HARDWOOD CHIPS AS AN ALTERNATIVE MEDIA FOR CONTAINER PLANT PRODUCTION

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HARDWOOD CHIPS AS AN ALTERNATIVE MEDIA

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CHAPTER I

INTRODUCTION

Pine bark is a major component in the soilless media currently being used for growing commercial container nursery stock, particularly in the Southern and Western United States. However, the lack of local sources and the popularity of pine bark among producers and other industrial users has resulted in increased material and shipping costs. The components in a container medium are often dependent upon local resources. Polystyrene beads, rice hulls, rock wool, and crushed shale are examples of materials which have been successfully substituted for pine bark. Likewise, nurserymen in the Northern United States have been using bark from native hardwood trees successfully for the past decade (26).

Components of a growing medium must provide physical and chemical properties suitable for plant growth. The chemical property of primary concern when using hardwood materials is the wide carbon to nitrogen ratio. The small amount of nitrogen supplied by the material is readily absorbed and assimilated by efficient microorganisms, leaving insufficient amounts of nitrogen for plant growth (17). Suggested methods for reducing the wide C:N ratio and to meet the nitrogen requirements of plants grown in media containing hardwood materials include increased nitrogen fertilizer rates and composting of the material before use (8, 9, 19, 29, 31, 32).

Two abundant hardwood species found throughout Oklahoma are Siberian elm and post oak. The objectives of this study were 1) to examine the potential of these hardwood species as soilless media components and 2) to determine an optimum nutritional program for plant growth in these media.

CHAPTER II

LITERATURE REVIEW

Hardwood bark has been used successfully as a component in propagation and growth media for many greenhouse and woody ornamental crops. Gartner et al. (6) substituted hardwood bark for peat moss when growing Pelargonium hortorum 'Genie Irene' and 'Improved Richard' and found that various hardwood bark mixes compared favorably to the standard mix of soil:peat:perlite (v:v:v). The bark medium which provided the best plant growth was 2:1 hardwood bark and sand. Mathews and Bearce (19) showed that flower production of 'Parfait' roses was not significantly different in composted or uncomposted hardwood bark media compared to a peat:vermiculite control.

Bearce and Scott (3) grew Cyclamen indicum in mixes which contained either hardwood bark, hardwood sawdust, or a combination of the two components. Their standard mix of soil:peat:sand with the addition of NH_4NO_3 was the best growth medium. However, good growth was obtained when NH_4NO_3 was added to the bark:sand mix and when vermiculite was used in a 1:1 combination with either bark or sawdust. Scott and Bearce (24) stated that when properly managed, composted hardwood bark and hardwood sawdust can be used as basic constituents of growth media for Chrysanthemum morifolium 'Radiance' and Pelargonium hortorum 'Irene'.

Comparing bark of several hardwood species amended with sand or perlite, Szopa et al. (33) reported several chrysanthemum cultivars grew better in mixes with walnut, maple, or sycamore bark compared to oak or ash bark.

Working with hardwood bark as a component in propagation mixes, Maleike et al. (18) found that Chrysanthemum morifolium 'Nob Hill' cuttings rooted well in 100% composted bark. Rooting of Ilex cornuta 'Burfordi' and Cornus florida cuttings was significantly restricted in any of the hardwood bark mixes compared to the standard peat or the peat and perlite mixes. Varieties which showed no significant differences in rooting due to propagation media were Spirea vanhouttei, Forsythia x intermedia, Juniperus chinensis 'Hetzi', and Magnolia soulangeana. Worrall (34) varied proportions of peat moss and composted Eucalyptus and Tristania sawdust for successful propagation of foliage and bedding plants.

Klett et al. (15) studied the effects of several hardwood mixes on the production of woody ornamentals. Forsynthia intermedia 'Lynnwood Gold' grew better in a hardwood bark and sand (2:1) medium than in the soil:peat:perlite control. The growth response of Juniperus chinensis 'Pfitzeriana' was good in both a bark:soil:peat medium and in a 2:1 bark and sand medium.

Raker and Hoitink (22) stated that hardwood bark compost was an excellent substrate for production of ericaceous plants. They studied Pieris japonica and two Rhododendron cultivars, 'Nova Zembla' and 'Roseum Elegans', and found that growth responses were better in a composted hardwood bark and silica sand (2:1) medium than in either a peat and sand or a haydite:peat:sand medium. Sterrett and Fretz (27) reported that there were no significant differences among Cotoneaster dammeri 'Royal Beauty' plants grown in a 2:1 hardwood bark:sand or a 1:1:1

hardwood bark:sand:peat medium regardless of the nitrogen source used in the composting process.

Smith (25) compared two pine bark and vermiculite mixes to several composted hardwood bark and sand mixes where the ratio of bark to sand was varied. Growth of Juniperus horizontalis 'Plumosa', 'Compacta', and 'Youngstown' plants grown in the pine bark mixes had significantly greater growth than plants in any of the hardwood bark mixes. No significant difference in fresh weight was measured for plants grown in any of the hardwood bark:sand mixes. Smith and Treaster (26) compared mixes of hardwood bark, pine bark, and a commercial mix containing pine bark for woody ornamental production. They reported that Weigela florida grew best when the hardwood bark or the commercial mixes were used while Syringa vulgaris grew equally in both hardwood and pine bark mixes. Viburnum opulus grew best in pine bark mixes.

Physical Properties of Hardwood Media

Important physical properties which affect plant growth in any container medium include particle size, aeration, and water holding capacity. Particle size greatly influences both the water holding capacity and the drainable pore space (or aeration) of a container medium. A medium consisting of mostly fine particles has a large surface area and small pores which, by capillary forces, holds a large volume of water, hence it is poorly aerated. On the other hand, a medium composed of coarse particles has little surface area for holding capillary water thus is highly aerated and overly dry. The combination of fine and coarse particles and the use of porous materials can increase drainable pore space without decreasing water holding capacity (21).

