Spatial Pattern of Phytophthora Root Rot and Dieback of Azalea in Container-Grown Nursery Stock

D. M. BENSON and C. LEE CAMPBELL, Department of Plant Pathology, North Carolina State University, Raleigh 27695-7616

ABSTRACT

Benson, D. M., and Campbell, C. L. 1985. Spatial pattern of Phytophthora root rot and dieback of azalea in container-grown nursery stock. Plant Disease 69:1049-1054.

Spatial pattern of azaleas with visual symptoms of Phytophthora root rot caused by *Phytophthora cinnamomi* and Phytophthora dieback caused by several *Phytophthora* spp. was assessed for container-grown azaleas at three nurseries. Phytophthora root rot was found to be random. Indices of dispersion (variance-to-mean ratio and Morisita's index) and Poisson and negative binomial probability distributions were used to evaluate incidence of disease from quadrat sampling of nursery sections containing 400 plants. Each section had 40 quadrats. Disease incidence ranged from 4 to 58% depending on plant age and cultivar. Phytophthora dieback of azalea, a distinct phase of the *Phytophthora* syndrome, was aggregated at two nurseries and random at the third. Secondary production and dissemination of inoculum during favorable environmental periods may account for the spatial aggregation of plants with symptoms of Phytophthora dieback. Sampling procedures to estimate disease incidence of *Phytophthora* diseases should be improved with an understanding of spatial pattern.

Knowledge of spatial pattern of diseased plants in ornamental nurseries is important for developing estimates of crop loss and for studying the epidemiology of disease as influenced by various sources of inoculum. Little information is currently available on disease losses in ornamentals. A recent survey used systematic sampling to estimate losses caused by Phytophthora root rot and dieback in azaleas and rhododendrons because the pattern of the diseased plants was unknown (3). Improved sampling efficiency will be possible and more reliable estimates of disease loss will be obtained when more information on spatial pattern of diseased plants is available. More efficient sampling procedures, such as sequential sampling (14), also may aid disease management decisions in ornamental nurseries.

An indication of the degree of aggregation of diseased plants can be obtained from indices of dispersion (13) and goodness of fit to probability distributions (5,8,14,16). Spatial patterns of several plant diseases including alfalfa leaf spot (17), hypocotyl rot of snapbean (6), lettuce drop (7), black shank of tobacco (9), and southern stem blight of peanut (15) were described using these techniques. Spatial pattern of diseased plants in the field may be aggregated (9,15,18), or random (6,7,17).

The purpose of this study was to determine the spatial pattern of Phytophthora root rot of azalea caused by *Phytophthora cinnamomi* and of Phytophthora dieback of azalea caused by several species of *Phytophthora* in ornamental nurseries. The two diseases are distinct phases of the *Phytophthora* syndrome. Phytophthora dieback of azalea has not been reported from commercial container-grown plants, although the disease caused by *P. parasitica* has been described on forcing-type azaleas in the greenhouse (11). Studies are in progress to complete Koch's postulates for each species of *Phytophthora* isolated during this study.

MATERIALS AND METHODS

Description of nurseries sampled. Three nurseries growing azaleas (*Rhododendron obtusum* Planch.) in containers in the Coastal Plain region of North Carolina were chosen for sampling. Because the purpose of the study was to determine pattern of Phytophthora root rot and dieback at different nurseries and

Paper 9686 of the Journal Series of the North Carolina Agricultural Research Service, Raleigh 27695-7616.

Use of trade names does not imply endorsement by the North Carolina Agricultural Research Service of the products named or criticism of similar ones not mentioned.

Accepted for publication 14 June 1985 (submitted for electronic processing).

The publication costs of this article were defrayed in part by page charge payment. This article must therefore be hereby marked *"advertisement"* in accordance with 18 U.S.C. § 1734 solely to indicate this fact.

not to develop disease incidence estimates for the crop, no effort was made to choose the nurseries at random. Instead, the criterion used was the production of the azalea cultivar Hershey Red, a cultivar moderately susceptible to *P. cinnamomi* (1). At all nurseries, containers were placed on black plastic and irrigated by sprinklers as needed. Fungicides for control of root rot had not been applied. Plants sampled at each nursery had been rooted in 1983 either on the premises or by a propagator and thus were in the first growing season when sampled during the summer of 1984. Two additional cultivars (Coral Bells and Hino Crimson) at nursery 3 were 2-yr-old plants.

