Table 3. Soil and air temp measured inside (IN) and outside (OUT) the experimental greenhouse. "Single" and "Double" indicate a single layer and double layer of plastic covering, respectively. Heating cables were used to simulate the warm water pipes.

Date and time	Air temp (°C)			Soil temp (°C)			
						Depth: 51 cm	
	OUT	IN		Depth: 2.5 cm		Cable temp	Midpoint between cables
		Single	Double	OUT	IN		
March 8							
0000	2.0	4.6	6.6	4.5	14.6	37.0	20.5
0200	1.6	2.8	5.0	3.8	13.0	37.3	20.5
0400	0.3	2.0	4.1	3.2	11.9	37.6	20.6
0600	0.2	1.4	3.5	2.7	11.0	36.3	20.6
0800	2.7	9.0	11.7	4.2	11.5	35.2	20.6
1000	8.3	23.5	27.0	8.4	16.2	36.7	20.6
1200	12.5	32.1	36.8	11.1	22.2	37.3	20.6
1400	16.3	36.4	41.0	12.2	26.4	38.4	20.6
1600	15.7	28.6	32.1	12.2	26.9	35.3	20.6
1800	12.7	18.1	20.7	10.7	23.8	35.0	20.6
2000	11.4	13.3	15.4	9.2	20.7	34.9	20.6
2200	9.8	11.2	13.0	8.3	18.7	37.7	20.6
2400	8.2	9.1	11.0	7.5	17.2	35.3	20.6
Avg	7.8	14.8	17.5	7.5	18.0	36.5	20.6
March 10							
0000	8.0	9.1	11.0	7.5	17.2	35.3	20.6
0200	8.7	9.8	11.4	7.8	16.2	35.0	20.6
0400	8.1	9.1	10.6	7.4	15.6	37.9	20.6
0600	7.6	8.8	10.3	7.4	15.0	37.8	20.6
0800	9.4	11.5	12.7	8.7	15.2	37.4	20.6
1000	10.2	14.5	15.9	10.0	16.7	36.6	20.7
1200	11.4	18.0	19.4	11.8	18.4	37.6	20.7
1400	11.7	17.1	18.5	11.6	19.2	35.1	20.7
1600	11.7	15.5	17.0	11.2	19.2	36.7	20.7
1800	11.7	13.4	14.8	10.6	18.3	38.0	20.7
2000	11.6	12.5	13.5	10.1	17.2	37.2	20.7
2200	11.9	11.3	12.3	9.5	16.6	34.8	20.7
2400	11.9	11.5	12.4	9.7	16.1	37.1	20.7
Avg	10.3	12.5	13.8	9.5	17.0	36.7	20.7

Average daily profile temp to a depth of 100 cm were obtained by averaging the temp measured at several positions at each hr over a 24-hr period. These were 7.2°C and 18.2° on March 8 and 7.4° and 19.3° on March 10, outside and inside the greenhouse respectively. The soil temp were thus substantially increased. These temp differences decreased as the soil outside the greenhouse warmed up. The average daily profile temp in the greenhouse however, was still 8 to 10° higher in early June.

Maintaining heat source temp of about 36°C with heat sources at a depth of 52 cm, and spaced 122 cm apart increased the average daily profile soil temp about 11° over outside temp. The effect on air temp was less than 3°. The soil warming system can not deliver sufficient energy to keep the air temp above freezing when outside air temp fall below this level unless the pipes are near the soil surface and close together. The proposed system can not be used where heating of the air is required, but may be useful for those conditions where initial rapid warming of the soil in the spring is required. The economic feasibility of the proposed practice can be assessed by comparing the cost of owning and operating the oil warming system with the yield increases that may result from it. These increases in yield attributable to this practice must be determined for local conditions.

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Physical Properties of Hardwood Bark Growth Media[1]

A. R. Mazur[2], T. D. Hughes[3], and J. B. Gartner[4]

University of Illinois, Urbana

Abstract. **Physical properties of various hardwood bark-soil mixes for containers were compared to a soil-peat-perlite mix. Bark-soil mixes containing a wide range of bark particle sizes were found to possess superior physical properties initially and remained satisfactory after a 13-month incubation period. However, bark-soil mixes were much less stable and deteriorated to a significantly greater extent. For golf greens, physical properties of hardwood bark or peat and soil and sand mixes were studied following compaction at 40 cm moisture tension. Initially, the bark mixes were superior and this was postulated to be due to a more uniform distribution of bark within the mixes. Based on the deterioration that occurred in bark-soil mixes for containers, it is concluded that use of hardwood bark in golf green mixes does not appear feasible.**

Debarking operations in the primary forest products industry are producing large quantities of bark and wood fiber residues. These residues pose a difficult disposal problem, and recent regulations on air pollution are forcing many operators to abandon burning as a means of disposal. Finding beneficial uses for these residues constitutes a logical approach to the problem. Bark residues have been found beneficial as soil amendments for container-grown plants (3, 4) and the possibility exists that they can be used to advantage in golf green mixes.

