Disease Gradients of Fusiform Rust on Oak Seedlings Exposed to a Natural Source of Aeciospore Inoculum

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ABSTRACT

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Disease gradients on oak seedlings resulting from infection by aeciospores of *Cronartium quercuum* f. sp. *fusiforme* were quantified from the number of sori (uredia and telia) per square centimeter of oak leaf surface area occurring at increasing distances from an abundant source of sporulating pine galls. Averaged data from six gradients—two each during early (10 February–3 March), middle (7–19 March), and late (19 March–1 April) phases of aecial sporulation—indicated that 12.4, 5.6, 5.9, 4.2, 1.8, and 0.9 sori per square centimeter of oak leaf surface area (y) occurred at distances from the source (x) of 3.1, 15.2, 30.5, 61.0, 91.4, and 152.4 m, respectively. These data fit a decreasing exponential function, $y=9.78\,e^{-0.016x}$; $r^2 = 0.94$. Transformation of y yielded the linear equation, $\log_{10}y = 0.99 - 0.007x$; $r^2 = 0.94$. The number of sori occurring on oak was reduced ~90% in the distance of 3.1 to 152.4 m. Spore traps located at 15.2, 30.5, and 91.4 m (x) from the aeciospore source yielded relative catches of 537, 378, and 212 spores (y), respectively. These data fit the power function $y = 2{,}212\,x^{-0.52}$; $r^2 = 0.99$ and extrapolation suggests that the numbers of aeciospores decreased ~87% over the distance 3.1 to 152.4 m. These data indicate that the preponderance of aeciospores are deposited near the source and suggest that local sources of aeciospore inoculum are most important in the fusiform rust epidemic.

Additional key words: inoculum dispersal, epidemiology, disease management, slash pine.

Fusiform rust severely limits the efficient management of slash pine (*Pinus elliottii* Engelm.) and loblolly pine (*P. taeda* L.) throughout much of their commercial ranges (5). Rust incidence and distribution have increased significantly since about 1940 (4,7,11), concurrent with intensification of forest management. The pathogen, *Cronartium quercuum* (Berk.) Miyabe ex Shirai f. sp. *fusiforme* (Burdsall and Snow), is macrocyclic and heteroecious, producing pycniospores and aeciospores on galls on pine branches and stems and urediospores and basidiospores on leaves of susceptible oak species.

In north Florida aeciospores are produced in abundance on pine galls for a 6-wk period during February–April (2). These spores (yellow-orange, verrucose, thick-walled, oval-shaped, and ~ 15×25 μm) are wind-disseminated. Spore abundance in the atmosphere is typically diurnal with a peak about mid-day (R. A. Schmidt, *unpublished*). Aeciospores that impact on the lower surfaces of succulent oak leaves germinate and penetrate host tissues within 4–6 hr (10) provided adequate surface moisture is available. Within 2–10 days (10) uredial and subsequently telial sori occur on the lower surface of oak leaves most succulent at the time of infection.

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Only telia occur on leaves less succulent when infected and neither sorus forms on hardened leaves.

Rust incidence on pine is directly correlated with regional abundance of susceptible oak in north Florida (8) and in the southeastern United States (14). In north Florida, Hollis and Schmidt (8) reported a direct relation between the amount of inoculum on on-site oaks and rust incidence on pine.

Disease gradient data for white pine blister rust (16) and several other plant diseases (6) suggest that local sources of inoculum are most important to the epidemic. Even so, sanitation of local sources of inoculum of *C. quercuum* f. sp. *fusiforme* is not considered feasible because both aeciospores and basidiospores are assumed to be disseminated for great distances. With the exception of our previous abstract (12) no concise data on fusiform rust disease gradients are reported. This paper quantifies rust gradients on oak seedlings resulting from infection by aeciospores produced in an "isolated" pine plantation. The utility of these data for further research and fusiform pine rust management is discussed.

MATERIALS AND METHODS

The experimental area (Fig. 1) was a level grass field bordered on the west by slash pine plantings containing the aeciospore source and surrounded on the east and south by hardwood forest and on the west and north by slash pine seed orchards.

