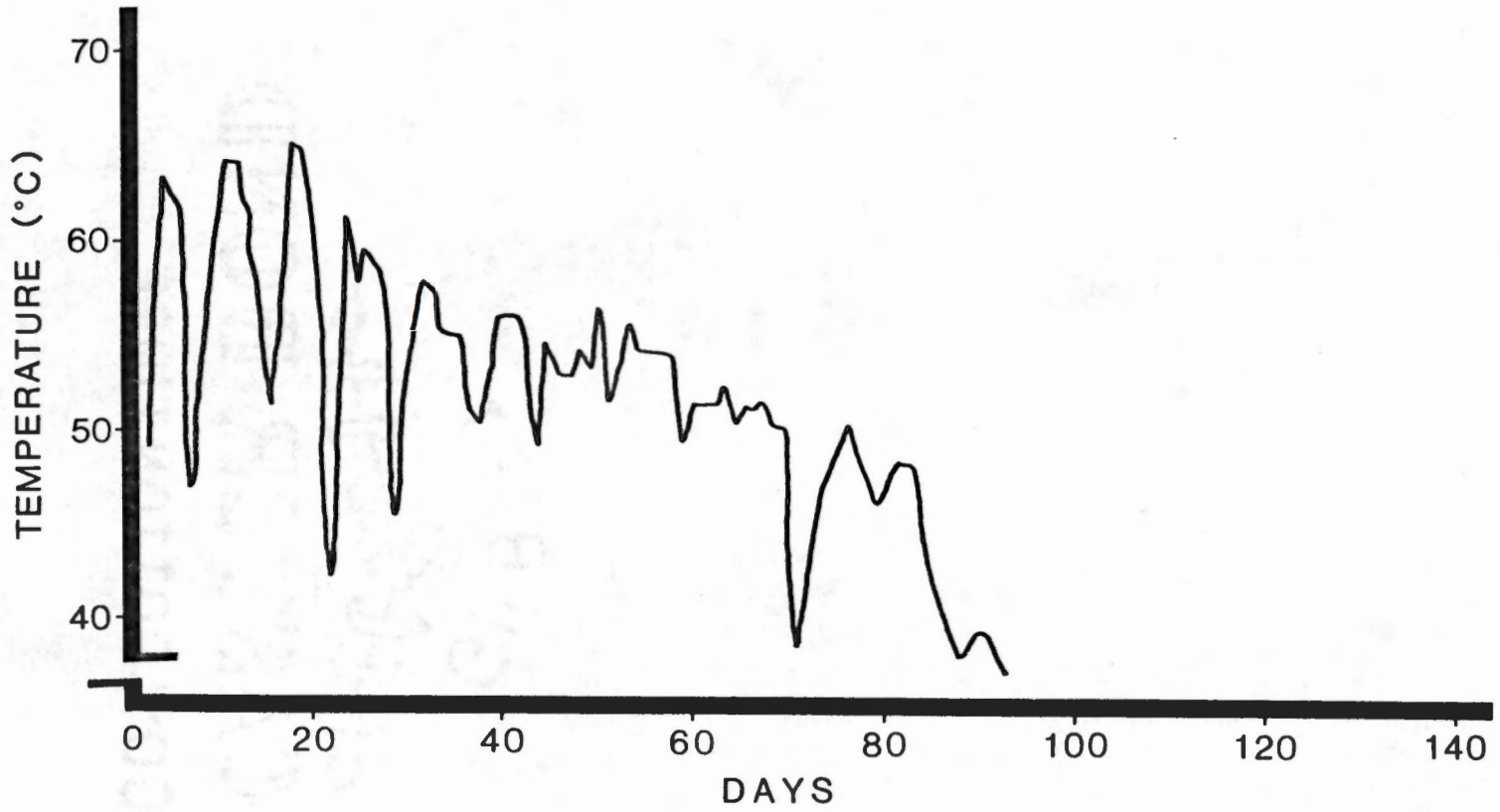


Figure 3. Daily temperature profile of blended hardwood:pine bark (50%:50% by volume) compost piles.

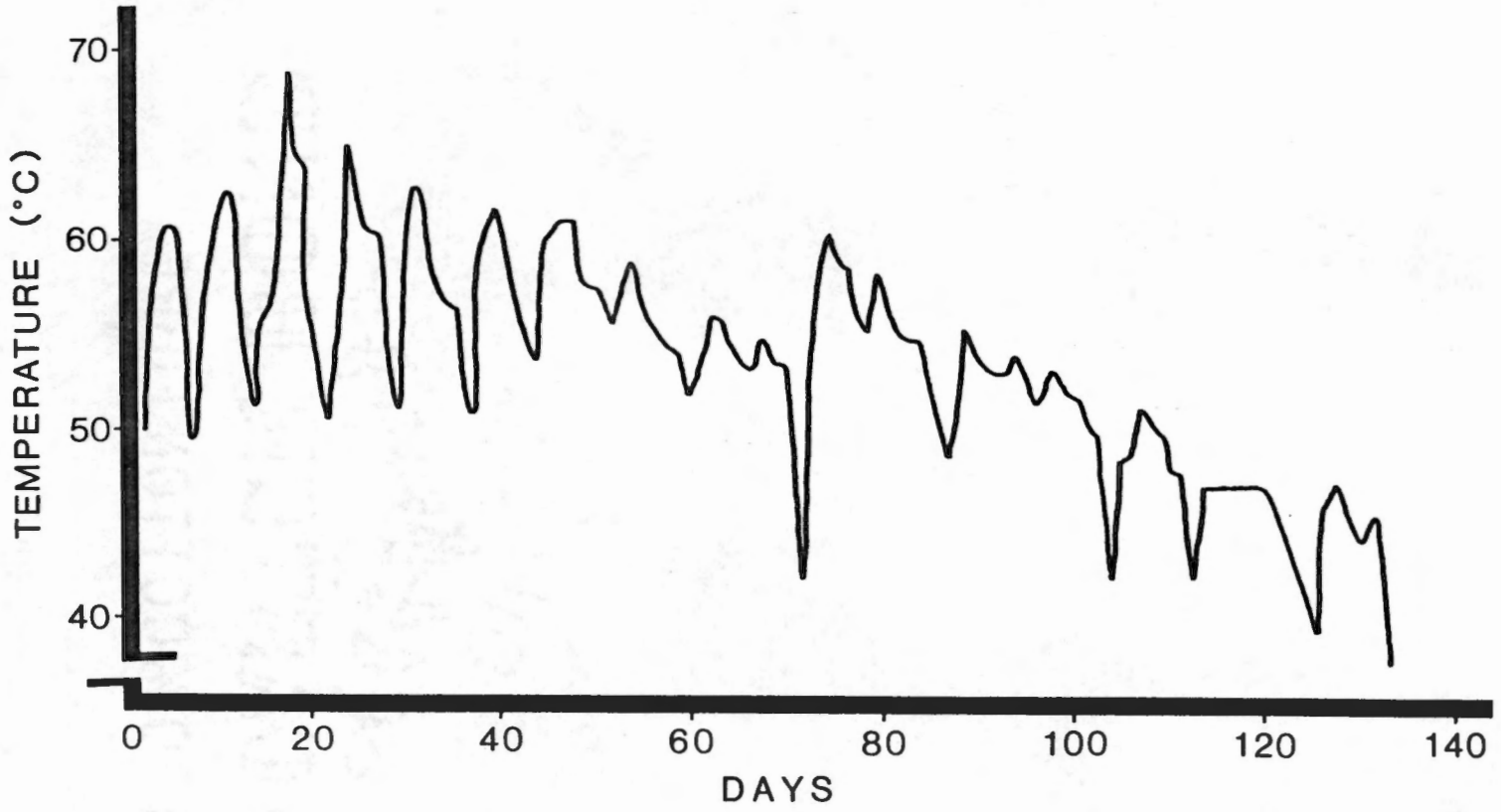


Figure 4. Daily temperature profile of blended hardwood:pine bark (75%:25% by volume) compost piles.

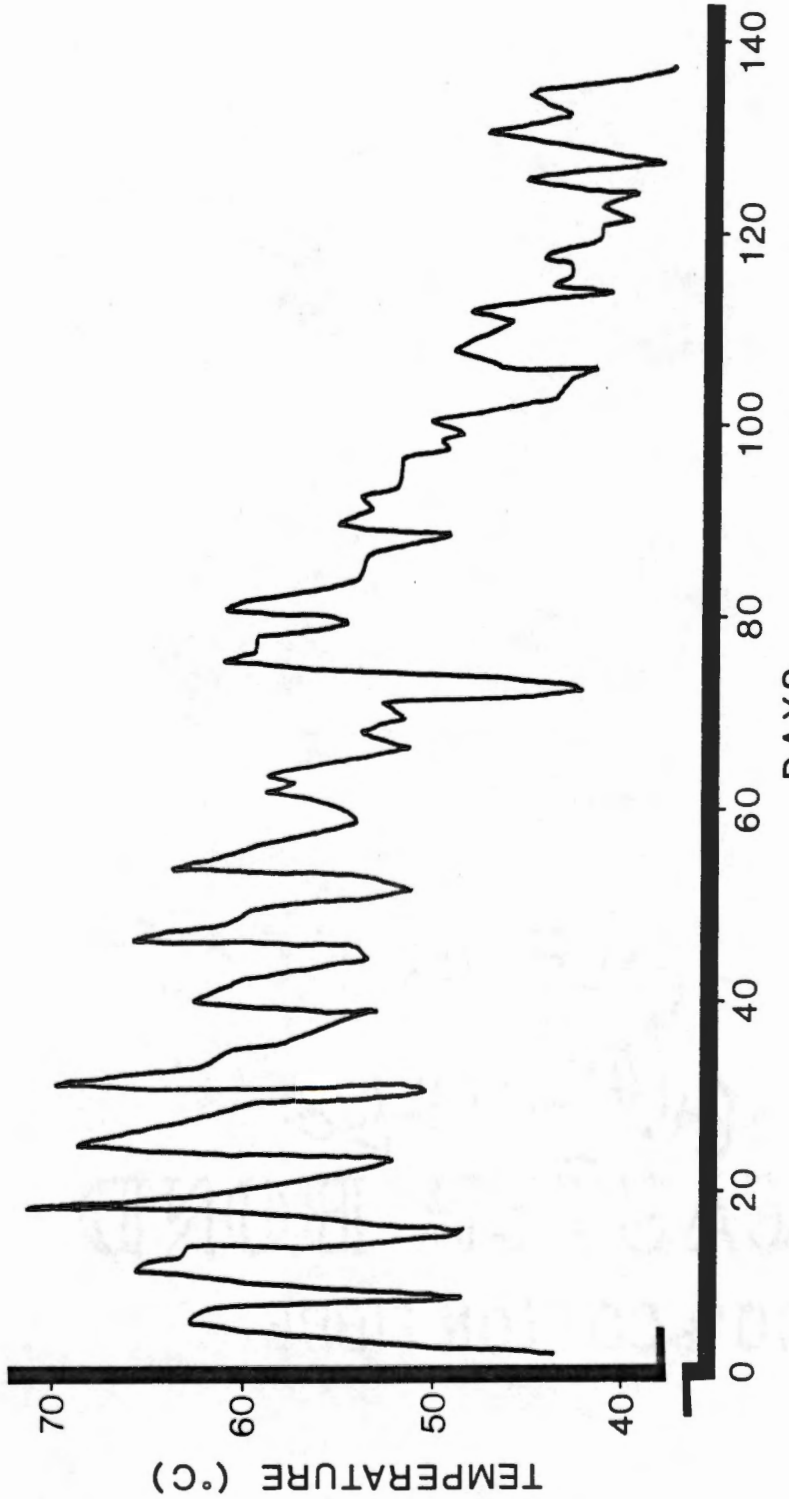


Figure 5. Daily temperature profile of hardwood bark compost piles.

turned and moisture added. On day 72, piles were turned, moisture added, and then 2 days of heavy rainfall occurred. This created a large drop in temperature (Figures 2 through 5), and 2 to 3 days passed before 50°C temperatures were recorded again.

The highest temperature (72°C) was recorded in the hardwood bark pile (Figure 5) on day 19 of composting; however, on day 20, the pile was only 62°C, indicating the extreme heat had killed a portion of the microbial population, lowering heat production.

Piles with 25% or 50% hardwood bark attained low temperature stability before 100% hardwood bark (Table 14), as expected. Hardwood bark contains more cellulose and other degradeable substrates upon which microbes feed; therefore, microbes depleted available substrates faster in piles containing less hardwood bark.

The number of days required to achieve low temperature stability in hardwood bark (137.5 days), and pine bark (59.5 days), was used to calculate the number of days required to reach low temperature stability in the blended bark piles (Table 15). The 50:50 blend required 88.5 days to compost, while 98.5 days were calculated. In contrast, other blends required longer than calculated. Differences in microbial composition, physical properties, and chemical properties combined probably contributed to faster composting in the 50:50 blend.

Table 14. Days to stabilization of hardwood and pine bark composts.

%HB:%PB[1]	Beginning Date	Stabilization Date	Mean[2] Days Required
100:0	5-31-85	10-14-85	137.5 c
75:25	5-31-85	10-10-85	133.0 c
50:50	5-31-85	8-26-85	88.5 b
25:75	5-31-85	8-23-85	85.5 b
0:100	5-31-85	7-29-85	59.5 a

[1] Percentage ratio of hardwood bark to pine bark by volume.

[2] Means followed by the same letter are not significantly different at the 5% level according to Duncan's New Multiple Range Test.

Table 15. Calculated and actual days to completion of hardwood:pine bark composts.

%HB:%PB[1]	Days Calculated[2]	Mean[3] Actual Days Required	Difference	Percent Of Calculated
75:25	118.0	133.0 a	+12.0	+10.2%
50:50	98.5	88.5 b	-10.2	-10.2%
25:75	79.0	85.5 b	+6.5	+8.2%

[1] Percentage ratio of hardwood bark to pine bark by volume.

[2] Calculated from the number of days required to compost the hardwood bark and pine bark from which blends were mixed.

[3] Means in columns followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range Test.

Hardwood bark lost 47.8% of its original volume, while pine bark lost only 5.1% (Table 16). Less shrinkage occurred in media as the percent of hardwood bark decreased. Loss in volume is due to microbial decomposition of cellulose and other readily degradeable carbonaceous materials. Carbon in carbonaceous material is converted to CO_2 or cell mass during microbial digestion. Material loss of carbon bulk, and more compact arrangement as the particles break down into smaller pieces, causes volume shrinkage. Hardwood bark contains more cellulose than pine bark; so, it loses more volume than pine bark.

Shrinkage in hardwood bark and pine bark was used to calculate expected shrinkage for blended hardwood: pine bark media (Table 17). While 50:50 blends were expected to lose 0.71 m^3 of volume, they lost only 0.40 m^3, which is a difference of 11.4% based on the original volume. Other blends also lost less volume than expected, but to a lesser degree than 50:50 blends. Clearly, more media volume can be retained by mixing hardwood bark and pine bark before composting.

For example, if one m^3 of hardwood bark and one m^3 of pine bark were composted separately, the yield after composting would be 0.52 m^3, and 0.95 m^3, respectively. Mixed together, this creates a 50:50 blend with a volume of 1.47 m^3. If one m^3 of hardwood bark and one m^3 of

Table 16. Volume loss (m^3) in hardwood and pine bark after composting.

%HB:%PB[1]	initial m^3	terminal m^3	m^3 loss	percent loss[2]
100:0	2.72	1.42	1.30	47.8%
75:25	2.72	1.96	0.76	27.9%
50:50	2.72	2.32	0.40	14.7%
25:75	2.72	2.49	0.23	8.5%
0:100	2.72	2.58	0.14	5.1%

[1] Percentage ratio of hardwood bark to pine bark by volume.
[2] Percentage calculated from the begining bark volume.