Information about physical

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[2] Former Research Assistant (now Assistant Professor of Turfgrass Management, Horticulture Department, Clemson University, Clemson, South Carolina).

[3] Assistant Professor of Turfgrass Management, Horticulture Department.

[4] Professor of Ornamental Horticulture, Horticulture Department.

properties of mixes containing hardwood bark is very limited; however, information for softwood barks is more readily available. Bollen (1) reported essentially equal bulk densities, porosities, moisture retentions and air space after drainage in a comparison of sphagnum peat + fine sand and redwood bark + fine sand. The porosity, moisture retention, and air space after drainage of the fine sand were increased and the bulk density decreased by both amendments. Thurman and Pokorny (6) have reported increased growth and recovery from cold treatment of 'Tifgreen' bermudagrass in milled pine bark mixed with soil as compared to soil alone when compaction pressures were applied.

The objectives of these studies were to describe the physical properties of various mixes containing various particle sizes and/or proportions of hardwood bark and to determine the effects of aging and compaction.

Containers

Hardwood barks of 2 different ages (January and July) were mixed with Drummer silty clay loam soil in the proportions of 2/3 bark and 1/3 soil by volume. The January bark came from logs harvested in January and was fresh whereas the July bark had been removed from logs harvested the previous July and piled outside for 6 months prior to initiation of this study. Particle size distributions are presented in Table 1. Species composition was the same with oak (*Quercus* sp.) predominating (3).

Various bark particle sizes were separated out and used as well as the ungraded materials. The separations were: all particles less than 1.6 and 0.8, and greater than 6.4, 3.2, 1.6, and 0.8 mm diam removed (<1.6R, <0.8R, >6.4R, >3.2R, >1.6R, >0.8R). A slow-release fertilizer, 14-6.1-11.6 (N-P-K) Osmocote, was added at the rate of 4.9 kg/m^3. A soil-peat-perlite mix (SPP) was also included.

All mixes were placed in acrylic plastic cylinders 10.2 cm diam by 30.5 cm high. The cylinders were filled to a depth of 15.2 cm thus creating a mix volume of 1240 cm^3. Brass screens were placed at both ends of the mixes.

Bulk density determinations were made by weighing the cylinders and correcting for moisture content. After soaking for 72 hr water flow rates were determined with a 30.5 cm hydraulic head. Volumes of water passing through the sample in 30 sec were determined and recorded in cm/hr. After allowing drainage to occur until the water level was at the surface of the mix, the cylinders were weighed and the amount of water present determined by comparing this to the oven dry weight. This was then expressed on a % by volume basis and labeled, total porosity. Air was then passed through the samples until the excess water was expelled and air permeability determined by measuring the time required for a 40.6 to 20.3 cm change in hydraulic head to occur as described by Reeve (5). The samples were then weighed and moisture holding capacity determined in the same manner as total porosity. Moist porosity was determined as the difference between total porosity and moisture holding capacity. The moist samples were then incubated at 25° ± 2°C for 13 months and the water flow rates determined as previously described. The data was analyzed statistically as a completely randomized design with 2 replications.

Table 1. Particle size distribution for bark sources.

Particle size (mm)	Distribution (% by wt) January (fresh)	 July (aged)
>12.8	.4	trace
6.4 - 12.8	4.5	2.7
3.2 - 6.4	21.6	12.9
1.6 - 3.2	21.4	23.8
0.8 - 1.6	12.8	18.0
0.5 - 0.8	16.1	10.8
<0.5	22.0	31.8

The average bulk density of bark mixes was .50 g/cm^3 as compared to .61 g/cm^3 for SPP and only 1 bark mix bulk density exceeded .61 g/cm^3 (Table 2). The moisture holding capacities were found to vary over a wide range and the mixes with <1.6R and <.8R particle sizes for both barks possessed extremely low moisture holding capacities (Table 2). In contrast to this, bark mixes such as >1.6R and >.8R from the January source were shown to have extremely large moisture holding capacities. Most other bark mixes possessed moisture holding capacities similar to SPP. The total porosities of bark mixes were at least as great as that for SPP (Table 2). However, the reverse was found in several instances for moist porosities and the moist porosity of >.8R January was especially inferior. The water flow rates (water permeability) and air permeability for bark mixes were in most cases superior to SPP (Table 2). The only exceptions were those mixes lacking large bark particles.

