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The effects of composting period and mineral amendments on a 50:50 blend of pine and hardwood bark

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THE EFFECTS OF COMPOSTING PERIOD AND MINERAL AMENDMENTS ON A 50:50 BLEND OF PINE AND HARDWOOD BARK

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

John Andrew Watkins
December 1990

To Leigh,

for her love, patience, and encouragement through all the rough times.

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ABSTRACT

This research was designed to refine a composting process for a 50:50 blend of pine and hardwood bark to be used as a container growing medium. The first experiment studied the effects of composting period and mineral amendments on the preparation of blended pine and hardwood bark media, and the succeeding experiments studied plant growth in the media prepared in the first experiment.

Equal volumes of pine bark and hardwood bark were composted in partitioned windrows. Daily heat production during composting was monitored and used to determine targeted endpoint temperatures. Targeted endpoint temperatures were 50^{o} C and 40^{o}C. Mineral amendments tested were S, KNO_3, and $MgSO_4$. For comparison with composted media, four media currently being used in the nursery industry were also tested. Physical and chemical properties of all media were examined.

Composting to 50^{o} C took only six weeks while nine weeks were required to reach 40^{o} C. Shorter composting to 50^{o} C resulted in 7% less shrinkage and a greater percent air capacity. Composting to 40^{o} C resulted in a greater amount of small particles, percent total pore space, and percent water holding capacity. Mineral amendments had little or no effect on physical properties of composted media. The pH and electrical conductivity of composted media were not influenced by endpoint temperature or mineral amendments. Physical and chemical properties of composted media were intermediate of comparison media.

Rhododendron cv. 'Red Ruffles', Photinia x fraseri, and Juniperus conferta cv. 'Blue Pacific' were grown in the previously described media. Photinia and juniper grew equally well in media composted to 50^{o} C and 40^{o} C. Azaleas grew best in media composted to 40^{o} C. Mineral amendments had little or no effect on plant growth. Plants grew as well or better in composted media than in comparison media. Since six weeks of composting to a 50^{o} C endpoint and elimination of S, KNO_3, and $MgSO_4$ frequently produced better growth than other media tested, it appeared to be an excellent medium for container nursery production.

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CHAPTER I

INTRODUCTION

Container production of ornamental plants utilizes large quantities of organic matter as the principal ingredient of the growing medium. In order for an organic material to be useful for container plant culture, there are certain physical and chemical characteristics it must possess. Physical properties should include a particle size distribution with enough coarse and fine particles to maintain adequate air and water supply, sufficient bulk density to anchor the plant yet light enough to facilitate ease of movement and transport, and stable structure to prevent excessive shrinking and swelling. Chemical properties should include high cation exchange capacity, adequate available nutrient levels, low salinity, and freedom from toxic elements. Other properties to be considered are reproducibility and availability of material, low cost, ease of handling, and freedom from weeds, insects, and pathogens.

The use of soilless plant growing media has increased markedly in recent decades (90). Imported peat moss used to be important in container production of ornamental plants (65), and still is for greenhouse pot plants. However, with continuing increases in cost, the need for less expensive media components for nursery production has become increasingly important.

Growers of ornamental crops in the Southeast and the West Coast of the United States have shifted to ground bark as a container growing medium (34). Growers have found processed redwood, pine and fir bark an excellent container growing medium for production of ornamental plants (33) with pine bark being favored in the southeast (65).

As a result of increased use of pine bark in the nursery industry, demand has sometimes surpassed the supply. During the last economic recession in the timber industry in the late 1970's and early 1980's, spot shortages occurred. The availability of bark is also influenced by the petroleum industry. As the costs of natural gas and fuel oil rise, many lumber mills turn to bark as a fuel source for electricity and/or steam generation (84). Another end use of bark that competes economically with its use as a container growing medium is as a landscape mulch (80). Production of bark mulch is attractive to lumber mills since it is cheaper to produce and can command a higher price.

Hardwood barks from various species have been used successfully as a container growing media component, despite some problems (26,29,32,52,56,61,66). As research on the use of hardwood bark continues, it is gaining more popularity as a container growing medium (56). With more stringent antipollution laws, pulp and sawmill industries are no longer allowed to incinerate bark waste as a means of disposal and they are, therefore, looking for other means of utilizing the bark as a byproduct (33). Hardwood bark is generally plentiful in supply throughout the midwest and southeast regions of the United States and can be obtained at a lower cost than pine bark. An attractive property of hardwood bark is its pathogen suppression capabilities. Studies have confirmed that a wide variety of soil-borne plant pathogens, including Rhizoctonia, Pythium, and Phytophthora, can be suppressed by growing plants in hardwood bark media (26,41,42). Problems with high pH, manganese toxicity, and allelopathy can be overcome by composting hardwood bark before use (21). Depending on how it is done, this composting process can take thirteen weeks (77) to a full year (41) before the compost stabilizes sufficiently for adequate plant growth.

Work at the University of Tennessee and North Carolina State has shown the use of a blended medium consisting of both pine and hardwood barks has consistently produced plants comparable or better than those grown in either component used alone (14,77). This blending process allows the grower to conserve on the quantities of more expensive pine bark and save money by using the less expensive hardwood bark.

This research project was designed to refine the process of composting blended hardwood bark and pine bark for use as a container growing medium. The first objective was to determine the effects of a shorter composting period and varying mineral amendments on the physical and chemical properties of a 50:50 blend of hardwood:pine bark medium. The second objective was to assess the growth of several plants in the various media produced in part one.

CHAPTER II

LITERATURE REVIEW

Bark as a Growing Media

As production of container grown nursery crops has increased, the search for more economical media has become more important. Traditional nursery container and pot plant growing media have been composed of mixtures of sphagnum peat, perlite, vermiculite, or sand (41,43). Growers of container nursery crops welcomed cheaper substitutes (33). Pine and hardwood barks are now the predominant components of nursery container growing media in many areas of the United States (3,25,33,34,75). Both barks are available in much of the southeastern United States. Large quantities of pine bark are shipped to the northeastern and midwestern parts of the United States where hardwood bark is available locally (14).

The advantages of using pine and other barks are : 1) they are a renewable resource; 2) they are currently available at lower cost to the grower than imported peat moss; and 3) bark can be processed by hammermill and screening to provide a material that is reproducible, thus providing a standardized product (65).

There are a number of different media containing bark and other components that are being used in the container growing industry. A common growing medium in Tennessee is 3 pine : 1 peat : 1 sand by volume (77). 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) (77). Reports have shown that 100% pine bark is a good growing medium when a complete fertilization program is applied (69).

During the past two decades, composted hardwood bark has been utilized as a replacement for more expensive sphagnum peat in container media. Success using bark from hardwood species mixed with sand has been noted (17). Excellent results using 4:1 hardwood bark : sand mixtures have been obtained (31). The use of fresh hardwood bark as a growing medium has been only partially successful (36,70). The use of composted hardwood bark is more favorable for plant growth (20,31,32,34,69).

Physical Properties of Bark

Grades of treebark used for container media can depend on which process is used to remove bark from the log. Many types of debarkers are in use by the lumber industry. Ring and drum debarkers remove bark by a tumbling action and generally produce a bark product with less than 10% wood (45). Cambio debarkers consist of a revolving head with several projections, which are spring-loaded so as to exert only enough pressure to remove the bark and cambium but not the wood (70). Because these two types remove less wood from the tree than other debarkers they are more suitable for harvesting bark for use in container growing media (45,64).

Bark for container media is generally hammermilled and screened to ensure suitable particle size distribution. There are several recommendations for correct particle size distribution of bark container growing media. Pokorny (65) suggested that milled pine bark with 70 to 80% of the particles in the range of 0.64 to 9.53 millimeters in diameter and 20 to 30% of the particles smaller than 0.64 millimeters will yield a very satisfactory potting medium and/or potting medium amendment. Gartner et al. (32) found that hardwood bark particle sizes should have approximately 35% of the particles smaller than 0.8 millimeters, and approximately 10% should be larger than 3.2 millimeters to insure good aeration and drainage. The rest should be between 0.8 and 3.2 millimeters. Witte and Svenson (86) found excellent growth occurred in a 50:50 blend of composted pine and hardwood bark which had approximately 38% of its particles smaller than 1 mm and 60.5% of particles between 1 mm and 8 mm.

Shrinkage of container growing media can have several different meanings. Shrinkage of media due to microbial breakdown of organic components can lead to losses of up to half of the total volume (12). Most pine barks contain less than 5% readily degradable material (cellulose) while most hardwood barks contain up to 40% degradable cellulose (41). Because pine bark contains so little cellulose, very little shrinkage takes place. Hardwood bark on the other hand, may have a great deal of shrinkage due to microbial breakdown of the large amounts of cellulose. Another type of shrinkage that occurs is related to the space-volume of the medium. This type of shrinkage occurs when small particles occupy large pore space created by larger particle sizes (77). Finally, moisture related shrinkage can occur in media components such as peat moss which expand when wet, and shrink as they dry out.

The water-holding capacity of a medium refers to the total amount of water that is held against the tension of gravity. Peat moss has been added to container growing media to increase the water-holding capacity. Like peat moss, pine bark possesses inner surfaces that increases its ability to hold water (3). Pine bark has been shown to have a saturated moisture content of 460% of its dry weight (2) while hardwood bark has a saturated moisture content of 239% of its dry weight (61). Water holding capacity of blended pine bark and hardwood bark is high enough to provide sufficient water to plants under normal and perhaps even extreme cultural conditions (88).

The air capacity of container media can often be improved by using either hardwood bark or pine bark as a media amendment (68,74,79). The ideal air capacity for container growing media is considered to be between 20 and 30% (27). The air capacity of composted hardwood barks may be limited since larger particles are broken down during the composting process (20). Because pine bark has a more stable structure, larger particles are not broken down during the composting process and therefore are able to retain a higher air capacity than composted hardwood bark (3). Composted blends of pine bark and hardwood bark generally have an air capacity intermediate of either component composted separately (88).

Chemical Properties of Bark

An organic material, to be useful for container plant culture, should possess certain chemical characteristics. These chemical properties include : 1) a high cation exchange capacity; 2) an adequate available nutrient level; 3) low salinity; 4) ability to maintain constant pH levels; and 5) freedom from toxic elements.

Cation exchange capacity (CEC) refers to the ability of a medium to exchange one cation for another in a solution phase (83). CEC is generally determined on a weight basis in milliequivalents per 100 grams of medium (meq/100g). Determining CEC on a weight basis often overestimates the CEC of a bark medium. To avoid such overestimates, it has been suggested that CEC should be reported on a volume basis (meq/100cc) for media used in container plant production

(50). Treebark has been shown to have a high cation exchange capacity (18). Pine bark has a CEC of 30 meq/100g (1) while the CEC of composted hardwood bark is generally around 43 meq/100g (28). Fresh hardwood bark can have a CEC as low as 8 meq/100g but this figure rises rapidly with aging or composting (19).