Several researchers investigating the use of hardwood materials in potting media studied the effect of particle size on plant growth. Gartner et al. (6) and Gartner et al. (10) reported that plant growth was superior when particles of 0.51 mm to 6.35 mm (1/50 in. to 1/4 in.) were used compared to when particles of 6.35 mm to 19.05 mm (1/4 in. to 3/4 in.) or less than 0.51 mm (1/50 in.) were used in various mixes. Gartner et al. (10) concluded that when particles less than 0.51 mm (1/50 in.) were used in too large a proportion, drainage of the medium was hindered and root sloughing occurred. Likewise, Black and van de Werken (4) stated that bark which passed through a 6.35 mm (1/4 in.) mesh resulted in better growth than coarse particles which passed through 12.7 mm (1/2 in.) mesh.

Chrysanthemum morifolium 'Princess Anne' grew poorly in a sawdust and soil mix because of poor drainage (31). Improvement of the structural characteristics of the mix due to the addition of perlite or wood chips resulted in increased growth. Equally important, as emphasized by Hoitink and Poole (12) is that an adequate amount of small diameter particles be maintained to raise the cation exchange capacity and the moisture holding capacity of the medium.

Raker and Hoitink (22) studied the percent drained pore space of three types of media. They reported that the composted hardwood bark and sand (2:1) medium had a higher percent drained pore space after two growing seasons compared to both a peat and sand medium and a haydite:peat:sand medium. They also stated that after composting, the hardwood bark was resistant to further breakdown. Smith and Treaster (26) reported that the percent air pore space for the various pine bark mixes they studied were generally higher than those for the hardwood bark mixes.

Bearce and Scott (3) measured the percent moisture of four medium components. Results obtained were vermiculite 235%, peat 165%, hardwood sawdust 94%, and hardwood bark 76%. Plant response was related to the moisture characteristics of the components. <u>Cyclamen indicum</u> grew better in mixes which contained vermiculite due to its moisture holding capacity.

Chemical Properties of Hardwood Materials and Media

Hoitink and Poole (12) stated that the pH of fresh bark ranges from 4.0 to 5.5. Prior to the addition of fertilizer amendments or composting, Sterrett and Fretz (27) measured a pH value of 5.8 for fresh bark. However, Bearce and Scott (3) reported the pH of shredded bark fines to be 7.2 and that of hardwood sawdust to be 4.4.

Various investigators concluded that the pH of hardwood bark media tended to be higher than mixes containing peat moss (7, 15). However, the hardwood bark media investigated by Raker and Hoitink (22) had a pH value which was slightly lower than the peat moss media (5.2 and 5.9, respectively). Gartner et al. (8) observed that as the proportion of hardwood bark in a growth medium increased, the pH of the media also increased.

Schusler et al. (23) compared pine bark and hardwood bark mixes. They concluded that the pH of the hardwood bark media was too high for good plant growth while the pH of the pine bark media was too low. Two pine bark and vermiculite mixes studied by Smith (25) had pH values of 4.5 and 5.1. In the study, a 100% composted hardwood bark mix had a pH of 5.6 as did 2:1, 3:1, and 6:1 hardwood bark and sand mixes. The pH of 4:1 and 5:1 mixes were slightly higher with 6.1 and 5.9, respectively. The pH values of these hardwood bark mixes differ from the conclusions of Schusler et al. (23).

Several researchers looked at the effect of time on the pH values of hardwood media. Gartner et al. (10) observed that during the growing season, the pH of the leachate from the media increased. Similarly, the pH of hardwood bark kept moist with distilled water increased from 5.2 to 6.2 in a period of 30 days (11). Gartner et al. (8) noted that the pH of a soil:bark mix rose from about 5.0 to about 7.8 in one and a half months. Contrary to this, the hardwood bark mix employed by Raker and Hoitink (22) remained nearly the same pH after two growing seasons. However, Sterrett and Fretz (27) noted the pH of a hardwood bark and sand medium and a hardwood bark:sand:peat medium increased during the first month of the growing season followed by a continued decline for the remainder of the season.

Sterrett and Fretz (27) concluded that the nitrogen source supplied to hardwood bark during the composting process effects pH. They reported that while $(NH_4)_2SO_4$ lowered the pH of composted bark, $Ca(NO_4)_2$ raised the pH, and NH_4NO_3 had no effect. In addition, as the rate of total nitrogen increased, the effect on pH was more pronounced. On the other hand, Yates and Rodgers (35) found a rise in pH during a four week composting period when urea or NH_4NO_3 was applied to hardwood bark.

Gartner et al. (11) reported that the nitrogen source used during the growing season affected the pH of hardwood media. They stated that ammonical nitrogen sources lowered pH while nitrate sources caused the pH to rise.

Bearce and Scott (3) reported soluble salt levels of .02, .02, and

.06 mmhos/cm for fresh hardwood bark, sawdust, and peat moss, respectively. This indicates that each component had little if any salt or nutrient content. Gartner et al. (8) tested the leachate of hardwood bark media for soluble salt content with various slow release fertilizers. Regardless of fertilizer levels, the salt content never exceeded 1.2 mmhos/cm.

Raker and Hoitink (22) amended a 2:1 hardwood bark and sand mix with 3.75 kg NH_4NO_3, 2.98 kg superphosphate, and 0.45 kg elemental sulfur per m^3 (6, 5, and 0.75 lbs./yd.^{3}, respectively). After six weeks of composting, the soluble salt content was 2.2 mmhos/cm which was considered an undesirable level for many plants. Raker and Hoitink said that the high salts indicated that the composting process had not been completed. After the second growing season, soluble salts were down to .1 and .2 mmhos/cm.

Bearce and Scott (3) measured the cation exchange capacity of several medium components. They found that peat moss was superior with a CEC equal to 134 meq/100 g compared to vermiculite 20-70 meq/100 g, hardwood bark 44 meq/100 g, and hardwood sawdust 18 meq/100 g. Plant response was partially related to CEC. Addition of ammonium nitrate to mixes containing peat moss resulted in better <u>Cyclamen indicum</u> growth, due to high CEC of the peat. Joiner and Conover (13) concluded that CEC is of value in container plant production only when reported in terms of milliequivalents (meq) per volume rather than meq/100 g, because root growth is restricted to the container volume. CEC reported in meq/100 g can be converted to meq/cc by multiplying it by the media bulk density and dividing by 100.

