that seedlings grown under less desirable nutritional regimes remained inferior to the better treatments 1 year later. A balanced slow-release fertility system combined with the fibrous root system produced by 'air pruning' resulted in significantly larger seedlings in 3 months than 2-year-old seedlings grown in conventional ground beds. In this study, no evidence was found to relate root:shoot ratios to plant height, survival or further growth in the field.

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Influence of Ozone on the Severity of Phytophthora Root Rot of Azalea and Rhododendron Cultivars[1]

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Abstract

The susceptibility of 21 azalea and rhododendron cultivars to colonization by *Phytophthora cinnamomi* and to injury caused by ozone was determined. Resistance to *P. cinnamomi* was lacking in most cultivars with only 3 rhododendron cultivars 'Caroline,' 'Chionoides' and 'English Roseum' and 3 azalea cultivars 'Hinodegiri,' 'Sweetheard Supreme' and 'Tradition' having resistance. All of the rhododendron cultivars, except 'Nova Zembla,' were highly resistant to ozone injury. Of the azalea cultivars, only 'Delaware Valley White,' 'Roadrunner' and 'White Water' exhibited injury following fumigation with 0.20 ppm ozone for 6 hours on 3 consecutive days. The fumigation of *P. cinnamomi*-inoculated plants with ozone significantly increased the severity of Phytophthora root rot only in 'Hinodegiri' plants, but a trend towards greater disease severity was evident in many cultivars.

Index words: Air pollution, *Phytophthora cinnamomi*

Introduction

Phytophthora root rot of *Rhododendron* species is destructive worldwide (20). We have found that *Phytophthora cinnamomi* Rands is the most common fungus we have isolated from diseased azalea and rhododendron roots in Virginia. This fungus is also the most important *Phytophthora* species involved in the root rot syndrome of *Rhododendron* species in the United States (8).

Azalea and rhododendron cultivars vary in their susceptibility to ozone, nitrogen dioxide and sulfur dioxide (4, 5, 17, 19). Some azaleas are extremely susceptible while others are very resistant to fumigations with ozone

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at levels as high as 0.30 ppm for 8 hours per day over a growing season (4, 5). Visible foliar injury of azalea plants was not induced by a combination of nitrogen dioxide and sulfur dioxide but did occur with fumigation by ozone plus nitrogen dioxide and sulfur dioxide (17).

Little is known about the influence of environmental stresses such as air pollutants on the susceptibility of plants to root diseases caused by fungi (6). Oxidant air pollution injury to foliage of Ponderosa and Jeffrey pines increased the susceptibility of roots to colonization by *Fomes annosus* (10). Fumigations at weekly intervals with an ozone concentration of 0.90 ppm for 4 hours inhibited the infection of 'Troyer' citrange roots by *Glomus fasciculatus,* a vesicular-arbuscular endomycorrhizal fungus (15). It has been documented, moreover, that ozone injury to foliage of soybean plants can result in reduced root growth and loss of general vigor (3). Ozone exposure also affects the metabolite content of plant roots (11, 18).

The primary objective of this investigation was to determine the effect of ozone exposure on the severity of *P. cinnamomi* induced root rot of selected azalea and rhododendron cultivars.

Materials and Methods

The azalea and rhododendron cultivars were obtained as rooted cuttings either from LeMac Nurseries Inc., Hampton, VA 23669 or Virginia Polytechnic Institute and State University, Blacksburg. The plants were potted in a mixture of pine bark:Weblite® (heat expanded shale):Canadian sphagnum peat moss (1:1:1 by vol.) and selected fertilizers as described by Lambe *et al.,* (13) and were maintained in 1 l (6 in) azalea pots in a greenhouse, without supplemental light, provided with ambient air at 25-30°C (77-86°F). Prior to fumigation, the plants were transferred to a greenhouse supplied with charcoal filtered air and immediately rated for foliar injury due to ambient levels of air pollution.

