Physical Properties of Container Media and Relation to Severity of Phytophthora Root Rot of Rhododendron

B.H. Ownley[1], D.M. Benson[2], and T. E. Bilderback[3]
Department of Plant Pathology, North Carolina State University, Raleigh, NC 27695-7616

Additional index words. air space, bulk density, *Phytophthora cinnamomi*, pine bark, *Rhododendron*, total porosity

Abstract. One-year-old *Rhododendron* L. 'Nova Zembla' were grown in four container media infested with *Phytophthora cinnamomi* Rands. The media (all v/v) were pine bark, 3 pine bark :1 sand, 3 pine bark :1 peat, and 1 peat : 1 sand : 1 soil. After 20 weeks, plants were evaluated for root rot symptoms and the total porosity, air space, moisture-holding capacity, and bulk density were determined for all media. All media provided adequate moisture-holding capacity for container production of rhododendron in noninfested media. Shoot fresh weight in noninfested media was positively correlated with bulk density and water (percent by volume) held in the 1.0- to 5.0-kPa matric tension range and negatively correlated with total porosity and air space. Root rot severity was greatest in peat : sand : soil, intermediate in pine bark : peat, and least in pine bark and pine bark : sand. Root rot severity was negatively correlated with total porosity and air space and positively correlated with bulk density and water (percent by volume) held in the 5.0- to 10.0-kPa matric tension range.

Phytophthora cinnamomi causes a serious root and crown rot disease of rhododendron in the United States (Benson, 1982; Hoitink and Schmitthenner, 1974). Plant stress resulting from prolonged medium saturation increases the severity or occurrence of root rot caused by *P. cinnamomi* in normally resistant *Rhododendron* sp. (Blaker and MacDonald, 1981). Plants with roots in an oxygen-deficient environment are less able to withstand the effects of Phytophthora root rot compared to plants in a well-drained medium. This reaction is due to impaired generation and growth of new roots (Blaker and MacDonald, 1981; Filmer et al., 1986; Stolzy et al., 1965), increased root exudation of substances that attract zoospores (Kuan and Erwin, 1980) and stimulate germination of chlamydospores of *P. cinnamomi* (Mircetich et al., 1968), and disruption of metabolic pathways involved in host resistance (Blaker and MacDonald, 1981). Saturated soil conditions also favor reproduction and pathogenicity of *P. cinnamomi* (Kenerley et al., 1984) due to matric tensions in media that favor sporangium formation and release and motility of zoospores (Benson, 1984; Gintis and Benson, 1986).

The water-holding capacity, total porosity, and air space of a container medium can be described in terms of matric tension with a moisture retention curve (DeBoodt and Verdonck, 1972; Fonteno et al., 1981). These characteristics have been investigated primarily for their effect on plant growth (Bilderback et al., 1982; DeBoodt and Verdonck, 1972; Fonteno et al., 1981; Tilt et al., 1987; Tomlinson and Bilderback, 1985), and not severity of root rot diseases.

We determined the effects of bulk density, total porosity, air space, and moisture-holding characteristics of four container media on growth response of 'Nova Zembla' rhododendron and severity of Phytophthora root rot.

Materials and Methods

Four container media were prepared with commercial grade, hammermilled pine bark (Summit Lumber, Louisburg, N.C.), Canadian sphagnum peat, sand, and a sandy loam soil [68% sand, 17% silt, 15% clay (Day, 1965)]. Media were pine bark (PB), 3 pine bark : 1 sand (v/v) (PBS), 3 pine bark : 1 peat (v/v) (PBP), and 1 peat : 1 sand : 1 soil, (by volume) (PSS). Dolomitic lime at 1.2 kg·m^{-3}, triple superphosphate (0N–44P–0K) at 1.2 kg·m^{-3}, micronutrients (C-trel, Coor Farm Supply, Smithfield, N. C.) at 0.9 kg·m^{-3} and S-coated fertilizer (21N-6P-12K) at 0.5 kg·m^{-3} were incorporated into all media.

Size distribution of medium particles was determined using oven-dried cores of medium and roots removed from the containers at the conclusion of the experiments. Core samples were placed in a Ro-Tap shaker and rotated at 160 r·min^{-1} for 3 min onto U.S. standard sieves with mesh openings of 6.3, 4.00, 2.80, 2.00, 1.40, 1.00, 0.710, 0.500, 0.355, 0.250, 0.180, and 0.106 mm. Particles that passed through these screens were also collected. The quantity of medium collected on each screen was weighed and the data prepared in the form of a summation curve (Bilderback et al., 1982).

One-year-old plants of 'Nova Zembla' rhododendron were potted into 6-liter polyvinyl containers on 8 and 30 May and placed on drip irrigation under 50% shade for 20 weeks at University Research Unit 4, Raleigh. Plants were watered to saturation once every 2 days between 1030 and 1200 HR for 0.5 hr.

Five isolates of *P. cinnamomi,* 100 (from H.A.J. Hoitink, Ohio State Univ.), 101 (ATCC 46292), 116, 128, and 150 were grown separately on sterile, moistened oat grains [1 dry oats : 1 demineralized water (v/v)] in 20- × 30-cm disposable autoclave bags and combined at the time of infestation. Oat cultures were maintained at 25C for 4 weeks before infestation of container media. *Phytophthora cinnamomi* was added 4 weeks after potting, at the rate of 9 colonized oat grains per container. The inoculum was divided among three sites around the periphery of the root ball at a depth of 2.5 to 5 cm. Controls received no inoculum.