The physical properties of bark mixes were quite acceptable even though some exceptions were noted when either the extremely large or extremely small particles had been removed. Invariably, the measurements indicated that mixes containing ungraded bark were superior to SPP. These conclusions however, were drawn strictly on the basis of initial properties and provided no indication as to how long bark mixes retain satisfactory physical properties.

A single physical property, water flow rate was measured after 13 months of incubation. Water flow rates were much slower in most of the mixes as compared to initial rates, however, the extent of the decrease varied considerably (Table 2). The changes in the January bark were much greater than the July bark which would be expected in view of the fact that the January bark had undergone no decomposition prior to being mixed with soil whereas the July bark was 6 months old. Likewise, since peat has been subjected to extensive decomposition, the water flow rate for SPP was relatively stable. In some instances, large increases in water flow rates were measured. It is thought that these increases are due to decomposition of small bark particles thus resulting in formation of voids in the mixes. Under actual growing conditions, repeated surface watering would probably cause sufficient particle movement and reorientation to close these voids.

The data also indicate that ungraded July was the most satisfactory of the bark mixes. Although the water flow rate for this mix was nearly double that for SPP after 13 months incubation, the difference was not statistically significant. More importantly, the decrease in water flow rate during this 13-month period 3.5 times greater for this mix than for SPP and was statistically significant. Thus, the physical properties of this bark mix are less stable than SPP and eventually this mix can be expected to possess a lesser permeability to water than SPP.

Golf greens

Water flow rates and capillary and noncapillary porosities of 24 different mixes were determined. These mixes contained varying proportions of sand (particle size distribution; 31% between 0.32 and 0.16 cm, 51% between 0.16 and 0.08 cm, and 18% between 0.08 and 0.5 cm), Drummer silty clay loam soil, and hardwood barks with all particles less than 0.32 cm of Sphagnum peat from Canadian bogs.

The mixes were placed in polyvinylchloride cylinders 7.6 cm high by 7.6 cm diam with a double thickness of cheesecloth covering one end. They were saturated with water and allowed to come to equilibrium for 24 hours and then brought to 40 cm tension on a tension table prior to compaction. An impact type compactor was used to subject the mixes to 30.7 cm-kg/cm^2 surface area (2).

Measurements of water flow rates were made under saturated conditions (5) using a 1.27 cm hydraulic head. The samples were weighed at saturation, 40 cm moisture tension, and oven dry (constant weight at 45°C) and capillary

Table 2. Physical properties of soil-peat-perlite and hardwood bark-soil mixes.

Mix	Bulk density (g/cm^3)	H_2O holding capacity (% by vol)	Porosity (% by vol)		Air permeability (sec)	H_2O flow rates, (cm/hr)	
			Total	Moist		Initial	Final^z
SPP	.61	32.4	60.2	27.8	12.0	704	594
July (aged)							
ungraded	.49	32.4	60.9	28.5	4.7	1524	1148
<1.6 R	.40	23.2	61.6	38.4	2.0	4031	4039
<0.8 R	.43	27.8	63.6	35.8	3.3	2774	2626
>6.4 R	.46	32.2	63.6	31.4	4.4	1816	1613
>3.2 R	.47	34.3	61.0	26.7	7.5	1029	488
>1.6 R	.52	34.2	62.2	28.0	9.0	871	521
>0.8 R	.48	34.4	62.2	27.8	9.5	650	1643
January (fresh)							
ungraded	.50	35.3	64.1	29.8	4.3	1191	450
<1.6 R	.49	27.3	65.8	38.5	2.7	1224	1742
<0.8 R	.51	30.4	65.3	34.9	3.5	2540	800
>6.4 R	.50	33.3	65.1	31.8	4.3	1910	953
>3.2 R	.50	36.1	65.9	29.8	7.3	968	475
>1.6 R	.52	37.6	63.7	26.1	11.7	500	762
>0.8 R	.68	39.8	61.8	22.0	14.3	381	203
LSD, 5% level	.03	1.6	2.5	3.1	2.2	318	754

^{z}Measurements taken after 13 months incubation.

and noncapillary porosity calculated.

The data was analyzed statistically as a randomized complete block design with 2 replications.