Several investigators determined the mineral composition of fresh and composted hardwood bark, sawdust, and wood chips (5, 7, 9, 27, 28, 31). The results of these analyses performed on fresh materials are listed in Table I. Still et al. (28), studying the decomposition of several species of hardwood barks, stated that the mineral composition of each composted bark was higher than the fresh bark, particularly nitrogen.

Researchers have found bark and wood chips to contain between two and four percent calcium dry weight (7, 27, 28, 31). Gartner et al. (11) stated that additional calcium and magnesium was not needed in hardwood media as there were sufficient amounts in the bark for good plant growth. In another study, the same amount of $CaSO_4$ and $MgSO_4$ was added to bark amended mixes and the standard soil:peat:perlite mix (15). Klett et al. (15) observed that the bark amended mixes had higher levels of Ca and Mg. They suggested that the high levels resulted from the fairly high concentrations of Ca and Mg in the bark itself or in the irrigation water.

Gartner et al. (11) stated that hardwood bark analysis showed sufficient amounts of micronutrients present to support plant growth. Contrary to this, Milbocker and Palmer (20) reported that some plants grown in hardwood bark media showed symptoms of iron deficiency along with slow growth, yet chemical analysis of the bark showed sufficient iron present. Analysis of the growth medium leachate, on the other hand, suggested that manganese was leached from the bark more readily than iron. Hence, the readily available Mn rendered Fe unavailable to the plants. Albery (1) observed zinc and manganese toxicity symptoms on a few woody ornamental species, especially Liquidambar, when grown in eucalyptus sawdust amended media.

When utilizing wood materials in container media, the problem of

TABLE I

AVERAGE MINERAL COMPOSITION OF HARDWOOD SPECIES USED AS MEDIA COMPONENTS FOR SEVERAL INDEPENDENT STUDIES

	Mineral Element						
	-------------%-------------				--------ppm--------		
Study	P	K	Ca	Mg	Fe	Mn	Zn
				Total			
Mixed species bark (7)	.12	.62	3.96	.08	743	485	53
White oak bark (31)	.11	.32	3.86	.04	177	563	16
White oak wood chips (31)	.05	.25	3.64	.05	76	272	11
Hackberry bark (28)	.09	.44	3.59	.22	1137	---*	--
Cottonwood bark (28)	.04	.25	1.74	.11	664	---	--
Silver Maple bark (28)	.04	.25	0.97	.06	766	---	--
Sycamore bark (28)	.07	.25	1.85	.09	594	---	--
Mixed species bark (5)	.01	.22	--	.05	--	---	--
Mixed species bark (27)	.04	.21	2.50	.076	1160	380	--
				Available			
Mixed species bark (9)	.0002	.052	0.68	.038	2370	---	--

*Element concentration not reported.

nitrogen draft must be addressed. The small amount of nitrogen supplied by wood materials is readily absorbed and assimilated by microorganisms, leaving insufficient nitrogen for plant growth (17). This is especially important when hardwood materials are utilized as they are more readily attacked than most softwood materials thus requiring more nitrogen (2).

Allison and Murphey (2) investigated the decomposition rates of wood and bark particles of several hardwood species and reported little variation between species when adequate nitrogen was supplied. The average decomposition of hardwood materials in the presence of adequate nitrogen is six times that of softwood bark. In addition, the hardwood pulp was found to decompose much more readily than the bark.

Hardwood components have high carbon-nitrogen ratios, ranging from 73:1 for fresh bark of mixed species (5) to 320:1 and 450:1 for white oak bark and white oak wood, respectively (31). Gartner et al. (7), Schusler et al. (23), and Sterrett and Fretz (27) are among researchers who observed reductions in plant growth when the medium contained fresh hardwood bark. Suggested methods for reducing the C:N ratio and to meet the nitrogen requirements of plants grown in hardwood mixes include nitrogen fertilizer additions and composting.

Several researchers concluded that additional nitrogen supplied to fresh hardwood bark media in a slow release form helps overcome the nitrogen deficiency due to natural decomposition of the media during the growing season. Gartner et al. (9) found that addition of either 4.76 kg/m^3 (8 $lbs./yd.^3$) Osmocote (18-9-9) or Mag Amp (7-40-6) to the various hardwood bark mixes, in addition to a liquid feed program of 200 ppm nitrogen at each watering, resulted in good growth of several woody ornamental species. <u>Taxus media</u> 'Hicksii' and <u>Forsythia intermedia</u> 'Beatrice

Ferrand' grew significantly better when nitrogen was applied in slow release forms compared to liquid feed only (8). Growth response of both species was better when 4.46 kg/m^3 (7.5 lbs./$yd.^3$) Osmocote 18-9-9 was applied compared to 1.79 kg/m^3 ureaform (38-0-0), 3.57 kg/m^3 nitroform, or 8.93 kg/m^3 Osmocote (18-9-9) (3, 6, or 15 lbs./$yd.^3$, respectively). In the same study, Gartner et al. (8) concluded that more fertilizer was needed as the proportion of bark in the medium was increased.

Still and Gartner (31) grew Chrysanthemum morifolium 'Princess Anne' in several mixes containing white oak wood chips. Good growth was observed when Osmocote was added at 7.44 and 14.8 kg/m^3 (12.5 and 25 lbs./$yd.^3$) with the higher rate providing the best growth. 'Parfait' roses were another crop which performed well in hardwood bark mixes if nutrient requirements were met by slow release fertilizers (19).

Scott and Bearce (24) stated that Chrysanthemum morifolium 'Radiance' and Pelargonium hortorum 'Irene' grown in mixes consisting of composted hardwood bark and sawdust performed best when the nitrogen source was ammonium nitrate rather than calcium nitrate. Likewise, Gartner et al. (11) found that plant response to NH_4NO_3 was consistently better than urea, $(NH_4)_2SO_4$, $CaNO_3$, and $NaNO_3$.

Bearce and Scott (3) investigated the response of Cyclamen indicum plants grown in various hardwood bark and sawdust mixes to the addition of ammonium nitrate as a supplemental nitrogen source in a 59.9 g N/100 liters (0.5 lbs. N/100 gal.) constant liquid feed program. Incorporation of 3.35 kg/m^3 (5.63 lbs./$yd.^3$) NH_4NO_3 had little effect on cyclamen growth within a single type of mix.