The pH of a growing media does not directly influence plant growth but rather is considered important only as it influences the availability of plant nutrients (40). The pH of treebark can vary drastically with tree species and age of the bark. Pine bark is typically acidic, ranging in pH from 3.9 to 5.4 (12). Several other studies have reported initial pH readings of 4.1, 4.2, and 5.5 which increase slightly with composting (1,65,70). The pH levels of a media can directly affect the amount of nutrients available for the plant. Pine bark pH can alter the adsorbed amounts of NH_4^+, K^+ , Ca^{++} , and Mg^{++} which may directly affect plant growth (30). Hardwood bark pH values are generally higher than that of pine bark because of a high calcium content of 3.5 to 4% of its dry weight (34). Hardwood bark has an initial pH of 5.2 to 5.5 but can rise dramatically with aging or composting (41). The pH of hardwood bark has been shown to rise from 5.2 to 7.0 or greater in one growing season (31). For this reason, the addition of calcium could lead to dangerously high pH levels that would be unfavorable for plant growth. Blends of pine and hardwood barks have a low initial pH which generally rises to suitable levels for container plant production after composting (87).

Treebark mineral composition varies due to species and age of bark. The carbon/nitrogen (C:N) ratio can be a limiting factor for plant growth in a treebark container medium (45,67,73,74). With hardwood bark the C/N ratio starts out at 150/1, where pine bark starts out at 300/1. After composting, the hardwood barks have a C/N ratio of 40/1, where pine was only reduced to 150/1 (31). Adequate N must be applied during the composting process to ensure good plant growth. Nitrogen source is an important factor and researchers agree that ammonium nitrate is best (32,30,34). Poor growth resulted when utilizing urea, straight ammonium sources, and sodium nitrate as the N source (32).

Phosphorus (P) amendments to treebark are added primarily to facilitate microorganisms during composting. Some researchers claim that treebark contains sufficient P (6,22) while others claim an increase in decomposition rates by P additions. Regardless of these results, a N:P ratio of 5:1 has been suggested as the optimum level (49). Calcium levels in hardwood bark may run as high as 4% of dry weight (20) while that of pine bark is much lower. Hardwood bark has a plentiful supply of micronutrients compared to pine bark (34,65). Additions of small amounts of micronutrients such as copper, boron, and molybdenum have, however, been made to secure good plant growth (73).

Results of several studies indicate that bark should be composted before use as a growing medium to remove certain inhibitory or allelopathic elements (19,34). Fresh pine bark contains some compounds harmful to some seedlings and young rooted cuttings (70), however, fresh bark can be used successfully. Composting may destroy the pathogen suppression compounds in pine bark (44). It has been generally accepted that hardwood bark, unlike pine bark, must be composted before use as a container growing medium (69). Solbraa et al. (73) found that hardwood bark contains phenolic compounds which are dominated by tannins. These phenolic compounds had an inhibitory effect on plant growth. Removal of these tannins through composting completely eliminated inhibitory effects. Bark harvested in the winter was more inhibitory to growth than bark harvested in other seasons (34).

Pathogen Suppression Characteristics of Bark

Bark used as a container growing medium has been shown to have pathogen suppression capabilities (12,16,32,34,41, 43,47,57,62). The use of pine bark for a growing medium effectively suppresses a wide range of pathogens but is not able to suppress *Rhizoctonia solani* (45). Gugino et al. (38) found that pine bark suppressed *Pythium irregulare* Buis. They noted increased root fresh weights of *Ilex crenata* 'Helleri' with increasing bark content. The mode of suppression could be due to the physical properties of pine bark. Occasionally, Phytophthora cinnamomi has been identified in mixes containing pine bark, presumably removed from infected trees (70). However, composted pine bark has been shown to suppress Phytophthora and Pythium root rots (41).

As a result of the increased use of hardwood bark in container media, a noticeable decrease in soil-borne diseases has occurred (26). Hardwood bark has some fungicidal properties and has been shown to suppress all soil-borne pathogens examined (41,42,43), including nematodes (46,57). Daft et al. (26) found the suppressive effects of composted hardwood bark on several Pythium spp. were equal to that of a sterilized peat medium drenched twice with fungicides. They stated that use of composted hardwood bark amended media by commercial growers might eventually eliminate steam pasteurization and soil fungicide treatments. The mechanism of suppression of plant pathogens by hardwood bark has yet to be clearly defined. Some studies link the suppression effects to the presence of chemical inhibitors of plant pathogens in soil moisture (47) and the activity of microbial antagonists (60). Nelson et al. (63) stated that disease suppression is dependent not only on the presence of antagonistic microorganisms, but also on undefined factors associated with compost age. Media amended with hardwood barks that are not fully composted have significantly less disease suppression than media containing mature composts (53).

Blended Pine and Hardwood Bark Media

While many studies have been conducted using either pine or hardwood bark alone, relatively little work has been conducted on blending the two to produce a container growing medium. The composition of pine bark and hardwood bark are considerably different and this results in large differences in their physical and chemical characteristics (3,18,29,47).

Bilderback (11) listed several possible advantages of using a combined blend of pine bark and 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 the overall cost of the medium.
3. If the two components were mixed before composting, the medium would be pasteurized by the heat of the composting process and the wood content of both the pine and hardwood bark would be removed, reducing the possibility of shrinkage after potting.
4. The increased airspace provided by the pine bark may allow the mix to compost more quickly.
5. 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.

6. The blend might possess increased water holding capacity from hardwood bark, and increased air capacity form pine bark, producing a medium with better physical properties than either component used separately.
7. 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.

Excellent growth of a wide variety of ornamental crops has been obtained in a 50:50 (v:v) blend of hardwood bark and pine bark (14,78). The composting period of a 50:50 blend of hardwood and pine bark (88 days) has been shown to be intermediate between that of pine bark (59 days) and hardwood bark (137 days) (77). Water holding capacity and air space of the blended media were found to be intermediate between pine bark and hardwood bark (14). Blends of hardwood bark and pine bark have pH values ranging from 4.4 to 6.2 (14,77). Blending the two barks may create a buffered environment that resists dramatic changes in pH.

Careful attention must be made regarding the minerals added to start the composting process of a blended media. Problems associated with extreme pH conditions or mineral deficiencies can be overcome by the proper application of mineral nutrients prior to composting. Svenson (77) noted that extractable nutrient levels were much higher in a blended media composed of composted bark than in media composed of noncomposted bark. Calcium levels in a 50:50 blend of pine and hardwood bark may increase dramatically after composting (77) and therefore lime should not be added prior to composting.

High levels of Mn in hardwood barks have been observed (15,28,60). High Mn levels may cause problems such as induced Fe deficiency in a number of plants (28,60,77). Svenson (77) suggested that a thorough leaching of media containing at least 50% composted hardwood bark and the addition of Fe to reduce the Mn:Fe ratio may reduce the chance of Mn toxicity. Copper levels are known to be deficient in highly organic soils (83). It has been proposed that Cu deficiencies in a blended media may be overcome by lowering the pH to increase its availability or by incorporating additional Cu into the media before composting (77).

Bilderback (11) recommended the addition of Mg (epsom salts) and micronutrients, along with a complete NPK fertilizer, to the pine:hardwood bark medium. The growth of X <u>Cupressocyparis</u> <u>leylandii</u> 'Haggerston Grey' increased with increases in N in the $NH_4 NO_3$ form (13). Tilt et al. (81,82) have shown success using 1 Kg Micromax (Sierra Chemical Company, Milpitas, CA), and 0.3 Kg triple superphosphate (0-46-0) per cubic meter of medium. Svenson (77) showed excellent results by adding 1.67 Kg urea, 0.67 Kg potassium nitrate, 2.0 Kg superphosphate, 0.33 Kg iron sulfate, and 0.33 Kg sulfur per cubic meter.

Review of Composting

Composting is said to be the oldest form of solid waste disposal known to man. The first modern composting method was developed in the 1930's by Albert Howard. This three month process is now commonly referred to as the Indore Method and is the basis of contemporary windrow composting (64).

Composting is an aerobic biological decomposition process which converts biodegradable solid organic matter into a stable humus material (10). Composting is further described as the result of the actions of a microbial community which converts easily degradable 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 (59).

Composting plays an important role in the preparation of organic matter for use as a container growing medium. In the case of bark preparation, the most important factor of composting is to reduce the carbon to nitrogen (C:N) ratio. As stated earlier, bark contains from 100 to 300 parts of carbon for each part N (7,10). Since microbes are more efficient scavengers of N than plant roots, microbes may 'tie-up' most available N in fresh bark media, leaving little N available for plant use (9,73). Composting bark allows rapid release of excess carbon as CO_2 through decomposition of cellulose, narrowing the C:N ratio to levels where N becomes available for plant use (77).

Many researchers recommend composting bark to remove compounds that may inhibit plant growth (19,34,54,73,89, 90). Composting hardwood bark for as little as two weeks has reduced amounts of inhibitory organic compounds to non-toxic levels (72). Unlike hardwood bark, pine bark does not have to be composted before use as a container growing media. While composting pine bark does remove potentially toxic substances (69), plants grow equally well in fresh or composted pine bark (25,65,70,89).

The Composting Process

In order for composted bark media to be useful in container nursery production, there are three phases through which it must proceed to ensure the completion of the composting process. These phases include the mesophilic phase, the thermophilic phase, and a stabilization period (43,45,64).

In the mesophilic phase, bark hosts an assortment of fungi and bacteria that live when temperatures remain below 40^{o} C (77). Some of these microorganisms feed on sugars and starches (9,64), while others feed on cellulose and hemicellulose producing carbon dioxide and sugar as by-products (6). After a "lag period" of one or two days (41,45), this feeding activity generates enough heat to raise the bark pile's temperature above 40° C (9,64). Mesophilic microbes cannot survive above 40° C (41), and when temperature reaches this point, the thermophilic phase begins.

During the thermophilic phase, fungi, bacteria, and actinomycetes that survive from 40° C to 60° - 65° C colonize the bark pile (51). Thermophilic microorganisms perform the most rapid degradation of organic materials in the bark pile (59). Because of their high respiratory activity, bark pile temperatures often rise well above 60° C, thus killing the thermophilic microbes and causing the composting process to stop. To avoid high temperature buildups, the pile should be turned as soon as temperatures reach 60° C. Svenson (77) noted that this microorganism-heat combination results in the following conditions: 1) stabilization of 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 ratios, 5) creates a substrate less likely to shrink, 6) increases bulk density, 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 (41). As thermophilic microbes deplete food reserves, temperatures decrease, marking the beginning of the stabilization period.