Quadrat sampling technique. The nurseries grew containerized plants in sections that were six to eight units (containers) wide and 70 or more units long. Spacing between the 15-cm-diameter containers varied at each nursery from touching to 10 cm apart. Adjoining sections of the same cultivar were separated by a walkway 0.3–0.6 m. A quadrat consisted of two adjoining rows of five plants each within a section. The section was divided into four by 10 quadrats consisting of 400 plants per section for 1-yr-old plants. Sections were divided into two by six quadrats consisting of 120 plants per section for 2-yr-old plants. Three to nine sections of plants were used to determine the pattern of diseased plants.

Each plant in the quadrat was assessed as healthy (apparently free of *Phytophthora*), symptomatic, or dead. Nurseries 1, 2, and 3 were sampled on 19 July, 2 August, and 26 July, respectively, for Phytophthora root rot, and nurseries 2 and 3 were sampled on 16 and 9 August, respectively, for Phytophthora dieback. The three nurseries were sampled again on 26 September for both Phytophthora root rot and dieback, but removal (sales) of plants from the quadrats by the nursery workers at nurseries 1 and 2 precluded additional analysis.

Symptom recognition. Phytophthora root rot of azalea was distinguished from Phytophthora dieback on the basis of symptom expression. Symptoms of Phytophthora root rot included a general chlorosis, stunting, wilting, and/or necrosis of the entire foliage. Symptoms of Phytophthora dieback were distinct. The principal symptom was lesion development on individual leaves or necrosis (dieback) of one to a few individual stems while others on the plant appeared healthy.

Root samples were arbitrarily collected from 20 plants of each cultivar of the apparently healthy, symptomatic, and dead plants and assayed for *P. cinnamomi* as described previously (4) to compare with visual assessment of disease. Shoot samples also were assayed for species of *Phytophthora* for comparison with visual assessments.

Analysis of data. Frequency classes for the number of symptomatic plants in each quadrat were developed for each section (40 quadrats) and examined for goodness-of-fit to data using a FORTRAN program (10). Although the program has several distributions, only the results of the Poisson and negative binomial distribution are reported. The results for the Poisson, which is taken to indicate randomness of symptomatic plants, and the results for the negative binomial, which is taken to indicate aggregation of symptomatic plants, were assumed to describe the data when the chi-square value was not significant at $P = 0.05$.

Indices of dispersion including the variance-to-mean ratio and Morisita's index were calculated from the quadrat data. A random pattern is indicated when the variance-to-mean ratio is not significantly greater than 1.0, and an aggregated pattern is indicated when the variance-to-mean ratio is significantly greater than 1.0. Morisita's index (8,13) also was calculated. Values of 1.0 imply randomness of symptomatic plants, whereas values greater than 1.0 imply aggregation.