Still et al. (32) reported that reduction of Chrysanthemum morifolium 'Bright Golden Anne' growth was compensated for by increasing the amount of nitrogen applied in a liquid feed program, even in mixes containing fresh white oak sawdust. Ten and fifteen year old sawdust, in combinations with sand or soil and perlite, grew plants of equal quality when fertilized with 400 ppm N compared to the soil:peat:perlite control mix fertilized with 200 ppm N.

To determine the effect of nitrogen form and pH on growth of Chrysanthemum morifolium 'Bright Golden Anne', Klett and Gartner (14) added elemental sulfur and $Ca(OH)_2$ to a white oak bark and sand medium (2:1) to obtain low and high pH ranges (4.5 to 5.5 and 6.5 to 7.5, respectively). Nitrogen was applied in a daily 400 ppm liquid feed program with the nitrogen sources being either $(NH_4)_2SO_4$, KNO_3, or NH_4NO_3. They reported that $(NH_4)_2SO_4$ or NH_4NO_3 gave greater dry weights at the high pH range while KNO_3 gave greater dry weights at the low pH range.

Still et al. (29) investigated Chrysanthemum morifolium 'Bright Golden Anne' growth in fresh and composted bark media in response to various nitrogen rates applied as liquid feed. The rate of 100 ppm N was insufficient for either fresh or composted media. Rates of 200 and often 400 ppm N were needed to produce plant growth in bark media which was comparable to that obtained in the soil:peat:perlite control medium fertilized with 100 ppm N.

A different approach to nitrogen tie-up caused by decomposition of hardwood materials in container media was attempted by Klimkowski and Whitcomb (16). To lower the pH below the optimum composting range of 6.5 to 8.5, several rates of sulfur were added to a 2:1:1 elm wood chip, peat moss, and sand medium. They reported that only the 3.47 kg/m^3 (6 $lbs./yd.^3$) rate of sulfur was effective in stimulating growth of Euonymus kiautschovica 'Manhattan' and Ilex crenata 'Hetzi'. The pH of the media, measured at the end of the season, showed no difference due to sulfur rates and could not be correlated to the improved growth of plants. They speculated that the elm chips adsorbed or absorbed the sulfur which in some way caused a reduction in nitrogen tie-up and utilization by microorganisms.

Some investigators have been concerned that the hardwood bark may contain chemical plant growth inhibitors. Gartner et al. (7) stated that fresh bark gave reduction of plant growth, therefore, they suggested that the bark should be composted for at least 30 days to avoid inhibitors. In the same study, they found the inhibition was higher in bark harvested during the growing season.

Gartner et al. (11) reported that growth or germination inhibition seen in hardwood media was dependent not only on the season when the bark was harvested but also on the species of bark used and the degree of composting. Young chrysanthemum plants grown in sycamore and cottonwood bark were taller and weighed more than those grown in hackberry and silver maple bark. The root growth of the plants grown in hackberry and silver maple was also much slower. Another study (7) showed the inhibition due to bark species was almost eliminated after 30 days of composting.

Still et al. (30) cultured mung bean (Phaseolus aureus) cuttings and cucumber (Cucumis sativus 'Marketer') seedlings in water extracts from four hardwood species. Root elongation of the cucumbers and adventitious rooting of the mung beans were inhibited by the extract made from fresh silver maple bark. Inhibition was reduced after the silver maple bark had been composted for 30 days before preparing the extract. Further investigation indicated that the inhibitory compound was phenolic in nature.

Several researchers found no chemical toxicity or growth inhibition when growing plants in hardwood bark media (6, 14, 32).

CHAPTER III

MATERIALS AND METHODS

Chips of Siberian elm, *Ulmus pumila*, and post oak, *Quercus stellata*, were used as components in soilless media, with pine bark from *Pinus taeda* and *P. echinata*, used as a standard. The oak and elm chips were obtained by grinding entire trees, including leaves, twigs, bark and wood, through a large chipper. The wood chips were approximately 5.1 to 7.6 cm (2 to 3 in.) by 1.3 to 2.5 cm (0.5 to 1 in.). They were subsequently processed through a hammermill with a 7.6 X 7.6 cm (3 X 3 in.) screen which provided slivers up to 2.54 cm (1 in.) in length yet only 0.3 to 0.6 cm (1/8 to 1/4 in.) in width. Each type of wood chip was mixed in a 3:1:1, by volume, ratio with sphagnum peat moss and concrete sand and amended with various levels of sulfur, Micromax and Osmocote 17-7-12. Treatment combinations are listed in Table II. The study was conducted as a randomized block design and factorial arrangement of treatments. Single superphosphate (0-20-0) and dolomite were included in all treatments at rates of 1.78 and 3.57 kg/m^3 (3 and 6 $lbs./yd.^3$), respectively. All nutrients were incorporated into the growth medium at the time of mixing except for Osmocote treatments which were top dressed at planting time.

Pyracantha X 'Mojave' cuttings were taken in mid-November 1980 and rooted in 254 cm^3 (15.5 $in.^3$) plastic pots containing a 1:1 peat moss and perlite propagation mix which was amended with 0.595 kg/m^3 (1 lb./

TABLE II

TREATMENT COMBINATIONS OF SULFUR, MICROMAX, AND OSMOCOTE

OAK	ELM	PINE BARK
SULFUR		
0, 0.60, 1.19, 2.38 kg/m^3	0, 1.19, 2.38, 3.57 kg/m^3	0.0
(0, 1, 2, 4 lbs./$yd.^3$)	(0, 2, 4, 6 lbs./$yd.^3$)	0.0
MICROMAX MICRONUTRIENTS		
0.45, 0.89, 1.34 kg/m^3	0.45, 0.89, 1.34 kg/m^3	0.45, 0.89, 1.34 kg/m^3
(0.75, 1.50, 2.25 lbs./$yd.^3$)	(0.75, 1.50, 2.25 lbs./$yd.^3$)	(0.75, 1.50, 2.25 lbs./$yd.^3$)
OSMOCOTE		
8.93, 11.90, 14.88 kg/m^3	8.93, 11.90, 14.88 kg/m^3	8.93, 11.90 kg/m^3
(15, 20, 25 lbs./$yd.^3$)	(15, 20, 25 lbs./$yd.^3$)	(15, 20 lbs./$yd.^3$)

yd.^{3}) Micromax and 3.57 kg/m^3 (6 lbs./yd.^{3}) Osmocote 18-6-12. Cuttings were placed in an unshaded fiberglass propagation house until rooted, then transferred to a double poly solar greenhouse and held until spring planting. The liners were planted in 7.57 l (2 gal.) black poly bags containing the various treatments on May 5, 1981.