During the stabilization period, maximum temperatures fall below 40° and mesophilic microbes begin recolonizing the pile. The recolonization microorganisms can be antagonistic to soil-borne plant pathogens (41,45).

Factors Affecting Composting Rates

Physical, biological, and chemical factors affect the composting rate of a bark pile. Physical properties include moisture content, pore space, aeration, and temperature. Biological factors include microorganism concentration and type. Chemical factors include mineral content, pH, and soluble salt levels.

Pore space, moisture content and aeration of the media are interrelated during the composting process. The decomposer microorganisms require moisture and oxygen. Pore space influences the amount of moisture held by the media, thus directly affects the rate of composting. High moisture levels can lead to the accumulation of free water at the bottom of the composting pile resulting in an anaerobic environment. 'Sour' compost produced by anaerobic decomposition can accumulate toxic compounds and have pH levels well below 4.0 which are not suitable for a growing medium (45). There are many reports discussing the optimal moisture levels for composting. Moisture levels below 40% of dry weight significantly reduce the rate of decomposition (37). Bell et al. (10) stated that for rapid stabilization by composting, the material undergoing decomposition should have a moisture content near 50%. Other reports claim that the moisture content should be 50 to 70% on a wet weight basis (22,49,59). Svenson (77) reported success by maintaining moisture levels of 70% of dry weight throughout the composting process.

Temperature is a dominant physical parameter controlling microbial activity and biomass during the composting process (59). Heat produced in a composting bark pile is the direct result of microbial metabolism of organic matter (64). Optimum temperatures reported for composting pine and hardwood barks are between 40 and 50^{o} C (22,41,73). These temperatures allow rapid degradation of organic matter while destroying several pathogenic organisms. Temperatures during composting can increase from 15^{o} C to 70^{o} C in as little as nine days (48). Since thermophilic microbes cannot survive temperatures above 60 to 65^{o} C, careful attention must be paid to the regulation of temperature throughout the composting process. Svenson (77) found that turning the piles on approximately a weekly basis successfully maintained temperatures near optimum levels for rapid decomposition.

The mineral composition of the material being composted affects the rate at which microorganisms are able to break down that material. With the exceptions of N, P, and K, most substrates contain amounts of minerals in excess of microbial need (77).

Most researchers agree that N is the most important mineral addition for bark composts (21,25,34,52,89). The N source also has an effect on decomposition rate. Addition of N in the form of ammonium nitrate has consistently produced faster decomposition rates than other sources of N such as urea, ammonium sulfate, calcium nitrate, and sodium nitrate (32).

The need for additional P prior to composting is a debatable issue. Svenson (77) noted that levels of extractable P were relatively similar in hardwood and pine bark before composting. Cappaert et al. (22) claim that adding P before composting is unnecessary because tree bark contains sufficient P to meet the needs of the composting microorganisms. Other researchers claim the addition of P leads to increased decomposition rates (10,49).

Other mineral amendments affecting composting rates include S, Mg, and Ca. Sulfur is generally added as either iron sulfate or as elemental sulfur to maintain pH levels below 7.0, thus controlling the unwanted formation of ammonia gas (77). The addition of magnesium sulfate to composted hardwood bark has improved the growth of a variety of crops (45). Both Mg and Ca have an alkaline reaction which increase the pH of the medium. While Ca is often added to pine bark to raise pH levels, addition of Ca to hardwood bark leads to high pH levels that risk the formation of ammonia gas and toxic nitrites (19).

The pH levels of a composting bark pile influence the composition and activity of the microorganisms responsible for decomposition processes. The mixed composition of microorganisms present at pH values near neutral perform the most rapid decomposition (6). A slightly alkaline condition at the start of composting accelerates decomposition, but care must be taken to control high pH levels to avoid the generation of ammonia gas (64).

Composting Pine Bark

Many growers use aged or composted bark because poor initial plant growth has been observed in fresh softwood bark (76). The advantages of composting pine bark lie in the reduction of the C:N ratio, which minimizes competition between plant and microorganisms for N, and in the destruction of pathogenic organisms due to the heat buildup with the compost pile (65). This biological thermogenesis can raise the temperature of the composting pile to 65 to 75^{o} C, which effectively destroys weed seeds and most pathogenic microorganisms (10). Fresh pine bark and milled pine bark, which is sometimes hot-air dried to facilitate processing and storage, are very hard to wet initially (4).

Fungal penetration and microbial breakdown during composting may create openings that allow water to enter or move into the particle (3).

Composting of pine bark increases the amount of extractable or plant available nutrients (77). As stated earlier, N must be added prior to composting to lower the C:N ratio. Cappaert et al. (23) suggest that the optimum amount of N added to the compost would be 0.75% of the dry weight. Other reports have shown good success by using 7 Kg/m^3 of NH_4NO_3 (54). Svenson (77) showed excellent results by adding 2.67 Kg urea, 1.33 Kg potassium nitrate, 3.33 Kg superphosphate, 0.67 Kg iron sulfate, and 0.67 Kg of elemental sulfur to each cubic meter of pine bark.

One of the outstanding characteristics of pine bark is its resistance to decay. Svenson (77) noted that composting pine bark resulted in only a 1% increase in its bulk density and water holding capacity. It was also found that the air capacity and total pore space were virtually unchanged after composting. The time required to produce a stabilized pine bark compost is considerably less than for either hardwood bark or blends of hardwood bark and pine bark. Sufficient stability has been reached in as little as one month of composting (73). Svenson (77) recorded a time period of 8.5 weeks of composting to reach a stabilization point of 40° C.

Composting Hardwood Bark

Most researchers agree that hardwood bark must be composted before it can be used as a container growing medium. They list a number of reasons why composted hardwood bark is more favorable for plant growth than fresh hardwood bark.

Lumbermills and papermills often process a mixture of hardwood tree species from different locations at the same time (32). Barks obtained from these mills may contain up to 60% wood content. Failure to compost hardwood bark before using it as a container growing medium can lead to shrinkage of up to 50% of the volume of the medium in one growing season (11).

There have been many studies concerning phytotoxicity of hardwood bark (19,34,73,90). Composting for as little as two weeks can reduce these inhibitory organic compounds to non-toxic levels (73). Gartner et al. (32) stated that phytotoxic effects of hardwood bark can be overcome by 'stockpiling' the bark for 30 days.

Growth suppression of plants in hardwood bark is often due to lack of N, instead of the presence of toxic materials (52,55). Composting bark allows rapid release of excess carbon as CO_2 through decomposition of cellulose, narrowing the C:N ratio to levels where N becomes available for plant use (77).

Research conducted using different N sources showed that NH_4NO_3 consistently produced the fastest decomposition (32). Several researchers advise against using only urea or NH_4-N sources when composting hardwood bark because ammonia gas can be released when the pH is above 7.0 (19,22,64). Addition of S in the form of iron sulfate or elemental S can help keep pH levels below this level. Svenson (77) reported excellent results with composted hardwood bark by incorporating the following mineral amendments to each cubic meter of media prior to composting: 2.67 Kg urea, 1.33 Kg potassium nitrate, 3.33 Kg superphosphate, 0.67 Kg iron sulfate, and 0.67 Kg elemental sulfur.

The time required to compost hardwood bark can range from 6 to 48 weeks (8,9,52,71,73). This factor alone may limit the use of hardwood bark as a growing medium for many nurserymen. Partially favorable results have been obtained using fresh hardwood bark (36,39,58). Svenson (77) found partially favorable results using hardwood bark blended with pine bark.

Composting Blends of Pine Bark and Hardwood Bark

Bilderback (11) has listed several possible advantages of using a combined blend of pine bark and hardwood bark. Self (69) stated that it was necessary to compost the mixture of softwood and hardwood bark produced by some sawmills, especially if problems associated with tannic acid, high pH, excess Mn, or other unknowns were to be avoided.

Svenson (77) and Svenson and Witte (78) have conducted studies on the composting efficiency of hardwood and pine bark blends. Their results showed that a 50:50 (v:v) blend of composted pine and hardwood bark consistently produced a higher growth rate of a number of plant species than either pine bark or hardwood bark used alone.

Svenson (77) also conducted experiments to compare hardwood and pine bark blends mixed before or after composting. Physical and chemical properties of blends mixed prior to composting were very similar to blends mixed after composting. However, since less composting time was required, and more media volume was obtained by mixing the blends before composting, it would be more economical to mix the blends prior to composting.

Changes in pH can be experienced by composting blends of hardwood bark and pine bark. Svenson (77) and Witte and Svenson (87) found that a 50:50 blend of hardwood and pine bark had an initial pH of 4.4 which rose to 5.6 after composting. This resulting pH may be lower than desired for optimal growth of many plant species. Levels of extractable Mg in the composted blend averaged only 11 ppm. Additional amounts of Mg fertilizer prior to composting could offset the low pH readings. Both hardwood bark and pine bark contain a fair supply of K. The addition of KNO_3 at 1.33 Kg/m^3 in previous experiments (77) resulted in K levels up to 83 ppm, which may be excessive for optimum plant growth.

CHAPTER III

EFFECTS OF A REDUCED COMPOSTING PERIOD AND MINERAL AMENDMENTS ON A HARDWOOD:PINE BARK MEDIUM

Introduction

In recent years researchers have found that composted pine and hardwood bark media can grow plants as well or better than more expensive media (26,29,33,34,56,65,77). A need has emerged to refine the composting method for hardwood:pine bark composts that will take less time to compost yet result in superior quality potting media.

Results from previous research (77,78) showed that many species of container grown nursery plants had superior growth in a 50:50 blend of composted hardwood bark:pine bark media. The 50:50 blend composted more efficiently, losing less material by shrinkage than expected in comparison with other ratios. Therefore, only the 50:50 ratio of pine bark:hardwood bark was used in this experiment.

In previous composting experiments, 12.6 weeks of composting were required for the 50:50 blend of hardwood bark:pine bark to reach a stabilization temperature of 40° C (77). It would be desirable to shorten the composting time required. Faster composting would have more appeal to nurserymen.

Partially favorable results using noncomposted blends of hardwood bark and pine indicated that a semi-stabilized bark compost may be suitable for use as a container growing media (77). This would be more efficient as a shorter time would be required to prepare the compost and probably less shrinkage would occur.

Chemical analysis of previous experiments using a 50:50 blend of hardwood bark and pine bark (77) showed high K levels. Conversely, Mg levels were lower than desired. The pH of the finished blend of compost was 5.6. A higher pH level may be more favorable for adequate plant growth, as it would tend to reduce the availability of excess Mn contributed by the hardwood bark component.