Following the third or fourth flush of new growth, when the plants had crown diameters of 15-20 cm (5.9-7.9 in), the roots were inoculated with *P. cinnamomi.* The fungus, VA isolate No. 2551 from azalea, was grown in unamended 10% V-8 broth in distilled water for 14 days in the dark at 26°C (79°F). The mycelium was then filtered on cheesecloth, washed three times with tap water to remove the V-8 broth, resuspended in an original volume of water and blended 20 sec in a Waring blender. At equal distances around each pot, three holes were made in the potting medium surrounding each plant with a 1 cm (0.4 in) diameter corkborer to injure the roots. Next, 100 ml of the aqueous mycelial suspension was added to each pot, and the holes filled with potting medium. Both inoculated and uninoculated plants were then placed in shallow pans containing a 2-3 cm (0.8-1.2 in) layer of tap water to insure that the potting medium would remain saturated.

Three to four weeks after inoculation one-half of the inoculated and the uninoculated plants of each cultivar were fumigated in continuous stirred tank reactors (CSTR) (7), with 0.20 ppm (480 $\mu g/m^3$) ozone for 6 hours on 3 consecutive days. Environmental conditions within the CSTRs were maintained at 28±2°C, (82±4°F) 70±15% relative humidity, and 410±25 $\mu E/m^2/sec$ PAR (ca 830 ft-c). After fumigation the plants were returned to the greenhouse supplied with charcoal filtered air.

The plants were evaluated for ozone induced foliar injury 48 hours after the last fumigation when symptom expression began to reach a maximum intensity and at 4 wk after the last fumigation. An index of 1 to 5 was used with 1 = healthy foliage, 2 = sporadic amount of stipple on lower foliage, 3 = up to 30% stipple on older foliage, 4 = up to 60% stipple on lower foliage and 5 = severe stipple on older foliage, light stipple on younger foliage. On the second evaluation the plants were checked for foliage symptoms associated with air pollution and root rot damage. The following index was used: 1 = healthy foliage; 2 = slightly off-color foliage; 3 = moderately discolored foliage and some wilting; 4 = severe wilting, leaf loss, and/or discoloration and 5 = dead plant. The crown of each azalea cultivar was measured and a growth index was calculated by the following formula (width x height/2).

The root system of each plant was rated for root rot at 8 wk when the experiment was terminated. A root rot index (RRI) of 1 to 5 was employed with 1 = healthy root system; 2 = fine roots necrotic, little decay; 3 = coarse roots necrotic, moderate decay; 4 = some crown rot, severe decay and 5 = dead plants. Tissue was plated from necrotic roots onto a Phytophthora selective medium to confirm the presence of *P. cinnamomi.*

Each experiment consisted of 4 treatments: noninoculated plants (controls), noninoculated/fumigated plants, inoculated/non-fumigated plants and inoculated/fumigated plants. There were 8 to 12 plants per replication and each cultivar was evaluated in at least 2 experiments. Results are reported as averages among experiments. Data were analyzed at $P < 5\%$ according to a Duncan's multiple range test since there was no significant interaction between ozone and Phytophthora treatments.

Results and Discussion

Plants grown in the unfiltered greenhouse exhibited no symptoms of ozone injury. Ozone injury appeared on susceptible azalea and rhododendron cultivars as upper surface stippling. The stipples were reddish-brown spots up to 2 mm (0.8 in) in diameter. They occurred on mature fully-expanded foliage, but not on expanding or old foliage. None of the cultivars were highly susceptible to ozone at the dosage (concentration x time) tested, but 2 azalea cultivars, 'Delaware Valley White' and 'Roadrunner,' and the rhododendron cultivar, 'Nova Zembla' were moderately susceptible (Table 1). The symptoms observed on these cultivars were less severe than those reported by Davis and Coppoline (4), Gesalman and Davis (5) and Wood (19) possibly because they fumigated with 0.25-0.30 ppm ozone. Since ambient ozone levels this high have not been reported for most areas of the United States (16), most of the azalea and rhododendron cultivars used in this investigation could be grown in areas outside of California. In some parts of California, however, ambient ozone levels may exceed 0.15-0.20 ppm (16).