The parameters measured for pyracantha growth were visual grade (based on a scale, 1 = poorest, 10 = best) and fresh top and root weights. Visual grades were determined on November 6, while the fresh top and root weights were measured from November 8 through November 17, 1981.

Seeds of Liquidambar formosana, Formosan sweetgum, were germinated in flats containing a 1:1 peat moss and perlite mix amended with 0.595 kg/m^3 (1 lb./yd.^{3}) Micromax and 3.57 kg/m^3 (6 lbs./yd.^{3}) Osmocote 18-6-12. On April 23, 1981, selected seedlings were transferred from the flats to individual 147.6 cm^3 (9 in.^{3}) paper pots and top dressed with 4.76 kg/m^3 (8 lbs./yd.^{3}) Osmocote 18-6-12. The seedlings were taken out of the tree seedling house and planted into 7.57 l (2 gal.) black poly bags containing the various treatment combinations on May 26, 1981.

Formosan sweetgum trees were evaluated for stem caliper and plant height from September 24 through October 1, while fresh top and root weights were evaluated from November 19 through 23, 1981.

Ronstar (oxidiazon) 2G was applied to the soil surface one week after planting at the rate of 3.57 kg (6 lbs.) aia (active ingredient per acre). Orthene was applied as needed for control of unicorn moth larvae on pyracantha. Water was supplied by overhead sprinklers as needed.

The mixes containing pine bark were not given the 14.88 kg/m^3 (25 lbs./yd.^{3}) rate of Osmocote nor any of the elemental sulfur treatments. Pine bark does not have as wide a carbon to nitrogen ratio as hardwood materials (2). Therefore, increased nitrogen rates or inhibition of microbial decomposition, achieved by lowering media pH, was not required. In order to contrast the elm, oak, and standard pine bark mixes, an analysis of variance was performed as a 3 X 3 X 2 (wood, Micromax, Osmocote) factorial. These are referred to in this study as Comparison I, for growth responses of pyracantha, and Comparison III, for growth responses for Formosan sweetgum. This permitted direct comparison between treatment combinations which had the same rates of Micromax and Osmocote. When contrasting growth responses between the two hardwood chip media, excluding pine bark, the analysis of variance was performed as a 2 X 3 X 3 (wood, Micromax, Osmocote), factorial. These are referred to as Comparisons II and IV, for growth responses of pyracantha and Formasan sweetgum, respectively. Sulfur was not included in the data analysis for the two hardwood chip media. See Table III for factors included in the statistical analyses.

Selected media samples were taken June 26, August 3, September 22, and November 9, 1981 (approximately six week intervals) to determine how time, wood species, sulfur, and Osmocote influenced pH and soluble salt content of the media. Selected treatments are listed in Table IV. The first three replications of the pyracantha plants were selected for treatment sampling. Media samples were taken from the sides of containers approximately 12.7 cm (5 in.) from the bottom. Soluble salt content and pH readings were taken after the growth media had remained overnight in a 2:1 volume ratio of media to distilled water.

Osmocote's effect on media chemical properties was evaluated by

TABLE III

STATISTICAL ANALYSES OF GROWTH RESPONSE COMPARISONS

Comparison I	Comparison II
pyracantha	Pyracantha
elm, oak, pine bark	elm, oak
no sulfur	no sulfur
all Micromax rates	all Micromax rates
2 Osmocote rates	all Osmocote rates
Comparison III	**Comparison IV**
sweetgum	sweetgum
elm, oak, pine bark	elm, oak
no sulfur	no sulfur
all Micromax rates	all Micromax rates
2 Osmocote rates	all Osmocote rates

TABLE IV

TREATMENTS WITH A FIXED MICROMAX LEVEL (0.89 KG/M^3) ANALYZED FOR pH AND SOLUBLE SALT CONTENT

Treatment Number	Factor Combinations		
	Wood Species	Sulfur (kg/m^3)	Osmocote (kg/m^3)
1	Elm	0	8.93
2	"	1.19	8.93
3	"	2.38	8.93
4	"	3.57	8.93
5	"	0	11.90
6	"	0	14.88
7	Oak	0	8.93
8	"	0.60	8.93
9	"	1.19	8.93
10	"	2.38	8.93
11	"	0	11.90
12	"	0	14.88
13	Pine	0	8.93
14	"	0	11.90

contrasting treatments containing no sulfur while Osmocote rates were varied. These Osmocote data were analyzed as 3 X 4 (Osmocote, sampling date) factorials for each individual hardwood media and as a 2 X 3 (Osmocote, sampling date) factorial for the pine bark media. Likewise, the effect of sulfur on chemical properties of the media was determined by comparing treatments containing 8.93 kg/m^3 (15 $lbs./yd.^3$) Osmocote while sulfur levels were varied. These sulfur data were analyzed as 4 X 4 (sulfur, sampling date) factorials for each individual hardwood media.

Available and total elemental analyses of elm and oak chips and pine bark were conducted on a Perkin-Elmer atomic absorption unit (Model 303).

CHAPTER IV

RESULTS

The addition of elemental sulfur to media with elm or oak chips was either of no benefit or detrimental to the growth of both species (Table V).