A composting experiment was designed to determine the physical and chemical properties of a semi-stabilized bark compost with different mineral amendments added prior to composting.

Materials and Methods

Milled pine bark was obtained from Joe K. Smith Trucking (Cummings, GA), and hardwood bark was obtained locally from Pozey Lawn and Garden Center (Knoxville, TN).

Composting was carried out in partitioned windrows to ensure that each pile was exposed to similar conditions. The windrows provided excellent drainage and insulation compared to smaller, individual piles.

On July 12, 1988, precisely 1.56 m^3 of pine bark and

1.56 m^3 of hardwood bark were placed in each of ten bins. The material was thoroughly mixed using a Kubota B8200D tractor (Kubota LTD, Osaka, Japan) with a BF300A front mounted loader. Five-gallon samples of each media were then removed from each pile, labeled, and stored in a cooler at 4° C for later physical and chemical analysis. The varying mineral amendments (Table 1) were applied by scattering the formulations evenly over each pile. The piles were then again mixed thoroughly by the methods listed above. Each pile was wetted to achieve a moisture content of 70% of dry weight.

Beginning July 12, 1988, daily temperatures of the ten compost piles were measured using a Keithly 865 Digital Thermometer with a 8662 Thermistor General Purpose/Immersion Probe (Keithly Instruments, Inc., Cleveland, OH) mounted on the end of a fiberglass rod. At 9:30 AM each day, a 2 ft. deep hole was poked into each bark pile with a broom handle. The probe was inserted into the hole for one minute, and the temperature recorded. The hole was covered after the probe was removed.

In previous experiments (77) piles were turned when temperatures dropped 7 to 10° below the most recent peak in temperatures. This worked out to roughly weekly intervals, therefore bark piles in this experiment were turned on a weekly basis.

Targeted endpoint temperatures for this experiment were

40° C and 50° C. Endpoints were considered to be reached when a pile which had previously been hotter than the endpoint was turned and then failed to exceed that endpoint temperature after 3 or 4 days.

The quantity of material remaining after each endpoint was reached was measured and the percentage shrinkage from the original volume determined. Two 5-gallon samples were obtained from each pile at each end point, labeled, and held in a cooler pending further analysis of physical and chemical properties.

When the 50° C endpoint was reached, fifty 2-gallon containers were filled from each pile. The containers were then labeled and placed in a cooler at 4° C to retard further microbial activity. Upon reaching the 40° C endpoint, an additional fifty 2-gallon containers were filled from each pile. All one thousand containers were then placed in a nursery area pending the plant growing phase of this experiment.

Four replications were averaged to determine the following physical characteristics of each media : particle size distribution (PSD), bulk density (BD), percentage total pore space (TPS), percentage water holding capacity (WHC), and percentage air capacity (AC).

The PSD of each media was determined by passing 600 ml of oven-dry samples through U.S. Standard Sieves with openings of 12.5, 8.0, 5.6, 4.0, 2.8, 2.0, 1.4, 1.0, 0.71, and 0.50 mm. The samples were agitated for 5 minutes using a Tyler Model RX-24 Portable Sieve Shaker. The weight of material remaining on each screen was then divided by total weight of the sample to obtain a percent by weight.

Bulk density, TPS, WHC, and AC were determined for each media by following a volume loss method adapted from Gessert (35) and Whitcomb (85). Plastic freezer bags were placed in standard 2.5 l nursery containers. Containers were filled with 2.25 l of each medium, firmly packed as though a plant were being potted. Tare weight of individual bags and containers were recorded and each filled container weighed. Tare weight was subtracted to obtain initial weight of the medium. Bulk density was calculated by dividing the weight of the medium by the 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 poured into each container until the media appeared fully saturated (water film visible at the surface of the medium). Plastic bags were sealed tightly and the media allowed to soak for 24 hrs. At the end of this period, the bags were reopened and an additional known volume of water added to again bring the media to saturation. The total ml of water added was recorded and divided by 1% of the initial volume of the medium (22.5 ml) to obtain %TPS as a percent by volume.

Each container with saturated media was then set on an upside-down container in a level collection pan. Holes were poked through the container's drain holes with a pencil. The ml of water that drained into the pan after two hours was recorded, and divided by 1% of the initial volume of the medium (22.5 ml) to obtain percent AC as a percent by volume. Percent WHC was calculated by subtracting percent AC from percent TPS.

The pH levels were measured on each media using a Corning Model 5 pH Meter (Corning Glass Works, Medfield, MA). Electrical conductivity readings were measured using a Hach Portable Conductivity Meter Model 16300 (Hach Company, Loveland, CO). A 2:1 ratio of water:media (v:v) was placed in a container and thoroughly mixed for 3 minutes. The resulting solution was then measured to determine initial pH and electrical conductivity levels.

Data were analyzed by ANOVA using Statistical Analysis System software (SAS Institute, Inc., Cary, NC) running on an NEC computer. A 1% level of significance was chosen for this experiment. Mean separations were calculated using Duncan's New Multiple Range test.

Results and Discussion

The 50° C endpoint was reached for all ten compost piles after 6 weeks of composting. An additional 3 weeks of composting were required for all ten piles to reach the 40° C endpoint (Figure 1). Thus, composting the 50:50 blends to

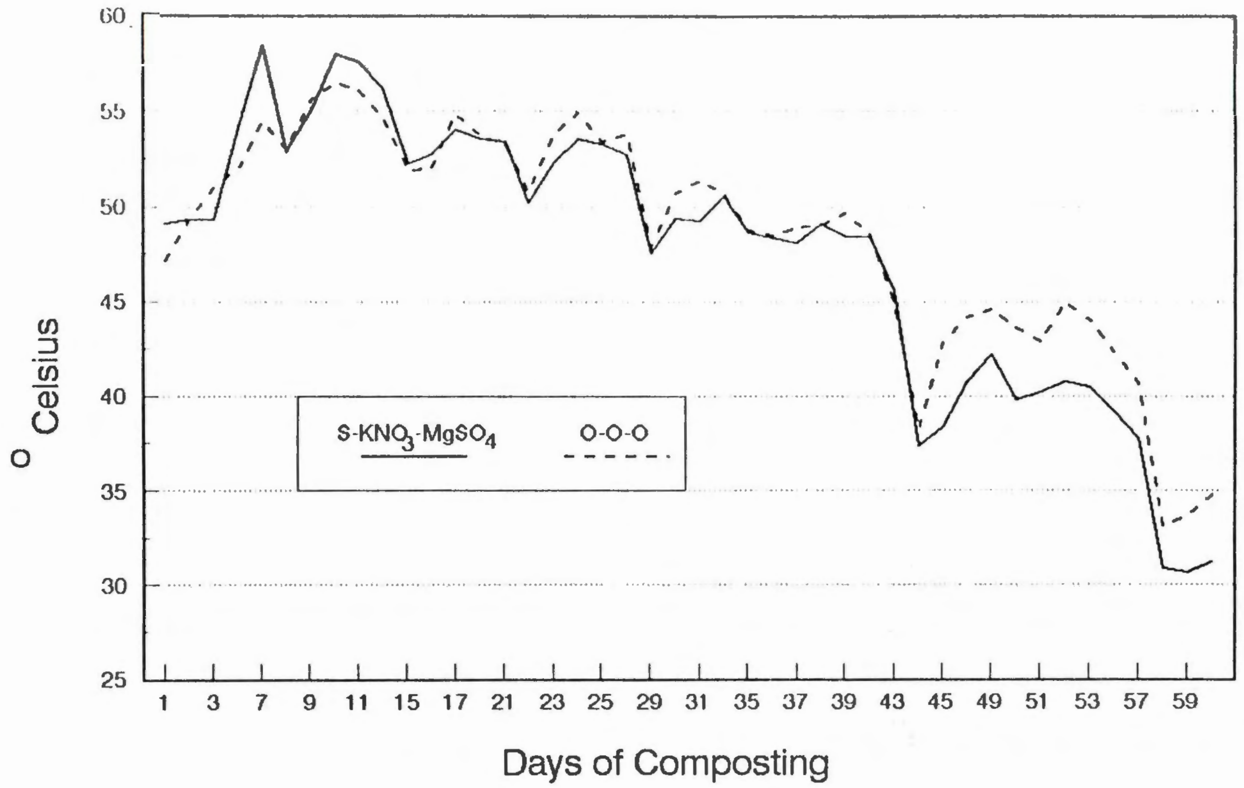

Figure 1. Daily temperature profiles of composting media with and without mineral amendments.

a 50^{0} C endpoint resulted in a 33% time savings. Peak temperatures were reached during the second week of composting. A steady decrease in maximum temperatures after this time indicated that the microorganisms in the composting pile were depleting cellulose food reserves.

No differences in physical or chemical properties were found in media composted without Zn or Cu and other composted media. Therefore, these media were not included in the remainder of the experiment.

Measurements of the volume of media remaining after each endpoint was reached showed that media composted to the 50^{0} C endpoint lost an average of only 17.6% of its volume due to shrinkage while media composted to 40^{0} C lost an average of 24.0% of its volume (Table 2).

Volume shrinkage was most likely due to continued microbial decomposition of cellulose and other degradable material resulting in evolution of carbon dioxide and water. As the material continues to break down, particle sizes become smaller, resulting in a more compact arrangement and loss of volume.

Significant differences in PSD were found between endpoints (Table 3). Media composted to the 40^{0} C endpoint had a larger percentage of fine particles falling below 0.6 mm. There were no significant main factor differences in particle sizes due to mineral amendments added prior to composting. Although differences in PSD were found between

Table 2. Effects of endpoint temperatures and mineral amendments on volume shrinkage of composted media.

Media Code			initial	50° C		40° C	
S	K	Mg	m^3	m^3	% loss	m^3	% loss
+	-	-	3.12	2.51	19.6%	2.27	27.2%
+	-	+	3.12	2.50	19.9%	2.41	22.8%
+	+	-	3.12	2.59	17.0%	2.34	25.0%
+	+	+	3.12	2.62	16.0%	2.54	18.6%
-	-	-	3.12	2.58	17.3%	2.25	27.9%
-	-	+	3.12	2.80	10.3%	2.44	21.8%
-	+	-	3.12	2.51	19.6%	2.38	23.7%
-	+	+	3.12	2.46	21.2%	2.36	24.4%
Mean			3.12	2.57	17.6%	2.37	24.0%

Table 3. Particle size distribution of composted media.

	Mean Percent of Particle Sizes[1]		
	> 9.5 mm[2]	9.5 - 0.6 mm	< 0.6 mm
50° C	0.4 a	64.7 a	34.9 b
40° C	0.1 a	64.1 a	35.8 a

[1] Mean of three replications.