The natural aeciospore source was 377 sporulating galls on 5- to 12-yr-old slash pine located in plantings I, II, and III. Galls occurred from 1–6 m above the ground and were concentrated along the eastern edge of these three plantings. As such, these galls represented an elevated, continuous-volume source of inoculum. The relative strength of the source was determined by recording, at weekly intervals, the number of sporulating galls.

Pots containing water oak seedlings (*Quercus nigra* L.) with succulent leaves were placed in 0.6-m-high racks; the foliage was ~1 m above ground level. These racks, containing ~10 seedlings each, were arranged in two rows (lines 1 and 2) and were placed at distances of 3.1, 15.2, 30.5, 61.0, and 152.4 m from the aeciospore source, as measured from the east boundary of plantings I and II. Disease gradients were characterized as the number of sori per square centimeter of succulent oak leaf surface area (one side only) occurring at increasing distances from the source of aeciospores. Six such gradients were determined—two (lines 1 and 2) for each of three sequential experiments during early, middle, and late spore production periods.

In experiment A, seedlings were exposed in the field from 10 February–13 March and sori were counted during the next 2 days. In experiments B and C, seedlings were exposed during 7–19 March and 19 March–1 April, respectively, and then moved to the greenhouse where sori were counted after 2 wk.

Kramer-Collins spore samplers (9) were located at a height of 1 m at 15.2, 30.5, and 91.4 m from the aeciospore source on line 2. Relative spore numbers were calculated by totaling the spores caught by each sampler for several contiguous periods when all traps were functioning properly.

Wind direction was measured with a wind vane located at a height of 3.6 m near line 2. Data were recorded electronically at 5-min intervals and summarized for known periods of abundant aeciospore release, ie, 0700 hours to 1700 hours (R. A. Schmidt, *unpublished*).

RESULTS

Aeciospore source and wind direction. The numbers of sporulating galls recorded at weekly intervals (Fig. 2) indicate that aeciospores were abundantly present during experiments A and B, but were probably greatly reduced during experiment C. Relative abundance of inoculum as judged by the areas under the curves in Fig. 2 was 4:2:1 for A, B, and C, respectively. Subsequent spore trap and sori data also suggest that the amount of inoculum was similar for A and B, but greatly reduced for experiment C.

A summary of wind direction during periods of abundant aeciospore release, ie, 0700 hours to 1700 hours, indicates that air