TABLE V

EFFECT OF SULFUR ON TOP WEIGHT OF PYRACANTHA AND SWEETGUM GROWN IN ELM AND OAK CHIP MEDIA

Wood Species	Sulfur (kg/m^3)				
	0	0.60	1.19	2.38	3.57
			PYRACANTHA		
Elm	240.4*c	----	237.5 c	206.4 b	66.8 a
Oak	287.6 c	223.6 b	207.7 b	96.2 a	----
			SWEETGUM		
Elm	174.2 c	----	164.3 bc	138.2 b	106.5 a
Oak	167.7 c	132.4 b	128.5 b	81.9 a	----

*Duncan's multiple range test. Means within a row followed by the same letter are not significantly different at the 5% level.

Comparison I

Top and root weights were similar for pyracantha grown in pine bark, elm, and oak chip media. However, visual quality for plants grown in elm media ($\bar{x}$ = 7.83) were significantly lower at the 0.05 level than plants grown in either oak chip or pine bark media ($\bar{x}$ = 8.75 and $\bar{x}$ = 8.72, respectively). As the amount of Osmocote 17-7-12 was increased from 8.93 to 11.90 kg/m^3 (15 to 20 lbs./yd.^{3}), top weight and visual grade improved from 261.87 g to 297.24 g and 8.1 to 8.8, respectively. A Micromax* Osmocote interaction for top weight and visual grade is presented in Table VI though significance was only at the 0.07 level. Plants given 11.90 kg (20 lbs.) of Osmocote 17-7-12 increased in top weight and visual quality when given the intermediate and high levels of Micromax compared to the decreased top weight and visual quality of plants given the 8.93 kg (15 lbs.) level of Osmocote 17-7-12.

TABLE VI

MICROMAX*OSMOCOTE INTERACTION FOR TOP WEIGHT AND VISUAL GRADE OF *PYRACANTHA* X 'MOJAVE'

(kg/m^3) Osmocote	MICROMAX (kg/m^3)		
	0.45	0.89	1.34
		Top Weight	
8.93	291.4^x	263.6	230.6
11.90	283.7	311.5	296.5
		Visual Grade	
8.93	8.7	8.0	7.5
11.90	8.5	9.2	8.8

^{x}Means are not significantly different at the 5% level.

Comparison II

Top and root weight, and visual grade of pyracantha grown with 0.45 and 0.89 kg/m^3 (0.75 and 1.5 $lbs./yd.^3$) Micromax in the oak chip mix were statistically greater than plants grown with the same Micromax treatments in the elm chips (Table VII). There were no differences in top weight and visual grade of plants grown in either elm or oak chip media with 1.34 kg/m^3 (2.25 $lbs./yd.^3$) Micromax. The simple effects of micromax within the elm chip media showed that greater top and root weights and visual grade were achieved when the rate was 1.34 rather than 0.89 kg/m^3, while the 0.45 kg/m^3 rate provided intermediate growth. Within the oak chip media, Micromax did not significantly effect top weight or visual grade, however, as Micromax increased, root weight decreased. Generally, pyracantha plants grown in oak chip media had greater top weight and visual grades than those grown in elm chip media.

All growth responses improved as the amount of Osmocote 17-7-12 applied to the media was increased from 8.93 to 11.90 kg/m^3 (15 to 20 $lbs./yd.^3$) although significant only for root weight, and yet growth was significantly reduced at the 14.88 kg (25 lbs.) rate for all responses (Table VIII).

Comparison III

The analysis of variance for Comparison III showed that growth media and fertilizer treatments had no effects on Formosan sweetgum growth.

Comparison IV

Top and root weight, and stem caliper showed that the 8.93 and

TABLE VII

MICROMAX*WOOD SPECIES INTERACTION AND WOOD SPECIES MAIN EFFECTS ON GROWTH OF PYRACANTHA X 'MOJAVE'

Wood Species	Micromax $(kg/m^3)^y$ 0.45	0.89	1.34	Main Effects of Wood Species[z]
		Top Weight		
Elm	$231.6^x ab_1$	$213.6\ a_1$	$276.2\ b_1$	$240.4\ _1$
Oak	$294.6\ a_2$	$303.7\ a_2$	$264.6\ a_1$	$287.6\ _2$
		Root Weight		
Elm	$148.7\ ab_1$	$125.9\ a_1$	$173.7\ b_2$	$149.4\ _1$
Oak	$192.6\ b_2$	$169.6\ ab_2$	$135.3\ a_1$	$165.8\ _1$
		Visual Grade		
Elm	$6.94\ a_1$	$6.61\ a_1$	$8.50\ b_1$	$7.35\ _1$
Oak	$8.94\ a_2$	$8.67\ a_2$	$7.78\ a_1$	$8.50\ _2$

[x]Means within a row with the same letter, or means within a column with the same number, are not significantly different.

[y]$LSD_{(0.05)}$ = 55.8 for simple effects for top weight.
= 42.8 for simple effects for root weight.
= 1.26 for simple effects for visual grade

[z]$LSD_{(0.05)}$ = 32.3 for main effects for top weight.
= 24.7 for main effects for root weight.
= 0.76 for main effects for visual grade.

TABLE VIII

EFFECTS OF OSMOCOTE 17-7-12 ON GROWTH OF *PYRACANTHA* X 'MOJAVE'

	Osmocote (kg/m^3)		
	8.93	11.90	14.88
Top Weight	264.2*ab	294.4 b	232.9 a
Root Weight	168.0 b	173.7 c	131.9 a
Visual Grade	8.0 ab	8.6 b	7.2 a

*Duncan's multiple range test. Means within a row followed by the same letter are not significantly different at the 5% level.

11.90 kg/m^3 (15 and 20 lbs./yd.^{3}) Osmocote rates were similar, and produced larger trees than the 14.8 kg/m^3 (25 lbs./yd.^{3})rate (Table IX). Formosan sweetgum trees were significantly taller with 8.93 kg/m^3 (15 lbs./yd.^{3}) Osmocote compared to 14.88 kg/m^3 (25 lbs./yd.^{3}) while 11.90 kg/m^3 (20 lbs./yd.^{3}) was intermediate. Top weights of trees given the 0.45 kg/m^3 (0.75 lbs./yd.^{3}) Micromax rate were significantly greater (200.4 g) at the 0.05 level than the 0.89 and 1.34 kg/m^3 (1.50 and 2.25 lbs./yd.^{3}) rates (160.5 g and 152.1 g, respectively).