Water flow rates increased with increasing proportions of sand, bark, and peat, however the effects of bark as compared to peat depended on sand content (Table 2). No differences between bark and peat were noted at a sand content of 80% but at lesser sand contents, bark was more effective in increasing water flow rates than peat. Apparently, in mixes containing less than 80% sand the proportions of bark and peat were sufficient to detect the differences. All mixes except those containing 25, 30, or 35% peat and 50% sand exhibited water flow rates greater than 2.54 cm/hr which was greater than the 1.27 cm/hr at .63 cm hydraulic head established by Ferguson (2) as the minimum acceptable flow rate for golf green mixes.

The water flow rate determinations also indicate that it is not advisable to include more than about 25% of a silty clay loam soil. Lesser amounts of soil are preferred as mixes containing 20% soil almost always exhibited significantly greater flow rates (Table 3). The amount of soil was more critical in peat mixes than in bark mixes. The water flow rates were reduced significantly by lesser amounts of soil in peat mixes and slightly larger proportions of sand were needed to obtain flow rates equivalent to those in bark mixes.

Noncapillary porosities of bark and peat mixes were not statistically different, but water flow rates were greater for bark mixes (Table 3). Thus, the increased water flow rates in bark mixes could not be explained on the basis of correspondingly greater noncapillary porosities. We postulate that the differences in water flow rates were due to the bark consisting of individual particles whereas there was some aggregation in the peat. The result was a more uniform distribution of bark and therefore a more uniform distribution of noncapillary pore spaces in bark mixes.

Capillary porosity of all mixes were within the range established by Ferguson (2) of 15 to 27% except the peat mixes with 50% sand and bark mixes with 80% sand (Table 3). The noncapillary porosities were either within or exceeded the range of 12 to 18% which was also established by

Table 3. Water flow rates, capillary porosity, and non-capillary porosity for various mixes.

Sand (% by vol)	Bark (% by vol)								Peat (% by vol)							
	0	55	10	15	20	25	30	35	0	5	10	15	20	25	30	35
Water flow rates (cm/hr)																
50	–^{z}	–	–	–	–	4.6ab^y	5.8a	7.9a	–	–	–	–	–	0	0	0
60	–	–	–	5.6d	11.4b	16.3a	–	–	–	–	–	5.8d	7.9cd	10.7bc	–	–
70	–	4.1e	16.5b	22.4a	–	–	–	–	–	5.1de	9.7cd	11.9c	–	–	–	–
80	22.4b	34.3a	37.1a	–	–	–	–	–	24.4b	33.3a	37.3a	–	–	–	–	–
Non-capillary porosity (%)																
50	–^{z}	–	–	–	–	14.3b^y	–	–	–	–	–	–	–	13.7b	13.8b	19.1a
60	–	–	–	14.1c	17.8abc	20.6a	–	–	–	–	–	15.8bc	19.2ab	20.9a	–	–
70	–	12.8c	18.6bc	27.8a	–	–	–	–	–	15.6bc	18.2bc	22.1ab	–	–	–	–
80	17.8d	22.2bc	24.1ab	–	–	–	–	–	17.8d	20.6c	25.1a	–	–	–	–	–
Capillary porosity (%)																
50	–^{z}	–	–	–	–	26.1c^y	–	–	–	–		–	–	30.4b	35.5a	35.0a
60	–	–	23.6b	22.5b	22.5b	21.6b	–	–	–	–		25.5a	25.8a	27.1a	–	–
70	–	19.1a	17.2a	–	–	–	–	–	–	19.3a	15.4a	21.0a	–	–	–	–
80	14.4ab	14.0ab	–	–	–	–	–	–	14.4ab	15.8ab	16.4a	–	–	–	–	–

^{z}Indicates no determination made.

^{y}Mean separation (in rows) by Duncan's multiple range test, 5% level.

Ferguson (2). Mixes containing 60 to 70% sand, 15 to 20% peat or bark, and 15 to 20% soil were quite desirable and bark was at least as effective as peat. However, this study evaluated the initial properties only and based on the study of mixes for containers, it is reasonable to expect that hardwood bark mixes are much less stable. Due to this lack of stability and the fact that golf greens are constructed to last for many years, use of hardwood bark in golf green mixes does not appear feasible.