Within 8 weeks after inoculation Phytophthora-susceptible azalea and rhododendron cultivars exhibited typical foliar and root rot symptoms due to *P. cinnamomi* colonization (20) (Table 1). Visible symptoms included discoloration of foliage, premature leaf drop, wilting and a reduction of the foliage growth index. Both young fibrous and older coarse roots were colonized in susceptible plants. Among the more susceptible cultivars crown rot and death occurred occasionally. There was little root rot resistance among most of the cultivars. As noted by Hoitink and Schmitthenner (9), the rhododendron cultivar 'Caroline' was highly resistant. We also observed that the rhododendron cultivars 'Chionoides' and 'English Roseum' and the azalea cultivars 'Hinodegiri,' 'Sweetheart Supreme' and 'Tradition' had moderate resistance. Following colonization cultivars generated new roots in the upper part of the containers, a response to colonization among resistant plants observed previously by Hoitink and Schmitthenner in 'English Roseum' plants (8).

None of the 11 azalea and rhododendron cultivars used in the inoculation/fumigation experiments exhibited appreciable ozone injury when the experiments were terminated (Table 2). Inoculation alone resulted in significant injury to foliage of 'Delaware Valley White,' 'Hershey Red,' 'Kingfisher,' 'Nova Zembla' and 'Rhythm' as comparsed to controls. Although not always statistically significant, inoculation coupled with fumigation resulted in greater foliar injury than inoculation alone in 'Chionoides,' 'Nova Zembla' and 'White Water' plants. The combined effect of inoculation plus fumigation was less than additive or additive, never more than the sum of the effects of ozone and Phytophthora individually.

Fumigation with 0.20 ppm ozone over a 3-day period did not result in root necrosis (Table 2) while inoculation alone caused appreciable root rot in 8 of the 11 cultivars. Only inoculated 'English Roseum,' 'Hinodegiri' and 'Tradition' plants had an insignificant amount of root rot compared to controls. In most plants, inoculation coupled with fumigation resulted in higher levels of root rot than inoculation alone. The only significant difference, however, was between the 2 treatments of 'Hinodegiri' plants. The greater increases in root rot following inoculation and fumigation were recorded, with 1 exception, among cultivars previously reported to be resistant to Phytophthora root rot (Table 2). The exception was 'Kingfisher' which was rated as moderately susceptible to root rot (RRI of 2.7 ± 0.7). Upon inoculation and fumigation, however, it had an RRI of 3.6 ± 1.4.

Fumigation alone caused no significant change in the growth index of the 6 azalea cultivars. Inoculation alone significantly reduced the growth index of 'Delaware Valley White,' 'Kingfisher' and 'Rosebud' plants as compared to their controls (Table 3). Inoculation accompanied by fumigation resulted in significant reductions in the growth index relative to the controls, in each of the 6 cultivars with the exception of 'Tradition.' No treatment had a depressive effect on the growth index of 'Tradition.' In those cases where the combined effect of inoculation plus fumigation on the growth index was greater than the effect of inoculation alone, the response was less than the sum of the effects of ozone and Phytophthora individually.

It is understandable that the combined effects of root inoculation and fumigation on the foliage, roots and growth index of the azalea and rhododendron cultivars used in this investigation were nearly always less than the sum of the individual effects. Nearly all of the cultivars tested had some susceptibility to *P. cinnamomi* and most were relatively resistant to visible ozone injury. Moreover the numbers of motile infective units, the zoospores of *P. cinnamomi,* are reported to increase tremendously in short time periods under favorable environmental conditions (20) such as we had in this investigation. There can be a short-latent period, a high infection rate and a "compound interest" increase in this disease (20). Furthermore, *P. cinnamomi* is a highly competitive saprophytic colonizer particularly at the high moisture level of the medium used in this study.

As noted earlier, ozone fumigation often results in the alteration of root biomass and general vigor of plants (11). Blaker and MacDonald (2) reported that soil moisture extremes predisposed normally resistant 'Caroline' plants to Phytophthora root and crown rot. Air pollution stress like soil moisture stress has a striking effect on the root systems of plants (12, 15, 18). That prolonged exposure of azalea and rhododendron cultivars to air pollution, such as one finds in major metropolitan areas, could be a factor in the ability of these plants to survive attack by *P. cinnamomi* is an hypothesis requiring further study.

Table 1. Relative susceptibility of 21 azalea and rhododendron cultivars to ozone and *Phytophthora* root rot.