TABLE IX

EFFECTS OF OSMOCOTE 17-7-12 ON GROWTH OF *LIQUIDAMBAR FORMOSANA*

	Osmocote 17-7-12 (kg/m^3)		
	8.93	11.90	14.88
Top Weight	189.3*b	198.0 b	125.6 a
Root Weight	83.5 b	75.2 b	51.1 a
Stem Caliper	0.9 b	0.9 b	0.7 a
Plant Height	93.6 b	90.3 ab	85.5 a

*Duncan's multiple range test. Means within a row followed by the same letter are not significantly different at the 5% level.

Growth Media Results

Generally, as time increased, elm chip media containing 1.19, 2.38, or 3.57 kg/m (2, 4, or 6 lbs./yd.) elemental sulfur, increased in pH (Table X). Elm media with no sulfur had no pH change over time. Each increasing sulfur level decreased the pH of elm media initially. As the growing season progressed, the effect of sulfur decreased and the pH of media containing sulfur approached the pH of media with no sulfur. However, only the high rate of sulfur at the end of the growing season maintained a significantly lower pH.

TABLE X

SULFUR*TIME INTERACTION FOR pH OF ELM CHIP MEDIA AT 8.93 KG/M^3 OSMOCOTE 17-7-12

Sulfur (kg/m^3)	Sampling Date			
	June	Aug.	Sept.	Nov.
0	6.7^x a_4	6.6 a_3	6.5 a_3	6.9 a_2
1.19	5.5 a_3	6.2 b_3	6.1 b_{23}	7.0 c_2
2.38	4.7 a_2	5.6 b_2	5.6 b_2	6.7 c_2
3.57	3.6 a_1	4.5 b_1	5.2 c_1	6.0 d_1

^{x}LSD = 0.53 for simple effects. Means within a row followed by the same letter, or within a column followed by the same number, are not significantly different at the 5% level.

Oak chip media containing 0 and 0.60 kg/m^3 (0 and 1 lb./yd.^{3}) sulfur had similar pH values (Table XI), yet as the amount of sulfur increased to 1.19 kg/m^3 (2 lbs./yd.^{3}), a significant drop in pH occurred.

The lowest pH value was measured when 2.38 kg/m^3 (4 lbs./yd.^{3}) sulfur was incorporated into the mix. The pH of oak chip media during the first two sampling intervals remained similar. Media pH significantly increased during the third and fourth sampling intervals (Table XI).

TABLE XI

EFFECTS OF TIME AND SULFUR FOR pH OF OAK CHIP MEDIA AT 8.93 KG/M^3 OSMOCOTE 17-7-12

Date	pH
June 28	5.2*a
Aug. 13	5.4 a
Sept. 29	5.7 b
Nov. 30	6.3 c

Sulfur	pH
0 kg/m^3	6.4 a
.60 kg/m^3	6.3 a
1.19 kg/m^3	5.9 b
2.38 kg/m^3	4.2 c

*Duncan's multiple range test. Means followed by the same letter are not significantly different at the 5% level.

Osmocote levels had no effect on pH of oak chip media for the first three sampling dates (Table XII). However, 14.88 kg/m^3 (25 lbs./yd.^{3}) Osmocote lowered media pH at the fourth sampling date compared to the other two levels. Media containing 8.93 kg/m^3 (15 lbs./yd.^{3}) Osmocote had similar values during the growing season until November when a significant increase occurred. Media containing the 11.90 kg/m^3 (20 lbs./yd.^{3}) rate in June and September had the same pH which was higher than that seen in August.

TABLE XII

OSMOCOTE*TIME INTERACTION FOR pH OF OAK CHIP MEDIA AT ZERO SULFUR LEVEL

Osmocote (kg/m^3)	Sampling Date			
	June	Aug.	Sept.	Nov.
8.93	6.2^{x}a$_1$	6.0 a$_1$	6.3 a$_1$	7.0 b$_2$
11.90	6.5 b$_1$	6.0 a$_1$	6.4 b$_1$	7.2 c$_2$
11.88	6.3 a$_1$	6.3 a$_1$	6.2 a$_1$	6.4 a$_1$

^{x}LSD = 0.04 for simple effects. Means within a row followed by the same letter, or within a column followed by the same number, are not significantly different at the 5% level.

Pine bark media containing 11.90 kg/m^3 (20 lbs./yd.^{3}) Osmocote 17-7-12 had lower pH values than the 8.93 kg/m^3 (15 lbs./yd.^{3}) treatments (5.6 and 5.3, respectively). Time had no effect on pH of pine bark media.

Time, sulfur, and Osmocote had no significant effects on the soluble salt content of the selected media treatments. The means for elm and oak media were 0.344 and 0.381 mmhos/cm, respectively.

The average percent drainable pore space of newly prepared elm chip media was 67.9%. Elm chip media at the end of one growing season had an average of 17.2% drainable pore space. Similarly, newly prepared oak chip media had an average percent pore space of 71.1% and 20.4% after one growing season.

Results of the available and total elemental content of elm and oak chips and pine bark are listed in Table XIII. Ca and Mg content in elm and oak chips were greater than in pine bark. There were no differences in total K among the wood species. Pine bark had a greater Fe content than either elm or oak chips which were similar. Oak chips had the highest amount of total Mn while elm chips had the lowest.

TABLE XIII

MINERAL COMPOSITION OF ELM AND OAK CHIPS AND PINE BARK

Wood Species	Mineral Element				
	-------------%-------------			------ppm------	
	K	Ca	Mg	Fe	Mn
			Total[x]		
Elm	0.18	0.80	0.05	42	19
Oak	0.10	0.92	0.06	24	227
Pine	0.05	0.47	0.04	198	130
$LSD_{.05}$	NS	0.161	0.013	53.0	87.1
			Available[y]		
Elm	0.08	0.20	0.03	13	14
Oak	0.04	0.13	0.05	9	183
Pine	0.03	0.09	0.02	36	63
$LSD_{.05}$	0.00[z]	NS	0.018	11.8	54.9

[x]Determined from ashed materials.
[y]Minerals obtained from dilute acid extraction.
[z]There was no variation among replications.