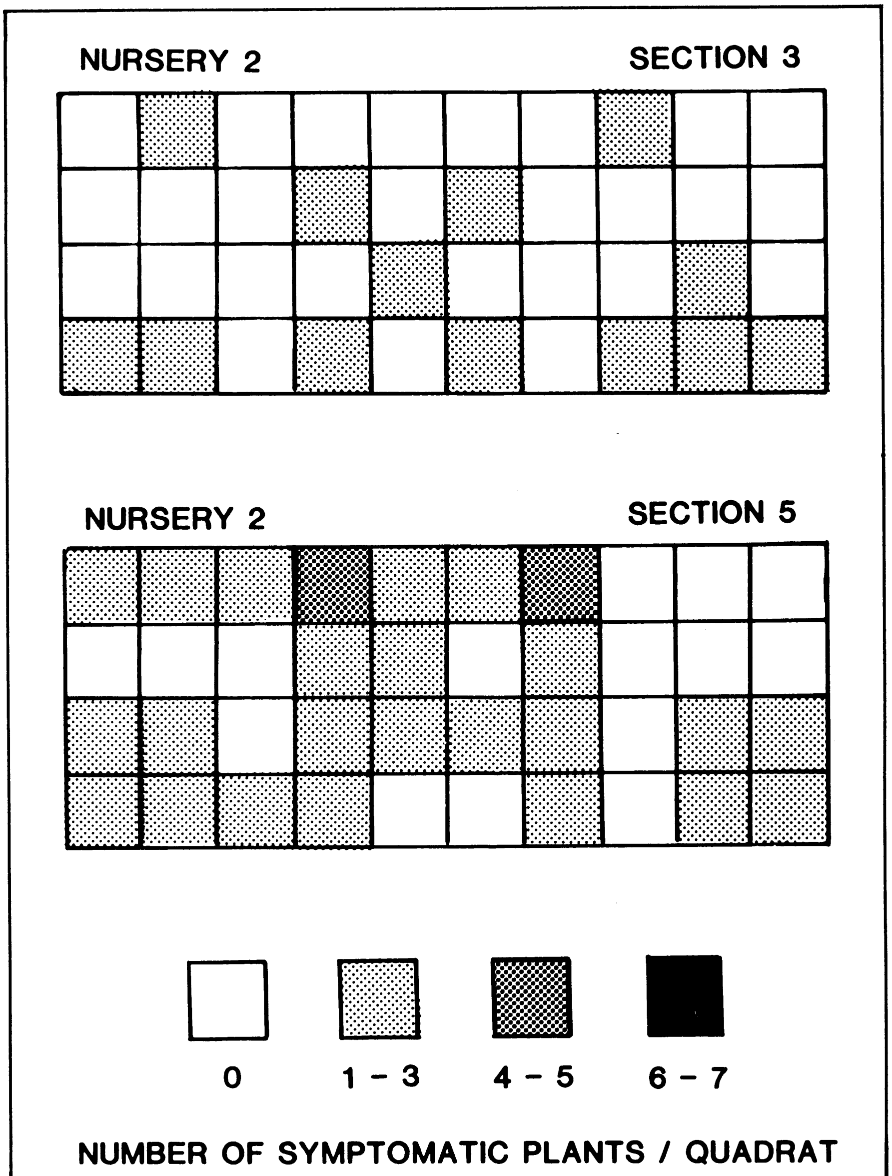

Fig. 1. Spatial pattern of the azalea cultivar Hershey Red in two sections at nursery 2 with symptoms of Phytophthora root rot caused by *P. cinnamomi*. Each section contained 400 plants arranged in 40 quadrats. Individual quadrats were two plants by five plants. Maps of each section represent the range of symptomatic plants observed at nursery 2. Sections 3 and 5 had 4.3 and 12.3% symptomatic plants, respectively, whose spatial pattern was best described as random.

RESULTS

The spatial pattern of plants with symptoms characteristic of Phytophthora root rot in the three nurseries as illustrated in Figure 1 was judged to be random because the data were best described by the Poisson distribution (Tables 1 and 2). The Poisson distribution fit 89–100% of the sections of the azalea cultivar Hershey Red at the three nurseries, whereas the negative binomial fit 33–67% of the sections at the three nurseries. At nursery 3, data for two additional cultivars of 2-yr-old plants

Table 1. Values for indices of dispersion and goodness to fit to the Poisson and negative binomial probability distributions for Phytophthora root rot in the azalea cultivar Hershey Red growing in containers at two nurseries

Section	Symptomatic plants[a] (%)	Variance-to-mean ratio[b]	Morisita's index[b]	Poisson[c]	Negative binomial[c]	*k* Value
			Nursery 1[d]			
1	16.5	2.4*	1.8**	NS	NS	1.5
2	19.2	1.9*	1.5**	NS	NS	2.9
3	25.8	2.2*	1.5**	NS	*	2.9
4	31.8	1.1 NS	1.0 NS	NS	NS	26.1
5	28.8	1.0 NS	1.0 NS	NS	NF	NF
6	24.0	1.1 NS	1.0 NS	NS	NS	30.7
7	27.5	1.3 NS	1.1 NS	NS	NS	6.7
8	18.2	1.3 NS	1.2 NS	NS	NS	5.2
9	20.5	0.6 NS	0.8 NS	**	NF	NF
			Nursery 2			
1	7.3	1.4 NS	1.6 NS	NS	NS	1.7
2	5.0	1.2 NS	1.5 NS	NS	NS	1.9
3	4.3	1.2 NS	1.5 NS	NS	NS	2.5
4	7.8	1.0 NS	1.0 NS	NS	NF	NF
5	12.3	1.2 NS	1.2 NS	NS	NS	4.4
6	6.4	1.4 NS	1.7 NS	**	*	0.9
7	7.8	0.9 NS	0.9 NS	NS	NF	NF
8	8.5	1.0 NS	1.0 NS	NS	NF	NF
9	11.9	1.3 NS	1.3 NS	NS	NS	3.2

[a] Percent symptomatic plants based on ratio of symptomatic to asymptomatic plants in each section of 400 plants.
[b] A value of 1.0 indicates random dispersion; values significantly greater than 1.0 indicate aggregation of diseased plants. NS = not significantly greater than 1.0 at $P = 0.05$; * = significantly greater than 1.0 at $P = 0.05$; and ** = significantly greater than 1.0 at $P = 0.01$.
[c] Test of null hypothesis was that either the Poisson or negative binomial distribution described the data for diseased plants if the chi-square value was not significant at $P = 0.05$. * = Probability of a greater chi-square value less than 0.05 and ** = probability of a greater chi-square value less than 0.01. NF = variance was less than the mean and thus the negative binomial distribution was not an appropriate model for the data for diseased plants.
[d] Nursery 1 was sampled on 19 July 1984 and nursery 2 was sampled on 2 August 1984.

with symptoms of Phytophthora root rot could be described by the Poisson distribution in 100 and 80% of the sections for the cultivars Coral Bells and Hino Crimson, respectively (Table 2). The negative binomial fit 0 and 20% of the sections of Coral Bells and Hino Crimson, respectively, with symptoms of Phytophthora root rot.