Table 17. Calculated and actual volume loss in composted hardwood and pine bark media.

%HB:%PB[1]	calculated m^3 loss	actual m^3 loss	m^3 difference	percent of original volume saved[2]
75:25	1.00	0.76	0.24	8.8%
50:50	0.71	0.40	0.31	11.4%
25:75	0.42	0.23	0.19	7.0%

[1] Percentage ratio of hardwood bark to pine bark by volume.

[2] Calculated from the volume lost upon composting in the hardwood bark and pine bark from which blends were mixed.

pine bark were mixed before composting, the yield would be 1.71 m^3 when composting is complete, which is 16% more. These calculations assume no volume change when the two bark types are mixed together. The lesser shrinkage of the blends mixed before composting provides more material in which plants can be potted, reducing the overall cost of the medium.

There may be several hypotheses for the lower shrinkage resulting from mixing blends before composting. One is that the arrangement of bark particles could have left less surface exposed to decomposition, but this should result in a longer composting period for the 50:50 blend while a shorter composting period was recorded. Also, the frequent turning of the composting bark piles should have exposed most surfaces to decomposition.

Mixing two media ingredients together usually results in a volume loss and an increase in BD. Analysis of BD before composting (Table 18) indicated some shrinkage when blending hardwood and pine bark; however, analysis of BD after composting shows little shrinkage. Thus, space-volume shrinkage by mixing pine bark with hardwood bark does not appear to be involved in reduced shrinkage.

Another possiblity is that blended composts lost less carbon as CO_2. This would imply the presence of a

Table 18. Change in bulk density (BD) of hardwood and pine bark media after composting.

%HB:%PB[1]	g/ml		
	Mean[2] initial BD	Mean[2] terminal BD	change in BD
100:0	0.23 e	0.32 a	0.09
75:25	0.26 cd	0.30 ab	0.04
50:50	0.26 cd	0.29 b	0.03
25:75	0.27 bc	0.28 bc	0.01
0:100	0.25 d	0.26 cd	0.01

[1] Percentage ratio of hardwood to pine bark by volume.
[2] Means followed by the same letter are not significantly different at the 5% level according to Duncan's New Multiple Range Test.

different composition of microbial species. Alexander (6) noted that mixed microbial populations and pH are prominent factors governing aerobic, mesophilic cellulose decomposition. In soils of near neutral pH, pH 6.5 to 7.0, the active population contains vibrios and fungi, with no vibrios found below pH 6.0. In soils of greater acidity, pH 5.7 to 6.2, the population contains few, if any, vibrios, and more cytophagas, which are important to aerobic decomposition of cellulose and hemicellulose. In acid soils, pH 5.5 or below, the flora is dominated by fungi. A similar microbial response to pH may have occurred during the aerobic, thermophilic decomposition in hardwood:pine bark media. Figure 6 and Table 19 show that media containing 100% and 75% hardwood bark were the only media where the pH ranged from pH 5.7 to 6.2, while media containing less hardwood bark remained at pH 5.75 or below. Therefore, media containing 75% or more hardwood bark were probably predominently populated by fungi and bacteria which tolerate slightly acid conditions, while media containing less hardwood bark probably contained mostly fungi. The larger physical structure of the fungi may have prevented them from decomposing cellulose contained in microscopic crevices that were accessable to the smaller bacteria; therefore, the media containing predominently fungi may have lost

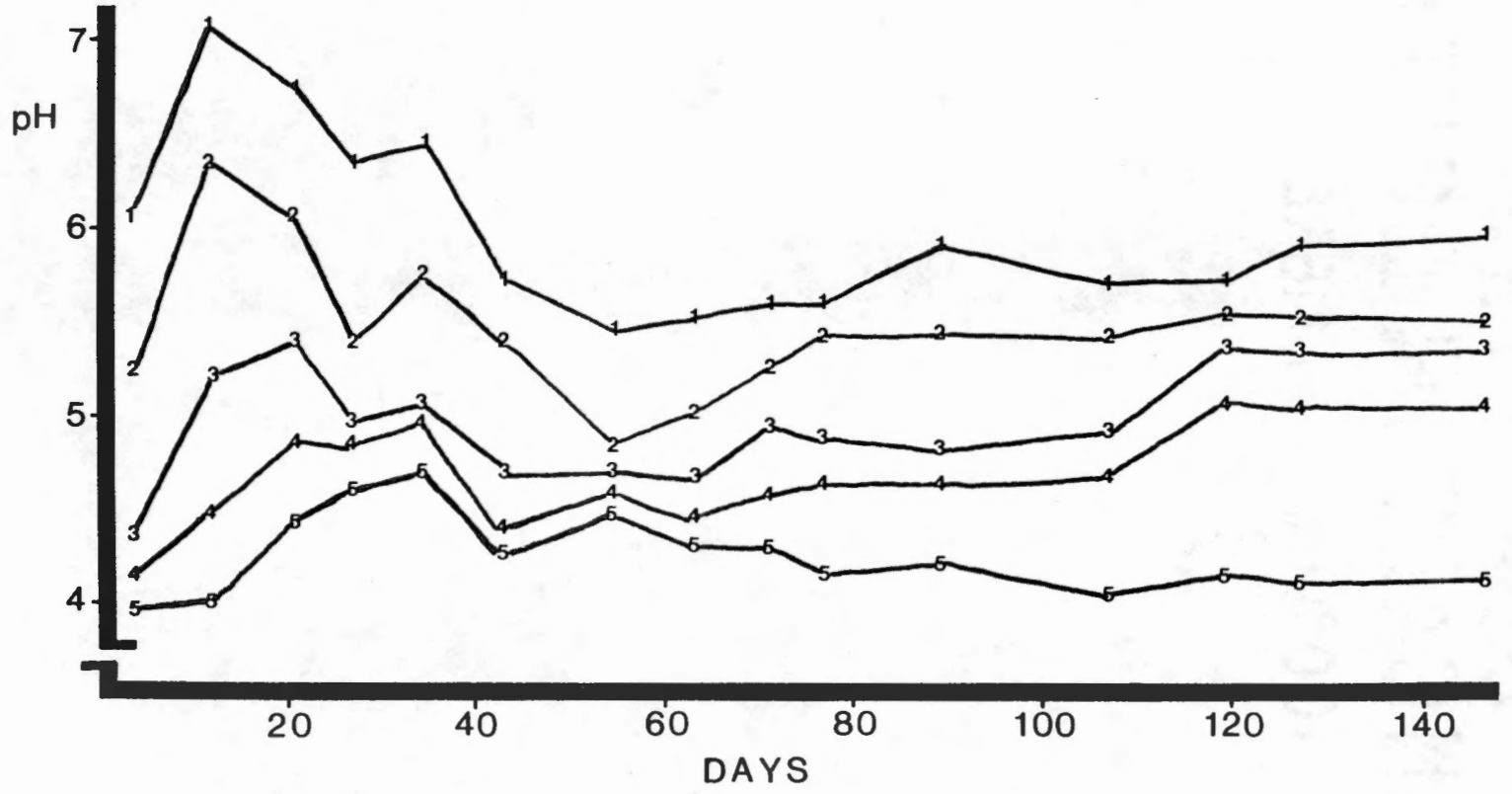


Figure 6. Profile of pH changes in composting bark piles. Hardwood bark (1), hardwood bark amended with 75% pine bark (2), hardwood bark amended with 50% pine bark (3), hardwood bark amended with 25% pine bark (4), and pine bark (5).

Table 19. Influence of composting on pH of hardwood and pine bark media.

%HB:%PB[1]	Mean[2] initial pH	Mean[2] terminal pH	change in pH	Peak pH
100:0	5.97	5.95	0.02	7.00
75:25	5.25	5.83	0.58	6.35
50:50	4.45	5.63	1.18	5.75
25:75	4.05	5.17	1.12	5.10
0:100	3.88	4.35	0.47	4.85

[1] Percentage ratio of hardwood bark to pine bark by volume.
[2] Means of six samples.

less cellulose upon stabilization than media containing mixed populations of fungi and bacteria.

The relative amounts of lignin may also have influenced the amount of shrinkage. Alexander (6) noted that the lignins in organic materials protect associated carbonaceous substances from destruction. The cellulose and hemicellulose in plant materials having a high lignin content are more resistent to microbial digestion. This helps explain how pine bark, which contains large amounts of lignin, resists decomposition. Resistence probably results from physical or physio-chemical barriers set up by close interlinkages between lignins and the cellulose in the bark, and possibly by means of lignin encrustation mechanically separating decomposers from the cellulose. The lignin from the pine bark in blended hardwood:pine bark media may have protected some of the cellulose in the hardwood bark from decomposition by providing a physical barrier to microbial decomposition. Thus, blended hardwood:pine bark media could have stabilized with less shrinkage, but shrinkage relative to the amount of pine bark should have been comparatively less in the 25:75 blend rather than in the 50:50 blend as was observed (Table 17).

Less than expected shrinkage in blended hardwood:pine bark media when calculated from the

shrinkage of hardwood and pine bark composted separately was probably caused by a combination of differences in microbial composition, and differences in lignin content, with microbial composition being influenced by pH.

Highest pH values were recorded in hardwood bark, and lowest values were recorded in pine bark (Table 19). The pH tended to increase as the percentage of hardwood bark in the blend increased. The largest change in pH was recorded for the 50:50 blend, even though the acidic influence of pine bark and the alkaline influence of the hardwood bark would be expected to create a buffered environment that resists changes in pH.

Figure 6 shows the dynamic nature of pH during the composting process, with an initial rise during the thermophilic phase, then a decline, and a slow increase during stabilization of hardwood bark and blended media. Pine bark shows a much smaller rise in pH initially, and slowly declines to a stable level.

Amounts of sulfur and iron sulfate incorporated into each medium containing hardwood bark appeared adequate to prevent excessive pH levels. No ammonia release was detected. All media ended with a pH in an acceptabe range for container plant production (72, 171), with the possible exception of pine bark.

Highest soluble salts levels were recorded in hardwood bark, and lowest in pine bark (Table 20). Salt levels after composting, change in salt levels, and peak salt levels increased as percentage of hardwood bark in the blend increased. Peak salt levels tended to coincide with peak pH levels. Salt levels in all media after composting were acceptable for container plant production (72, 171), but those in hardwood bark were close to being excessive.

Higher salt levels were recorded in hardwood bark for three reasons: 1) hardwood bark contains more soluble nutrients after composting than either pine bark or the blended media, 2) more minerals were added to hardwood bark before composting than were added to either pine bark or the blended media, 3) about 50% shrinkage in volume occurred in hardwood bark, effectively doubling the salt concentration.

Terminal salt levels were not high enough to account for all of the fertilizer amendments added before composting, and for the salts inherent in the bark. Salt may have been lost by leaching, volatilization, conversion to insoluble forms, or by being tied up in microbial cell mass.

Table 21 shows decomposition increased the amount of smaller particles of bark. All bark media decreased in percentage of larger particles (greater than 5.6 mm),

Table 20. Influence of composting on mmhos/cm soluble salts in hardwood and pine bark media.

%HB:%PB[1]	mean[2] initial mmhos/cm	mean[2] terminal mmhos/cm	change in mmhos/cm	peak mmhos/cm
100:0	0.19	1.93	1.74	2.85
25:75	0.16	1.57	1.41	2.30
50:50	0.21	1.08	0.87	2.00
75:25	0.18	0.48	0.30	0.90
0:100	0.13	0.30	0.17	0.40

[1] Percentage ratio of hardwood bark to pine bark by volume.
[2] Means of six samples.

Table 21. Particle size distribution before and after composting hardwood and pine bark media.

%HB:%PB[1]	mean percent weight on sieve[2] mm sieve size										
	12.7	8.0	5.6	4.0	2.8	2.0	1.4	1.0	0.7	0.5	pan
Before Composting											
100:0	38.9	3.7	6.4	7.0	7.4	5.4	5.0	5.9	6.4	4.6	9.5
75:25	21.8	3.6	7.4	10.2	10.9	7.6	7.6	6.9	8.0	5.3	11.0
50:50	8.7	3.3	9.2	12.0	13.8	10.1	9.6	8.0	8.1	5.2	11.6
25:75	7.8	3.8	7.2	12.9	14.7	10.4	9.3	8.2	7.8	5.4	12.5
0:100	0.0	0.2	6.3	18.5	19.4	14.8	12.2	9.3	8.1	5.0	6.2
After Composting											
100:0	0.9	5.4	7.6	8.8	8.6	7.5	9.0	7.1	9.3	9.4	26.4
75:25	0.5	4.6	6.8	10.5	11.5	9.1	10.6	8.4	10.0	8.2	19.8
50:50	0.0	1.5	3.7	10.0	13.8	11.1	13.4	8.8	10.5	7.2	20.0
25:75	0.6	2.8	4.0	11.1	13.9	11.5	11.5	9.4	8.9	6.9	19.4
0:100	0.0	0.0	2.2	10.9	16.0	12.5	11.9	10.1	10.3	7.5	18.6

[1] Percentage of hardwood bark to pine bark by volume.
[2] Mean of three samples.

while they increased in the percentage of smaller particles (less than 1.0 mm).

Hardwood bark initially had the highest percentage of particles larger than 5.6 mm, and showed the greatest loss of particles in this range. Hardwood bark initially had almost as few small particles (less than 1.0 mm) as pine bark (20.5% vs 19.3%), but had many more fines after composting compared to all other media. This explains the tremendous increase in %WHC (Table 22), and the large loss of %AC (Table 23) of hardwood bark as a result of composting.

There was very little difference in particle size distribution (PSD) among blended media mixed before or after composting (Table 24), indicating the mixing process did not degrade particle size. Differences that are present probably the resulted from sampling errors.

Comparison of PSD of FH (Table 24) with that of 100% hardwood bark before composting (Table 21), shows there was very little difference between the two, even though they were obtained 4 months apart. Four months of stockpiling pine bark (FP) produced a similar PSD to that of composted pine bark (CP).

Before composting, blended media had less %TPS than either hardwood bark or pine bark, with 50:50 blends having more %TPS than other blends (Table 25). After composting, 50:50 blends had more %TPS than all other

Table 22. Change in volume percent water holding capacity (%WHC) of hardwood and pine bark media after composting.

%HB:%PB[1]	Mean[2] initial %WHC	Mean[2] terminal %WHC	change in %WHC
100:0	14.9 j	38.3 a	23.4
75:25	18.8 i	37.5 b	18.7
50:50	23.8 g	35.3 c	11.5
25:75	20.8 h	33.8 d	13.0
0:100	28.7 f	29.5 e	0.8

[1] Percentage ratio of hardwood to pine bark by volume.
[2] Means followed by the same letter are not significantly different at the 5% level according to Duncan's New Multiple Range Test.

Table 23. Change in volume percent air capacity (%AC) of hardwood and pine bark media after composting.

%HB:%PB[1]	Mean[2] initial %AC	Mean[2] terminal %AC	loss of %AC
100:0	44.4 a	20.2 h	24.1
75:25	35.9 b	20.1 h	15.8
50:50	33.0 c	25.7 f	7.3
25:75	34.4 bc	23.1 g	11.3
0:100	30.6 d	29.4 e	1.2

[1] Percentage ratio of hardwood to pine bark by volume.
[2] Means followed by the same letter are not significantly different at the 5% level according to Duncan's New Multiple Range Test.

Table 24. Particle size distribution of composted and noncomposted hardwood and pine bark media.