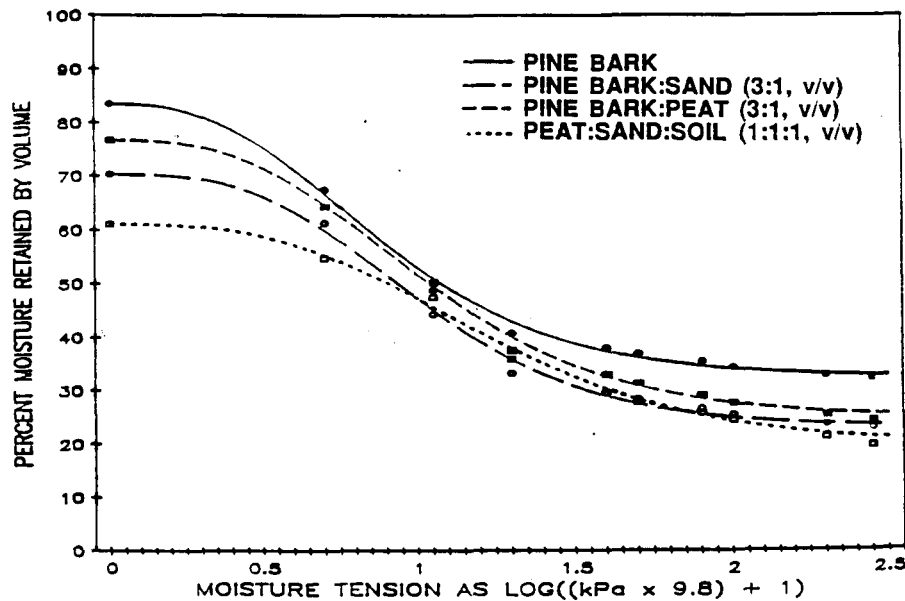Root rot severity of each plant was evaluated after 20 weeks.

Fig. 1. Moisture retention, curves for noninfested container media potted with rhododendron. Actual value means of five replications are represented by symbols on the predicted curves. Data shown for Trial 1.

A rating scale of 1 to 5 was used, with 1 = healthy, 2 = necrosis and discoloration of feeder roots, 3 = necrosis of larger roots, 4 = stem necrosis, and 5 = dead, plant. Infection by *P. cinnamomi* was confirmed by culturing washed root samples from each plant (five 1-cm^3 clumps per plate) on a semi-selective medium for *Phytophthora* (Eckert and Tsao, 1962). Shoot fresh weights also were recorded.

The experimental design was a 4 x 2 factorial in a randomized complete block. The experiment was repeated twice with five replications and two observations per replicate. Both observations were used for disease assessment, while only one observation of each replicate was used for physical properties determinations. The results of the two trials are similar. Unless significant differences between the two trials existed, only data for trial 1 are shown.

After 20 weeks, total porosity, air space, and water-holding characteristics were determined for each medium. A 347.5-cm^3 core of medium and roots was removed from each of five replicate containers. A porous pressure plate apparatus and procedures as reported by Fonteno et al. (1981) were used to determine the water-retention properties of the undisturbed cores. Total-porosity (TP) was defined as the ratio of the volume of air- and water-filled pores to the total volume of container medium at 0 kPa matric tension (DeBoodt and Verdonck, 1972). Air space (AS) was defined as the volume percent difference between total porosity and moisture content after drainage (DeBoodt and Verdonck, 1972).

Moisture retention curves were estimated from data with a form of the five parameter nonlinear model of Van Genuchten and Nielsen (1985): Mois = (J1 – J10) × (1/E)$^{(M + J10)}$, where Mois = percent moisture retained by volume; J1 = percent moisture retained by volume at 0 kPa; J10 = percent moisture retained by volume at 29.4 kPa; E = 1 + (A × Press)^N; each applied pressure (kPa) was calculated as Press = log$_{10}$[(kPa × 9.8) + 1]; N = 1 to 15; A = 0.2 to 2; and M = 1 to 15. The parameters N, A, and M were determined using the SAS nonlinear least-squares multivariate secant (DUD) iteration method (SAS, 1985a, 1985 b). The five parameters (J1, J10, N, M, and A) determined for each medium were used to generate predicted moisture retention curves from 51 selected pressure values within the 0- to 29.4-kPa range.

Significant correlations between TP, AS, bulk density, water-holding capacities, shoot weight, and root rot severity were determined with the SAS correlation procedure (SAS, 1985a, 1985b). Main effects and the interaction of medium and pathogen inoculum for physical properties and disease data were analyzed for significance with the SAS general linear model procedure and the F-protected LSD (P = 0.05) test (SAS, 1985a, 1985 b).

Results and Discussion

Moisture retention curves for noninfested (Fig. 1) and infested (Fig. 2) media indicate that PB and PBP retained more water than PBS or PSS over the matric tension range tested. Noninfested media generally held more water than infested media. The greater root proliferation observed for healthy plants may promote breakdown of peat and pine bark. The greater proportion of smaller particles produced may account for greater water retention by noninfested media. The curves were least variable for PSS, suggesting limited root growth even in the absence of *P. cinnamomi*. Soil anaerobiosis, created by excess soil moisture, impairs plant root function due to insufficient ATP generation during anaerobic respiration; a loss of membrane integrity with leakage of cell constituents; and toxicity from products of anaerobic metabolism (Drew and Lynch, 1980).