Incidence of symptoms characteristic of Phytophthora root rot on the azalea cultivar Hershey Red ranged from 16.5 to 31.8% at nursery 1, from 4.3 to 12.3% at nursery 2, and from 13.5 to 28% at nursery 3 (Tables 1 and 2). Many symptomatic plants at nurseries 1 and 3 also suffered from nutritional problems. Recovery of *P. cinnamomi* from roots in the subsample of plants with symptoms was negative at both nurseries at sampling (Table 3). In the 2-yr-old plants (Coral Bells and Hino Crimson), however, recovery of *P. cinnamomi* ranged from 10 to 100% in symptomatic plants and from 10 to 72% in apparently healthy plants. Visual assessment of plants with symptoms characteristic of Phytophthora root rot was lower at nursery 2, and recovery of *P. cinnamomi* from the root sample of azaleas with symptoms of Phytophthora root rot was 11% (Table 3).

Much lower estimates of plants with symptoms of Phytophthora root rot (2.8–6.3%) were found at nursery 3 at a sampling 60 days later (Table 2). The Poisson distribution adequately described

Table 2. Values for indices of dispersion and goodness of fit to the Poisson and negative binomial probability distributions for Phytophthora root rot in 1- and 2-yr-old azaleas growing in containers at nursery 3 on two sampling dates

Cultivar Section[a]	Symptomatic plants[b] (%)		Variance-to-mean ratio[c]		Morisita's index[c]		Poisson[d]		Negative binomial[d]		*k* value	
	26 Jul.	26 Sept.	26 Jul.	26 Sept.	26 Jul.	26 Sept.	26 Jul.	26 Sept.	26 Jul.	26 Sept.	26 Jul.	26 Sept.
Hershey Red												
1	13.5	3.0	1.2 NS	0.9 NS	1.2 NS	0.6 NS	NS	NF	NS	NF	6.4	NF
2	21.5	5.3	1.0 NS	1.4 NS	1.0 NS	1.7 NS	NS	NS	NF	NS	NF	2.3
3	13.5	2.8	0.8 NS	1.4 NS	0.9 NS	2.2 NS	NS	*	NF	NS	NF	0.7
4	21.3	5.0	0.8 NS	1.1 NS	0.9 NS	1.3 NS	NS	NS	NF	NS	NF	4.5
5	24.8	6.3	1.2 NS	0.9 NS	1.1 NS	0.8 NS	NS	NS	*	NF	10.4	NF
6	28.0	2.8	1.7*	1.1 NS	1.3*	1.5 NS	NS	NS	NS	NS	4.9	2.4
Coral Bells												
1	37.5	…	0.8 NS	…	1.0 NS	…	NS	…	NF	…	NF	…
2	50.0	…	0.8 NS	…	1.0 NS	…	NS	…	NF	…	NF	…
3	45.6	…	0.5 NS	…	0.9 NS	…	NS	…	NF	…	NF	…
Hino Crimson												
1	41.7	…	0.8 NS	…	1.0 NS	…	NS	…	NF	…	NF	…
2	46.7	…	0.9 NS	…	1.0 NS	…	NS	…	NF	…	NF	…
3	54.1	…	1.2 NS	…	1.0 NS	…	NS	…	NS	…	55.8	…
4	58.3	…	0.4 NS	…	0.9 NS	…	NS	…	NF	…	NF	…
5	57.5	…	0.8 NS	…	1.0 NS	…	*	…	NF	…	NF	…

[a] The azalea cultivar Hershey Red was 1-yr-old plants grown in 2.6-L containers and sampled on 26 July and 26 September 1984. The cultivars Coral Bells and Hino Crimson were 2-yr-old plants grown in 5.7-L containers sampled on 26 July 1984 only.
[b] Percent symptomatic plants based on ratio of symptomatic to asymptomatic plants. Each section of Hershey Red contained 400 plants. Each section of Coral Bells and Hino Crimson contained 120 plants.
[c] A value of 1.0 indicates random dispersion; values significantly greater than 1.0 indicate aggregation of diseased plants. NS = not significantly greater than 1.0 at $P = 0.05$ and * = significantly greater than 1.0 at $P = 0.05$.
[d] Test of null hypothesis was that either the Poisson or negative binomial distribution described the data for diseased plants if the chi-square value was not significant at $P = 0.05$. * = Probability of a greater chi-square value less than 0.05 and ** = probability of a greater chi-square value less than 0.01. NF = variance was less than the mean and thus the negative binomial distribution was not an appropriate model for the data for diseased plants.