[2] Means within columns followed by the same letter are not significantly different according to DMRT at $p = 0.01$

endpoint temperatures, both the 50° C and the 40° C composted media contained particle sizes that fell within acceptable levels for adequate plant growth (32,65).

Table 4 shows endpoint temperatures had significant effects on all other physical properties analyzed except for BD. As expected, composting to the 50° C endpoint resulted in a higher percent AC than media composted to 40° C. An increase in percent AC shows that media composted to 50° C allowed water to drain more readily, resulting in increased AC.

Media composted to the 40° C endpoint showed an increase in percent TPS (Table 4). This increase in percent TPS reflects the fact that media composted to the 40° C had a greater number of fine particles. Media composted to 40° C also had a higher percent WHC (Table 4). Smaller particle sizes create a greater volume of small pore space and a greater surface area for adherence of water films resulting in greater percent WHC.

Elimination of potassium nitrate and addition of magnesium sulfate had no significant effects on the physical properties of the composted media. However, elimination of sulfur generally resulted in higher %WHC (Table 5). Carrico (24) stated that addition of S to composts may promote the activity of certain microorganisms involved in making smaller pores in the bark particles, increasing the bark's water holding capacity. In our case, S provided by other

Table 4. Effect of endpoint temperature on physical properties of composted media.

Treatment	BD[1]	%TPS	%AC	%WHC
50° C Endpoint	364.5 a	62.7 b	23.9 a	38.8 b
40° C Endpoint	348.4 a	65.4 a	22.0 b	43.4 a

[1] Means within columns followed by the same letter are not significantly different according to DMRT at $p = 0.01$.

Table 5. Physical properties of composted and comparison media.

			BD[1]	%TPS	%AC	%WHC
Composted Media						
S	KNO_3	$MgSO_4$				
+	-	-	349.0 c	63.2 a	23.7 cd	39.5 c
+	-	+	365.7 bc	64.5 a	24.0 cd	40.5 bc
+	+	-	361.1 c	62.5 a	23.5 cd	39.0 c
+	+	+	354.6 c	63.0 a	22.9 d	40.2 bc
-	-	-	353.8 c	63.2 a	21.5 d	41.7 ab
-	-	+	359.4 c	64.3 a	21.7 d	42.6 a
-	+	-	353.0 c	65.4 a	23.1 d	42.3 a
-	+	+	355.6 c	65.9 a	23.1 d	42.8 a
Comparison Media						
	KNM		346.8 c	66.4 a	28.8 b	37.6 c
	SNM		331.7 c	67.3 a	26.3 bc	41.0 ab
	FPH		387.1 b	65.5 a	32.7 a	37.2 c
	MTM		488.2 a	59.1 b	30.4 ab	28.7 d

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[1] Means within columns followed by the same letter are not significantly different according to DMRT at $p = 0.01$.

sources may have been sufficient to promote this type of microorganism, with further additions inhibiting their action.

The BD of media composted to 40^{o} and 50^{o} C was intermediate between comparison media (Table 5). MTM, which included sand as one component, had the highest BD. The BD of FPH was also higher than most composted media or other comparison media.

MTM contained a less percent TPS than other comparison media or composted media (Table 5). Other comparison media were not significantly different from composted media.

Percent WHC of MTM was lower than other comparison media and composted media (Table 5). Percent WHC in KNM and FPH was lower than media composted without S.

Percent AC of FPH was significantly greater than SNM, KNM and composted media (Table 5). Other comparison media showed no differences in percent AC. However, comparison media generally had more percent AC than composted media.

Results showed only minor differences in the physical properties of the sixteen 50:50 blends of media composted to the two endpoint temperatures and the four comparison media. Physical properties of composted media tended to be intermediate of the comparison media and fell well within recommended standards for adequate plant growth.

Initial pH and electrical conductivity of the sixteen 50:50 blends of pine bark and hardwood bark are shown in

Table 6. The pH of composted media used to grow junipers increased steadily from July until September, then decreased slightly through November (Figure 2). Electrical conductivity of media composted to the 50° C endpoint that was used to grow juniper continued a steady decline from July 18 to a low of 150 umhos/cm in November (Figure 3). Media composted to 40° C used to grow juniper showed peak soluble salt levels during the first part of August when a level of 450 umhos/cm was recorded. Soluble salts then decreased to a low of 170 umhos/cm in November.

Comparison media had slightly higher initial pH readings than composted media (Table 6). After juniper was grown in each of the media, the readings followed a pattern of decline similar to that of composted media. KNM maintained the lowest pH readings throughout the experiment ending with a low of 5.2 in November (Figure 4).

Initial electrical conductivity levels for comparison media were highest in MTM (Table 6). After growing juniper, the other comparison media rose to a peak in early August (Figure 5). After this period, levels showed a steady decline through November. KNM exhibited a sudden increase in electrical conductivity from late October to early November which could not be explained.

In summary, data showed that BD, percent TPS, percent AC, and percent WHC of a 50:50 blend of pine bark and hardwood bark were influenced by length of composting.

Table 6. Initial pH and electrical conductivity (EC) of composted and comparison media.

Media			pH		EC umhos/cm	
			40° C	50° C	40° C	50° C
Composted						
S	KNO_3	$MgSO_4$				
+	-	-	5.0	5.8	590	580
+	-	+	5.1	5.2	600	560
+	+	-	5.2	5.5	680	510
+	+	+	5.3	5.3	700	510
-	-	-	5.9	5.8	120	130
-	-	+	5.5	5.5	270	320
-	+	-	5.8	5.7	160	125
-	+	+	5.7	5.4	330	400
Comparison Media						
KNM			6.0		280	
SNM			6.2		280	
FPH			5.9		230	
MTM			5.9		500	

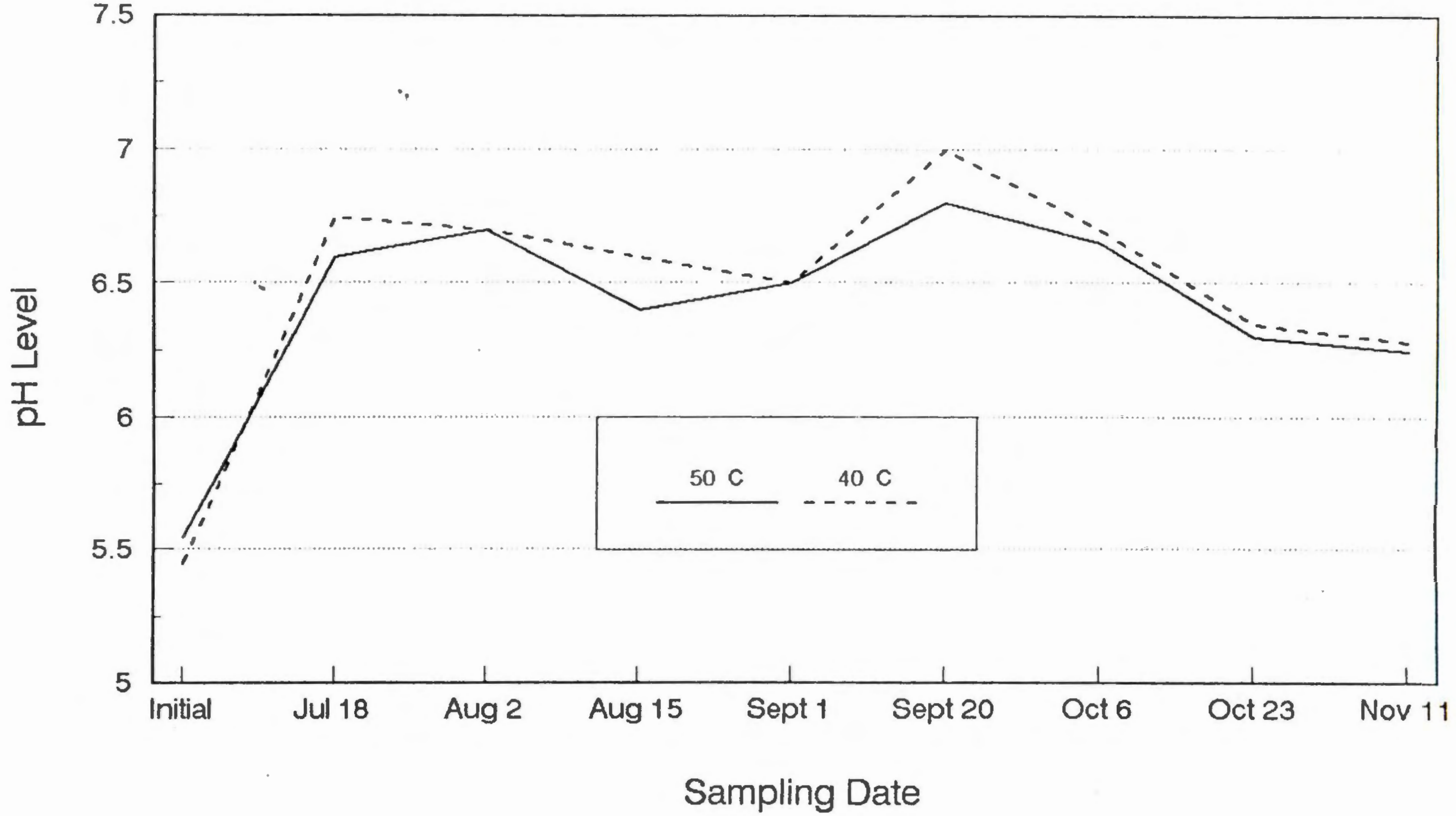

Figure 2. Profile of pH changes of composted media used to grow juniper.