	Relative Susceptibility	
Cultivar[z]	Ozone[y]	Phytophthora[x]
Album Elegans	+	+ +
Anna Kruschke	−	+ +
Blue Ensign	+	+ +
Cadis	−	+ +
Caroline	−	−
Chionoides	−	+
Delaware Valley White (M)	+ +	+ +
English Roseum	−	+
Hershey Red (K)	−	+ +
Hinodegiri (K)	−	+
Kingfisher (W)	−	+ +
Maximum Roseum	+	+ +
Nova Zembla	+ +	+ + +
Purple Splendour	+	+ +
Rhythm (P)	−	+ +
Roadrunner (W)	+ +	+ +
Rosebud (G)	+	+ +
Roseum Elegans	+	+ +
Sweetheart Supreme (P)	+	+
Tradition	−	+
White Water (W)	+ +	+ +

[z]*M = R. mucronatum,* K = Kurume, W = White Water, P = Pericat and G = Gable (1, 14).

[y]Fumigated with 0.20 ppm ozone for 6 hours per day on 3 consecutive days and rated 48 hours after the last fumigation. − = resistant (foliage index 1.0-1.5), + = moderate resistance (foliar index 1.6-2.5) and + + = moderate susceptibility (foliar index 2.6-3.5).

[x]Rated 8 weeks after inoculation, − = resistant (RRI 1.0-1.5), + = moderate resistant (RRI 1.6-2.5), + + = moderate susceptibility (RRI 2.6-3.5) and + + + = susceptible (RRI of 3.6-4.5).

Table 2. **Effects of colonization by *Phytophthora cinnamomi* and fumigation with ozone on the foliage and roots of azalea and rhododendron cultivars.[z]**

Cultivar	Control	Fumigated	Inoculated	Inoculated Fumigated
			Foliage[y]	
Chionoides	1.1±0.3 a[x]	1.0±0.0 a	1.6±1.2 ab	2.4±1.4 b
Delaware Valley White	1.4±0.5 a	1.4±0.5 a	2.5±0.7 b	2.4±0.9 b
English Roseum	1.1±0.3 a	1.0±0.0 a	1.6±1.4 a	1.6±1.4 a
Hershey Red	1.4±0.3 a	1.4±0.5 a	2.3±0.8 b	2.1±0.7 b
Hinodegiri	1.0±0.0 a	1.0±0.0 a	1.5±0.3 a	1.6±0.6 a
Kingfisher	1.3±0.3 a	1.4±0.4 a	2.5±0.6 b	2.7±0.7 b
Nova Zembla	1.0±0.8 a	1.1±0.4 a	2.8±1.9 b	3.5±1.7 b
Rhythm	1.1±0.4 a	1.1±0.4 a	2.8±1.0 b	2.9±0.9 b
Rosebud	1.2±0.3 a	1.4±0.5 a	1.6±0.4 a	1.6±0.6 a
Tradition	1.6±0.9 a	1.9±0.4 a	1.3±0.5 a	1.5±0.5 a
White Water	1.2±0.3 a	1.8±0.5 ab	1.2±0.5 a	2.2±0.3 b
			Roots[w]	
Chionoides	1.2±0.5 a	1.2±0.4 a	1.9±0.9 b	2.4±1.0 b
Delaware Valley White	1.3±0.5 a	1.0±0.0 a	2.6±0.9 b	2.3±0.8 b
English Roseum	1.3±0.7 a	1.4±0.5 a	1.8±1.2 a	2.3±1.4 a
Hershey Red	1.6±0.3 a	1.4±0.6 a	2.6±0.6 b	2.9±0.9 b
Hinodegiri	1.0±0.0 a	1.1±0.3 a	1.6±0.4 a	2.5±0.7 b
Kingfisher	1.0±0.0 a	1.0±0.0 a	2.7±0.7 b	3.6±1.4 b
Nova Zembla	1.1±0.4 a	1.6±0.7 a	3.4±1.6 b	3.5±1.3 b
Rhythm	1.0±0.0 a	1.0±0.0 a	3.2±0.7 b	3.2±0.5 b
Rosebud	1.1±0.3 a	1.2±0.3 a	2.6±0.9 b	2.7±0.7 b
Tradition	1.6±0.5 a	1.9±0.4 ab	1.9±0.9 ab	2.9±0.8 b
White Water	1.3±0.4 a	1.5±0.2 a	2.3±0.6 b	2.7±0.6 b

[z]Fumigated with 0.20 ppm ozone for 6 hours per day on 3 consecutive days.