Media Code[1]	Mean Percent Weight on Sieve[2] mm sieve size										
	12.7	8.0	5.6	4.0	2.8	2.0	1.4	1.0	0.7	0.5	pan
CH	0.9	5.4	7.6	8.8	8.6	7.5	9.0	7.1	9.3	9.4	26.4
FH	37.4	2.7	6.3	7.0	7.4	5.2	5.2	7.0	7.9	4.3	9.8
C3HP	0.5	4.6	6.8	10.5	11.5	9.1	10.6	8.4	10.0	8.2	19.8
A3HP	3.6	4.1	6.9	9.2	11.1	10.6	9.9	8.0	8.4	9.0	19.2
C3HFP	0.0	6.0	6.1	10.7	11.0	10.0	9.7	8.5	9.7	8.4	19.9
F3HFP	19.0	4.9	8.6	10.1	11.1	7.3	6.7	6.8	8.3	5.2	12.0
CHP	0.0	1.5	3.7	10.0	13.8	11.1	13.4	8.8	10.5	7.2	20.0
AHP	0.0	7.3	8.6	8.2	11.0	10.5	10.3	8.9	8.8	7.5	18.9
CHFP	3.3	1.5	6.9	8.4	11.7	9.5	10.6	8.2	10.5	8.8	20.6
FHFP	8.0	2.9	9.5	11.5	13.3	9.6	9.8	8.6	8.4	5.5	12.9
CH3P	0.6	2.8	4.0	11.1	13.9	11.5	11.5	9.4	8.9	6.9	19.4
AH3P	0.0	0.5	5.7	10.7	14.5	11.3	11.9	9.1	10.6	8.4	19.0
CH3FP	0.0	0.9	3.3	10.1	14.7	12.0	11.9	9.1	10.6	8.4	19.0
FH3FP	9.6	2.8	8.4	12.8	14.7	11.1	9.6	8.2	7.8	5.1	9.9
CP	0.0	0.0	2.2	10.9	16.0	12.5	11.9	10.1	10.3	7.5	18.6
FP	0.0	0.0	1.9	10.4	17.6	14.0	11.4	10.3	9.5	7.8	17.1
SNM	0.0	1.1	2.6	5.6	8.6	7.1	7.9	7.7	13.3	16.9	29.2
MUSH	0.0	0.1	0.0	0.3	12.0	12.1	13.5	13.2	13.7	15.7	19.4

[1] See Appendix A for description of media codes.
[2] Mean of three samples.

Table 25. Change in volume percent total pore space (%TPS) in hardwood and pine bark media after composting.

%HB:%PB[1]	Mean[2] initial %TPS	Mean[2] terminal %TPS	change in %TPS
100:0	59.3 b	58.6 b	-0.7
75:25	54.7 e	57.6 bc	2.9
50:50	56.8 cd	61.0 a	4.2
25:75	55.2 e	56.4 d	1.7
0:100	59.3 b	58.9 b	-0.4

[1] Percentage ratio of hardwood to pine bark by volume.
[2] Means followed by the same letter are not significantly different at the 5% level according to Duncan's New Multiple Range Test.

media, but the 25:75 blend had least, and other media were intermediate. Blends increased in %TPS during composting with the 50:50 blend increasing the most.

Before composting, hardwood bark had the greatest %AC, pine bark had the least %AC, and blended media were intermediate (Table 23). After composting, hardwood bark and the 75:25 blend had the lowest %AC, pine bark had the greatest %AC, and the other blended media were intermediate. %AC decreased in all media, with hardwood bark changing the most, and pine bark changing the least. The 50:50 blend decreased less in %AC than other blends.

The higher %AC in the 50:50 blend could have resulted from the PSD. In the particle size range from 1.0 mm to 4.0 mm, the 50:50 blend was very similar to pine bark (38.3% and 40.4%, respectively).

Before composting, hardwood bark had the lowest %WHC, pine bark had the greatest %WHC, and blended media were intermediate (Table 22). After composting, this was reversed, and %WHC increased as percentage of hardwood bark in the media increased. The 50:50 blend gained less %WHC than other blends.

Before composting, blended media had more BD than hardwood bark (Table 18). This increased weight for a given volume showed that the hardwood bark and pine bark particles were interlocking, and indicated that some

volume shrinkage occurred. This coincides with lower %TPS (Table 25) in blended media before composting. After composting, BD increased as percentage of hardwood bark in the media increased. The greatest change in BD was in 100% hardwood bark, with lesser change in the 75:25 and 50:50 blends. BD of 25:75 and pine bark media remained unchanged.

There was very little difference in physical properties between blended media mixed before or after composting (Table 26). With the exception of the higher %WHC in CP, there was no difference between CP and FP. Similarity in %WHC among CH, SNM, and MUSH corresponds with the large amount of particles smaller than 1.0 mm in these three media (Table 24).

Fresh hardwood and pine bark contained relatively little available nitrogen (Table 27). Extractable NH_4-N and NO_3-N levels after composting probably were affected by the urea and potassium nitrate added before composting (Table 13). Highest NO_3-N levels were found in 50:50 blends after composting. Since the composting process terminated before expected in the 50:50 blend (Table 15), it had a comparatively longer time period for ammonium to nitrate converting bacteria (Nitrosomonas, Nitrosolobus, Nitrosospira, and Nitrobacter) to populate the finished compost. These microbes cannot survive thermophilic conditions. A

Table 26. Physical properties of composted and non-composted hardwood and pine bark media.

media code[1]	total pore space	air capacity	water holding capacity	bulk density
	mean percent by volume[2]			
Mixed Before Composting				
CH	58.6 de	20.2 h	38.3 b	0.32 b
C3HP	57.6 e	20.1 h	37.5 cd	0.30 cd
CHP	61.0 b	25.7 f	35.3 ef	0.29 de
CH3P	56.4 f	23.1 g	33.8 h	0.28 e
CP	58.9 d	29.4 e	29.5 i	0.26 f
Mixed After Composting				
A3HP	58.0 e	20.1 h	37.9 c	0.30 c
AHP	61.6 b	25.9 f	35.7 e	0.29 d
AH3P	57.1 ef	23.0 g	34.1 gh	0.28 de
Mixed After Composting Using Non-composted Pine Bark				
C3HFP	57.7 e	20.2 h	37.5 cd	0.30 c
CHFP	61.1 b	26.1 f	35.3 ef	0.28 d
CH3FP	56.9 ef	23.2 g	33.7 h	0.28 de
Not Composted				
FH	61.1 b	46.5 a	14.6 n	0.19 i
F3HFP	54.4 g	36.4 b	18.0 m	0.20 i
FHFP	57.4 ef	34.2 d	23.2 k	0.22 h
FH3FP	55.7 fg	35.0 c	20.7 l	0.23 g
FP	59.1 d	30.1 e	29.0 j	0.26 f
Controls				
SNM	56.7 f	14.8 i	41.9 a	0.50 a
MUSH	65.3 a	23.6 g	41.7 a	0.32 b

[1] See Appendix A for description of media codes.
[2] Means followed by the same letter are not significantly different at the 5% level according to Duncan's New Multiple Range Test.

Table 27. Extractable nitrogen, phosphorus, and potassium concentration in hardwood and pine bark media before and after composting.

	Before Composting				After Composting			
	PPM[1]				PPM[1]			
%HB:%PB[2]	NH_4-N	NO_3-N	P	K	NH_4-N	NO_3-N	P	K
100:0	1.0	0.7	3.4	97.4	6.0	2.5	20.9	336.5
75:25	1.5	0.5	3.3	84.8	17.5	23.0	30.8	258.2
50:50	1.0	1.0	4.2	83.3	28.5	51.0	39.0	175.9
25:75	1.0	1.5	3.6	73.5	7.0	3.0	32.5	130.9
0:100	2.0	1.6	4.1	60.4	13.5	4.0	17.9	49.5

[1] Means of two replications.
[2] Percentage ratio of hardwood bark to pine bark by volume.

similar response would be expected from pine bark alone and from 25:75 blends, except that these media were originally amended with less nitrogen (Table 13). It could have been that the amount of nitrogen added to the 50:50 blends was more than required for the composting process.

Lohr et al. (100) stated that stockpiling spent mushroom compost (SMC) might not be effective in eliminating excess NH_4-N. However, in this test, SMC was stockpiled and exposed to weather for one year, and then mixed in equal volumes with noncomposted pine bark, resulting in a media (MUSH) that had only 22 PPM NH_4-N.

Levels of extractable phosphorus P were relatively similar in hardwood and pine bark before composting, with hardwood bark having only 0.7 PPM less than pine bark (Table 27). Highest P levels both before and after composting were found in the 50:50 blends. After composting, levels did not reflect the increasing amount of superphosphate added as the percentage hardwood bark in the media increased (Table 13). Either the micro-organisms utilized phosphorus, converting it into unextractable organic forms, or it converted into unavailable inorganic forms.

Both hardwood bark and pine bark contained a fair supply of K before composting, with levels increasing as the percentage of hardwood bark in the media increased.

Analysis after composting showed this same pattern, with levels reflecting the increasing amounts of potassium nitrate added to the media as the percentage of hardwood bark in the media increased (Table 13), as well as the concentration effect due to volume shrinkage. Levels of K in pine bark, which received no potassium nitrate before composting, decreased, indicating the possibility that the composting microorganisms require a small amount of K for metabolic processes. The amount of K before composting may have been sufficient to meet microbial needs in all of the media. Therefore, addition of K fertilizers before composting seems unnecessary.

Levels of Ca before composting were highest in the 50:50 blend (Table 28). After composting, levels of Ca had increased dramatically. The greater the percentage of hardwood bark in the medium, the greater the increase. Hardwood bark is known to contain around 4% Ca by dry weight (ash analysis) (20), and this is revealed in increased Ca levels after composting. Apparently, as the bark decomposed, the Ca in cell walls and the middle lamellae was released in extractable form.

After composting, Mg levels increased as the percentage of hardwood bark in the medium increased (Table 28). Although increases in Mg levels were

Table 28. Extractrable calcium, magnesium, manganese, and iron concentration in hardwood and pine bark media before and after composting.

%HB:%PB[2]	Before Composting PPM[1] Ca	Mg	Mn	Fe	After Composting PPM[1] Ca	Mg	Mn	Fe
100:0	20.6	6.4	2.5	0.65	259.3	30.3	2.8	1.24
75:25	23.2	7.2	2.8	0.99	204.1	24.9	4.3	0.48
50:50	30.3	11.0	3.9	1.96	143.7	23.0	5.1	0.45
25:75	22.8	8.3	2.9	1.38	93.9	16.9	4.1	0.60
0:100	17.9	8.1	2.0	2.28	21.8	6.8	1.3	0.99

[1] Means of two replications.
[2] Percentage ratio of hardwood bark to pine bark by volume.

considerably lower in magnitude than Ca levels, the two nutrients responded similarly.

The change in extractable Mn, Fe, Al, B, Cu, and Zn appeared to be insignificant (Tables 28 and 29). An unknown amount of extractable elements could have been lost to leaching, volatilization, conversion to insoluble forms, or by incorporation into microbial cell mass.

Blends mixed after composting with composted hardwood bark and pine bark had amounts of exchangeable NH_4-N, P, K, Mn, and Cu similar to the blends mixed before composting (Table 30, Table 31, and Table 32). NO_3-N was probably similar, except for anomalous values in C3HP and CHP. Ca was higher in blends mixed after composting. The mixing process may have exposed undecomposed bark surfaces to microbial activity, releasing more Ca. For the same reason, Mg was also higher in blends mixed after composting. Fe, Al, and B were higher in blends mixed after composting. Like Ca, these nutrients could have become more available due to the physical mixing process. There was less Zn in blends mixed after composting.

Blends mixed after composting with noncomposted pine bark had less NH_4-N and P than blends mixed before composting (Table 30). This may be due to the higher NH_4-N and P levels in CP as compared to FP. Ca, Mg, Mn,

Table 29. Extractable aluminum, boron, copper, and zinc concentration in hardwood and pine bark media before and after composting.

	Before Composting				After Composting			
	PPM[1]				PPM[1]			
%HB:%PB[2]	Al	B	Cu	Zn	Al	B	Cu	Zn
100:0	1.7	0.21	0.01	0.05	2.0	0.34	0.03	0.04
75:25	3.0	0.24	0.02	0.07	0.8	0.26	0.03	0.05
50:50	7.9	0.26	0.02	0.18	2.3	0.23	0.03	0.09
25:75	5.5	0.21	0.02	0.12	1.8	0.22	0.03	0.17
0:100	8.5	0.19	0.02	0.24	4.7	0.17	0.01	0.08

[1] Means of two replications.
[2] Percentage ratio of hardwood bark to pine bark by volume.

Table 30. Extractable nitrogen, phosphorus, and potassium concentration in composted and noncomposted hardwood and pine bark media.

Media Code[1]	NH_4-N	NO_3-N	PPM P	K
Mixed Before Composting				
CH	6.0	2.5	20.9	336.5
C3HP	17.5	23.0	30.8	258.2
CHP	28.5	51.0	39.0	175.9
CH3P	7.0	3.0	32.5	130.9
CP	13.5	4.0	17.9	49.5
Mixed After Composting				
A3HP	18.0	3.0	23.9	249.7
AHP	21.0	4.0	31.7	226.6
AH3P	14.0	4.0	32.5	144.6
Mixed After Composting Using Non-composted Pine Bark				
C3HFP	9.0	1.0	30.0	299.3
CHFP	11.0	2.0	22.2	149.9
CH3FP	7.0	3.0	25.0	162.7
Not Composted				
FH	1.0	0.7	3.4	97.4
F3HFP	2.0	0.5	3.8	34.7
FHFP	3.0	0.4	4.9	42.1
FH3FP	N/A[2]	N/A	N/A	N/A
FP	4.0	1.0	5.3	41.6
Controls				
SNM	2.0	1.0	2.0	22.8
MUSH	22.0	50.0	45.4	242.5

[1] See Appendix A for description of media codes.
[2] Indicates no analysis available.

Table 31. Extractable calcium, magnesium, manganese, and iron concentration in composted and noncomposted hardwood and pine bark media.

Media Code[1]	PPM Ca	Mg	Mn	Fe
Mixed Before Composting				
CH	259.3	30.3	2.8	1.24
C3HP	204.1	24.9	4.3	0.48
CHP	143.7	23.0	5.1	0.45
CH3P	93.9	16.9	4.1	0.60
CP	21.7	6.8	1.3	0.99
Mixed After Composting				
A3HP	219.0	27.4	3.8	1.01
AHP	203.9	28.8	5.8	0.68
AH3P	117.0	19.8	4.4	0.68
Mixed After Composting Using Non-composted Pine Bark				
C3HFP	236.4	32.8	5.6	0.68
CHFP	151.3	19.8	4.4	0.68
CH3FP	150.5	23.2	5.5	0.65
Not Composted				
FH	20.2	6.3	2.5	0.61
F3HFP	15.1	5.6	2.0	0.47
FHFP	19.5	6.9	2.7	0.52
FH3FP	N/A[2]	N/A	N/A	N/A
FP	13.9	6.3	1.4	0.71
Controls				
SNM	9.1	3.9	3.8	1.66
MUSH	419.9	57.5	2.1	0.42

[1] See Appendix A for description of media codes.
[2] Indicates no analysis available.

Table 32. Extractable aluminum, boron, copper, and zinc concentration in composted and noncomposted hardwood and pine bark media.

Media Code[1]	Al	B	Cu	Zn
		PPM		
Mixed Before Composting				
CH	2.0	0.34	0.03	0.04
C3HP	0.8	0.26	0.03	0.05
CHP	2.2	0.23	0.03	0.09
CH3P	1.8	0.22	0.03	0.17
CP	4.7	0.17	0.01	0.08
Mixed After Composting				
A3HP	1.7	0.31	0.03	0.04
AHP	1.6	0.34	0.03	0.07
AH3P	2.5	0.27	0.03	0.09
Mixed After Composting Using Non-composted Pine Bark				
C3HFP	1.2	0.39	0.04	0.06
CHFP	1.6	0.29	0.05	0.07
CH3FP	2.7	0.29	0.02	0.10
Not Composted				
FH	1.7	0.21	0.01	0.05
F3HFP	3.2	0.18	0.01	0.07
FHFP	3.4	0.23	0.02	0.08
FH3FP	N/A[2]	N/A	N/A	N/A
FP	5.7	0.16	0.02	0.14
Controls				
SNM	2.9	0.06	0.02	0.21
MUSH	0.6	0.39	0.08	0.07

[1] See Appendix A for description of media codes.
[2] Indicates no analysis available.