Pinebark and PBP had the largest proportion of particles > 6.3 mm (Figs. 3 and 4). The two media with soil components, PSS and PBS, had larger proportions of particles passing through the 0.355-mm sieve. There were no differences in the particle size distribution of noninfested and infested PSS and PBS. Noninfected PB and PBP had a larger proportion of smaller particles than infested media.

In the absence of *P. cinnamomi* (zero grains/container), there were no significant differences in shoot weight for plants in the four media with the exception of trial 1 (Fig. 5), in which growth in PSS was greater (P = 0.05) than in PB. Shoot fresh weight of plants in infested media of trial 1 (nine grains/container) was significantly greater in PBS than in the other media
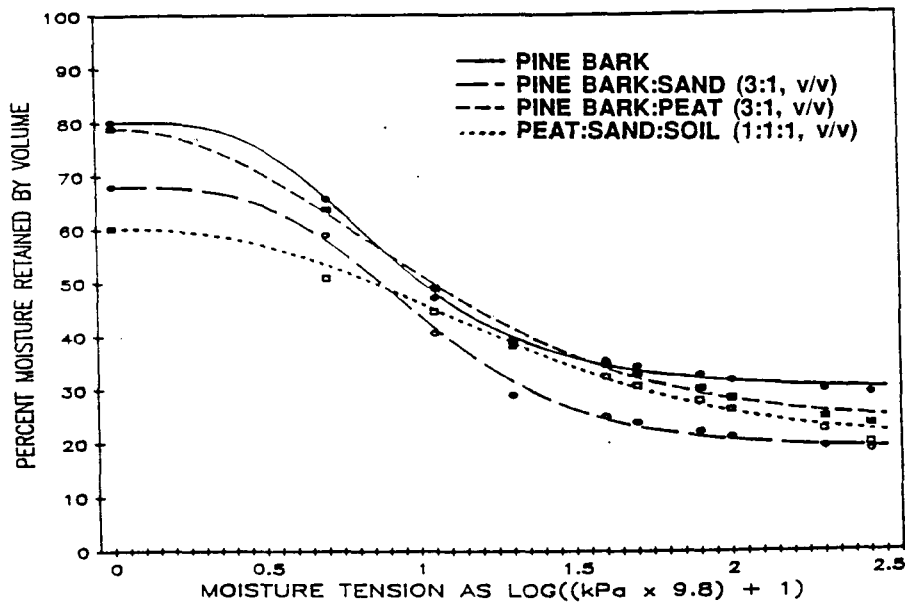
Fig. 2. Moisture retention curves for infested container media potted with rhododendron. Media were infested with nine oat grains colonized by *Phytophthora cinnamomi* per container. Actual value means of five replications are represented by symbols on the predicted curves. Data shown for Trial 1.
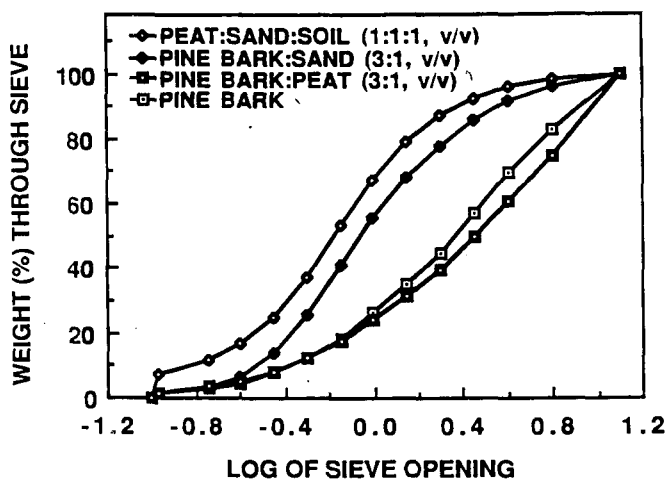

Fig. 3. Particle size distribution summation curves for noninfested container media. Data shown for Trial 1.
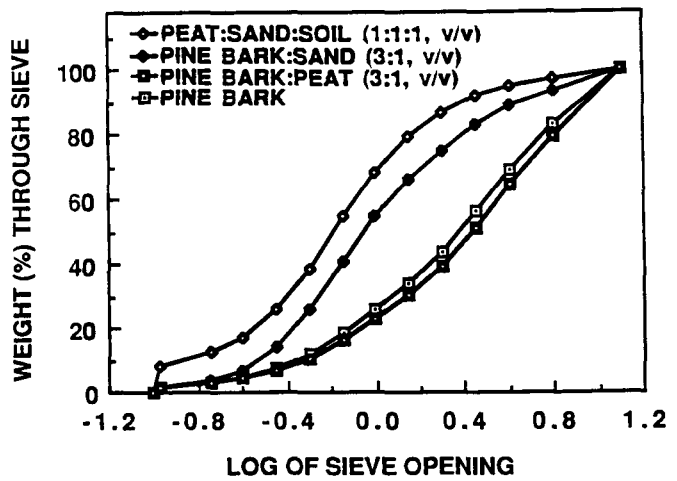

Fig. 4. Particle size distribution summation curves for infested container media. Media were infested with nine oat grains colonized by *Phytophthora cinnamomi* per container. Data shown for Trial 1.