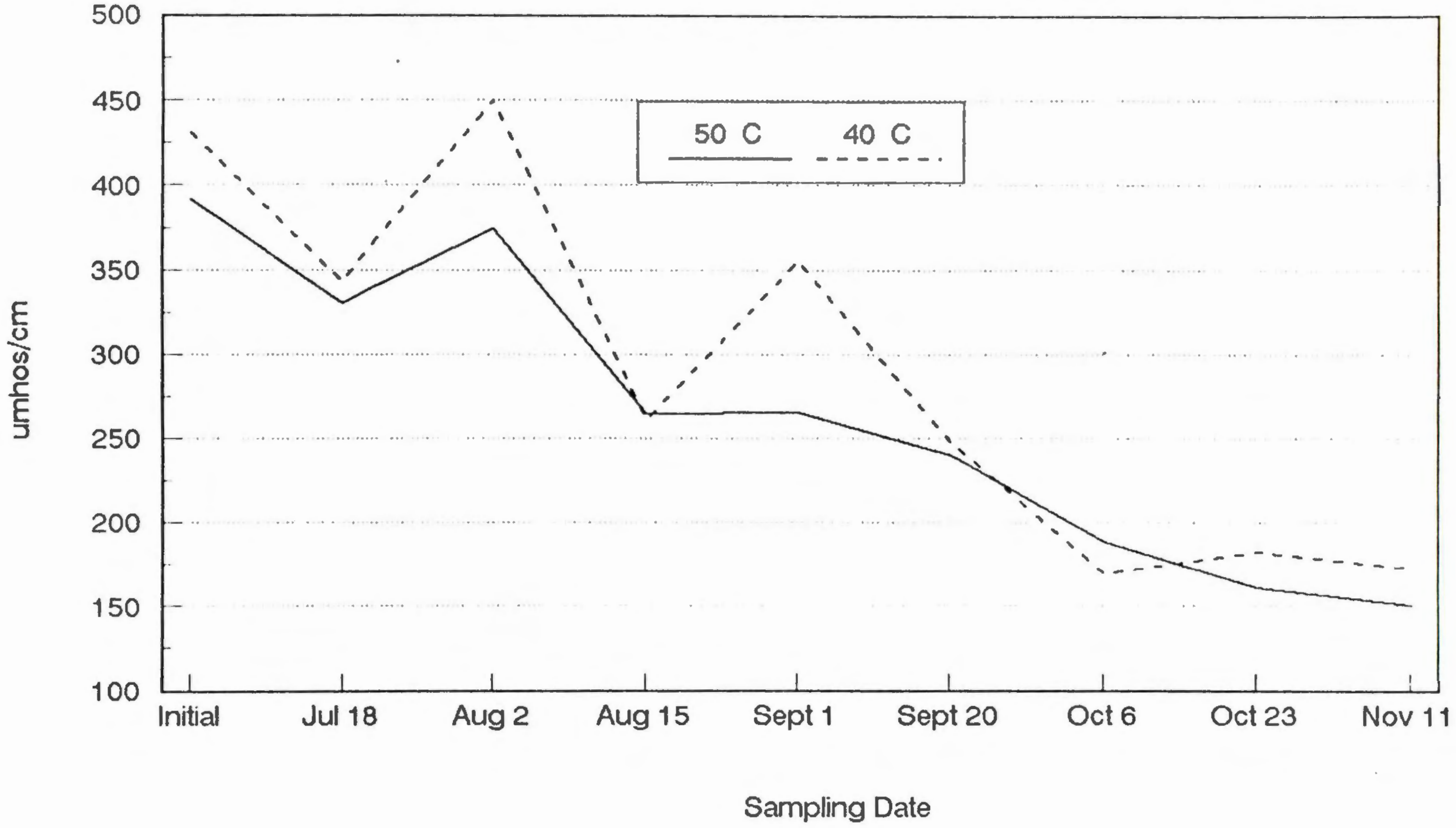

Figure 3. Profile of changes in electrical conductivity of composted media used to grow juniper.

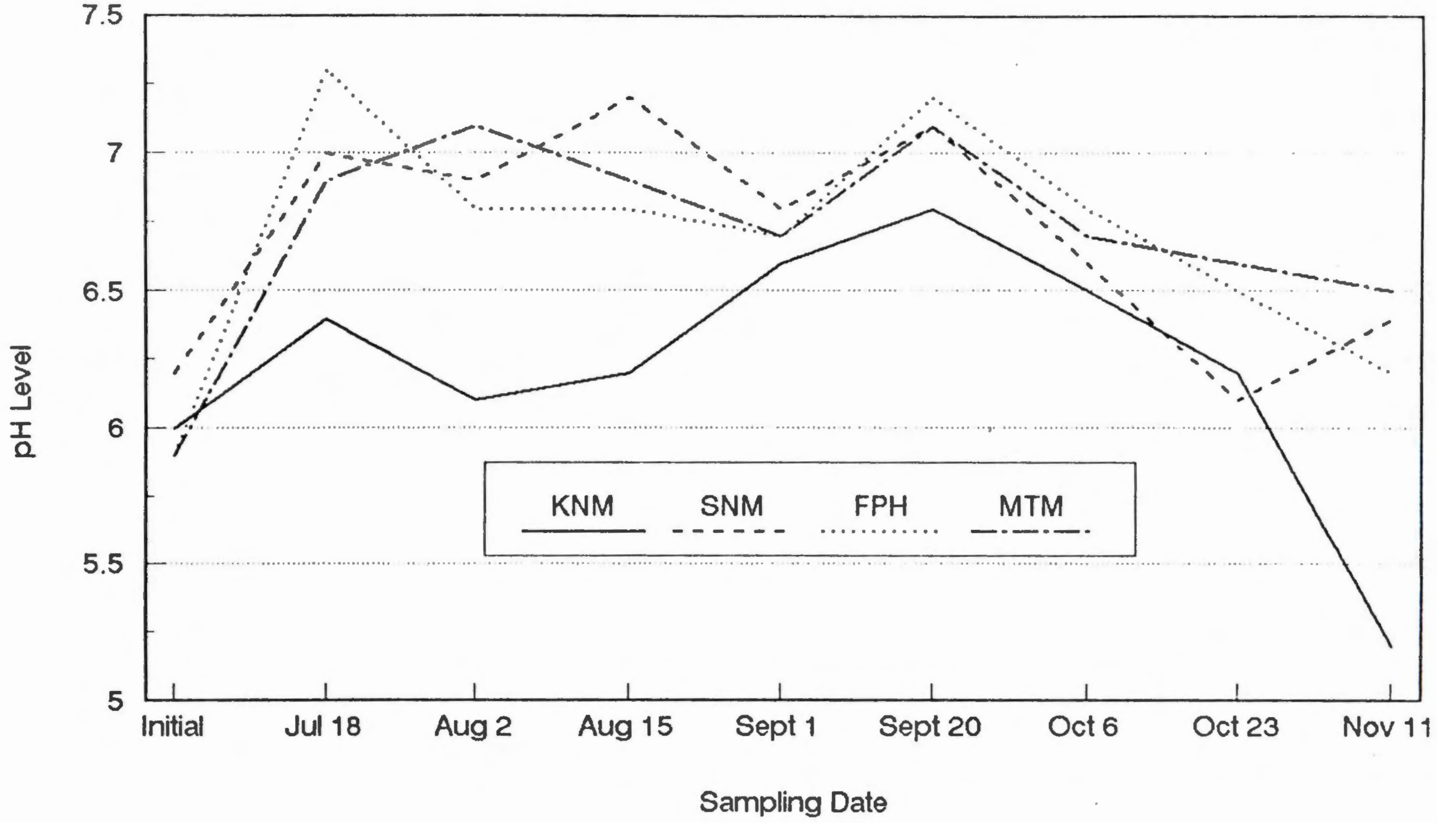

Figure 4. Profile of pH changes of comparison media used to grow juniper.

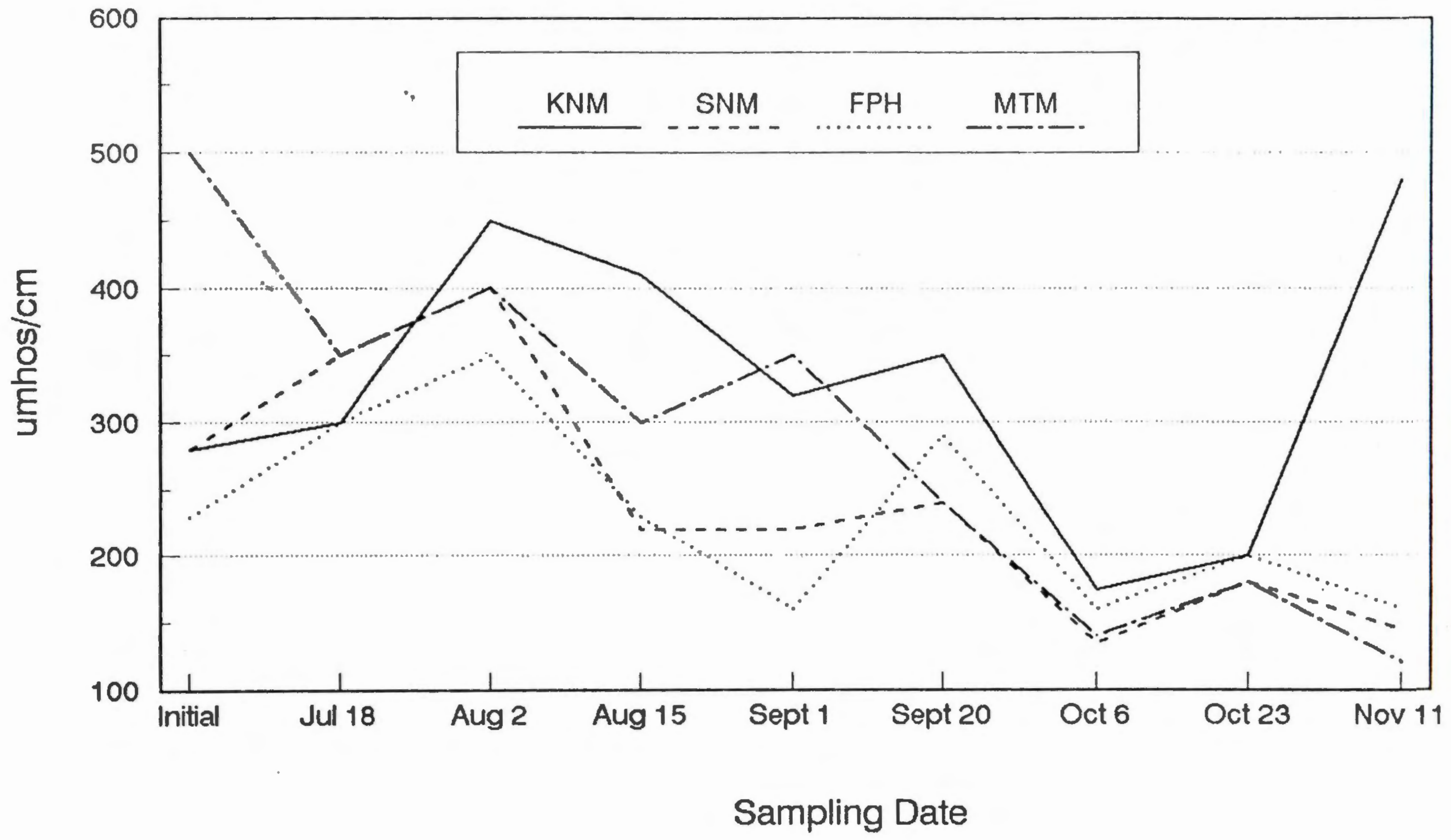

Figure 5. Profile of changes in electrical conductivity of comparison media used to grow juniper.