Table 3. Percent recovery of *Phytophthora cinnamomi* from azalea roots in a subsample of plants surveyed by the quadrat method at three nurseries

Location Cultivar[a]	Percent recovery of *P. cinnamomi* Apparently healthy	Symptomatic	Dead
Nursery 1			
Hershey Red	0	0	0
Nursery 2			
Hershey Red	0	11	0
Nursery 3			
Hershey Red	0	0	0
Hino Crimson	72	100	—[b]
Coral Bells	10	10	—
Hershey Red[c]	0	56	—

[a] The azalea cultivar Hershey Red at all locations was 1-yr-old plants in 2.6-L containers. The cultivars Coral Bells and Hino Crimson at nursery 3 were 2-yr-old plants growing in 5.7-L containers. Nurseries 1, 2, and 3 were sampled on 19 July, 2 August, and 26 July 1984, respectively.
[b] — = No dead plants in sample.
[c] Hershey Red in nursery 3 was sampled again on 26 September 1984.

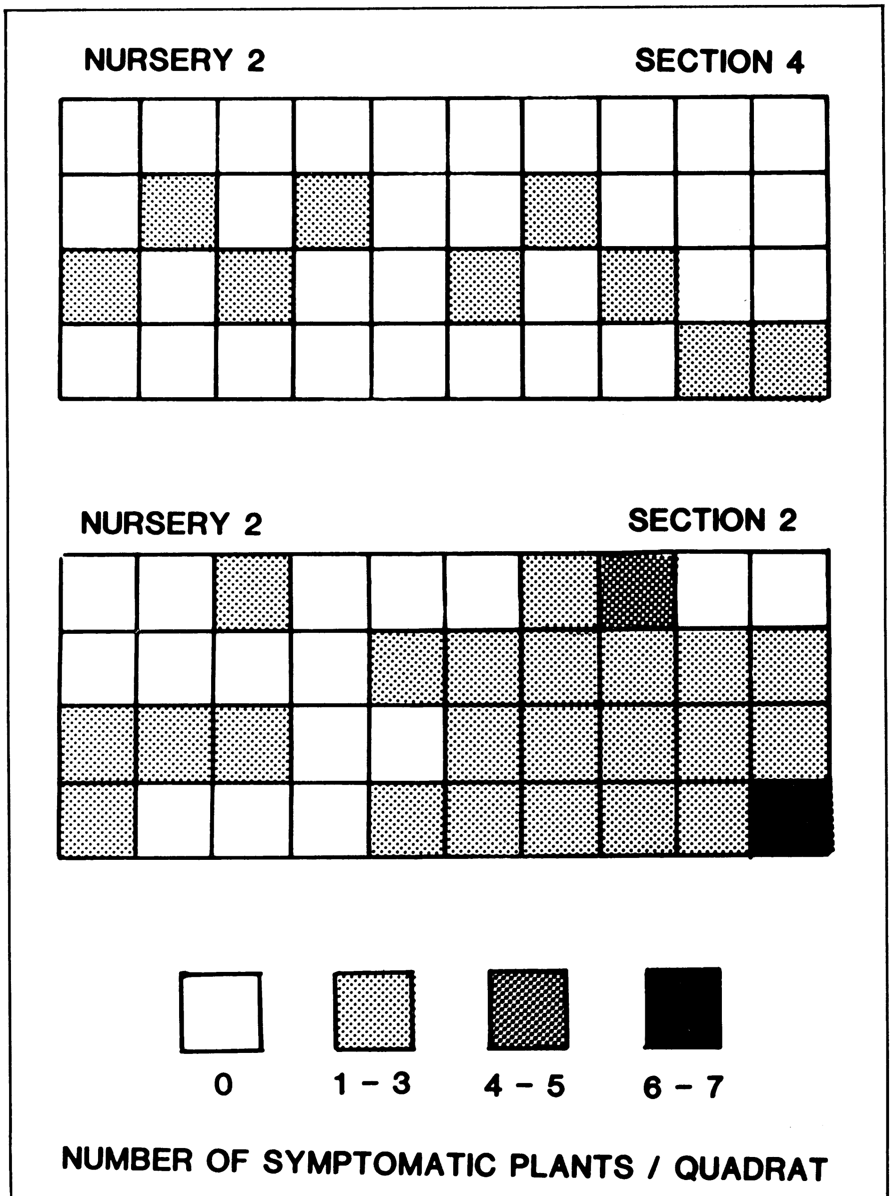

Fig. 2. Spatial pattern of the azalea cultivar Hershey Red in two sections at nursery 2 with symptoms of Phytophthora dieback caused by species of *Phytophthora*. Each section contained 400 plants arranged in 40 quadrats. Individual quadrats were two plants by five plants. Maps of each section represent the range of symptomatic plants observed at nursery 2. Sections 4 and 2 had 2.5 and 13.8% symptomatic plants, respectively, whose spatial pattern was best described as random for section 4 and aggregated for section 2.

data from 83% of the sections of the cultivar Hershey Red with symptoms of Phytophthora root rot, whereas the negative binomial described data from 66% of the sections. *P. cinnamomi* was recovered from 56% of the azaleas with symptoms and 0% from apparently healthy plants (Table 3).