Fe, and B levels were higher in media mixed after composting with noncomposted pine bark, except for Mg and Mn in CHFP (Table 31 and Table 32). The mixing process could have exposed more nutrients as previously discussed.

All nutrient levels except Zn were higher in CH than in FH. Except for Zn, Cu, Al, and Mn, all nutrient levels were higher in CP than in FP. Blended media composed of composted bark also had higher nutrient levels than blended media composed of noncomposted bark. Clearly, composting hardwood and pine bark, either alone or blended together, increased the amount of extractable nutrients.

Compared to composted bark media, SNM had little extractable nutrients, with the exceptions of Mn, Fe, Al, Cu, and Zn, which were similar. In contrast, MUSH had similar or higher levels of extractable nutrients, except for Al and Mn, which were lower (Tables 30, 31, 32). Amending SMC with 50% noncomposted pine bark appeared to have been sufficient to lower high soluble salt levels to an acceptable range for container plant production.

CHAPTER IV

TREEBARK AS A GROWING MEDIUM FOR POINSETTIA

Introduction

Good growth of poinsettia (Euphorbia pulcherrima Willd. ex Klotzch) has been obtained in treebark container growing media (41, 54, 64, 65, 104). To obtain information about the use of blended hardwood and pine bark as a growing medium, an experiment was performed using Euphorbia pulcherrima Willd. ex Klotzch 'Gutbier V-14 Glory' grown in media containing varying ratios of composted or noncomposted pine bark, and composted hardwood bark.

This experiment had the following main objectives: 1) to determine if poinsettia growth was better in composted pine bark compared to noncomposted pine bark; 2) to determine if poinsettia growth was better in composted hardwood bark than in composted or non-composted pine bark; 3) to determine which ratio of blended hardwood and pine bark supported the best growth of poinsettia; 4) to determine if there was a difference between blended media when mixed before or after composting; 5) to compare poinsettia growth in all treebark media with growth in an accepted industry standard medium.

Materials and Methods

Thirteen media were tested in this experiment. Codes and descriptions of each medium are available in Appendix A.

Rooted cuttings of 'Gutbier V-14 Glory' poinsettia were potted on September 30, 1985 for production as single stem plants in 15 cm pots. The potting medium was Pro-Mix BX (Premier Brands, Inc., New Rochelle, NY). Plants were fertilized at every watering with Peter's General Purpose Fertilizer 20-20-20 (W.R. Grace and Company, Fogelsville, PA) at 200 PPM nitrogen. This fertilizer is described in Appendix C. On October 4, 1985, plants received a single foliar spray of 1000 PPM chloromequat chloride (American Cyanamid) for height control.

On October 24, 1985, plants were removed from their pots, and all loose medium was gently shaken free from the root ball. Plants were then graded and placed by size into ten blocks of thirteen plants. Thirteen media treatments were randomly assigned within each block as part of a randomized complete block experimental design. The plants were repotted in 2.5 l nursery containers filled with 2.25 l of media, and then grown in a greenhouse under cultural conditions described in Appendix B.

On December 18, 1985, the greatest cm width of the largest flower-bract on each plant was recorded. Plant height in cm from the soil line to the tallest cyathia, and the number of blooms per plant was recorded. On January 6, 1986, the tops of poinsettias were cut off at the soil line, and dried in a forced-air drying oven at 180°F for 48 hours. Top shoot dry weight in mg was recorded using a Terralion Monostat Gram Balance.

Data were analyzed by analysis of variance (ANOVA) using Statistical Analysis System software (SAS Institute, Inc., Cary, NC) on IBM 4381 computer facilities through the University of Tennessee Computing Center. The 5% significance level was selected as an acceptable error level for this experiment. Mean separations were performed using Duncan's New Multiple Range Test.

Results and Discussion

Several plants became infected with root rot during the course of the experiment. As many as five plants in any given block showed reduced growth attributable to root rot. Incidence of root rot was more common in media containing less hardwood bark. Plants grown in media containing at least 75% hardwood bark had no disease, while plants grown in media containing less than 50% hardwood bark were frequently infested. Only two plants grown in 50:50 blends showed symptoms of

rot. Clearly, plants grown in media containing higher amounts of hardwood bark stood a better chance of good growth due to the pathogen suppressive characteristics of the hardwood bark.

ANOVA showed significant influence of media on the largest bract width, plant height, and shoot dry weight of 'Gutbier V-14 Glory' poisettias. Although the number of blooms per plant varied from 4 to 8, ANOVA showed that media did not influence this parameter.

As expected, largest bract width (Table 33), plant height (Table 34), and shoot dry weight (Table 35) did not differ between CP and FP. This response agrees with other reports (2, 127, 171).

Plants grown in CH had larger bracts than plants grown in CP or FP (Table 33). Plants grown in CP were as tall as CH grown plants, but FP grown plants were shorter (Table 34). FP grown plants were as heavy as those grown in CH, but CP grown plants were lighter (Table 35). Thus, growth in pine bark was not consistently as good as growth in CH, but this was probably due to the higher incidence of disease in the pine bark media.

Largest bract width (Table 33) and plant height (Table 34) did not differ among blended hardwood:pine bark media. Plants grown in A3HP, C3HFP, and CH3FP were not as heavy as plants grown in AH3P, but plants grown

Table 33. Mean cm width of largest flower-bract of 'Gutbier V-14 Glory' poinsettias grown in hardwood and pine bark media.

%HB:%PB[1]	blended before[3] composting code[2]/cm width	blended after[3] composting code/cm width	blended after[3] composting with aged pine bark code/cm width
100:0	CH/10.95 a		
75:25	C3HP/ 9.80 ab	A3HP/ 9.78 ab	C3HFP/ 9.04 b
50:50	CHP/ 9.75 ab	AHP/ 9.60 b	CHFP/ 9.02 b
25:75	CH3P/ 9.50 b	AH3P/ 9.47 b	CH3FP/ 8.94 b
0:100	CP/ 9.12 b		FP/ 9.22 b
control			SNM/ 9.09 b

1 Ratio of hardwood bark to pine bark by volume.
2 See Appendix A for media code definitions.
3 Means followed by the same letter are not significantly different at the 5% level according to Duncan's New Multiple Range Test.

Table 34. Mean cm height of 'Gutbier V-14 Glory' poinsettias grown in hardwood and pine bark media.

%HB:%PB[1]	blended before[3] composting code[2]/cm height	blended before[3] composting code/cm height	blended after[3] composting with aged pine bark code/cm height
100:0	CH/23.62 a		
75:25	C3HP/22.30 ab	A3HP/23.11 ab	C3HFP/22.30 b
50:50	CHP/23.37 a	AHP/22.68 ab	CHFP/22.35 ab
25:75	CH3P/22.99 ab	AH3P/24.21 a	CH3FP/21.59 ab
0:100	CP/21.59 ab	CP/21.59 ab	FP/20.52 b
control			SNM/20.55 b

[1] Ratio of hardwood bark to pine bark by volume.
[2] See Appendix A for media code definitions.
[3] Means followed by the same letter are not significantly different at the 5% level according to Duncan's New Multiple Range Test.

Table 35. Mean gram shoot dry weight of 'Gutbier V-14 Glory' poinsettias grown in hardwood and pine bark media.

%HB:%PB[1]	blended before[3] composting code[2]/grams	blended after[3] composting code/grams	blended after[3] composting with aged pine bark code/grams
100:0	CH/26.89 a		
75:25	C3HP/15.85 bc	A3HP/10.28 c	C3HFP/12.03 c
50:50	CHP/19.23 abc	AHP/14.40 bc	CHFP/15.48 bc
25:75	CH3P/16.05 bc	AH3P/22.88 ab	CH3FP/11.54 c
0:100	CP/11.46 c		FP/18.06 abc
control			SNM/ 9.30 c

[1] Ratio of hardwood bark to pine bark by volume.
[2] See Appendix A for media code definitions.
[3] Means followed by the same letter are not significantly different at the 5% level according to Duncan's New Multiple Range Test.

in all other blended media had similar shoot dry weight (Table 35). Other reports of blended hardwood:pine bark media on growth of woody ornamentals showed better growth in 50:50 blends, and better growth in blended media than in hardwood bark or pine bark alone (18, 19). The incidence of disease in this experiment may have negated any enhanced growth in blended media containing less than 75% hardwood bark.

Only plants grown in CH had larger bracts than SNM grown plants (Table 33). Plants grown in CH, CHP, and AH3P were taller than SNM grown plants (Table 34), and plants grown in CH and AH3P were heavier than SNM grown plants (Table 35). Plants grew as good or better in hardwood bark, pine bark, and blended hardwood:pine bark media as in SNM; therefore, any of the treebark media can substitute for SNM when growing poinsettias.

Data collected in this experiment were influenced by the incidence of root rot. It may be difficult to distinguish the effect of media from the effect of disease if some media were more suppressive toward root rot than others. This would explain why CH grown plants were consistently better since CH has been shown to be suppressive to root rot pathogens (36, 75, 77, 82, 145, 155, 156, 173). Data could have been influenced by the single spray treatment of chloromequat chloride; however, since the spray was applied to all plants

before media treatments were applied, the influence of the growth regulator should not differ among treatments. Differences in height or other parameters may have been greater if the growth regulator had not been applied. Differences in growth in the various media may have been more pronounced if a larger container size had been used.

CHAPTER V

TREEBARK AS A GROWING MEDIUM FOR GERANIUM

Introduction

Excellent geranium (Pelargonium X hortorum L.H. Bailey) and bedding plant growth has been demonstrated in hardwood bark container growing media (54, 55, 104). To evaluate blended hardwood and pine bark as a container growing medium, an experiment was performed using 'Aurora' geraniums grown in media composed of varying ratios of composted and noncomposted pine bark, and composted hardwood bark.

Main objectives were: 1) to determine if geranium growth was better in composted pine bark compared to noncomposted pine bark; 2) to determine if geranium growth was better in composted hardwood bark than in composted or noncomposted pine bark; 3) to determine which ratio of blended hardwood and pine bark supported the best growth of geranium; 4) to determine if geranium growth differed in blended hardwood and pine bark media when the media were mixed before or after composting; 5) to compare geranium growth in all treebark media with growth in an accepted industry standard medium; 6) to compare the tissue chemical analysis of geraniums grown in the different media; 7) to compare tissue chemical analysis with extractable nutrient analysis of the

media; 8) to record changes in pH of leachates from the media over time.

Materials and Methods

Thirteen media were tested in this experiment. Media codes and descriptions are available in Appendix A.

On October 10, 1985, two inch plugs of 'Aurora' geranium (Oglevee Products, Inc., McDonough, Georgia) were planted in 2.5 l plastic nursery containers filled with 2.25 l of media. Plants were potted, and sorted into ten blocks containing a single container of each media type as part of a randomized complete block experimental design. Block locations were chosen that minimized variation caused by differences in greenhouse location. Plants were placed in a greenhouse, and grown under cultural conditions described in Appendix B. Plants were initially spaced one foot by one foot, and spread to one foot by two feet on November 15, 1985.

Leachate pH values were determined for all containers in one block of plants on a monthly basis.

On January 2, 1986, the first fully expanded leaf from each of four main stems on each plant was removed and dried for chemical analysis. Samples from three blocks were combined into one replication to insure enough dried tissue would be available for analysis. Three replications were made from blocks one through

nine. No tissue was sampled from plants in block 10. Tissue was dried in a forced-air drying oven at 75°C for two days, and samples were sent to the Georgia Soil and Plant Analysis Laboratory (Athens, GA) for ash analysis.

On January 5, 1986, height in cm was measured from medium-level to the tallest stem apex. Two width measurements were taken by first recording the width of the widest portion of the plant, and then measuring the width at a right angle to the first measurement. A plant size index (PSI) was then calculated as follows:

$$PSI = \frac{\text{cm Height} + \frac{\text{cm Width} + \text{cm Width}}{2}}{2}$$

On January 6, 1986, plants were cut-off at the medium-level, and shoot fresh weight in grams was recorded using a Terralion Monostat Gram Balance. Shoots were bagged and dried at 80°C for 48 hours. Stems were insufficiently dry after 48 hours; so, they were clipped into small pieces, and returned to the drying oven for an additional 48 hours.

Data were analyzed by analysis of variance (ANOVA) using Statistical Analysis System software (SAS Institute, Inc., Cary, NC) on IBM 4381 computer facilities through the University of Tennessee Computing Center. The 5% significance level was selected as an

acceptable error level for this experiment. Mean separations were calculated using Duncan's New Multiple Range Test.

Results and Discussion

By October 29, a severe chlorosis was observed on the youngest leaves of many plants (see Figure 7). Symptoms included interveinal yellow blotches, upward cupping of leaf margins, and necrotic spots on leaf margins as leaves aged. Internode length also appeared to be shorter than non-chlorotic plants. Chlorosis was present on all plants growing in media containing at least 75% composted hardwood bark, and in one plant growing in CHP and one plant growing in AHP. No chlorosis was present on young leaves of any plants on November 16; however, plants growing in media containing hardwood bark showed reddish tones near the margins of young leaves. This symptom was no longer present on December 1, 1985.

PSI did not differ among CP, FP, and CH (Table 36). There was no difference among blended media mixed before or after composting. PSI of plants grown in media containing at least 50% pine bark were larger than plants grown in SNM. Only the control medium produced a PSI below 35.

Shoot weights (Table 37 and Table 38) were similar among plants grown in CP, FP, and CH. Hardwood and pine



Figure 7. Manganese toxicity symptoms on 'Aurora' geranium grown in composted hardwood bark. Leaves have interveinal yellow blotches, upward-cupped leaves, and dark brown necrotic spots on leaf margins.

Table 36. Mean plant size index (PSI) of 'Aurora' geraniums grown in hardwood and pine bark media.

%HB:%PB[1]	blended before[3] composting code[2]/PSI	blended after[3] composting code/PSI	blended after[3] composting with aged pine bark code/PSI
100:0	CH/36.6 cde		
75:25	C3HP/35.8 de	A3HP/36.9 bcde	C3HFP/35.8 bcde
50:50	CHP/38.9 abc	AHP/39.4 ab	CHFP/40.2 a
25:75	CH3P/37.7 abcd	AH3P/38.7 abc	CH3FP/37.7 abcd
0:100	CP/37.6 abcd		FP/37.5 bcd
Control			SNM/34.9 e

1 Ratio of hardwood bark to pine bark by volume.
2 See Appendix A for media code definitions.
3 Means followed by the same letter are not significantly at the 5% level according to Duncan's New Multiple Range Test.

Table 37. Mean gram shoot fresh weight of 'Aurora' geraniums grown in hardwood and pine bark media.

%HB:%PB[1]	blended before[3] composting code[2]/grams	blended after[3] composting code/grams	blended after[3] composting with aged pine bark code/grams
100:0	CH/287.4 bc		
75:25	C3HP/289.9 bc	A3HP/327.4 ab	C3HFP/324.0 ab
50:50	CHP/353.6 a	AHP/354.4 a	CHFP/361.9 a
25:75	CH3P/333.3 ab	AH3P/340.1 a	CH3FP/329.8 ab
0:100	CP/328.2 ab		FP/329.4 ab
Control			SNM/263.2 c

[1] Ratio of hardwood bark to pine bark by volume.
[2] See Appendix A for media code definitions.
[3] Means followed by the same letter are not significantly different at the 5% level according to Duncan's New Multiple Range Test.