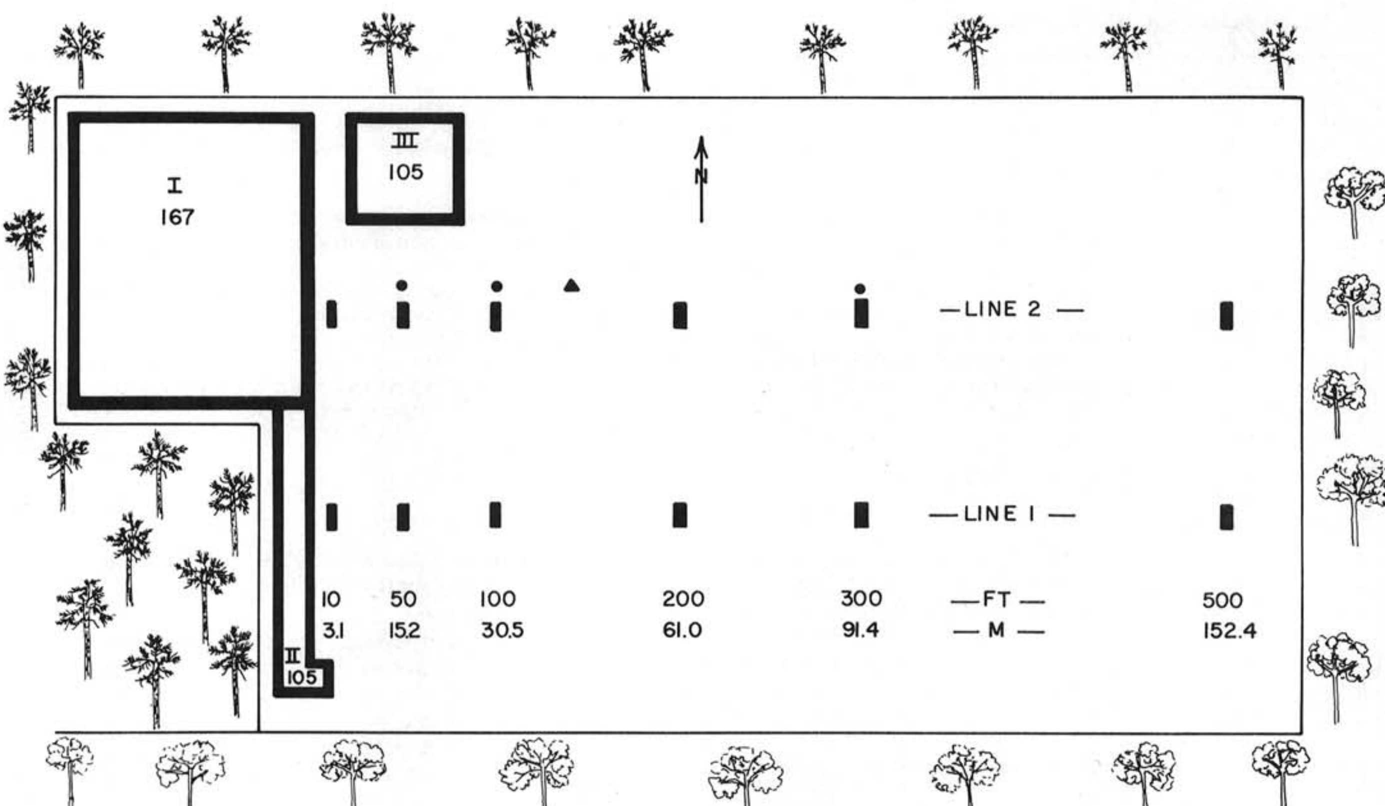

Fig. 1. Map of fusiform rust disease gradient experimental area. The number of sporulating aecial galls on pine are shown for plantations I, II and III. The locations of racks of oak seedlings ■, spore traps •, and meteorology equipment ▲ are shown for gradient lines 1 and 2.

traveled from the inoculum source to the oak seedlings (SW, W, and NW) 48, 33, and 36% of the time for experiments A, B, and C, respectively.

The numbers of aeciospores caught in the traps were appreciable only during experiments A and B and were quite variable. Numbers of spores were totaled for experiments A and B for those periods when uninterrupted samples were available for all traps. These data fit the power function $y = 2{,}212\ x^{-0.52}$; $r^2 = 0.99$, in which y is the relative number of spores trapped and x is the distance from the source. Extrapolation of these data indicate that aeciospores diminished by 87% between 3.1 and 152.4 m from the aeciospore source.

Disease gradients. The data points, regression lines, and equations for the six disease gradients (lines 1 and 2, experiments A, B, and C) are shown in Fig. 3. The number of sori decreased with increasing distance from the source and can be characterized by a decreasing exponential function $y = ae^{-bx}$, in which y = the number of sori per square centimeter of oak leaf surface area; a is a constant (the y intercept); e is the base of the natural log; b is the rate constant and x is the distance (in meters) from the source.

The gradients during experiment C, when the aeciospore source strength was greatly reduced, were relatively flat and did not fit this exponential function as well as the gradients in A and B. Apparently line 1 was exposed to more inoculum than line 2. A large positive deviation from the regression line, perhaps due to the elevated source, occurred in three of the four gradients of experiments A and B.