Addition of S generally resulted in lower percent WHC while other mineral amendments tested showed no effects. Although differences between composting endpoint temperatures were observed, the physical properties of the media all fell within acceptable levels for suitable plant growth. Initial pH levels of composted media tended to be lower than comparison media. Electrical conductivity of media composted with S was higher and media composted without S tended to be lower than comparison media. All media showed a decrease in pH and electrical conductivity after being placed in containers.

Therefore, this experiment showed that a 6 week composting period to a 50° C endpoint and elimination of sulfur, potassium nitrate, and magnesium sulfate amendments prior to composting yielded a growing medium with suitable physical and chemical properties for container plant production.

CHAPTER IV

EFFECTS OF MEDIA PREPARATION METHODS ON CONTAINER PRODUCTION OF AZALEA

Introduction

Successful production of 'Red Ruffles' azalea has been accomplished in composted pine and hardwood bark blends (77). Partially favorable results using fresh pine and hardwood bark indicated that semi-stabilized bark compost may yield a suitable container growing medium for azalea. To determine the effects of a shortened composting period and differing mineral amendments on preparing a container growing medium, an experiment was designed to grow Rhododendron hybrid 'Red Ruffles' in media composted to two endpoints with different amendments added prior to composting.

Materials and Methods

Thirty media were tested in this experiment. A 50:50 blend of pine and hardwood bark was prepared as described previously to yield 16 of the media. The 14 comparison media tested resulted in very few differences in plant growth. Therefore, four comparison media, representing the two best and the two worst, were chosen for presentation. Comparison media codes and descriptions are listed in the

Appendix.

Four-inch potted liners of 'Red Ruffles' azaleas were obtained from Flowerwood Nursery, Inc. (Mobile, Alabama). Plants were graded by size into ten blocks of plants. Media were randomly assigned within a block to obtain a randomized complete block experimental design.

Liners of <u>Rhododendron</u> cv. 'Red Ruffles' were planted April 7, 1988 in 2 gal. containers filled with the assigned media. Plants were liquid fertilized two times with Peter's 20-20-20 (W.R. Grace and Co., Fogelsville, PA) at the rate of 300 ppm N. A single application of Osmocote 18-6-12 (Sierra Chemical Co., Milpitas, CA) was dibbled into each pot at the labelled rate of 20 grams/pot two weeks after planting. Uniform watering was accomplished by the use of a drip irrigation system using Dramm dribble rings.

Growth measurements were recorded on November 17, 1989. To evaluate growth response, a growth index (GI) was developed. Plant height was measured as cm from medium level to tip of the tallest stem. Plant width was measured as cm of the plant's widest dimension (width A) and again perpendicular to this (width B). The growth index was calculated using the following formula :

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

On November 20, 1989, plants were severed at media level and weighed on a Terralion Monostat Gram Balance, and grams fresh weight recorded.

Data were analyzed by ANOVA using Statistical Analysis System software (SAS Institute, Inc., Cary, NC) running on an NEC computer. A 1% level of significance was chosen for this experiment. Mean separations were calculated using Duncan's New Multiple Range Test.

Results and Discussion

Plants grown in media composted to the 40° C endpoint had a higher GI (Table 7) and fresh weight (Table 8) than plants grown in media composted to the 50° C endpoint, except for two media (+ + -, and - + +). ANOVA showed no differences in growth due to the main factors of mineral amendments, however, a complex interaction between S, $MgSO_4$, and endpoint, did lead to a significant difference in GI (Table 7). Media composted to 40° C, receiving KNO_3 but no S or $MgSO_4$ prior to composting, resulted in higher GI than treatments involving S and KNO_3 with no $MgSO_4$, and KNO_3 and $MgSO_4$ with no S, at the 40° C endpoint. At the 50° C endpoint, there was no difference between these three media. Lowest fresh weights occurred in media composted to 50° C.

Increased fresh weight in media composted to the 40° C endpoint may be partially explained by the physical properties of the media. Media composted to the 40° C

Table 7. Growth index of 'Red Ruffles' azalea grown in composted and comparison media.

Media			Composting Endpoint Temperature	
Composted Media				
S	KNO_3	$MgSO_4$[1]	40° C[2]	50° C
+	-	-	39.0 ab	35.0 cde
+	-	+	38.9 ab	33.5 de
+	+	-	35.7 bcde	36.1 bcd
+	+	+	38.9 ab	33.2 de
-	-	-	37.7 abc	32.6 de
-	-	+	37.7 abc	33.7 de
-	+	-	40.2 a	32.3 e
-	+	+	34.7 cde	33.7 de
Comparison Media				
	KNM		37.8 abc	
	SNM		32.5 de	
	FPH		26.5 f	
	MTM		26.8 f	

---

[1] '+' received mineral amendment, '-' received no amendment.

[2] Means followed by the same letter are not significantly different according to DMRT at $p = 0.01$.

Table 8. Grams fresh weight of 'Red Ruffles' azalea grown in composted and comparison media.

Media			Composting Endpoint Temperature	
Composted Media				
S	KNO_3	$MgSO_4$[1]	40° C[2]	50° C
+	-	-	150.0 abc	111.9 fg
+	-	+	153.6 ab	112.9 efg
+	+	-	144.0 abc	123.3 cdefg
+	+	+	149.6 abc	97.7 g
-	-	-	141.6 abcd	110.0 fg
-	-	+	159.3 a	114.5 defg
-	+	-	165.8 a	114.7 defg
-	+	+	129.3 bcdef	105.9 fg
Comparison Media				
KNM			140.1 abcde	
SNM			102.7 fg	
FPH			60.3 h	
MTM			67.0 h	

[1] '+' received mineral amendment, '-' received no amendment.

[2] Means followed by the same letter are not significantly different according to DMRT at p = 0.01.

endpoint had higher percent TPS and percent WHC which may have been more conducive to plant growth. Visible differences in plant growth were not subjectively apparent. The minimum significant difference for the mean separation procedure of fresh weights was 31.65 grams, which would have been too small to notice visually.

Tables 7 and 8 show KNM resulted in high GI and fresh weight equivalent to most of the media composted to 40° C endpoint. FPH and MTM consistently had the lowest GI and fresh weight. The poor growth which occurred in FPH and MTM may have been due to the low percent WHC of both media. This would help explain the fact that the highest growth rate in the composted media was obtained in media composted to 40° C, which had a higher percent WHC. High pH levels from 5.9 to 6.2 probably inhibited growth somewhat, as azaleas prefer a lower pH of 4.5 to 5.0 (28).

This experiment shows that growth of 'Red Ruffles' azaleas in a 50:50 blend of pine and hardwood bark was influenced by the length of composting. Few differences in growth were found due to mineral amendments when the media was allowed to stabilize to 40° C. Therefore, composting 50:50 blends of pine bark and hardwood bark for nine weeks to a stabilization temperature of 40° C, with or without the addition of sulfur, potassium nitrate, and magnesium sulfate prior to composting should produce a superior container growing medium for azaleas.

CHAPTER V

EFFECTS OF MEDIA PREPARATION METHODS ON CONTAINER PRODUCTION OF PHOTINIA

Introduction

Composted blends of pine bark and hardwood bark have been shown to be an excellent growing media for a wide variety of ornamental crops (14,77,78,81,82). Svenson (77) found that composted 50:50 blends of pine and hardwood bark consistently produced better growth than other ratios. To determine the effects of a shortened composting period and differing mineral amendments on a 50:50 blend of pine and hardwood bark, an experiment was designed to grow *Photinia* x *fraseri* in composted media and some comparison media used in commercial nurseries.

Materials and Methods

Twenty-eight media were tested in this experiment. A 50:50 blend of pine and hardwood bark was prepared as described previously to yield 16 of the media. The 12 comparison media tested resulted in very few differences in plant growth. Therefore, four comparison media, representing the two best and the two worst, were chosen for presentation. Comparison media codes and descriptions are listed in the Appendix.

On March 20, 1989, ten replications of uniform one-quart potted liners of Photinia x fraseri were potted in 2 gal. containers filled with each of the 20 media treatments. Plants were then liquid fertilized two times each week with Peter's 20-20-20 (W.R. Grace and Co., Fogelsville, PA) at the rate of 300 ppm N until April 17, 1989, when a single application of Osmocote 18-6-12 (Sierra Chemical Co., Milpitas, CA) was applied at the labelled rate of 40 grams/pot. Uniform watering was accomplished by the use of a drip irrigation system using Dramm dribble rings.

Growth measurements were recorded on November 29, 1989. Height in cm was measured from media surface to the terminal growing point of each plant. Caliper in mm was measured 4 inches above the media surface. Grams fresh weight was determined by severing plants at media level and weighing on a Terralion Monostat Gram Balance.

Data were analyzed by ANOVA using Statistical Analysis System software (SAS Institute, Inc., Cary, NC) running on an NEC computer. A 1% level of significance was chosen for this experiment. Mean separations were calculated using Duncan's New Multiple Range Test.

Results and Discussion

ANOVA of height and caliper showed no differences due to endpoint temperature, differing mineral amendments, or comparison media. Table 9 shows cm height and Table 10

Table 9. Height (cm) of photinia grown in composted and comparison media.

Media			Composting Endpoint Temperature	
Composted Media				
S	KNO_3	$MgSO_4$[1]	40^{o} C[2]	50^{o} C
+	-	-	90.3	96.1
+	-	+	90.9	90.7
+	+	-	92.7	93.7
+	+	+	89.7	97.0
-	-	-	88.7	98.8
-	-	+	96.5	92.7
-	+	-	88.3	89.7
-	+	+	89.9	105.5
Comparison Media				
KNM			99.3	
SNM			91.8	
FPH			92.1	
MTM			91.8	

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[1] '+' received mineral amendment, '-' received no amendment.

[2] Means within rows and columns are not significantly different according to DMRT at p = 0.01.

Table 10. Caliper (mm) of photinia grown in composted and comparison media.

Media			Composting Endpoint Temperature	
Composted Media				
S	KNO_3	$MgSO_4$[1]	40° C[2]	50° C
+	-	-	13.3	12.7
+	-	+	13.4	12.7
+	+	-	14.0	14.0
+	+	+	14.4	13.1
-	-	-	13.9	14.2
-	-	+	14.1	12.8
-	+	-	12.8	14.0
-	+	+	13.6	14.2
Comparison Media				
	KNM		14.4	
	SNM		12.9	
	FPH		11.9	
	MTM		13.3	

[1] '+' received mineral amendment, '-' received no amendment.

[2] Means within rows and columns are not significantly different according to DMRT at $p = 0.01$.

shows mm caliper of photinia.

Photinia are better adapted to a wide variety of media and soils than azalea. Therefore, lack of differences in height and caliper may be the result of all media being within the parameters required for growth of this species.