Table 38. Mean shoot dry weight of 'Aurora' geraniums grown in hardwood and pine bark media.

%HB:%PB[1]	blended before[3] composting code[2]/grams	blended after[3] composting code/grams	blended after[3] composting with aged pine bark code/grams
100:0	CH/34.4 bc		
75:25	C3HP/33.9 bc	A3HP/38.2 ab	C3HFP/37.0 ab
50:50	CHP/41.5 a	AHP/41.9 a	CHFP/42.0 a
25:75	CH3P/41.1 a	AH3P/39.4 ab	CH3FP/38.5 ab
0:100	CP/38.0 ab		FP/38.1 ab
Control			SNM/31.0 c

[1] Ratio of hardwood bark to pine bark by volume.
[2] See Appendix A for media code definitions.
[3] Means followed by the same letter are not significantly different at the 5% level according to Duncan's New Multiple Range Test.

bark blends were of similar weight except for C3HP. There was no difference among plants grown in blended media mixed before or after composting. Shoot fresh weights (Table 37) and shoot dry weights (Table 38) were greater in blended media containing 50% or more pine bark than in SNM.

Media showed no consistent influence on tissue P levels (Table 39). Extractable P in the media was equally inconsistent (Table 30). All tissue P levels were near normal (0.4% to 0.67%) or above normal for geraniums (95). Since uptake of P is active, and since the P content in root cells and xylem sap is about 100 to 1000 times higher than in the soil solution (112), sufficient P was probably available in all media, and plants pumped in what was needed without being influenced by the differing concentrations of P in the different media.

Higher amounts of P were added to the treebark media as the percentage of hardwood bark increased (Table 13), and shrinkage was higher in media containing more hardwood bark (Table 16) making the P concentration even higher. Amounts of extractable P were expected to be higher as the percentage of hardwood bark in the media increased; however, this trend was not found in the media analysis, nor in the tissue analysis. Since tissue analysis did not follow the expected pattern, it

Table 39. Foliar nutrient concentration of 'Aurora' geranium grown in hardwood and pine bark media.

Media Code[1]	mean percent[2] P	K	Ca	Mg
CH	0.58 bc	3.01 a	1.22 a	0.28 a
C3HP	0.60 bc	2.84 ab	1.09 ab	0.24 ab
A3HP	0.62 bc	2.77 ab	1.12 ab	0.25 ab
C3HFP	0.70 b	2.86 ab	1.01 ab	0.24 ab
CHP	0.57 bc	2.57 b	0.81 b	0.23 ab
AHP	0.65 bc	2.68 ab	0.89 b	0.22 ab
CHFP	0.64 bc	2.76 ab	0.92 b	0.23 ab
CH3P	0.57 bc	2.62 b	1.02 ab	0.21 ab
AH3P	0.60 bc	2.75 ab	0.86 b	0.19 ab
CH3FP	0.80 a	2.80 ab	0.85 b	0.20 ab
CP	0.53 c	2.74 ab	0.90 b	0.16 b
FP	0.56 bc	2.90 a	0.89 b	0.16 b
SNM	0.62 bc	2.93 a	1.01 ab	0.17 b

[1] See Appendix A for definition of media codes.
[2] Means in columns followed by the same letter are not significantly different at the 5% level according to Duncan's New Multiple Range Test.

was difficult to determine whether the excess P in media containing more hardwood bark was converted to insoluble forms, or if the method of extraction was inadequate for testing P levels.

Extractable K increased as the percentage of hardwood bark in the media increased (Table 30); however, tissue K levels were not influenced by media. All tissue K levels were near normal (2.5% to 4.3%) for geraniums (95). Since the active uptake mechanism for K is inhibited by higher K concentrations (112), plants probably pumped in sufficient K without being influenced by the differing concentrations of K in the different media. Higher levels of extractable K could have been leached before they influenced levels in the tissue.

Levels of Ca and Mg were higher in plants grown in CH than in either CP or FP, and there was no difference between CP and FP (Table 39). Ca and Mg levels did not differ among blended media mixed before or after composting. Plants grown in CH had more tissue Ca and Mg than SNM. Tissue levels of Ca and Mg were in the normal range (0.81 to 1.2, and 0.20 to 0.52 for Ca and Mg, respectively) for geraniums (95).

Extractable Ca and Mg in the media tended to increase as the percentage of hardwood bark in the media increased (Table 31); however, this trend is not reflected in the tissue levels. Unlike P and K which

have very active uptake mechanisms, Ca and Mg uptake is limited to an area just behind the root tips where the cell walls of the endodermis are still unsuberized (112); therefore, tissue Ca and Mg levels were expected to be more easily influenced by the levels in the different media. Higher levels of extractable Ca and Mg may have been leached or displaced by other cations such as K^+ before they could influence tissue levels.

Plants grown in CH had more tissue Fe and Mn than plants grown in CP, FP, or SNM, and Fe and Mn levels in CP and FP did not differ (Table 40). In blended media containing 75% pine bark, tissue Fe and Mn were higher when the media was mixed before composting (CH3P); however, other ratios of blended hardwood and pine bark did not show this trend for Fe levels. Tissue Fe and Mn levels tended to increase as the percentage of hardwood bark in the medium increased. However, while extractable Fe levels in the media tended to be higher as the percentage of hardwood bark increased, extractable Mn levels were frequently higher in the 50:50 blends (Table 31). The method used to determine extractable Mn in the media may not have yielded accurate data. Plants grown in media containing hardwood bark had normal (158 PPM) or above normal Fe levels, while plants grown in CP, FP, and SNM were close to or below levels of incipient deficiency (60 PPM)

Table 40. Foliar micronutrient concentration of 'Aurora' geraniums grown in hardwood and pine bark media.

Medium[1]	Mean[2] PPM Fe	Mn	Zn	Cu	Al	B
CH	349.3 a	453.2 a	41.89 b	1.81 cde	12.75 a	30.74 a
C3HP	364.4 a	450.9 a	46.53 b	2.16 bc	12.11 a	32.41 a
A3HP	263.2 abc	344.9 ab	41.19 b	1.66 cde	13.43 a	30.97 a
C3HFP	171.5 bcde	232.1 bc	38.55 b	2.01 cde	12.15 a	32.44 a
CHP	176.2 bcde	449.2 a	38.17 b	1.23 de	13.74 a	29.29 ab
AHP	181.3 bcde	221.7 bc	43.32 b	1.35 cde	12.62 a	29.41 ab
CHFP	218.9 abcd	231.1 bc	39.62 b	1.90 cde	12.36 a	28.43 ab
CH3P	305.4 ab	476.7 a	39.73 b	1.43 cde	12.28 a	25.43 bc
AH3P	120.0 cde	179.3 cde	36.22 b	1.16 e	11.29 a	23.65 bc
CH3FP	117.6 cde	214.5 bcd	39.38 b	2.88 b	11.48 a	29.60 ab
CP	70.3 de	86.3 de	45.18 b	5.10 a	13.10 a	11.75 c
FP	53.6 e	53.0 e	60.79 a	5.42 a	11.29 a	12.77 c
SNM	59.2 e	61.3 e	47.45 b	2.05 cd	12.33 a	10.79 c

[1] See Appendix A for definition of medium codes.
[2] Means in columns followed by the same letter are not significantly different at the 5% level according to Duncan's New Multiple Range Test.

(95). Plants grown in media containing hardwood bark had above normal (42 to 135 PPM) Mn levels, while plants grown in CP, FP, and SNM had normal levels (95).

As previously noted, plants growing in media containing at least 75% composted hardwood bark and 50:50 blended media containing CP exhibited severe chlorosis that matched the description for Mn toxicity (112). Plants that exhibited chlorosis tended to have higher tissue Mn levels than non-chlorotic plants (Table 40).

Excess Mn causes an uneven distribution of chlorophyll (112), which explains the mottled chlorosis in the leaves (Figure 7). Movement of Ca to growing points is inhibited when Mn levels are high (inhibiting cell expansion), which explains the shorter internodes and cupped leaf margins on chlorotic plants. Brown spots on leaf margins were probably caused by deposited Mn oxides (112).

Many factors could have caused the incidence of manganese toxicity to decline as the plants grew. Toxic levels of Mn in the media could have been leached from the medium by November 16. Also, increased pH levels at this same time may have reduced the availability of Mn (Table 41). Finally, other cations such as Fe, Cu, and Zn could have gradually replaced the available Mn on the binding sites in the media.

Table 41. Monthly leachate pH of hardwood and pine bark media in which 'Aurora' geraniums were grown.

Media Code[1]	pH by date			
	10-14-85	11-14-85	12-14-85	1-14-86
CH	5.95	6.25	6.40	6.50
C3HP	5.95	6.10	6.25	6.35
A3HP	5.95	6.05	6.20	6.35
C3HFP	5.95	6.05	6.20	6.35
CHP	5.80	5.80	5.85	5.85
AHP	5.85	5.85	5.85	5.85
CHFP	5.85	5.85	5.85	5.85
CH3P	5.60	5.60	5.60	5.60
AH3P	5.60	5.60	5.60	5.60
CH3FP	5.60	5.60	5.60	5.60
CP	5.20	5.25	5.25	5.30
FP	5.00	5.10	5.15	5.30
SNM	4.80	4.85	4.90	4.95
water	6.15	6.20	6.15	6.15

[1] See Appendix A for definition of media codes.

Fe, Zn, and Cu are known to influence uptake and movement of Mn in plants, and Mn availability decreases as the pH of the media increases (112). Media in this experiment that had higher Zn and Cu (Table 31) levels with lower pH (Table 41) produced less Mn toxicity than media that had lower Zn and Cu levels with higher pH. Toxic levels of available manganese may best be countered by the addition of competitive divalent cations rather than by increasing the pH with lime, especially when high levels of available Ca are already present. A thorough leaching of media containing at least 50% composted hardwood bark before potting could help reduce the chances of Mn toxicity problems. It may also be beneficial to add available Fe to reduce the Mn:Fe ratio, reducing the chance of Mn toxicity (112).

Tissue Zn levels did not differ among the media treatments except for a higher level in FP (Table 40). Plants grown in all media had above normal (8 to 25 PPM) Zn levels for geranium (95).

Plants grown in CP and FP contained more Cu than all other media, but there was no difference between CP and FP. Plants grown in blended media mixed after composting with non-composted pine bark tended to have more Cu than plants grown in other blended media, probably due to the slightly higher Cu levels in FP.

Kofranek and Lunt (95) found severe Cu deficiency when geranium tissue Cu levels were at 4 PPM. Only CP and FP grown plants had Cu levels above 4 PPM in this experiment. Cu deficiency may have been responsible for the reddish tones observed on younger leaves in November. Cu levels are known to be deficient in highly organic soils, and above normal Zn levels may have complicated the Cu deficiency problem (112). Trace amounts of Cu supplied in the liquid fertilizer (Appendix C) may have eventually overcome the deficiency.

Media did not influence tissue Al levels (Table 40). Extractable Al was higher in CP and FP (Table 32), but this was not reflected in the tissue analysis.

Tissue B of plants grown in media containing at least 75% composted hardwood bark were higher than media containing less than 50% composted hardwood bark, with the exception of CH3FP (Table 40). Plants grown in CH contained more B than those grown in CP, FP, or SNM, while there was no difference among CP, FP, or SNM. There was no difference between blended media mixed before or after composting, except for CH3FP. Tissue B levels were normal (30 to 280 PPM) for plants grown in media containing hardwood bark. Plants grown in CP, FP, and SNM had deficient levels of B (95), but no symptoms

of B deficiency were observed. Low levels of B and Fe may have inhibited growth of plants in CP, FP, and SNM.

Tissue analysis revealed some discrepancies in the extractable element analysis of the media. For example, extractable element analysis showed the highest Mn levels in the 50:50 blend, but tissue analysis showed that Mn was more available in media containing more hardwood bark. Warnke (170) stated that the saturated medium extraction method used to determine extractable element concentration is influenced by the judgement of the point of saturation, with higher soluble salt concentrations occurring when less water is used. The point of saturation may have been misjudged in some of the media in this test, yielding inaccurate concentrations of Mn.

Leachate pH values were stable in blended media containing 25% and 50% composted hardwood bark (Table 41). In all other media, pH tended to increase with time. Greater pH increases were recorded as the percentage of hardwood bark in the medium increased. Levels of pH were higher in media containing more hardwood bark, even though media containing more hardwood bark received more sulfur amendment (Table 13).

For all parameters except tissue copper levels, there is no difference in geranium growth or elemental

levels in tissue between CP and FP; therefore, there appears to be no need to compost pine bark before using it as a growing medium. This agrees with other reports (2, 127, 172), and was expected.

Growth of geraniums in composted hardwood bark is comparable to growth in composted or noncomposted pine bark.

Plants grown in a blends of hardwood and pine bark were larger and heavier than plants grown in other media. Increased growth in blends of hardwood and pine bark has been previously reported on several woody ornamental species (18, 19). This increased growth can not be explained by the physical properties (Table 26) of the blended media since %TPS, %WHC, and %AC in all media were within acceptable ranges for container production (42), except for low %AC of SNM. The configuration (topography) of the pores in blended media may have been more conducive to root respiration and growth than other media. While CP, FP, and SNM may have been deficient in B and Fe, CH probably contained deficient Cu and excessive Mn. Plants grown in 50:50 blended hardwood and pine bark may have benefitted from this medium having neither extremely deficient or toxic levels of any element.

CHAPTER VI

TREEBARK AS A GROWING MEDIUM FOR CHRYSANTHEMUM

Introduction

'Bright Golden Anne' (96, 104) 'White Horim' (136), and other cultivars (54, 163, 164) of Chrysanthemum X morifolium Ramat. have been successfully grown in hardwood and softwood bark container media. To obtain information about the use of blended hardwood and pine bark as a growing medium, an experiment was designed using 'May Shoesmith' chrysanthemums grown in media containing varying ratios of composted or noncomposted pine bark, and composted hardwood bark.

Main objectives were: 1) to determine if chrysanthemum growth was better in composted pine bark compared to noncomposted pine bark; 2) to determine if chrysanthemum growth was better in composted hardwood bark than in composted or noncomposted pine bark; 3) to determine which ratio of blended pine and hardwood bark supported the best growth of chrysanthemum; 4) to determine if chrysanthemum growth differed in blended pine and hardwood bark media when the media were mixed before or after composting; 5) to compare chrysanthemum growth in all treebark media with growth in in an accepted industry standard medium; 6) to observe root growth in the different ratios of blended pine and

hardwood bark media; 7) to record changes in pH of leachates from the media over time.

Materials and Methods

Thirteen media were tested in this experiment. Media codes and descriptions are listed in Appendix A.

Rooted cuttings of 'May Shoesmith' chrysanthemum were obtained from Yoder Brothers, Inc. (Barberton, OH). On November 14, 1985, 130 uniform rooted cuttings were sorted into ten blocks of thirteen plants as a part of a randomized complete block experimental design, and one rooted cutting per pot was planted in 2.5 l nursery containers filled with 2.25 l of media. Potted plants were placed in a glass greenhouse where day-length was artificially extended with incandescent lamps to facilitate vegetative growth and prevent flowering. Temperatures were maintained at 65°F nights and 75°F days. Each pot was top-dressed with 9 grams of Osmocote 14-14-14 (Sierra Chemical Company, Milpitas, CA) on November 15, and plants were fertilized during each watering with Peter's General Purpose Fertilizer 20-20-20 (W.R. Grace & Company, Fogelsville, PA) at 200 ppm nitrogen. This fertilizer is described in Appendix C. Plants received only water on weekends.