Data from the six disease gradient curves were averaged and fitted to the exponential function and to a logarithmic linear function (Fig. 4). The exponential function with parameters as previously described is $y = 9.78\ e^{-0.016x}$; $r^2 = 0.94$. Transforming y to $\log_{10}$ yields the linear function: $\log_{10} y = 0.99 - 0.007x$; $r^2 = 094$. From these data it is calculated that the number of sori on oak diminished by 91.5% between 3.1 and 152.4 m from the aeciospore source.

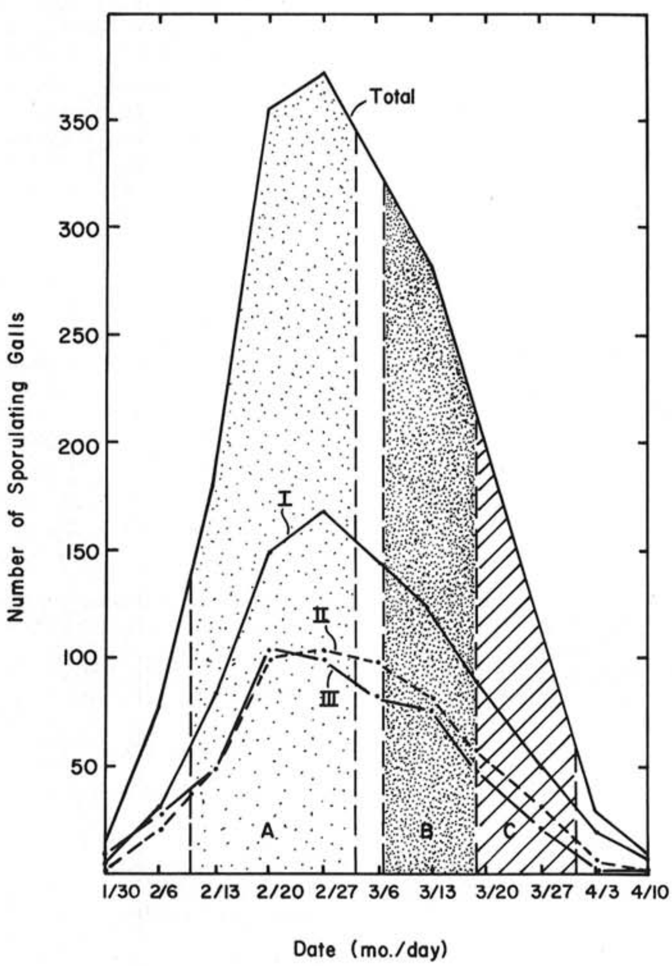

Fig. 2. The number of aecial galls of *Cronartium quercuum* f. sp. *fusiforme* sporulating at weekly recording dates in three slash pine plantations (I, II, and III) and the total sporulating during disease gradient experiments (A, B, and C).