(Fig. 5). In trial 2 (data not shown), shoot fresh weights in PBS and PBP were higher than those in PB and PSS. Compared to noninfested controls, shoot fresh weight of plants in infested media was significantly less only in PSS.

Root rot severity in infested containers was greater $(P = 0.05)$ than in the controls in PSS and PBP media (Fig. 6) and in PB also in trial 2 (data not shown).

There were no differences $(P = 0.05)$ in bulk density between infested containers and noninfested controls for a given medium (Fig. 7). Noninfested and infested PSS had higher bulk densities than all other media (Fig. 7). Pine bark amended with sand (PBS) had the second highest bulk densities. Bulk densities for noninfested and infested PB and PBP were lowest and similar. As bulk density decreases, the proportion of large pores increases. Larger pores will become air-filled at low matric tensions and will interfere with the release, motility, and chemo-attraction of zoospores of *P. cinnamomi*.

Total porosity tended to be higher $(P = 0.05)$ for infested

and noninfested PB and PBP at ≈80% (Fig. 8). The TP of PBS was intermediate in pore space at saturation. Peat : sand : soil had the lowest TP at ≈60% (Fig. 8). For each medium there were no differences in TP between noninfested controls and infested containers. High TP values of media containing pine bark are probably due to more large pores. A TP of 85% for container media has been suggested as optimal for plant growth (DeBoodt and Verdonck, 1972).

In both noninfested and infested media, air-filled porosity was least $(P = 0.05)$ in PSS at ≈15 to 20 (Fig. 9), intermediate in PBS and PBP, and greatest in PB at ≈35% (Fig. 9). There were no differences in air space between infested containers and non-infected controls for a given medium. In the medium with the lowest air space, PSS, root disease was also greatest (Fig. 6). Less air volume in disease-conducive media is consistent with previous studies. Root rot severity of cuttings of toyon *[Het-eromeles arbutifolia* (Ait.) M.J. Roemer] was greater in a me-
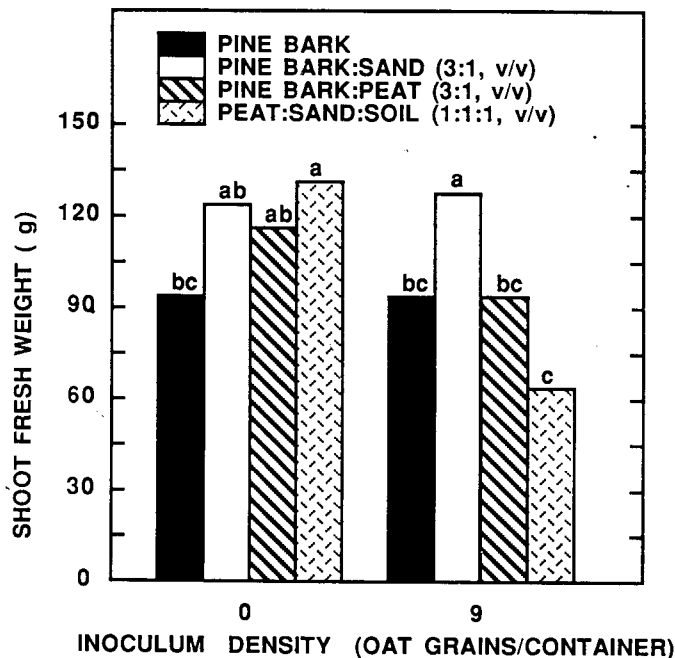
Fig. 5. Effect of medium composition and inoculum density of *Phytophthora cinnamomi* on shoot fresh weight of rhododendron. Media were infested with zero or nine oat grains colonized by *P. cinnamomi* per container. Mean separation among bars within a given FLSD test at $P = 0.05$. Data shown for Trial 1.