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Hardwood Bark as a Soil Amendment for Suppression of Plant Parasitic Nematodes on Container-grown Plants[1]

R. B. Malek and J. B. Gartner[2]

University of Illinois, Urbana-Champaign

Abstract. **Hardwood bark as a soil amendment for container-grown plants suppressed several species of parasitic nematodes in greenhouse tests. Volumetric bark to soil ratios of 4:1, 2:1, 1:1 and 1:2 greatly reduced incidence of root-knot caused by *Meloidogyne hapla* Chitwood and *M. incognita* (Kofoid and White) Chitwood on tomato (*Lycopersicon esculentum* Mill.). A 2:1 bark to soil mixture inhibited galling by *M. incognita* and population development of *Pratylenchus penetrans* (Cobb) Filipjev and Schuurmans Stekhoven and *Trichodorus christiei* Allen on *Forsythia intermedia* Zabel.**

Hardwood bark has been a waste material of the wood products industry. Costly disposal problems and recent regulations against elimination by burning have stimulated a search for uses for this timber by-product. The potential value of this material in media for growing ornamentals in containers has been demonstrated by several workers (1, 3, 4, 5, 6, 7, 8).

Plant-parasitic nematodes can be a problem on container-grown plants, particularly when the growing medium is not sterilized or infected plants are introduced into sterile media. Many types of organic matter, when incorporated into soil, suppress parasitic nematode populations (9, 10), but the effects of hardwood bark on nematodes have not been investigated. This study was undertaken to determine the influence of hardwood bark on populations of several nematode species with different feeding habits.

Initially, 4 ratios of bark to soil were tested against 2 species of *Meloidogyne* (root-knot nematodes), which are sedentary endoparasites of a wide variety of ornamental plants. Bark was a commercial ground mixture of several hardwood tree species (Table 1) with particle size ranging from less than 0.5 to 12.7 mm (Table 2). The bark was composted for 30 days and was used without sterilization. Soil was a steam-pasteurized loamy fine sand. Components were mixed together in a twin-arm dry blender in appropriate amounts to produce volumetric bark to soil ratios of 4:1, 2:1, 1:1 and 1:2. *Meloidogyne hapla* (northern root-knot nematode) and *M. incognita* (southern root-knot nematode) were reared in the greenhouse on 'Rutgers' tomato. Infective larvae for inoculation of the media were extracted from roots under mist (11).

Table 1. Tree species represented in hardwood bark used in experiments.

Species	% by volume
Eastern cottonwood	21
Pin oak	13
Black oak	5
Other oaks (red, white, shingle)	17
White ash	5
Silver maple	15
Hickory (shellbark, pignut, shagbark)	5
Elm (American, red)	3
Sycamore	2
Miscellaneous other^{z}	14

^{z}Approx equal amounts of yellow poplar, river birch, sugar maple, bigtooth aspen, black willow, black cherry, sassafras and red gum.

Table 2. Particle size distribution in hardwood bark used in experiments.

Particle diam (mm)	% by wt
6.4 - 12.7	2.4
3.2 - 6.4	17.6
1.6 - 3.2	18.4
0.7 - 1.6	14.7
0.5 - 0.7	21.6
<0.5	25.3

A 4-week-old 'Rutgers' tomato seedling was transplanted into each of twenty-four 15-cm clay pots containing 1400 cc of bark-soil mixture/pot. During transplanting a 10-ml suspension of 2000 nematode larvae was pipetted just beyond the boundary of the root system of the plant. There were 6 replications of each ratio. The controls consisted of 12 additional pots with a like amount of steamed soil alone and 1 seedling/pot. Half of these pots were inoculated as described above and half received 10 ml of decant water/pot from the nematode storage beaker.

Pots were arranged in randomized complete block designs on a greenhouse bench and watered as necessary. In the *M. hapla* test conducted in May and June, each pot received 250 ml of a 20–8.6–16.7 (N–P–K) soluble fertilizer twice weekly. Fertilizer concn were 600, 500, 400 or 300 ppm N for the highest bark ratio to the lowest, respectively. Pots with soil alone received 200 ppm N. In the *M. incognita* test conducted in July and August, a slow-release fertilizer (18–2.6–5.2, N–P–K) was incorporated into the bark at the rate of 4.5 kg/m^3 prior to mixing with the soil. Once a week, these pots received 250 ml of soluble fertilizer at 200 ppm N. Six weeks after transplanting, tomato roots were carefully washed free of growing medium and examined for nematode infection.

Amendment of soil with bark significantly (P=1%) reduced galling by both species of root-knot nematodes (Table 3). The no. of galls caused by *M. hapla* was reduced 75-86% and those by *M. incognita* 94-99%. There were no significant differences in degree of gall suppression among the various ratios of bark to soil. Galls were widely scattered among roots in bark treatments, and each swelling usually contained a single nematode. Developing galls from second generation nematodes were scarce. In pure soil, galls from first generation nematodes were often contiguous on

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[2] Assistant Professor of Nematology, Department of Plant Pathology; and Professor of Ornamental Horticulture, Department of Horticulture, respectively.