Extended day-length was discontinued November 23 when plants were 10 cm tall, and plants were moved to a double-poly greenhouse, where they were grown under

cultural conditions described in Appendix B. Fertilization was changed to Peter's Dark Weather Feed 15-0-15 (W.R. Grace company, Fogelsville, PA) at 200 ppm nitrogen on January 15, 1986. Complete fertilizer descriptions are in Appendix B.

On December 28, plants were disbudded, and all side shoots removed to force a single stem and flower. This procedure was repeated weekly for a month.

Several parameters were measured to evaluate influence of media on chrysanthemum growth. Numbers of days from potting to the presence of floret color in the flower bud was recorded for each plant. On February 11, stem height from soil line to base of the receptacle was recorded. On February 13, cm flower diameter and cm flower height were recorded and flower volume estimated with the following formula:

$$\text{Flower Volume} = (1/2 \text{ diameter})^2 \text{ X height X pi}$$

On February 14, plants were cut off at the soil line, and plant shoots dried in a forced air drying oven at 180^{o}F for 48 hours. Dried plant shoots were weighed using a Terralion Monostat Gram Balance.

Leachate pH from the containers of one block were recorded initially on November 24, and terminally on

February 15. Visual subjective root growth observations were made on February 16.

Data were analyzed by analysis of variance (ANOVA) using Statistical Analysis System software (SAS Institute, Inc., Cary, NC) on IBM 4381 computer facilities through the University of Tennessee Computing Center. The 5% significance level was selected as an acceptable error for this experiment. Mean separations were performed using Duncan's New Multiple Range Test.

Results and Discussion

ANOVA showed media treatments influenced stem height, flower volume, and shoot dry weight of 'May Shoesmith' chrysanthemum, but not number of days to floret color in the flower buds. Floret color was present in all plants within 65 days after potting. Precision was gained for all parameters except dry weight by blocking plants according to greenhouse bench location.

On Jaouary 28, an automatic vent on the greenhouse failed to close at night, and an entire block of plants was severely damaged by frost. Plants from the damaged block were not included in the analysis.

Stem heights of plants grown in CP were equivalent to those in FP, while plants grown in CH were taller than plants grown in FP, but not CP (Table 42). Stem heights of plants grown in blended media mixed before

Table 42. Mean cm stem height in of 'May Shoesmith' chrysanthemums grown in hardwood and pine bark media.

%HB:%PB[1]	blended before composting[3] code[2]/cm height	blended after composting[3] code/cm height	blended after composting with aged pine bark[3] code/cm height
100:0	CH/66.6 abc		
75:25	C3HP/66.4 abc	A3HP/65.1 bcd	C3HFP/67.0 ab
50:50	CHP/67.3 ab	AHP/68.4 a	CHFP/67.4 ab
25:75	CH3P/66.4 abc	AH3P/68.1 ab	CH3FP/66.9 ab
0:100	CP/63.6 cd		FP/63.2 d
Control			SNM/63.2 d

[1] Ratio of hardwood bark to pine bark by volume.
[2] See Appendix A for media code definitions.
[3] Means followed by the same letter are not significantly different at the 5% level according to Duncan's New Multiple Range Test.

composting did not differ from plants grown in blended media mixed after composting. With the exception of A3HP, plants grown in all media containing hardwood bark were taller than plants grown in the SNM (Figure 8), while plants grown in pine bark did not differ from the control medium.

Flower volume did not differ between plants grown in CP or FP, but plants grown in CH had more flower volume than either CP or FP (Table 43). Plants grown in the three media containing at least 75% hardwood bark had more flower volume than CP, FP, and SNM. Whether blended media were mixed before or after composting did not influence flower volume.

Shoot dry weight of plants grown in CP did not differ from plants grown in FP, and plants grown in CH were heavier than plants grown in CP or FP (Table 44). Shoot dry weight was equivalent among plants grown before or after composting and among plants grown in blends of differing ratios of pine and hardwood bark. All plants grown in media containing hardwood bark were heavier than those grown in SNM, while plants grown in pine bark did not differ from those in the control.

More root growth was observed in 1:1 blends of pine and hardwood bark than in CH or CP (Figure 9). Plants grown in CP appeared to have fewer roots than those grown in 50:50 blends, and CP grown plants had a coarser



Figure 8. Photograph of 'May Shoesmith' chrysanthemums grown in treebark. Non-composted pine bark, composted pine bark, composted hardwood bark, and standard nursery media (left to right).

Table 43. Mean cm^3 flower volume of 'May Shoesmith' chrysanthemums grown in hardwood and pine bark media.

%HB:%PB[1]	blended before[3] composting code[2]/volume	blended after[3] composting code/volume	blended after[3] composting with aged pine bark code/volume
100:0	CH/714.1 ab		
75:25	C3HP/725.5 a	A3HP/698.7 ab	C3HFP/724.9 a
50:50	CHP/682.3 abcd	AHP/728.5 a	CHFP/660.0 cde
25:75	CH3P/666.3 bcde	AH3P/667.8 bcde	CH3FP/643.1 de
0:100	CP/646.7 cde		FP/622.9 e
Control			SNM/630.0 de

[1] Ratio of pine bark to hardwood bark by volume.
[2] See Appendix A for media code definitions.
[3] Means followed by the same letter are not significantly different at the 5% level according to Duncan's New Multiple Range Test.

Table 44. Mean gram shoot dry weight of 'May Shoesmith' chrysanthemums grown in hardwood and pine bark media.

%HB:%PB[1]	blended before[3] composting code[2]/grams	blended after[3] composting code/grams	blended after[3] composting with aged pine bark code/grams
100:0	CH/27.61 ab		
75:25	C3HP/28.47 ab	A3HP/28.31 ab	C3HFP/28.92 ab
50:50	CHP/29.26 ab	AHP/29.19 ab	CHFP/30.51 a
25:75	CH3P/27.72 ab	AH3P/27.59 ab	CH3FP/28.30 ab
0:100	CP/25.40 bc		FP/25.30 bc
Control			SNM/22.84 c

[1] Ratio of hardwood bark to pine bark by volume.
[2] See Appendix A for media code definitions.
[3] Means followed by the same letter are not significantly different at the 5% level according to Duncan's New Multiple Range Test.

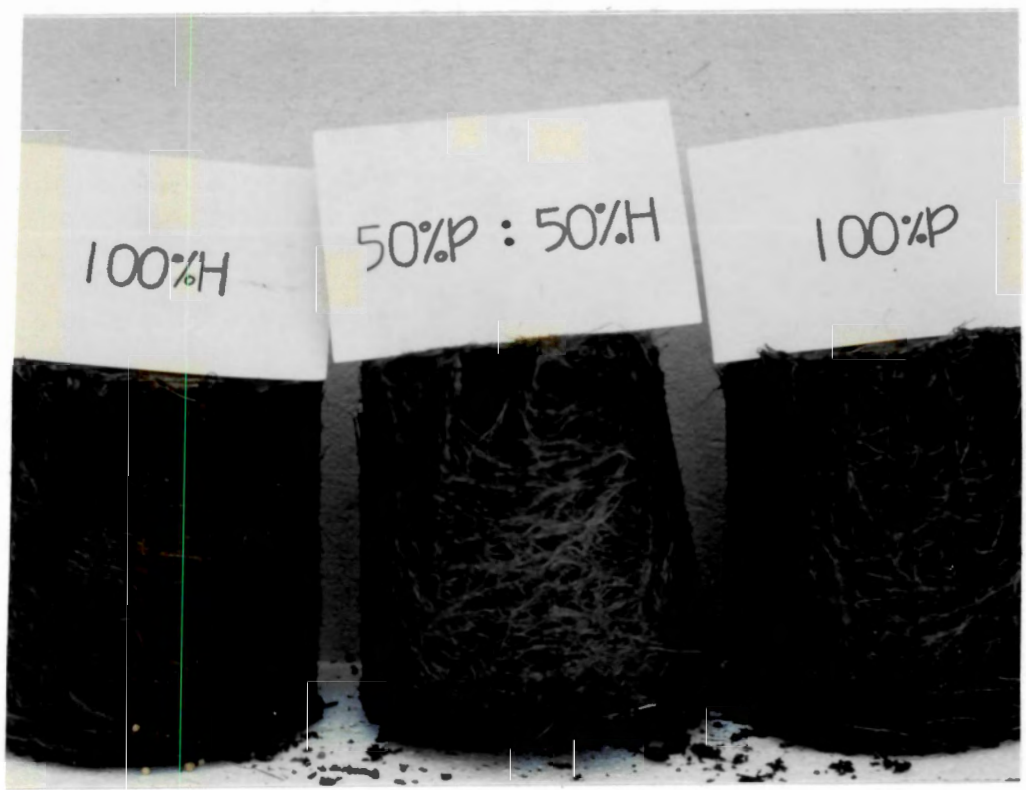


Figure 9. Photograph of root growth of 'May Shoesmith' chrysanthemums grown in treebark media. Plants were grown in composted pine bark (left), composted 50:50 hardwood:pine bark (center), and composted hardwood bark (right) media.

root system than those grown in CH. Roots of plants grown in CH were confined to the upper two-thirds of the medium. Root growth of plants grown in SNM was similar to growth in CP, and root growth in 25:75 or 75:25 blends of hardwood and pine bark were intermediate between 50:50 blends and CP or CH respectively.

Leachate pH did not change over 92 days in 50:50 and 25:75 blends of hardwood and pine bark (Table 45), while pH of all other media increased. Change in pH did not differ between blended media mixed before or after composting, and FP had a larger increase in pH than CP. SNM pH increased more than any other media, though initially it had the lowest pH.

For all parameters measured, there was no difference in chrysanthemum growth in CP and FP; therefore, there appears to be no need to compost pine bark before using it as a growing medium. This agrees with other reports (2, 127, 171), and was expected.

Shoot dry weight and flower volume was larger when plants were grown in CH, than in either CP or FP, and plants grown in CH were taller than those grown in FP. Thus, CH appears to be a better growing medium for chrysanthemums than CP or FP. Chrysanthemums have been shown to root better in hardwood bark media than in standard propagation media (104).

Table 45. Change in leachate pH of hardwood and pine bark media in which 'May Shoesmith' chrysanthemum were grown.

%HB:%PB[1]	blended before composting			blended after composting			blended after composting with aged pine bark		
	media[2]	start[3] pH	stop[4] pH	media	start pH	stop pH	media	start pH	stop pH
100:0	CH	6.25	6.45						
75:25	C3HP	6.05	6.20	A3HP	6.05	6.20	C3HFP	6.05	6.20
50:50	CHP	5.95	5.95	AHP	5.95	5.95	CHFP	5.95	5.95
25:75	CH3P	5.60	5.60	AH3P	5.60	5.60	CH3FP	5.60	5.60
0:100	CP	5.35	5.40				FP	5.00	5.35
Control							SNM	4.80	5.25

[1] Ratio of hardwood bark to pine bark by volume.
[2] See Appendix A for media code definitions.
[3] Medium leachate pH at potting.
[4] Medium leachate pH at harvest.

For all parameters measured, plants grown in blended hardwood and pine bark media tended to be better than those grown in hardwood or pine bark alone. Better stem growth of plants in blends was accompanied by better root growth in blends (Figure 9). Better root growth can be explained in part by the better physical properties of the blended media (Table 26), but the physical properties of all the media were within acceptable ranges (42) for container production, except for the low %AC for SNM. There appears to be no difference in the growth of plants in blended media mixed before or after composting. Configuration (topography) of the pores in blends probably were more conducive to root respiration and growth than were other media.

Media containing hardwood bark tended to support better plant growth than the control medium. This can be explained in part by the physical properties of the media (Table 26), because of the low %AC of SNM. Pine bark alone was not consistently better than the control medium, although parameter values tended to be higher than the control medium.

Increasing pH values over time in media containing at least 75% hardwood bark could be a result of the high calcium content (Table 31) in the hardwood bark, as has been previously reported (18, 19). Increasing pH values

in CP, FP, and SNM are the result of the dolomitic lime added to these media. The pH change was less in CP than in FP or SNM because the lime had been present in the CP medium for a longer period of time, allowing the pH to stablize. The acidic tendencies of pine bark, and alkaline tendency of hardwood bark appear to off-set each other in the 50:50 and 25:75 blends of hardwood and pine bark. These two media appear resistant to changes in pH.

Other reports on woody ornamental plants have shown that 50:50 blends of hardwood and pine bark support better plant growth than either component used alone (18, 19). This experiment has shown that blends of hardwood and pine bark are better media than an accepted standard medium (SNM), and that the two bark types can be mixed before or after composting with equal plant growth quality. Of all the media tested in this experiment, a 50:50 blend of hardwood and pine bark appears to be the best medium for chrysanthemum growth.

CHAPTER VII

TREEBARK AS A GROWING MEDIUM FOR HOLLY

Introduction

'Rotundifolia' (127), 'Burford' (104), and 'Nellie R. Stevens' (19) holly have been successfully grown in treebark growing media. Pokorny (127) studied growth of 'Rotundifolia' holly in aged and fresh pine bark media. Malieke et al. (104) studied growth of 'Burford' holly in composted hardwood bark media. Bilderback (19) studied growth of 'Nellie R. Stevens' holly in blended hardwood and pine bark media. To obtain information about the use of blended hardwood and pine bark as a container growing medium, an experiment was designed using Ilex crenata Thunb. 'Hetzii' grown in media containing varying ratios of composted or noncomposted pine bark, and composted hardwood bark.

Main objectives of the experiment were: 1) to determine if holly growth was better in composted pine bark compared to noncomposted pine bark; 2) to determine if holly growth was better in composted hardwood bark than in composted or noncomposted pine bark; 3) to determine which ratio of blended hardwood and pine bark supported the best growth of holly; 4) to determine if holly growth differed in blended hardwood and pine bark media when the media were mixed before or after

composting; 5) to compare holly growth in all treebark media with growth in an accepted industry standard medium.

Materials and Methods

Thirteen media were tested in this experiment. Media codes and descriptions are listed in Appendix A.

On October 10, 1985, 'Hetzii' hollies grown in 10 cm pots were planted in 2.5 l plastic nursery containers filled with 2.25 l of the thirteen media treatments. Plants were arranged by size in a randomized complete block experimental design. Plants were grown in a greenhouse under cultural conditions described in Appendix B.

Because plants within blocks lacked uniformity, a plant size index (PSI) was calculated for each plant on October 20. Plant height in cm from the medium level to the tip of the tallest stem, cm plant width at the plant's widest dimension (width A), and cm plant width perpendicular to that dimension (width B) was recorded. PSI was then calculated using the following formula:

$$PSI = \frac{\text{cm height} + \frac{\text{cm width A} + \text{cm width B}}{2}}{2}$$

On October 22, several plants were identified that were not 'Hetzii' hollies. These plants of an unknown

cultivar were not included in the analysis of data, but were left in place to maintain the integrity of the experimental blocks.

Plants were moved to an outdoor shade house (30% light exclusion) on May 1, 1986. Liquid fertilization was discontinued on this date, and plants were hand watered as needed. Plants were arranged in rows by block, with treatments randomized within each row.

On June 12, 1986, 245 days after the plants were potted, PSI was again determined. The difference between terminal and initial PSI was used as a plant growth index (PGI), indicating how much plants had grown.

Data were analyzed by analysis of varience (ANOVA) using Statistical Analysis System software (SAS Institute, Inc., Cary, NC) on IBM 4381 computer facilities through the University of Tennessee Computing Center. The 5% significance level was chosen as an acceptable error for this experiment. Mean separations were performed using Duncan's New Multiple Range Test.

Results and Discussion

ANOVA showed significant influence of media treatments on the growth of 'Hetzii' holly. No precision was gained in blocking plants by greenhouse bench location.

There was no difference in holly growth among CP, FP, and CH (Table 46). Plants grown in 50:50 and 25:75

Table 46. Mean plant growth index (PGI) of 'Hetzii' holly grown in hardwood and pine bark media.