Fig. 7. Effect of medium composition and inoculum density of *Phytophthora cinnamomi* on bulk density (g·cm^{-3}) of container medium. Media were infested with zero or nine oat grains colonized by *P. cinnamomi* per container. Mean separation among bars within a given FLSD test at $P = 0.05$. Data shown for Trial 1.
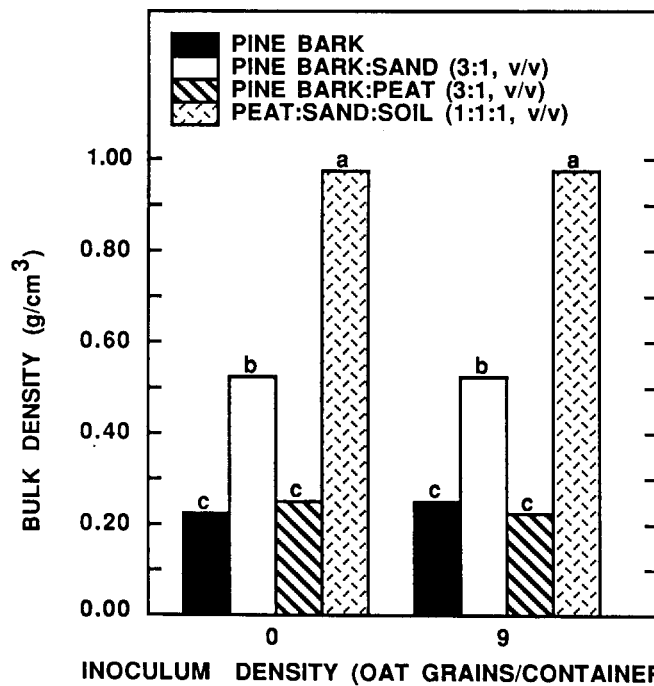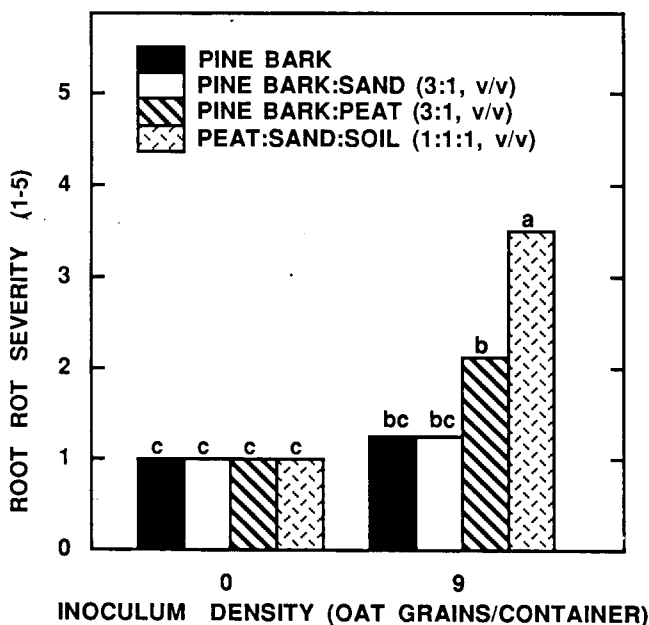

Fig. 6. Effect of container medium and inoculum density on severity of Phytophthora root rot of rhododendron. Media were infested with zero or nine oat grains colonized by *Phytophthora cinnamomi* per container. Mean separation among bars within a given FLSD test at $P = 0.05$. Data shown for Trial 1.

Fig. 8. Effect of medium composition and inoculum density of *Phytophthora cinnamomi* on total porosity (percent by volume) of container medium. Media were infested with zero or nine oat grains colonized by *P. cinnamomi* per container. Mean separation among bars within a given FLSD test at $P = 0.05$. Data shown for Trial 1.
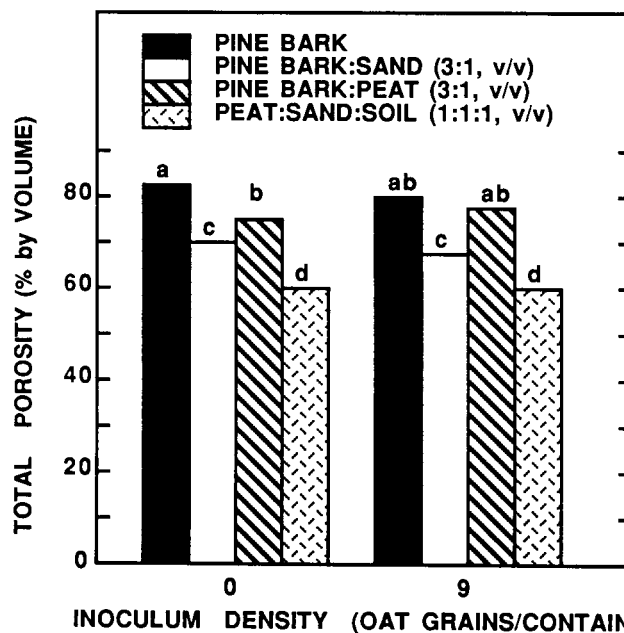
dium with air-filled porosity < 10% than in plants in media with air-filled porosities of 10% to 20% (Filmer et al., 1986). DeBoodt and Verdonck (1972) suggested that a range of 20% to 30% air-filled pore space in container media is optimal for plant growth. At low matric tensions, within the range 0 to 1.0 kPa, pores with neck diameters <300 μm are filled with water (Hillel, 1982).

Pine bark held only 10% to 13% moisture by volume in the matric tension range of 1.0 to 5.0 kPa, whereas other media held 12% to 20% (Fig. 10). Compared with noninfested controls, the corresponding infested containers held significantly ($P = 0.05$) less water for PSS medium in both trials and for all other media in trial 2 (Fig. 10 B). The decrease for infested PSS
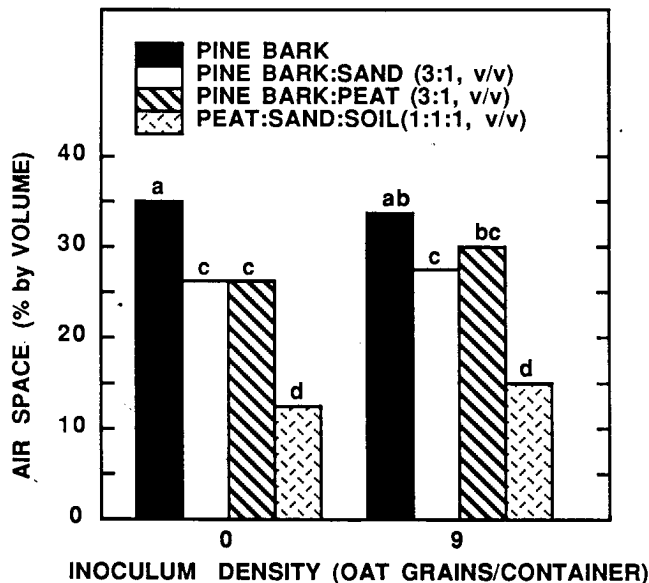
J. Amer. Soc. Hort. Sci. 115(4):564–570. 1990.