Fresh weight of photinia was greatest in KNM (Table 11). Fresh weight in the FPH treatment was no different than in MTM and SNM treatments. Lowest fresh weight occurred in FPH, and only two composted media produced plants that weighed more. However, the trend toward increased fresh weight in composted media was clear.

Therefore, a six week composting period to a 50° C endpoint with or without addition of S, KNO_3, and $MgSO_4$ prior to composting should yield a superior container growing medium for Photinia x fraseri.

Table 11. Grams fresh weight of photinia grown in composted and comparison media.

Media			Composting Endpoint Temperature	
Composted Media				
S	KNO_3	$MgSO_4$[1]	40° C[2]	50° C
+	-	-	203.0 abc	208.1 abc
+	-	+	215.9 abc	209.5 abc
+	+	-	220.4 abc	227.9 abc
+	+	+	236.9 abc	221.1 abc
-	-	-	231.9 abc	214.3 abc
-	-	+	250.4 ab	231.0 abc
-	+	-	211.1 abc	266.2 ab
-	+	+	209.0 bc	220.5 abc
Comparison Media				
KNM			266.5 a	
SNM			193.4 bc	
FPH			172.0 c	
MTM			190.2 bc	

[1] '+' received mineral amendment, '-' received no amendment.

[2] Means followed by the same letter are not significantly different according to DMRT at p = 0.01.

CHAPTER VI

EFFECTS OF MEDIA PREPARATION METHODS ON CONTAINER PRODUCTION OF JUNIPER

Introduction

Successful production of juniper has been obtained in media containing either pine or hardwood bark (52,86). Excellent growth of a wide variety of plants has been obtained by using a composted 50:50 blend of pine and hardwood bark (77). To determine the effects of a shortened composting period and differing mineral amendments on preparing a composted 50:50 blend of pine and hardwood bark container growing medium, an experiment was designed to grow Juniperus conferta cv. 'Blue Pacific' in media composted to two endpoint temperatures with different amendments added prior to composting.

Materials and Methods

Twenty-eight media were tested in this experiment. A 50:50 blend of pine and hardwood bark was prepared as previously described to yield 16 media treatments. The 12 comparison media tested resulted in very few differences in plant growth. Therefore, four comparison media, representing the two best and the two worst, were chosen for presentation. Comparison media codes and descriptions are listed in the Appendix.

On March 20, 1989, ten replications of uniform one quart potted liners of Juniperus conferta cv. 'Blue Pacific' were planted in 2 gal. containers filled with each of the 20 media. Plants were then liquid fertilized twice a week with Peter's 20-20-20 (W.R. Grace and Co., Fogelsville, PA) at the rate of 300 ppm N until April 17 when Osmocote 18-6-12 (Sierra Chemical Co., Milpitas, CA) was applied at the labelled rate of 40 grams/pot. Uniform watering was accomplished by the use of a drip irrigation system using Dramm dribble rings.

The pH and electrical conductivity readings for all media treatments of one replication of juniper were recorded on a biweekly basis from July 18 to November 11, 1989 using a pour-through method. Containers were placed in a collection pan and 500 ml of distilled water was poured through the top of the media. Water which drained through the bottom of the pot was used for pH and electrical conductivity measurements.

The experiment was terminated on November 29, 1989. Data recorded on growth of each plant were mean cm length of the four longest runners and grams fresh weight.

ANOVA was performed on the data using Statistical Analysis System software (SAS Institute, Inc., Cary, NC) running on an NEC computer. A 1% level of significance was chosen for this experiment. Mean separations were calculated using Duncan's New Multiple Range Test.

Results and Discussion

ANOVA on plant growth data showed few differences due to composting length or mineral amendments of composted media.

Table 12 shows media composted to 40° C with KNO_3 and $MgSO_4$ but no S produced plants with greater mean runner length (38.1 cm) than media composted to 50° C with $MgSO_4$ but no S or KNO_3 (30.2 cm). All other composted media were intermediate in mean runner length.

Table 13 shows media composted to 40° C with KNO_3 but no S or $MgSO_4$ produced plants with greater fresh weight (147.0 gm) than media composted to 50° C with $MgSO_4$ but no S or KNO_3 (95.4 gm). All other composted media produced plants intermediate in fresh weight.

Growth data for plants in comparison media showed few differences from composted media. FPH produced plants with shorter mean runner length (30.9 cm) than media composted to 40° C with KNO_3 and $MgSO_4$ but no S (38.1 cm) and media composted to 50° C with S but no KNO_3 or $MgSO_4$ (36.9 cm). However, mean runner length in FPH was no different from other comparison media. Fresh weights in FPH (101.9 gm) and MTM (111.1 gm) were lower than in media composted to 40° C with KNO_3 but no S or $MgSO_4$ (147.0 gm). No differences in fresh weight were found between comparison media. The trend

Table 12. Average length (cm) of four longest runners of juniper grown in composted and comparison media.

Media			Composting Endpoint Temperature	
Composted Media				
S	KNO_3	$MgSO_4$[1]	40° C[2]	50° C
+	-	-	36.3 abc	36.9 ab
+	-	+	35.6 abcd	32.9 abcd
+	+	-	36.4 abc	35.1 abcd
+	+	+	35.2 abcd	34.8 abcd
-	-	-	34.5 abcd	32.6 abcd
-	-	+	36.6 abc	30.2 d
-	+	-	35.4 abcd	34.9 abcd
-	+	+	38.1 a	36.5 abc
Comparison Media				
	KNM		31.9 bcd	
	SNM		35.3 abcd	
	FPH		30.9 cd	
	MTM		32.8 abcd	

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[1] '+' received mineral amendment, '-' received no amendment.

[2] Means followed by the same letter are not significantly different according to DMRT at $p = 0.01$.

Table 13. Grams fresh weight of juniper grown in composted and comparison media.

Media			Composting Endpoint Temperature	
Composted Media				
S	KNO_3	$MgSO_4$[1]	40° C[2]	50° C
+	-	-	122.5 abc	142.4 ab
+	-	+	127.9 abc	113.3 abc
+	+	-	133.4 abc	126.5 abc
+	+	+	127.1 abc	129.2 abc
-	-	-	123.7 abc	124.2 abc
-	-	+	143.7 ab	95.4 c
-	+	-	147.0 a	126.2 abc
-	+	+	141.5 ab	130.9 abc
Comparison Media				
KNM			116.9 abc	
SNM			126.9 abc	
FPH			101.9 bc	
MTM			111.1 bc	

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[1] '+' received mineral amendment, '-' received no amendment.

[2] Means followed by the same letter are not significantly different according to DMRT at $p = 0.01$.

for poorer growth in FPH indicates that blends of pine and hardwood barks should be composted to some degree, either with or without addition of amendments, to obtain a superior container growing medium for juniper.

CHAPTER VII

SUMMARY AND CONCLUSIONS

The first purpose of this experiment was to determine the effects of composting period and mineral amendments on the physical and chemical properties of a 50:50 blend of pine bark and hardwood bark.

Piles of 3.12 m^3 of a 50:50 blend of pine bark and hardwood bark were composted to 50° C or 40° C for six or nine weeks respectively, in partitioned windrows. Combinations of three mineral amendments, S, KNO_3, and $MgSO_4$, were added to or excluded from each pile prior to composting. Piles were turned and aerated weekly.

The profile of daily compost pile temperature showed 6 weeks was required to reach the 50° C endpoint. An additional 3 weeks was required to reach the 40° C endpoint. Mineral amendments had no effect on reaching endpoint temperatures.

Terminal volume recorded after composting showed 17.6% shrinkage occurred in media composted to 50° C while 24.0% shrinkage occurred in media composted to 40° C.

All of the physical properties of composted media, except BD, were influenced by endpoint temperature, but few were influenced by mineral amendments. Media composted to 40° C had a greater percentage of fine particles falling below 0.6 mm and a greater percent TPS and WHC. Media composted to 50° C resulted in a higher percent AC, confirming that these media contained larger particle sizes allowing free drainage.

KNO_3 and $MgSO_4$ had no effects on physical properties, but elimination of S prior to composting generally resulted in higher percent WHC.

Physical properties of composted media were intermediate to comparison media and fell well within recommended standards for adequate plant growth.

Composted media used to grow juniper showed a slight initial increase in pH before stabilizing to about 6.4. Electrical conductivity of composted media used to grow juniper showed a steady decline throughout the experiment to a low of about 160 umhos/cm.

The pH and electrical conductivity of composted media was intermediate to comparison media.

Photinia and juniper grew equally well in media composted to 40° C and 50° C. Azaleas grew best in media composted to 40° C. Plant growth in media composted with mineral amendments was generally no better in this experiment than in media composted without mineral amendments.

Plants grew as well or better in composted media than in comparison media. Growth of azalea and photinia was significantly better in KNM than in other comparison media.

Therefore, this experiment showed that 6 weeks of composting to a 50° C endpoint and elimination of S, KNO_3, and $MgSO_4$ amendments prior to composting yielded a superior container growing medium with suitable physical and chemical properties for nursery production of a variety of ornamental plants. Acid loving plants such as azalea grew best in media composted to a 40° C endpoint.

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APPENDIX

IDENTIFICATION OF COMPARISON MEDIA CODES AND DESCRIPTION OF COMPARISON MEDIA

Media Code	Description
KNM	Container media used by Kinsey Gardens, Inc. (Knoxville, TN). 3:1 pine bark:peat mix with the following mineral amendments added to each m^3 : 0.9 Kg 0-20-0, 1.5 Kg dolomitic lime, 0.6 Kg Esmigran, 0.2 Kg urea, and 0.2 Kg KNO_3.
SNM	Standard nursery mix used by the University of Tennessee Ornamental Horticulture Department. 100% fresh pine bark with the following mineral amendments added to each m^3 of media : 4.2 Kg dolomitic lime, 1.2 Kg triple superphosphate, 1.33 Kg gypsum, and 0.9 Kg Micromax (Sierra Chemical Company, Milpitas, CA).
FPH	Blend of 50% noncomposted pine bark and 50% noncomposted hardwood bark with the following mineral amendments added to each m^3 of media : 0.3 Kg elemental sulfur, 0.3 Kg KNO_3, 0.6 Kg $MgSO_4$, 1.5 Kg urea, 2.3 Kg superphosphate, 0.4 Kg $FeSO_4$, 40 g $CuSO_4$, and 40 g $ZnSO_4$.
MTM	Morton's Tennessee Mix. Commercially available container growing media obtained from Morton's Horticultural Products (McMinnville, TN). 3:1:1 pinebark:sand:beechwood with the following mineral amendments added to each m^3 of media : 5.9 Kg lime, 3.6 Kg gypsum, 3.6 Kg Nursery Special (12-6-6), and 0.2 Kg fritted trace elements.

VITA

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