%HB:%PB[1]	blended before composting code[2]/PGI	blended after composting code/PGI	blended after composting with aged pine bark code/PGI
100:0	CH/16.37 cd		
75:25	C3HP/16.02 d	A3HP/16.16 cd	C3HFP/17.20 bcd
50:50	CHP/23.22 a	AHP/22.43 a	CHFP/22.26 a
25:75	CH3P/20.26 ab	AH3P/20.24 ab	CH3FP/19.68 abc
0:100	CP/16.67 cd		FP/15.84 d
Control			SNM/17.99 bcd

[1] Ratio of hardwood bark to pine bark by volume.
[2] See Appendix A for media code definitions.
[3] Means followed by the same letter are not significantly different at the 5% level according to Duncan's New Multiple Range Test.

blends produced the most growth. There was no difference between blended media mixed before or after composting. Only plants grown in 50:50 blended media produced more growth than the control (SNM) medium.

Since hollies grew as well in CP as in FP, there appears to be no need to compost pine bark before using it as a growing medium for holly. This agrees with earlier reports (2, 127, 171), and was expected.

The physical properties of the 50:50 blend are not sufficiently better than the physical properties of other media (Table 26) to explain the better growth. The structure (topography) of the pore space in the 50:50 blend probably supports more efficient root respiration and growth than other media.

Bilderback (19) reported better growth of 'Nellie R. Stevens' holly in 50:50 blended hardwood:pine bark media. This experiment showed that a 50:50 blend of hardwood:pine bark media supported better growth of 'Hetzii' holly than composted hardwood bark, or composted or noncomposted pine bark used alone. A 50:50 blend of hardwood:pine bark media supported better growth of 'Hetzii' holly than an accepted standard nursery medium (SNM), and any medium tested in this experiment would be an adequate substitute for SNM.

CHAPTER VIII

TREEBARK AS A GROWING MEDIUM FOR AZALEA

Introduction

'Red Ruffles' azalea has been successfully grown in composted hardwood bark (44). To obtain information about the use of blended hardwood and pine bark as a container growing medium, an experiment was designed using Rhododendron hybrid 'Red Ruffles' grown in media containing varying ratios of composted or noncomposted pine bark, and composted or noncomposted hardwood bark.

Main objectives were: 1) to determine if azalea growth was better in composted pine bark than in noncomposted pine bark; 2) to determine if azalea growth was better in composted hardwood bark than in non-composted hardwood bark; 3) to determine if azalea growth was better in composted or non-composted pine bark than in composted or noncomposted hardwood bark; 4) to determine if there is a difference in azalea growth in blends of pine bark and hardwood bark that were mixed before or after composting; 5) to determine which ratio of blended pine and hardwood bark supported the best growth of azalea; 6) to determine if aged mushroom compost is a suitable amendment for azalea growing media; 7) to compare azalea growth in all the media tested with an accepted industry standard medium.

Materials and Methods

Eighteen media were tested in this experiment. Media codes and descriptions are listed in Appendix A.

Liners of 'Red Ruffles' azaleas in 2 1/2 in pots were obtained from Cottage Hill Nursery (Irvington, Alabama). Plants were graded by size into ten blocks of eighteen plants. Eighteen media treatments were randomly assigned within each block as part of a randomized complete block experimental design.

Plants were potted November 19, 1985 in 2.5 l plastic nursery containers filled with 2.25 l of the eighteen media treatments. After potting, all plant tops were sheared at a height of 10.1 cm. Plants were placed in greenhouse, and grown under cultural conditions outlined in Appendix B.

Plant growth was evaluated on May 1, 1986 using a plant size index (PSI). Plant height in cm from the medium level to the tip of the tallest stem, cm plant width at the plant's widest dimension (width A), and cm plant width perpendicular to that dimension (width B) was recorded. PSI was then calculated using the following formula:

$$PSI = \frac{\text{cm height} + \frac{\text{cm width A} + \text{cm width B}}{2}}{2}$$

Data were analyzed by analysis of variance (ANOVA) using Statistical Analysis System software (SAS Institute, Inc., Cary, NC) on IBM 4381 computer facilities through the University of Tennessee Computing Center. The 5% significance level was chosen as an acceptable error for this experiment. Mean separations were calculated using Duncan's New Multiple Range Test.

Results and Discussion

Minor chlorosis was observed on azaleas growing in FH on January 14, 1985 (Figure 10). Nitrogen deficiency caused by microbial tie-up of nitrogen in the medium was a likely cause of the chlorosis due to the general yellowing of the plants; however, deficient Fe or excessive Mn could have contributed to the chlorosis. Media containing at least 50% fresh hardwood bark produced abundant mushrooms from January through March.

One plant growing in CP was dead by December 15; so data were analyzed with a single missing experimental unit. Inspection of the dead plants root system indicated probable presense of root-rot pathogens.

Plants grown in CP were no larger than those grown in FP (Table 47). Similarly, plants grown in CH were no larger than those grown in FH. Plants grown in CH and FH did not differ from plants grown in CP and FP (Table 47).



Figure 10. Chlorosis symptom on 'Red Ruffles' azalea grown in fresh hardwood bark medium. Azaleas grown in fresh hardwood bark (left) have a light green foliage color compared to normal green of plant grown in composted 50:50 hardwood:pine bark medium (right).

Table 47. Mean plant size index (PSI) of 'Red Ruffles' azaleas grown in hardwood and pine bark media.

%HB:%PB[1]	blended before composting code[2]/PSI[3]	blended after composting code/PSI[3]	blended after composting with aged pine bark code/PSI[3]	not composted code/PSI[3]
100:0	CH/27.1 cdef			FH/25.5 f
75:25	C3HP/27.0 def	A3HP/28.9 abcd	C3HFP/28.2 bcde	F3HFP/26.2 ef
50:50	CHP/29.6 ab	AHP/30.3 ab	CHFP/29.5 abc	FHFP/28.1 bcde
25:75	CH3P/28.7 abcd	AH3P/28.9 abcd	CH3FP/28.7 abcd	FH3FP/30.8 a
100:0	CP/27.0 def		FP/27.9 cdef	
Control			SNM/26.6 def	
Control			MUSH/26.9 def	

[1] Ratio of hardwood bark to pine bark by volume.
[2] See Appendix A for media code definitions.
[3] Means followed by the same letter are not significantly different at the 5% level according to Duncan's New Multiple Range Test.

There was no difference between plants grown in blended hardwood and pine bark mixed before or after composting (Table 47).

Plants grew well in the medium containing 50% spent mushroom compost (SMC). Growth in this medium was comparable with all other media tested in this experiment except 50:50 blended media containing composted hardwood bark, or FH3FP.

The control medium (SNM) grew plants equally as large as all other media except, CHP, AHP, CHFP, and FH3FP. Plants grown in MUSH were almost identical to those grown in SNM.

Since there was no difference between growth in CP and FP, there appears to be no need to compost pine bark before using it as a media component. This conclusion has been previously reported (2, 127, 171), and was expected.

According to the mean separation used, there is no difference between growth in CH and FH, even though plants grown in FH exhibited chlorosis symptoms. These results indicate that there may not be a need to compost hardwood bark before using it as a media component, especially if an adequate fertilization program is used. Noncomposted hardwood bark would probably have a high N requirement.

Earlier research has indicated that hardwood bark must be composted before use as a media component (56, 99, 121, 140, 142, 148, 176), but recent reports have shown success with fresh hardwood bark (59, 60). Guthrie and Bearce (59, 60) reported 'Brilliant Diamond' poinsettias grew as well in noncomposted hardwood bark as in a Pro-Mix (Premier Brands, Inc., New Rochelle, NY) control. They had amended noncomposted hardwood bark with Osmocote 14-14-14 (Sierra Chemical Company, Milpitas, CA) and Magamp (W.R. Grace and Company, Fogelsville, PA), and liquid fed plants every fourth watering with a 20-20-20 liquid fertilizer. It may be that this experiment was discontinued before differences in growth between composted and noncomposted hardwood bark could be detected. Fresh hardwood bark may be a suitable medium for short-term crops.

Aged mushroom compost proved to be a satisfactory medium amendment for growing azaleas. Excellect growth in media containing mushroom compost has been previously reported (100), and a lower percentage of mushroom compost in the medium may have produced a better response by providing greater %AC.

Excellent growth in blends of hardwood and pine bark has been previously reported on other woody ornamental species (18, 19). In this study, growth in

50:50 blends containing composted hardwood bark was larger than in the control medium (SNM).

SNM and MUSH supported as much growth as all the tested media except for CHP, AHP, CHFP, and FH3FP. Azaleas grew best in FH3FP. Increased growth in FH3FP and in the 50:50 blends cannot be explained by the physical properties of the media (Table 26). While FH3FP provided better %AC than the 50:50 blends, it provided less %TPS and less %WHC. The configuration (topography) of the pores in the 50:50 blends and in FH3FP may have been more conducive to plant growth than other media. It may be that the experiment was terminated before more stable media could produce better growth. These results indicate that the addition of 25% fresh hardwood bark to pine bark could be beneficial to plant growth, while extending the more expensive pine bark supplies.

For the cultural regimen used in this experiment, all media appeared to be adequate substitutes for SNM as a growing medium for azalea, with the possible exception of FH which produced symptoms of chlorosis.

CHAPTER IX

SUMMARY AND CONCLUSION

The first purpose of this research was to determine the effect of amending hardwood bark with pine bark on the pace of decomposition during composting, and the effect of composting on the physical and chemical properties of hardwood bark and pine bark, when composted separately, or when blended together in varying ratios.

2.72 m^3 piles of hardwood bark, pine bark, and hardwood bark amended with 25%, 50%, or 75% pine bark (by volume) were composted using a partitioned windrow. Fertilizer amendments were added to each pile prorated on the amount of hardwood bark in each pile. Heat production was recorded to determine when decomposition in each pile stabilized.

Pine bark, and hardwood bark amended with 50% and 75% pine bark finished composting before 100% hardwood bark. Although Solbraa et al. (150) reported that hardwood bark finished composting faster when amended with 10% or 20% spruce bark (by volume), amending hardwood bark with 25% pine bark did not decrease the time required to finish composting in this experiment.

The time required to finish composting hardwood bark and pine bark was used to predict the time required to compost blends of hardwood bark and pine bark. Hard-

wood bark amended with 50% pine bark finished composting 10% sooner than expected, while hardwood bark amended with either 75% or 25% pine bark finished composting 8.2% and 10.2%, respectively, longer than expected. Conditions during composting may have been closer to optimal in the 50% amended piles than in other piles, but further study is required before this effect can be adequately understood.

Researchers (79) have recommended that no sulfur source be added to hardwood bark before composting, stating that faster decomposition takes place under the neutral to alkaline conditions that occur when no sulfur amendment is used. They noted that 16 to 24 weeks were required to complete the composting process. High pH risks the loss of nitrogen and the death of needed microorganisms through the generation of ammonia gas. In this study, hardwood bark that was amended with 0.67 Kg/m^3 of sulfur and iron sulfate finished composting in 17 weeks, showing that hardwood bark can be composted in windrows as quickily under slightly acid conditions as under slightly alkaline conditions. Composting under slightly acid conditions avoided the risk of nitrogen loss and microbial death associated with the formation of ammonia gas.

The terminal volume recorded for hardwood bark and pine bark composted separately was used to predict the

terminal volume in blended hardwood:pine bark media. All media amended with pine bark had more volume than expected after composting, with media amended with 50% pine bark having the least volume loss (11.4% above the projected volume). Early completion of the 50:50 blend might have left some bark undecomposed, increasing the volume; however, other piles amended with either more or less pine bark also finished with more volume than expected even though they took longer than expected to stabilize. Less volume loss in blended hardwood:pine bark media was probably caused by differences in microbial composition and differences in lignin content in the blended media. Further study is necessary before the excess volume can be adequately explained. Percent cellulose and percent carbon analysis both before and after composting may provide some explanation.

The greater volume obtained by blending hardwood and pine bark before composting indicated that hardwood bark should be amended with pine bark before composting if the blend is to be used as a growing medium. The greater volume leaves more medium available in which plants can be potted, probably reducing the unit cost of the medium.

Because of the levels of calcium in hardwood bark, pH was consistently higher in bark piles containing higher percentages of hardwood bark. The prorated

amounts of sulfur and iron sulfate incorporated into each media were sufficient to keep pH below 7.0, preventing the loss of nitrogen through the generation of ammonia gas. Io all media except 100% hardwood bark, the terminal pH was higher than the initial pH.

A concern of using composted hardwood bark as a container medium is the risk of injuring plant roots with excess soluble salts. Terminal soluble salt concentrations in composted hardwood bark were close to excessive, but no plants grown in this medium showed salt injury. Solable salt concentration declined as the composted hardwood bark in the media declined. Salt levels increased as the bark lost volume, but terminal levels were not high enough to account for all of the fertilizer amendments added before composting. Salt may have been lost by leaching, volatilization, or by conversion to insoluble forms by microorganisms. Some of the salts could be present in the cell mass of microbes. Further study is necessary before soluble salt transformations can be adequately explained. An ash analysis accompanying the extractable nutrient analysis both before and after composting may help explain some of the soluble salt transformations.

In all media, particle size tended to decrease in percentage of particles larger than 8.0 mm, and increase in percentage of particle smaller than 1.0 mm. Loss of

large particles and gain of small particles was greater as the amount of hardwood bark in the media increased.

%TPS did not change in hardwood bark and pine bark media, but media of blended hardwood:pine bark had more terminal %TPS than initial %TPS. Terminal %AC was lower than initial %AC in all media. 50:50 blends lost less %AC than all other media except 100% pine bark. Terminal %WHC was higher than initial %WHC in all media. Terminal %WHC increased as the percentage of hardwood bark in the media increased. BD was initially higher in media that contained pine bark, but terminal BD increased as the percentage of hardwood bark in the media increased. None of the changes of physical properties lessened the quality of the bark as media; in fact, increases in %WHC and %TPS were beneficial.

With few exceptions, terminal extractable element levels were higher than initial levels in all media except pine bark. In hardwood bark, only levels of iron and zinc declined. In blended media, iron, aluminum, and zinc declined. In pine bark, only extractable ammonium nitrogen, nitrate nitrogen, phosphorus, and calcium increased, while levels of all other elements declined. Some oddities were observed with the results of the extractable element analysis of media. For example, composted hardwood bark had a manganese concentration of 2.8 PPM while pine bark had 1.3 PPM.

The addition of pine bark to hardwood bark should have diluted the manganese concentration in media containing both hardwood and pine bark; however, extractable analysis showed that manganese levels were higher in blended media than in either hardwood or pine bark. Tissue analysis of geraniums indicated that manganese availability did, in fact, increase as the percentage of hardwood bark in the media increased. This showed that what the extractable element analysis of the media indicated was available to the plant was not really available, demonstrating the need for further research on element extraction methods in organic media, specifically with the saturated medium extraction method.

When composted hardwood bark was amended with composted pine bark (after both were composted separately) or with noncomposted pine bark, the physical and chemical properties were very similar to hardwood: pine bark blends mixed before composting; therefore, there appeared to be no difference among blended hardwood:pine bark media mixed before or after composting. Since less composting time was required, and more bark volume was obtained, it would be more economical to blend hardwood and pine bark before composting; however, if composted hardwood bark were purchased, a medium of equal quality can be obtained by mixing after composting.

The second maio objective of this research was to determine if Tennessee hardwood bark can be successfully used as a container growing medium amendment. This research evaluated the growth of poinsettias, geraniums, chrysanthemums, hollies, and azaleas in blended hardwood:pine bark media, in hardwood bark or pine bark used separately, in pine bark amended with spent mushroom compost, and in a standard nursery medium.