567

Fig. 9. Effect of medium composition and inoculum density of *Phytophthora cinnamomi* on air space (percent by volume) of container medium. Media were infested with zero or nine oat grains colonized by *P. cinnamomi* per container. Mean separation among bars within a given FLSD test at $P = 0.05$. Data shown for Trial 1.

is probably related to fewer pores of the size that drain in this range, possibly as a consequence of limited root proliferation by infected plants. This may also be the case for infested PB and PBS in trial 2, in which shoot weights were lower and root rot severities were higher (data not shown) than in trial 1 (Figs. 5 and 6), suggesting more-limited root proliferation in trial 2. The reason for the decrease for infested PBP is unclear, as root rot severity was lower and shoot fresh weight was greater in trial 2 (data not shown) than in trial 1 (Figs. 5 and 6). Within the matric tension range of 1.0 to 5.0 kPa, pores with neck diameters of 300 to 60 μm drain. DeBoodt and Verdonck (1972) suggested that 20% to 30% water held within this range was optimal for plant growth.

At matric tensions between 5.0 and 10.0 kPa, infested PSS and PBP (trial 1 only) (Fig. 11) held 10% to 12% moisture, whereas the lowest volumes of water were held in infested and noninfested PB and PBS and also in infested PBP (trial 2 only) with 3% to 6%. Noninfested PSS and PBP held 6% to 870. In contrast with matric tensions of 1.0 to 5.0 kPa (Fig. 10), the proportion of water held in the 5.0- to 10.0-kPa range was greater in infested PSS and also in PBP (trial 1 only) compared to the noninfested controls. The reason for this difference is unclear, but it is probably related to root health, since the highest levels of root disease (Fig. 6) were found for plants in these media. Also, root disease was more severe in PBP in trial 1 (Fig. 6) compared to trial 2 (data not shown). Within the 5.0- to 10.0-kPa matric tension range, pores with neck diameters of 60 to 30 μm drain. In general, all media were within a range (4% to 10%) considered to be optimal for plant growth (DeBoodt and Verdonck, 1972).

Four physical properties of the media and Phytophthora root rot severity had significant correlations (Table 1). Root rot severity was positively correlated with bulk density and water (percent by volume) held in the 5.0- to 10.0-kPa matric tension range, and negatively correlated with total porosity and air space.

Higher bulk densities and greater volumes of water held between 5.0 and 10.0 kPa probably reflect greater proportions of
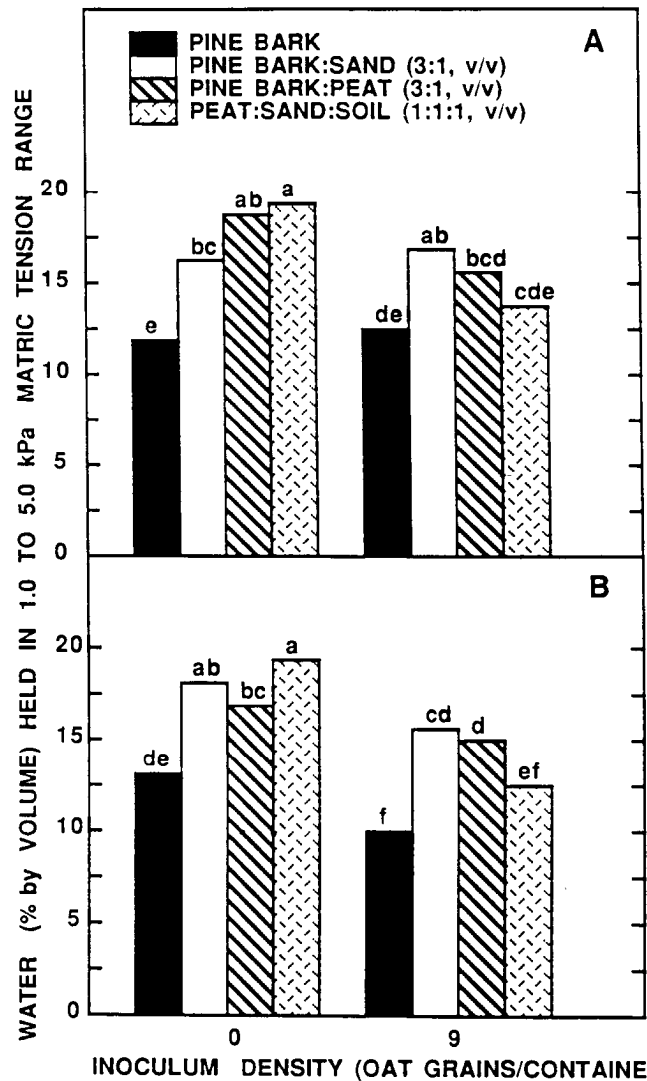

Fig. 10. Effect of medium composition and inoculum density of *Phytophthora cinnamomi* on water (percent by volume) held in the 1.0- to 5.0-kPa matric tension range. Media were infested with zero or nine oat grains colonized by *P. cinnamomi* per container. Mean separation among bars within a given FLSD test at $P = 0.05$. A = Trial 1, B = Trial 2.

micropores in the media. Such media have a higher proportion of water-filled pores extending over a greater portion of the container profile (Filmer et al., 1986). These media remain saturated for longer periods (Gintis and Benson, 1986), predisposing plants to severe Phytophthora infection by exposing roots to oxygen deficiency, and enhance pathogen activity through stimulation of production and dispersal of zoospores (Filmer et al., 1986).