The variance-to-mean ratio and Morisita's index for symptomatic plants were not significantly greater than 1.0 in 67–100% of the sections of the cultivar Hershey Red at the three nurseries (Tables 1 and 2). We concluded that the pattern of diseased plants was random. Although these two indices of dispersion are calculated differently, the absolute value and level of significance for each section agreed quite closely in most cases. The variance-to-mean ratio and Morisita's index for diseased plants in the 2-yr-old plants of the cultivars Coral Bells and Hino Crimson also were not significantly greater than 1.0 in all sections tested.

The pattern of plants with Phytophthora dieback in the nursery sections was aggregated in nursery 1 with k values from the negative binomial distribution of 0.6–3.6 and random in nursery 2 as illustrated in Figure 2. The data were described equally well by either the Poisson or negative binomial in nursery 3. The Poisson distribution adequately described data from 67–78% of the sections of the cultivar Hershey Red with symptoms of Phytophthora dieback at the three nurseries, whereas the negative binomial described data from 56–89% of the sections at the three nurseries (Tables 4 and 5). At nursery 3 a second cultivar, Hino Crimson, with symptoms of Phytophthora dieback was sampled. The frequency counts of diseased plants were best described by the Poisson distribution, although the negative binomial fit data from 50% of the sections (Table 5).

Disease incidence of the cultivar Hershey Red with symptoms of Phytophthora dieback ranged from 3.0 to 18.5% at nursery 1, from 2.5 to 13.8% at nursery 2, and from 2.5 to 10.5% at nursery 3, depending on the section. Dieback in the cultivar Hino Crimson at nursery 3 ranged from 0.8 to 5.5%. At the sampling 48 days later, disease incidence was lower for Hershey Red (2.3–5.6%) in nursery 3 but increased for Hino Crimson (4.3–9.3%) (Table 5).

The variance-to-mean ratio for quadrats of the cultivar Hershey Red with Phytophthora dieback was significantly greater than 1.0 for 67% of the sections at nurseries 1 and 3 (Tables 4 and 5). At nursery 2, 33% of the sections had variance-to-mean ratios greater than 1.0. Dieback was apparently aggregated at nurseries 1 and 3 and random at nursery 2. Values of Morisita's index and variance-to-mean ratios indicated similar spatial patterns. A change in pattern from aggregated to random was found at nursery 3 for Phytophthora dieback in the cultivar Hershey Red sampled 48 days later on the basis of estimates of variance-to-mean ratio and Morisita's index (Table 5). A similar shift in patterns was found for the cultivar Hino Crimson on the two sampling dates at nursery 3.

DISCUSSION

The random pattern of Phytophthora root rot in nursery sections of container-grown plants was not unexpected because of suspected sources of inoculum, crop management procedures, and age of crop at sampling. The random pattern may occur because plants in containers coming to the growing area may have been infected during the propagation phase or potted in infested medium. In either case, the operation of potting, loading trailers, and off-loading the containers in nursery sections may distribute the infected plants at random in the sections. Contaminated irrigation water would be expected to distribute propagules at random in the nursery sections as well, and we could not eliminate irrigation water as a potential source of inoculum. Because the containers were placed on plastic and the disease pattern was predominantly random, splashing of propagules from aggregated sources of inoculum in the soil under the plastic would not be expected. Apparently, dissemination of inoculum from the soil surface in the container did not occur, because this source of inoculum should result in an aggregated spatial pattern.

A change in pattern of symptomatic plants from random at the July and August sampling dates to an aggregated distribution at the September sampling date would have been evidence for the dissemination of secondary inoculum within nursery sections. On the basis of sampling at nursery 3, no secondary dissemination of inoculum occurred within 48 days, however.