[y]Foliage rating index with standard deviation, 16 observations per treatment. 1 = healthy foliage, 2 = slightly off-color foliage, 3 = moderately discolored foliage and some wilting, 4 = severe wilting, leaf loff, and/or discoloration and 5 = dead plant.

[x]Means separated within a row followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test.

[w]Root rot index of 1 to 5 with standard deviation, 16 observations per treatment. 1 = healthy root system, 2 = fine roots necrotic, little decay, 3 = course roots necrotic, moderate decay, 4 = some crown rot, severe root decay and 5 = dead plants.

Table 3. **Effects of colonization by *Phytophthora cinnamomi* and fumigation with ozone on the growth index of azalea cultivars.[z,y]**

Cultivars	Control	Fumigated	Inoculated	Inoculated Fumigated
Delaware Valley White	477±71 a[x]	504±95 a	411±65 b	389±64 b
Kingfisher	446±59 a	503±64 a	321±75 b	317±78 b
Rhythm	469±52 a	431±49 ab	373±94 ab	345±79 b
Rosebud	356±85 b	306±49 ab	206±71 b	242±19 ab
Tradition	247±50 a	259±71 a	231±66 a	233±59 a
White Water	359±72 a	297±58 ab	263±53 ab	205±24 b

[z]Fumigated with 0.20 ppm ozone for 6 hours per day on 3 consecutive days.

[y]Growth Index = the height x the width divided by two, with standard deviation, 16 observations per treatment.

[x]Means separated within a row followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test.

Significance to the Nursery Industry

Exposure of *P. cinnamomi*-infected azaleas and rhododendron cultivars to a relative acute dosage of 0.20 ppm ozone for 6 hours on 3 consecutive days did not appreciably increase the amount of colonization of the roots. The potential loss due to *P. cinnamomi* alone would dictate the choice of cultivars. Of the cultivars we tested, the rhododendron cultivars 'Caroline,' 'Chionoides' and 'English Roseum' and the azalea cultivars 'hinodegiri,' 'Sweetheart Supreme' and 'Tradition' had resistance to *P. cinnamomi*. Moreover, none of these cultivars which have high levels of resistance to *P. cinnamomi* had sufficient susceptibility to ozone pollution to warrant their rejection. The relative susceptibility of certain azalea and rhododendron cultivars to *P. cinnamomi* and ozone pollution have been published in this article as well as in Benson and Cochran (1), David and Coppolino (4), Gesalman and Davis (5), Hoitink and Schmitthenner (9) and Sanders and Reinert (17). This information can be used by plant breeders, nurserymen and landscape architects in breeding and selecting the best cultivars to be used under conditions where relatively high levels of ozone and Phytophthora root rot are prevalent.

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Survey of Insecticide and Miticide Usage by 158 Nurseries in Pennsylvania[1]

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Abstract

Of 254 nurserymen surveyed in 7 Pennsylvania counties in 1979, 158 responded. Respondents used 3719.5 kg (8184 lb) of insecticides/miticides with an estimated cost of $64,436. They applied an average of 2.5 kg (2.2 lb/a) ai/ha. Seven pesticides accounted for 88.7% of the 29 pesticides used. The nurserymen tended to use low to moderate toxicity chemicals (96%); 74% used power spray equipment and 47% used wetting agents. The most commonly reported pests are listed.

Index words: Nursery pests, insecticides, miticides, spray equipment, pesticide cost

Introduction

Pesticide usage by non-agronomic industries is difficult to assess but sorely needed to determine current and future decisions on research efforts, state and federal regulations, and industry voids (1). Estimates are available on the amount of pesticides manufactured in the United States (9, 10, 11), but minimal information exists on how these pesticides are distributed and used. Since knowledge of pesticide utilization by urbanites is minimal and reasonable estimates are difficult to make (3, 4, 12), we selected the nursery industry to survey for pesticide usage. This industry provides landscape plants for

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