Higher total porosity and air space enhance aeration, resulting in an increase in the generation and growth of plant roots (Blaker and MacDonald, 1981; Filmer et al., 1986; Stolzy et al., 1965), and a reduction in the number of water-filled pores of the size that favor reproduction and pathogenicity of *P. cinnamomi* (Benson, 1984; Newhook et al., 1981).

In the absence of the pathogen, significant positive correlations with shoot weight were found for bulk density (trial 2 only) and water held in the 1.0- to 5.0-kPa matric tension range, while significant negative correlations existed for total porosity (trial 2 only) and air space (Table 2).
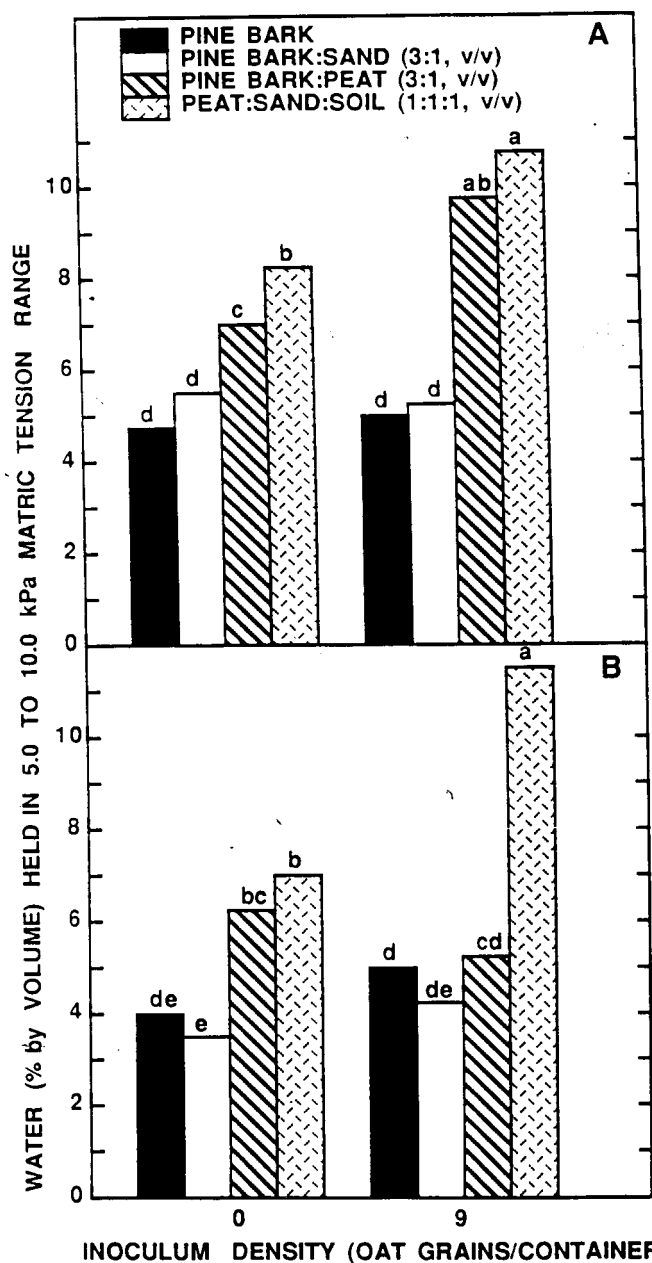
Fig. 11.   Effect of medium composition and inoculum density of *Phytophthora cinnamomi* on water (percent by volume) held in the 5.0- to 10.0-kPa matric tension range. Media were infested with zero or nine oat grains colonized by *P. cinnamomi* per container. Mean separation among bars within a given FLSD test at *P* = 0.05. A = Trial 1, B = Trial 2.

Our results indicate that all four media have sufficient moisture-holding capacities for plant growth, but result in large differences in the severity of Phytophthora root rot of rhododendron. Less disease was found for media with the higher total porosity (68% to 86%) and air space (25% to 36%) and lower bulk density (0.15 to 0.53 g·cm⁻³) and water content held in the 5.0- to 10.0-kPa matric tension range (3% to 6%).

A variety of soilless media is currently used in production of container ornamental. Large variations in bulk density, total porosity, air space, and moisture-holding capacities may provide sufficient moisture for plant growth, but the severity of Phytophthora root rot may be affected greatly by variations in

Table 1.   Correlation coefficients for severity of Phytophthora root rot of rhododendron caused by *Phytophthora cinnamomi* and physical properties of container media.

Physical property[z]	Correlation coefficient	
	Trial 1	Trial 2
Bulk density	0.70***	0.76***
Total porosity	− 0.54*	− 0.65**
Air space	− 0.76***	− 0.56*
Water held in the 1.0- to 5.0-kPa matric tension range	− 0.18[NS]	− 0.39[NS]
Water held in the 5.0- to 10.0-kPa matric tension range	0.76***	0.86***

[z]Bulk density g·cm⁻³, the others, percent by volume.
[NS],*,**,***Nonsignificant or significant at *P* = 0.05, 0.01, or 0.001, respectively.