Reliable distinctions between symptoms of Phytophthora root rot and other root problems such as nutrient imbalance could not be made early in the growing season. The decrease in frequency of symptomatic plants in nursery 3 in September suggests that only diseased plants were symptomatic later in the growing season. Because foliar symptoms caused by Phytophthora root rot are a manifestation of root dysfunction including mineral deficiency, abiotic problems such as low fertility levels will confuse estimates of visual symptoms. The correlation between expression of visual symptoms and recovery of *P. cinnamomi* from roots in subsamples was poor except in the 2-yr-old plants. In the future, surveys of 1-yr-old plants should not be conducted until late in the growing season to improve the reliability of assessments based on visual symptoms.

Spatial pattern of plants with Phytophthora dieback was aggregated in nurseries 1 and 3. If initial infection of individual plants was random as described, then

Table 4. Values for indices of dispersion and goodness of fit to the Poisson and negative binomial probability distributions for Phytophthora dieback in the azalea cultivar Hershey Red growing in containers at two nurseries

Section	Disease incidence[a] (%)	Variance-to-mean ratio[b]	Morisita's index[b]	Poisson[c]	Negative binomial[c]	*k* Value
			Nursery 1 (16 August 1984)			
1	7.8	2.4*	2.8**	*	NS	0.6
3	18.5	1.5*	1.3*	NS	NS	3.6
5	15.5	2.0*	1.6**	*	NS	1.4
7	3.0	1.2 NS	1.8 NS	NS	NS	1.0
9	3.0	1.2 NS	1.8 NS	NS	*	1.9
			Nursery 2 (9 August 1984)			
1	7.5	1.6*	1.8*	NS	NS	1.1
3	7.4	1.5 NS	1.5 NS	*	NS	1.3
5	7.0	0.7 NS	0.6 NS	NS	NF	NF
7	4.8	0.9 NS	0.7 NS	NS	NF	NF
8	6.3	1.0 NS	1.1 NS	NS	NS	34.1
9	8.8	1.7*	1.9*	NS	NS	1.1

[a] Disease incidence based on 400 plants per section.
[b] A value of 1.0 indicates random dispersion; values significantly greater than 1.0 indicate aggregation of diseased plants. NS = not significantly greater than 1.0 at $P = 0.05$, * = significantly greater than 1.0 at $P = 0.05$, and ** = significantly greater than 1.0 at $P = 0.01$.
[c] Test of null hypothesis was that either the Poisson or negative binomial distribution described the data for diseased plants if the chi-square value was not significant at $P = 0.05$. * = Probability of a greater chi-square value less than 0.05 and ** = probability of a greater chi-square value less than 0.01. NF = variance was less than the mean and thus the negative binomial distribution was not an appropriate model for the data for diseased plants.

Table 5. Values for indices of dispersion and goodness of fit to the Poisson and negative binomial probability distributions for Phytophthora dieback in 1-yr-old azaleas growing in containers at nursery 3 on two sampling dates in 1984

Cultivar	Disease incidence[a] (%)		Variance-to-mean ratio[b]		Morisita's index[b]		Poisson[c]		Negative binomial[c]	
Section	9 Aug.	26 Sept.	9 Aug.	26 Sept.	9 Aug.	26 Sept.	9 Aug.	26 Sept.	9 Aug.	26 Sept.
Hershey Red										
1	2.5	2.5	1.0 NS	1.6*	0.9 NS	3.6*	NF	NS	NS	NS
2	5.3	2.5	2.1*	1.0 NS	3.0*	0.9 NS	*	NS	NS	NF
3	7.0	4.5	1.6*	1.3 NS	1.9*	1.6 NS	NS	NS	NS	NS
4	4.8	2.3	1.9*	1.0 NS	3.0*	1.1 NS	*	NS	*	NF
5	6.8	2.3	1.4 NS	2.0 NS	1.6 NS	1.1 NS	NS	NS	NS	NF
6	10.5	5.6	1.8*	2.5*	1.7*	3.6*	NS	**	NS	NS
Hino Crimson										
1	3.7	5.3	1.6*	1.2 NS	2.7*	1.3 NS	NS	NS	NS	NS
2	3.3	4.3	1.8*	1.2 NS	3.6*	1.5 NS	*	*	NS	*
3	5.5	5.5	0.9 NS	1.4 NS	0.4 NS	1.8 NS	NS	*	NF	NS
4	0.8	9.3	0.9 NS	1.5*	0.0	1.6*	NS	**	NF	*

[a] Disease incidence based on 400 plants per section.
[b] Percent symptomatic plants based on ratio of symptomatic to asymptomatic plants. Each section of Hershey Red contained 400 plants. Each section of Coral Bells and Hino Crimson contained 120 plants.
[c] A value of 1.0 indicates random dispersion; values significantly greater than 1.0 indicate aggregation of diseased plants. NS = not significantly greater than 1.0 at $P = 0.05$, * = significantly greater than 1.0 at $P = 0.05$, and ** = significantly greater than 1.0 at $P = 0.01$.
[d] Test of null hypothesis was that either the Poisson or negative binomial distribution described the data for diseased plants if the chi-square value was not significant at $P = 0.05$. * = Probability of a greater chi-square value less than 0.05 and ** = probability of a greater chi-square less than 0.01. NF = variance was less than the mean and thus the negative binomial distribution was not an appropriate model for diseased plants.