Oak chips had high levels of available Mg and Mn compared to elm chips or pine bark. Pine bark had greater amounts of available Fe than either elm or oak chips. There were no differences for percent available K and Ca among the wood species.

CHAPTER V

DISCUSSION

The addition of elemental sulfur to elm and oak chip media lowered pH values below the optimum composting range of 6.5 to 8.5. At low pH values, percent drainable pore space should not decrease if decomposition is inhibited. The large differences measured in drainable pore space for newly prepared media compared to that measured after one growing season suggests that decomposition of elm and oak chips did occur regardless of the incorporation of sulfur. It should be noted, however, that during the time interval from September to November, media pH increased to an average value above 6.5.

Elm and oak chip media containing sulfur increased in pH as the growing season progressed. This is similar to the findings of Gartner et al. in several studies (8, 10, 11) though they did not include sulfur in such high concentrations. The pH of elm media when no sulfur was incorporated did not change during the growing season. Raker and Hoitink (22) reported that the pH of their hardwood bark media remained nearly the same after two growing seasons.

Sulfur added to the elm and oak chip media had no positive effect on the growth of pyracantha and Formosan sweetgum. In fact, the sulfur treatments often decreased plant growth of both species. These results were due to the high concentrations of sulfur which lowered media pH. In contrast, Klimkowski and Whitcomb (16) reported that 3.57 kg/m^3 (6 lbs./yd.) elemental sulfur incorporated in their elm chip medium stimulated plant growth of Euonymus kiautschovica 'Manhattan' and Ilex crenata 'Hetzi'.

Several researchers have studied the use of hardwood bark in container media because it is a by-product of pulp industries. On the other hand, very few workers have investigated the use of hardwood chips in growth media. Still and Gartner (31) used white oak wood chips to grow Chrysanthemum morifolium 'Princess Anne' and reported that better growth occurred at the 14.88 kg/m^3 (25 $lbs./yd.^3$) Osmocote level compared to lower rates. However, the Osmocote formulation they used was not reported. In this study, pyracantha and Formosan sweetgum growth in elm and oak chip media containing 8.93 kg/m^3 (15 $lbs./yd.^3$) Osmocote 17-7-12 was generally equal to or greater than growth in media containing the 11.90 kg/m^3 (20 $lbs./yd.^3$) level. This suggests that the use of more than 1.52 kg/m^3 (2.55 $lbs./yd.^3$) of actual nitrogen in a slow release form may not be required for production of pyracantha and Formosan sweetgum. This rate was sufficient for both plant growth and media decomposition.

Mineral composition of hardwood materials reported by several investigators varied for certain elements (Table I, p. 11). It was suggested that these differences were due to the use of different wood species. In addition, laboratory procedures and instrument capabilities could cause some of this variation in results. The pine bark, elm or oak chips analyzed in this study did not possess the high percentage of Ca reported by Gartner et al. (11) and other researchers (7, 27, 28, 31).

Still and Gartner (31) were the only researchers to analyze wood chips for mineral composition. The mineral content of the post oak chips in this study can be compared more directly with their results for white oak wood chips. The chips of both oak species were similar in content for all elements except Ca. White oak chips contained 3.64% Ca dry weight while post oak chips had only 0.90% Ca dry weight.

Pyracantha and Formosan sweetgum grown in elm and oak chip media showed no micronutrient deficiency symptoms during the growing season. This was due to the presence of micronutrients supplied by Micromax and not due to the micronutrients present in the wood components as suggested by Gartner et al. (11). Although micronutrients were present in the wood chips, only small amounts were directly available for plant growth.

Milbocker and Palmer (20) reported that Mn was leached from their hardwood bark media more readily than Fe and that Fe was unavailable to plants. Results from this study demonstrate that 183 and 63 ppm Mn was available compared to 9 and 36 ppm Fe for oak chips and pine bark, respectively. The occurrence of the Fe deficiency reported by Milbocker and Palmer may have been prevented by incorporating Micromax micronutrients in the container media which maintained the Fe:Mn ratio in a more favorable proportion.

The results of this experiment suggest that elm chip media may need higher rates of Micromax micronutrients than oak chip media. Pyracantha growth in elm chip media was greatest when it contained the 1.34 kg/m^3 (2.25 $lbs./yd.^3$) Micromax level, though this was significant only for visual grade at the 0.05 level. On the other hand, growth of pyracantha in oak chip media and Formosan sweetgum in elm and oak chip media containing the 0.45 kg/m^3 (0.75 $lbs./yd.^3$) rate was equal to or greater than that containing the higher rates. The 0.45 kg/m^3 (0.75 $lbs./yd.^3$)

Micromax level was sufficient for plant growth in oak chip media yet depending on the plant species being produced, higher levels may be required for growth in elm chip media.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Siberian elm, Ulmus pumila, and post oak, Quercus stellata, were studied to determine their potential as components in soilless container media. To obtain a nutritional program which would support plant growth in these media, treatments included various levels of Osmocote 17-7-12, a slow release fertilizer, and Micromax, a micronutrient fertilizer. Moreover, various amounts of elemental sulfur were incorporated to lower media pH in an attempt to reduce microbial decomposition.

Results of this investigation suggest that chips from elm and oak in Oklahoma can be used successfully as components in soilless media. Growth of Formosan sweetgum trees and Mojave pyracantha grown in oak and elm chip media equalled that in a standard pine bark media.

The percent drainable pore space of the media after one growing season remained acceptable although it drastically decreased from the beginning of the study. This suggests that media structural characteristics were adequate for plant growth. Sulfur, incorporated into the mix, did not affect drainable pore space yet it significantly lowered pH. Plant growth in media containing sulfur was poor. Growth of both species was best when no sulfur was added.

For Formosan sweetgum and pyracantha grown in elm and oak chip media, 8.93 kg/m^3 (15 $lbs./yd.^3$) Osmocote 17-7-12 was found to provide the best plant growth. Generally, the best Micromax micronutrient fertilizer level for oak and elm chip media was 0.45 kg/m^3 (0.75 lbs./ yd.^{3}). Contrary to this, pyracantha in elm chip media grew best when 1.34 kg/m^3 (2.25 lbs./yd.^{3}) Micromax was incorporated.

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