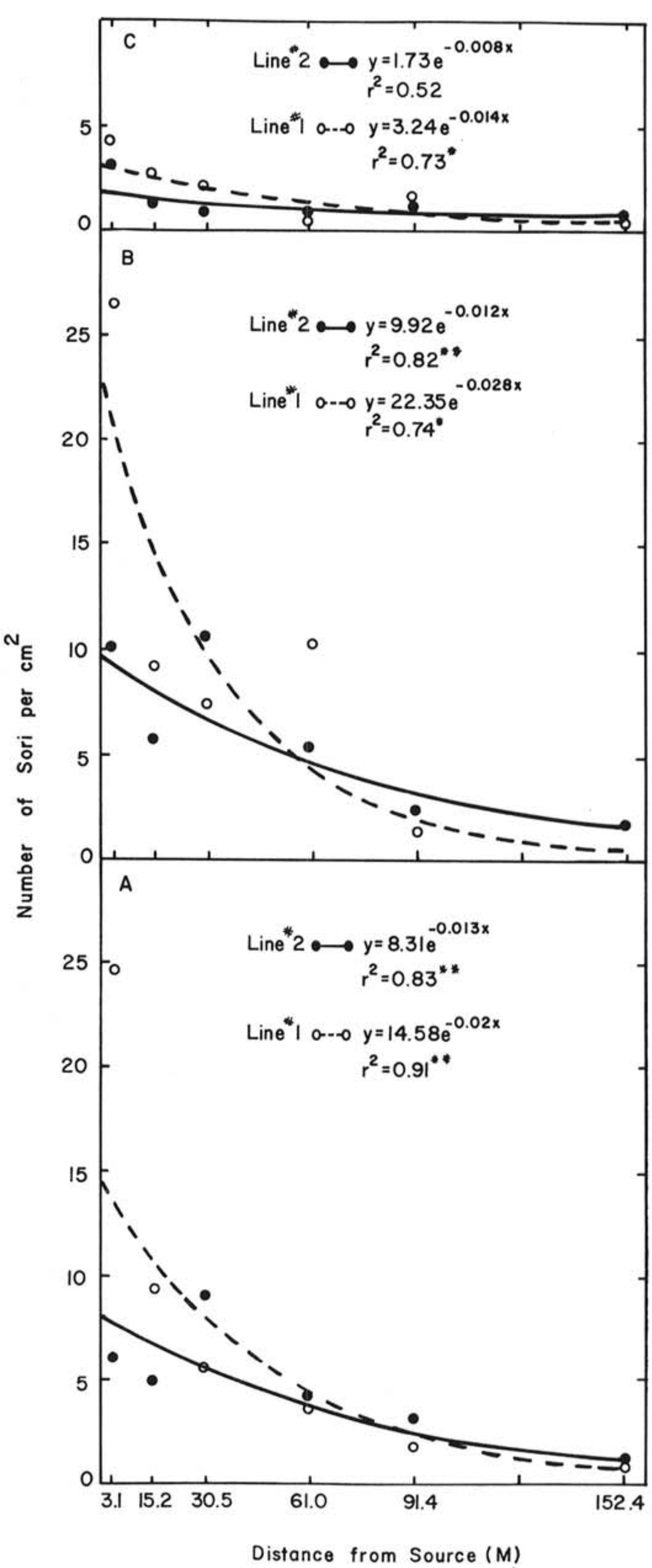

Fig. 3. Disease gradients for *Cronartium quercuum* f. sp. *fusiforme* as characterized by the number of sori formed on leaves of water oak seedlings located at increasing distances from the source of aeciospore inoculum on pine. **A,** 10 February–3 March; **B,** 7–19 March, and **C,** 19 March–1 April.

DISCUSSION

The disease gradients described herein resulted from an abundant, elevated volume source of inoculum, typical of fusiform rust in natural conditions. The gradients were not significantly influenced by aeciospores from adjacent areas, secondary infection by urediospores, or obvious environmental gradients and, as such, are judged to be representative. Even though inoculum source III was "off-line," it did not appear to unduly affect the general shape of the gradient curves since line 1, which was more distant from this source, apparently received more inoculum than line 2.

Compared with the disease gradients summarized by Gregory (6), these fusiform gradients were relatively flat, such that log-log transformations were not appropriate. If both x and y are transformed to $\log_{10}$, such that $y = a/x^b$ in which b is the slope of the regression line, $\log_{10} y = a - b\log_{10}x$; then b is approximately 0.25. In theory, these gradients result from three-dimensional spore dispersal (3) and the value for b might be expected to approach 2.0 (6) or 1.75 for average values of atmospheric stability in Sutton's equation (15). The relatively low value of b in our data may be explained by several factors: aeciospores originated from a continuous volume source rather than a point source; the oak seedlings were downwind from the source only part of the time, at other times the wind was at right angles to or directly opposite the downwind direction; the gradients were established over a 2–3 wk period and are the result of varying atmospheric and environmental conditions. These factors would condition a flatter gradient, ie, reduce the slope coefficient b. Unlike spore dispersal gradients, disease gradients include germination, penetration, and sorus development, each of which are dependent on environmental conditions subsequent to deposition.