Table 2.   Correlation coefficients for shoot fresh weight of rhododendron in noninfested media and physical property characteristics of container media.

Physical property[z]	Correlation coefficient	
	Trial 1	Trial 2
Bulk density	0.25[NS]	0.54*
Total porosity	− 0.25[NS]	− 0.51*
Air space	− 0.47*	− 0.49*
Water held in the 1.0- to 5.0-kPa matric tension range	0.66**	0.66**
Water held in the 5.0- to 10.0-kPa matric tension range	0.43[NS]	0.10[NS]

[z]Bulk density g·cm⁻³, the others, percent by volume.
[NS],*,**Nonsignificant or significant at *P* = 0.05 or 0.01, respectively.

water-holding characteristics of container media. Sufficiently large pores, reflected by lower bulk density and lower volumes of water held in the 5.0- to 10.0-kPa range are needed to reduce the number of water-filled pores of adequate size available for production of sporangia and movement of zoospores of *P. cinnamomi*. Air space also must be sufficient (> 20%) to reduce host susceptibility by promoting root growth and maintaining root cell membrane integrity.

Literature Cited

Benson, D.M. 1982. Phytophthora root rot —*Phytophthora cinnamomi*, p. 14-17. In: R.K. Jones and R.C. Lambe (eds.). Diseases of woody ornamental plants. N.C. Agr. Ext. Serv., Raleigh.

Benson, D.M. 1984. The effect of matric potential, and pH on sporangium production in *Phytophthora cinnamomi*. Phytopathology 74:1359-1363.

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

Blaker, N.S. and J.D. MacDonald. 1981. Predisposing effects of soil moisture extremes on the susceptibility of rhododendron to Phytophthora root and crown rot. Phytopathology 71:831-834.

Day, P.R. 1965. Particle fractionation and particle size analysis, p. 545-566. In: C.A. Black (ed.). Methods of soil analysis. Part I. Monogr. 9. Amer. Soc. Agron., Madison, Wis.

DeBoodt, M. and O. Verdonck. 1972. The physical properties of the substrates in horticulture. Acta Hort. 26:37-44.

Drew, M.C. and J.M. Lynch. 1980. Soil anaerobiosis, microorganisms, and root function. Annu. Rev. Phytopathol. 18:37–66.

Eckert, J.W. and P.H. Tsao. 1962. A selective antibiotic medium for isolation of *Phytophthora* and *Pythium* from plant roots. Phytopathology 52:771–777.

Filmer, C.L.R., J.D. MacDonald, J.L. Paul, and A.T. Leiser. 1986. Influence of air-filled porosity of container media on Phytophthora root rot of toyon. HortScience 21:1010–1011.

Fonteno, W.C., D.K. Cassel, and R.A. Larson. 1981. Physical properties of three container media and their effect on poinsettia growth. J. Amer. Soc. Hort. Sci. 106:736-741.

Gintis, B.O., and D.M. Benson. 1986. Matric potential relations in container mixes of pine bark and suppression of Phytophthora root rot of *Rhododendron* spp. Phytopathology 76:1072. (Abstr.)

Hillel, D.H. 1982. Introduction to soil physics. Academic, New York.

Hoitink, H.A.J. and A.F. Schmitthenner. 1974. Resistance of Rhodo-*dendron* species and hybrids to Phytophthora root rot. Plant Dis. Rptr. 58:650-653.

Kenerley, C.M., K. Papke, and R.I. Bruck. 1984. Effect of flooding on development of Phytophthora root rot in Fraser fir seedlings. Phytopathology 74:401-404.

Kuan, T.L. and D.C. Erwin. 1980. Predisposition effect of water saturation of soil on Phytophthora root rot of alfalfa. Phytopathology 70:981-986.

Mircetich, S.M., G.A. Zentmyer, and J.B. Kendrick, Jr. 1968. Physiology of germination of chlamydospores of *Phytophthora cinna-momi.* Phytopathology 58:666-671.

Newhook, F.J., B.R. Young, S.D. Allen, and R.N. Allen. 1981. Zoospore motility of *Phytophthora cinnamomi* in particulate substrates. Phytopathology Z. 101:202–209.

SAS Institute, Inc. 1985a. SAS user's guide: Basics. 1985 ed. SAS Institute, Inc., Cary, N.C.

SAS Institute, Inc. 1985b. SAS user's guide: Statistics. 1985 ed. SAS Institute, Inc., Cary, N.C.

Stolzy, L.H., J. Letey, L.J. Klotz, and C.K. Labanauskas. 1965. Water and aeration as factors in root decay of *Citrus sinensis.* Phytopathology 55:270–275.

Tilt, K.M., T.E. Bilderback, and W.C. Fonteno. 1987. Particle size and containerize effects on growth of three ornamental species. J. Amer. Soc. Hort. Sci. 112:961–964.

Tomlinson, J.D. and T.E. Bilderback. 1985. The effects of moisture extenders, bentonite and irrigation frequency on a pine bark medium and growth of 'Nellie R. Stevens' holly and leyland cypress. Proc. South. Nurserymen's Assn. Res. Conf., 30th Annu. Rpt. p. 50–54.

Van Genuchten, M.T. and D.R. Nielsen. 1985. On describing and predicting the hydraulic properties of unsaturated soils. Ann. Geophysicae 3:615-628.