secondary dissemination of inoculum may have occurred before sampling. An aggregated pattern for Phytophthora dieback was expected because previous work (2,12) demonstrated that sporangia were formed on infected foliage during wet periods with subsequent dissemination of zoospores by splashing water. The random pattern of Phytophthora dieback in the azalea cultivar Hershey Red at nursery 2 may be explained by the lack of favorable environmental conditions leading to production and dissemination of secondary inoculum after initial plant infection.

Spatial pattern of diseased plants in the nursery is important for developing sampling procedures to assess disease incidence accurately and adequately. The random pattern of Phytophthora root rot and the variable pattern of Phytophthora dieback should aid researchers when they survey nurseries for disease incidence of Phytophthora diseases.

ACKNOWLEDGMENTS

We wish to thank Billy I. Daughtry, Gary Calder, and Bonnie Ownley Gintis for technical assistance.

LITERATURE CITED

1. Benson, D. M., and Cochran, F. D. 1980. Resistance of evergreen hybrid azaleas to root rot caused by *Phytophthora cinnamomi*. Plant Dis. 64:214-215.
2. Benson, D. M., and Jones, R. K. 1980. Etiology of rhododendron dieback caused by four species of *Phytophthora*. Plant Dis. 64:687-691.
3. Benson, D. M., Jones, R. K., and Barker, K. R. 1982. Disease loss assessment for azalea, rhododendron, and Japanese holly in North Carolina nurseries. Plant Dis. 66:125-128.
4. Benson, D. M., Shew, H. D., and Jones, R. K. 1982. Effects of raised and ground-level beds and pine bark on survival of azalea and population dynamics of *Phytophthora cinnamomi*. Can. J. Plant Pathol. 4:278-280.
5. Campbell, C. L., and Noe, J. P. 1985. Spatial analysis of soilborne pathogens and root diseases. Annu. Rev. Phytopathol. 23:129-148.
6. Campbell, C. L., and Pennypacker, S. P. 1980. Distribution of hypocotyl rot caused in snapbean by *Rhizoctonia solani*. Phytopathology 70:521-525.
7. Dillard, H. R., and Grogan, R. G. 1985. Relationship between sclerotial spatial pattern and density of *Sclerotinia minor* and the incidence of lettuce drop. Phytopathology 75:90-94.
8. Elliott, J. M. 1977. Some Methods for the Statistical Analysis of Samples of Benthic Invertebrates. 2nd ed. Scientific Publication 25. Fresh-water Biological Association, Ferry House, Ambleside, Cumbria, UK. 160 pp.
9. Ferrin, D. M., and Mitchell, D. J. 1984. The influence of density and patchiness of inoculum on the epidemiology of tobacco black shank. (Abstr.) Phytopathology 74:839.
10. Gates, C. E., and Ethridge, F. G. 1972. A generalized set of discrete frequency distributions with FORTRAN program. Math. Methods Geol. 4:1-24.
11. Hoitink, H. A. J., Daft, J. G., and Gerlach, W. W. P. 1975. Phytophthora shoot blight and stem dieback of azalea and pieris and its control. Plant Dis. Rep. 59:235-237.
12. Kuske, C. R., and Benson, D. M. 1983. Survival and splash dispersal of *Phytophthora parasitica* causing dieback of rhododendron. Phytopathology 73:1188-1191.
13. Morisita, M. 1962. I_{α}-index, a measure of dispersion of individuals. Res. Pop. Ecol. Kyoto Univ. 4:1-7.
14. Pielou, E. C. 1977. Mathematical Ecology. John Wiley & Sons, New York. 358 pp.
15. Shew, B. B., Beute, M. K., and Campbell, C. L. 1984. Spatial pattern of southern stem rot caused by *Sclerotium rolfsii* in six North Carolina peanut fields. Phytopathology 74:730-735.
16. Southwood, T. R. E. 1978. Ecological Methods. 2nd ed. Chapman and Hall, London. 524 pp.
17. Thal, W. M. 1984. Sampling methods and spatial pattern of alfalfa leaf spot diseases. M.S. thesis. North Carolina State University, Raleigh. 54 pp.
18. Waggoner, P. E., and Rich, S. 1981. Lesion distribution, multiple infection, and the logistic increase of plant disease. Proc. Nat. Acad. Sci. 78:3292-3295.