These gradient data indicate that numbers of sori on oak leaves diminished approximately 90% within 152.4 m (500 ft) from the aeciospore source, implying that the preponderance of aeciospores are deposited near the source of inoculum. Approximately one telium per square centimeter of oak leaf tissue occurred at 150 m from the source of fusiform rust aeciospores. This underscores the epidemiological importance of local sources of inoculum and suggests the possibility of inoculum sanitation as a fusiform rust management strategy in certain situations. For comparison, Carlson (1) reported infection from aeciospores of western gall rust as "essentially nonexistent" beyond 300 yd (274.3 m) and Smeltzer and French (13) indicated that infection of sweet fern rust was observed at a maximum of 30 m (32.8 yd) from the aeciospore source.

Using these gradient data and data of Hollis and Schmidt (8) in north Florida, which give percent rust on pine as a function of on-site oak, we calculated the distances oak must be separated from pine to yield a given amount of rust on pine. These relationships (Table 1) are theoretical and based on few data and should not be used for management decisions. However, they do provide a basis for discussion and further research on the feasibility of inoculum sanitation for fusiform rust management. Future research should also consider sanitation ratios and the significance of the occurrence and "r" values of secondary cycles initiated by urediospores.

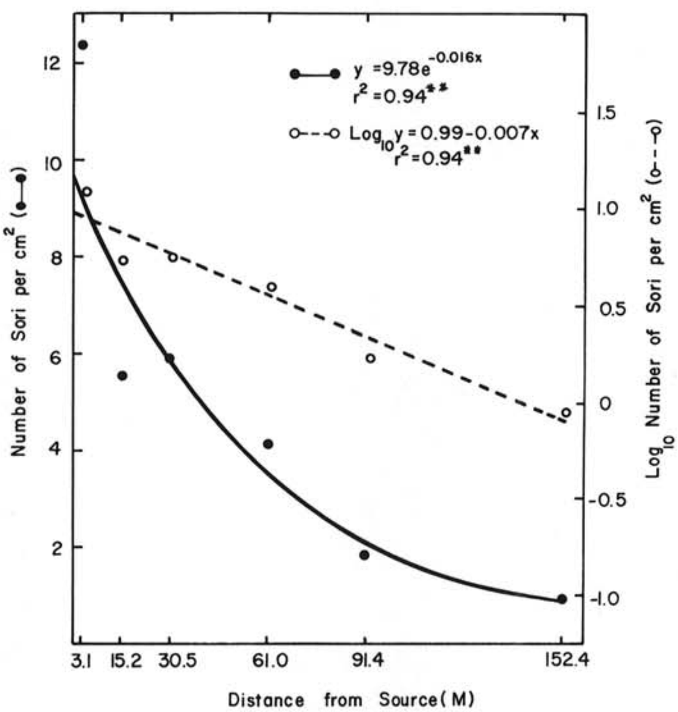

Fig. 4. Average disease gradient for *Cronartium quercuum* f. sp. *fusiforme* as characterized by the number of sori formed on leaves of water oak seedlings located at increasing distances from the source of aeciospore inoculum on pine (average of six gradients; two each in three experiments).

TABLE 1. Calculated effect of distance from an abundant source of aeciospores of *Cronartium quercuum* f. sp. *fusiforme* on rust severity on oak and the frequency of subsequent infection of on-site pines

Distance between aeciospore source and adjacent oak[a] x		Severity of rust on oak[b] y (telia/cm²)		Frequency of rust on pine (% of trees infected)
M	Ft	Number	$\log_{10}$	
404	1,325	0.01	−2.00	10
296	971	0.06	−1.20	20
228	748	0.20	−0.70	30
174	571	0.50	−0.30	40
134	440	1.00	0.00	50
107	351	1.58	0.20	60
66	217	3.16	0.50	70
39	128	5.01	0.70	80
12	39	7.94	0.90	90
...	...	12.88	1.10	100

[a]Calculated as $x = (\log_{10}y - 0.99)/-0.0074$, in which x = distance and y = telia per square centimeter; refer to average disease gradient in Fig. 4.

[b]Telia per square centimeter of oak leaf surface area (one side only) was calculated from data presented by Hollis and Schmidt (8).

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