The poinsettia experiment was highly influenced by the incidence of root rot. Plants grown in composted hardwood bark had no disease, demonstrating the pathogen suppressive characteristics of this medium. Bilderback (15) suggested that mixing hardwood bark with pine bark might impart the pathogen suppressive capacity of the composted hardwood bark to the blended medium. In this experiment, poinsettias grown in media containing 75% or more composted hardwood bark had no disease symptoms, while plants grown in media containing 25% or less composted hardwood bark were frequently diseased. Two plants of thirty grown in a 50:50 blend were diseased. Further research is required to determine how much pine bark can be mixed with hardwood bark before the pathogen suppressive characteristics contributed the hardwood bark are lost.

High levels of extractable manganese in composted hardwood bark caused manganese toxicity symptoms to

appear on geraniums grown in media containing composted hardwood bark, as has been previously reported on another crop (115). Considering the concentration of manganese found in the tissue, toxicity symptoms could have been more severe, and more persistent; however, the balancing effect of competitive cations, specifically iron, may have reduced toxicity. Further research is needed to determine whether adjusting pH or adjusting levels of competitive cations will help control toxicity problems, or if simple leaching is all that is required. Analysis of cation exchange capacity may provide helpful information.

Copper deficiency symptoms may have been observed on geraniums grown in media containing composted hardwood bark; however, plants grown in composted or noncomposted pine bark, or in standard nursery medium showed no deficiency of copper, even though extractable copper levels were very similar in all media. Values obtained for extractable copper may have been erroneous due to the inadequacies of the extraction method. Lower pH in the pine bark and nursery medium may have increased the availability of copper, and copper deficiency in composted hardwood bark might be overcome by lowering the pH of the medium. Copper deficiencies in media containing hardwood bark may also be overcome by incorporating copper into the media before composting

or potting, or by using a liquid fertilizer that contains sufficient amounts of copper.

Boron and iron levels may have inhibited growth in the pine bark and the standard nursery medium, although no obvious deficiency symptoms were observed. According to tissue boron and iron levels for boron and iron deficient 'Irene' geranium reported by Kofranek and Lunt (95), deficiencies should have existed. However, their study used a different cultivar, and plants may have responded differently to the balance of elements in nutrient solution culture compared to the balance of elements in the bark media with its high cation exchange capacity. The role of boron and iron in pine bark media needs further study, and further research needs to be done on comparing boron and iron nutrition in nutrient culture with proper boron and iron nutrition in organic media.

Geraniums, chrysanthemums, hollies, and azaleas tended to grow better in blends of composted hardwood: pine bark rather than in hardwood bark or pine bark alone, or in the standard nusery medium. Since the physical properties of all media were within acceptable ranges (42), except for the low %AC of the standard nursery medium, the enhanced growth in the 50:50 blends cannot be explained by physical properties. Chrysanthemums showed better root growth in the 50:50

blend compared to composted hardwood or pine bark, indicating that the higher %TPS in the 50:50 blend may be more conducive to good root growth. Enhanced growth may also have been the result of chemical properties.

Composted hardwood bark had very high to toxic levels of manganese, and very low to deficient levels of copper. Pine bark and the standard nursery medium may have had deficient levels of boron and iron. Plants grown in 50:50 blends of hardwood:pine bark may have benefitted from being neither deficient in boron, nor deficient in copper. The 50:50 blends may have had higher cation exchange capacity, an aspect of this medium that needs further study.

Azaleas grew best in noncomposted hardwood bark amended with 75% (by volume) noncomposted pine bark. Niether the physical not the chemical properties of this medium can adequately explain the increased growth. Solbraa (148) found that toxic phenolic compounds that inhibit plant growth in noncomposted hardwood bark will promote growth when diluted to small concentrations. It may be that toxic phenolics in the noncomposted hardwood bark were diluted enough by the presence of 75% noncomposted pine bark to promote azalea growth. This aspect of noncomposted hardwood bark needs further study.

There was no significant difference between the physical and chemical properties of composted and non-composted pine bark; thus, there appeared to be no gain in media quality from composting pine bark. Plants consistently grew the same in composted and noncomposted pine bark. This agreed with other reports (1, 39, 127, 139, 140, 171), and clearly confirmed there is no need to compost pine bark before using it as a growing medium.

Except for the poinsettia experiment, all plants grown in composted hardwood bark were similar to plants grown in composted or noncomposted pine bark; thus, composted hardwood bark from Tennessee appeared to be an adequate substitute for pine bark as a growing medium. If the pathogen suppressive capacity of the composted hardwood bark is considered, hardwood bark might be considered a better medium than pine bark.

Azaleas grown in noncomposted hardwood bark were slightly smaller, and of poorer quality than plants grown in composted hardwood bark, but overall growth was similar. Other plants have been successfully grown in noncomposted hardwood bark (65, 66), and further research is needed to determine proper fertilization practices for short-term crops grown in noncomposted hardwood bark. The permanent disadvantage of using noncomposted hardwood bark for long-term crops is that

the medium will eventually shrink due to microbial decomposition of the bark, reducing the volume of medium in which the plant can grow. Chemical treatments could be used to stop microbial decomposition, but such treatments would probably be overly expensive, and they would probably ruin the pathogen suppressive characteristics of the medium.

For all species tested, there was no difference between plants grown in blended hardwood:pine bark mixed before or after composting. Clearly, a medium of equal quality can be obtained by blending composted hardwood bark with composted or noncomposted pine bark, or by blending hardwood bark with pine bark before composting.

Blends containing noncomposted hardwood bark produced similar growth to blends containing composted hardwood bark, indicating that noncomposted hardwood bark may be a suitable medium amendment; however, further research is needed to determine optimal fertilization techniques. Problems with microbial tie-up of nutrients, and with excessive soluble salts should be studied.

Azaleas grew as well in pine bark amended with 50% spent mushroom compost (SMC) as in the standard nursery medium. Good plant growth has been reported in SMC (100). Therefore, SMC amended pine bark would be an

adequate substitute for the standard nursery medium; however, research should be done to determine if a different amount of SMC should be used, and to determine optimal fertilization practices in this medium.

In conclusion, 50:50 blends of hardwood bark and pine bark completed composting before expected, with less shrinkage than expected. This same medium produced better growth than the standard nursery medium in a variety of crops. Increased growth in 50:50 blends of hardwood and pine bark have been previously reported (18, 19, 167). Since the standard nursery medium contains expensive, imported peat moss, the 50:50 blend can produce better quality plants at less cost. With these advantages, a 50:50 blend of composted hardwood bark and composted or noncomposted pine bark appears to be an excellent growing medium for use in a container nursery production system.

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APPENDIXES

APPENDIX A

IDENTIFICATION OF MEDIA CODES AND DESCRIPTION OF MEDIA

Media Code	Description
CH	Composted hardwood bark. Amended and composted as described in Chapter 3.
C3HP	Blend of 75% hardwood bark:25% pine bark (by volume) mixed before composting. Amended and composted as described in Chapter 3.
CHP	Blend of 50% hardwood bark:50% pine bark (by volume) mixed before composting. Amended and composted as described in Chapter 3.
CH3P	Blend of 25% hardwood bark:75% pine bark (by volume) mixed before composting. Amended and composted as described in Chapter 3.
CP	Composted Pine Bark. Amended and composted as described in Chapter 3. Before potting, amended with 6 Kg dolomitic limestone, 1.2 Kg potassium nitrate, and 0.6 Kg micromax (Sierra Chemical Company, Milpitas, CA) per cubic meter.
A3HP	Blend of 75% CH:25% CP (by volume) mixed after composting. The hardwood bark and pine bark used to mixed the medium had been amended and composted as described in Chapter 3.
AHP	Blend of 50% CH:50% CP (by volume) mixed after composting. The hardwood bark and pine bark used to mixed the medium had been amended and composted as described in Chapter 3.
A3HP	Blend of 25% CH:75% CP (by volume) mixed after composting. The hardwood bark and pine bark used to mixed the medium had been amended and composted as described in Chapter 3.
FP	Noncomposted Pine Bark. Bark was obtained fresh (Joe K. Smith Trucking, Cummings, GA) and stockpiled uncovered for 5 months. The medium was then amended before potting with 6 Kg dolomitic limestone, 1.2 Kg potassium nitrate, and 0.6 Kg micromax (Sierra Chemcial Company, Milpitas, CA), and 0.6 Kg superphosphate 0-20-0 per cubic meter.

C3HFP — Blend of 75% CH:25% FP (by volume). Hardwood bark had been amended and composted as described in Chapter 3. Pine bark had been stored for 5 months as described for FP, but the pine bark was not amended before mixing this medium.

CHFP — Blend of 50% CH:50% FP (by volume). Hardwood bark had been amended and composted as described in Chapter 3. Pine bark had been stored for 5 months as described for FP, but the pine bark was not amended before mixing this medium.

CH3FP — Blend of 25% CH:75% FP (by volume). Hardwood bark had been amended and composted as described in Chapter 3. Pine bark had been stored for 5 months as described for FP, but the pine bark was not amended before mixing this medium.

FH — Fresh hardwood bark. Obtained fresh from a local hammermill (Posey Lawn and Garden Center, Knoxville, TN), and stockpiled for 2 weeks. Before potting, medium was amended with 1.33 Kg potassium nitrate, 3.33 Kg superphosphate (0-20-0), and 0.67 Kg sulfur per cubic meter.

F3HFP — Blend of 75% FH:25% FP (by volume). Hardwood bark was obtained and stored as described for FH, and pine bark was obtained and stored as described for FP. Before potting, medium was amended with 1.00 Kg potassium nitrate, 2.67 Kg superphosphate (0-20-0), and 0.50 Kg sulfur per cubic meter.

FHFP — Blend of 50% FH:50% FP (by volume). Hardwood bark was obtained and stored as described for FH, and pine bark was obtained and stored as described for FP. Before potting, medium was amended with 0.67 Kg potassium nitrate, 2.00 Kg superphosphate (0-20-0), and 0.33 Kg sulfur per cubic meter.

FH3FP — Blend of 25% FH:75% FP (by volume). Hardwood bark was obtained and stored as described for FH, and pine bark was obtained and stored as described for FP. Before potting, medium was amended with 0.33 Kg potassium nitrate, 1.33 Kg superphosphate (0-20-0), and 0.17 Kg sulfur per cubic meter.

MUSH — Blend of 50% FP:50% spent mushroom compost (SMC) by volume. Pine bark had been obtained and stockpiled as described for FP. SMC was obtained (source unknown) and stored uncovered for 11 months. No amendments were added before composting.

SNM — Blend of FP:sphagnum peat moss:river sand (3:1:1 by volume). Pine bark had been obtained and stored as described for FP. Before potting, medium was amended with 6 Kg dolomitic limestone, 1.2 Kg potassium nitrate, 0.6 Kg superphosphate (0-20-0) and 0.6 Kg micromax (Sierra Chemical Company, Milpitas, CA) per cubic meter.

APPENDIX B

CULTURAL CONDITIONS FOR CROPS GROWN IN GREENHOUSE 16 ON THE UNIVERSITY OF TENNESSEE AGRICULTURE CAMPUS FROM FALL 1985 TO SPRING 1986

General Description

Greenhouse 16 is a double-poly quonset greenhouse. The greenhouse contains snowfence benching, and is climate controlled by a Wadsworth Step Control System (Wadsworth Control Systems, Inc., Colorado).

Temperature

Heating and cooling controls were set to maintain 24°C days, and 17°C nights. 20 to 25 nights in October, and 5 to 8 nights in November remained above 24°C, which is typical for Fall months in East Tennessee. 5 to 6 nights in January, and 4 to 5 nights in February were below 13°C, including 2 or 3 nights lower than 5°C caused by faulty operation of an automatic vent.

Irrigation and Fertilization

Plants were watered daily using controlled irrigation dribble rings installed in each pot.

Plants were fertilized every fourth watering with Peter's General Purpose Fertilizer 20-20-20 (W.R. Grace and Company, Fogelsville, PA) at 300 PPM nitrogen. Occasionally, 5 or 6 waterings passed without fertilization when timing of fertilization fell on weekend dates. Plants growing in 2.5 l nursery containers were top-dressed with Osmocote 14-14-14 (Sierra Chemical Company, Milpitas, CA) at 12 g per pot. Descriptions of fertilizers are available in Appendix C.

Pest Control

On November 16, 1985, a smoke-bomb treatment of Fulex (Fuller Systems, Inc., Woburn, MA) was applied to control a population of greenhouse white fly (Trialeuroides vaporariorium Westwood).

On January 22, 1986, plants were sprayed with dicofel (Rohm and Haas, Philadelphia, PA) to control an infestation of two-spotted spider mite (Tetranychus urtical Koch).

On March 3, 1986, plants were sprayed with oxymeton-methyl (Mobay Chemical Corporation, Kansas City, MO) to combat a population of greenhouse white fly and greenhouse leaftier (Udea rubigalis Guenee). This treatment provided unsatisfactory control; so, on March 7, 1986, aldicarb (Union Carbide, Research Triangle Park, NC) was applied in each pot.

APPENDIX C

DESCRIPTION OF FERTILIZERS

Peter's General Purpose Fertilizer 20-20-20

A product of W.R. Grace and Company, Fogelsville, PA.

Primary nutrient sources in this fertilizer are urea, ammonium phosphate, and potassium nitrate, with nitrogen supplied as 5.61% nitrate nitrogen, 3.96% ammoniacal nitrogen, and 10.43% urea. At 300 PPM nitrogen, this fertilizer contains the following concentrations of micronutrients: 0.75 PPM magnesium, 0.75 PPM iron, 0.05 PPM manganese, 0.1 PPM boron, 0.04 PPM zinc, 0.05 PPM copper, and 0.01 PPM molybdenum. This fertilizer has an electrical conductivity of 1.20 mmhos/cm at 300 PPM nitrogen. Potential acidity is 597 lbs. of calcium carbonate equivalent per ton.

Peter's Dark Weather Feed 15-0-15

A product of W.R. Grace and Company, Fogelsville, PA.

Primary nutrient sources in this fertilizer are calcium nitrate, urea, and potassium nitrate, with nitrogen supplied as 13% nitrate nitrogen, and 2% as urea. At 200 PPM nitrogen, this fertilizer supplies the following concentrations of micronutrients: 0.67 PPM iron, 0.04 PPM manganese, 0.09 PPM boron, 0.03 PPM zinc, 0.05 PPM copper, and 0.01 PPM molybdenum. The electrical conductivity at 200 PPM nitrogen is 1.50 mmhos/cm. Potential acidity is 420 lbs. calcium carbonate equivalent per ton.

Osmocote 14-14-14

A product of Sierra Chemical Company, Milpitas, CA. The primary nutrient sources in this fertilizer are ammonium nitrate, ammonium phosphates, calcium phosphates, and potassium nitrate, with nitrogen supplied as 6.6% ammoniacal nitrogen, and 7.4% nitrate nitrogen. Fertilizer pellets are resin coated with a release rate of 3 to 4 months.

VITA

The author, Sven Eric-Dale Svenson, was born in Grass Valley, California on September 23, 1961. He graduated from Nevada Union High School in 1979. In 1982, he received his Associate of Arts Degree from Yuba College, with a major in English. In 1984, he received his Bachelor of Science Degree from California State University, Chico with a major in Plant and Soil Science. He was a member and president of the C.S.U., Chico Ornamental Horticulture Club. Upon graduation, he was honored as the Outstanding Student in the School of Plant and Soil Science.

In August 1986, he was granted the Master of Science Degree from the University of Tennessee, Knoxville with a major in Ornamental Horticulture and Landscape Design. While working toward this degree, he was employed by the University of Tennessee Agricultural Experiment Station as a Graduate Research Assistant in the Department of Ornamental Horticulture and Landscape Design.

The author is a member of Gamma Sigma Delta, the Agriculture Honor Society. He is a member and past vice-president of Pi Alpha Xi, the Floriculture and Ornamental Horticulture Honor Society.