Relation of Site Factors to Fusiform Rust Incidence in Young Slash and Loblolly Pine Plantations in the Coastal Plain of Florida and Georgia

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ABSTRACT

Schmidt, R. A., Miller, T., Holley, R. C., Belanger, R. P., and Allen, J. E. 1988. Relation of site factors to fusiform rust incidence in young slash and loblolly pine plantations in the coastal plain of Florida and Georgia. Plant Disease 72:710-714.

The relation of soil drainage, soil surface texture, site preparation methods, and site index to the incidence of fusiform rust, caused by *Cronartium quercuum* f. sp. *fusiforme*, was examined in more than 1,200 slash pine and 230 loblolly pine plantations in eight forest management areas of the Florida and Georgia coastal plain. Rust incidence was the percentage of living trees at age 5–6 years with at least one stem or branch gall. In a combined analysis of all management areas, rust incidence in both pine species was greatest on sites with well- or moderately well-drained soils with loamy sand or sandy loam surface texture and least on sites with poorly or somewhat poorly drained soils with a sandy surface texture. Individually, some management areas exhibited the same overall trend, but in other areas, especially high rust incidence areas, plantations had high rust incidence regardless of soil drainage or texture class. Old field sites had significantly greater rust incidence, which appears to be the consequence of these sites being located on the better-drained loamy soils. Regionwide, an estimated site index based on soil characteristics was negatively correlated with rust incidence in both pine species. This unexpected trend resulted because of the dependence of the site index system on soil drainage and texture. Within soil drainage/texture classes, the site index was positively correlated with rust incidence in slash pine. These forest inventory data are correlative and do not establish cause and effect. Nevertheless, they aid our understanding of fusiform rust distribution and management. A definitive rust hazard model at the stand level will require quantitative data on alternate host (oak) abundance and dispersal of inoculum.

Additional keywords: disease hazard, disease management, epidemiology, *Pinus elliottii* var. *elliottii*, *P. taeda*

Southern fusiform rust, caused by *Cronartium quercuum* (Berk.) Miyabe ex Shirai f. sp. *fusiforme*, is a major obstacle to effective management of slash (*Pinus elliottii* Engelm. var. *elliottii*) and loblolly (*P. taeda* L.) pines on substantial areas throughout the southern United States (6,14). Regional maps of rust incidence exist (15,19), but the ecological determinants of rust distribution are poorly understood. A better understanding of the role of site factors on rust incidence and distribution is a prerequisite to rust hazard rating and disease management.

Practices that improve site quality and promote early, rapid growth through improved site quality, e.g., fertilization and cultivation, favor increased rust incidence (1,3,7,10–12). Site quality (site index) has been positively related to rust incidence (2,13). Site factors (17), including soil drainage (8–11) and oak abundance (8,9,11,20), also have been associated with rust incidence and distribution. Guidelines to predict site hazard to fusiform rust have been developed both at a regional level (2) and on a stand basis (8,9).

A large regional data set of Container Corporation of America was available to examine rust incidence and distribution in relation to site factors in the Florida and Georgia coastal plain. This report presents information on the relation of rust incidence with soil drainage, soil texture, site preparation, and site index for young (5–6 yr old) slash and loblolly pine plantations.

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MATERIALS AND METHODS

These data were accumulated from an inventory of mostly 5- to 6-yr-old (4.5–8.5 range) operational pine plantations in eight forest management areas located in the Georgia and Florida coastal plain (Fig. 1). The data include fusiform rust incidence, soil drainage class, soil texture, site preparation method, and estimated site index from over 1,200 slash pine (38,000 ha) and 230 loblolly pine (6,000 ha) plantations that were planted with rust-susceptible seedlings between the years 1961 and 1980. Each plantation was inventoried when it became 5 years of age, or soon thereafter.

An earlier report (16) gives plantation frequencies for 1) years planted, 2) age at inventory, 3) area, and 4) percentage of rust, together with the temporal and spatial patterns of rust incidence in the eight management areas.

Rust incidence. Rust incidence data were collected from the live trees at five consecutive planting spaces in the row

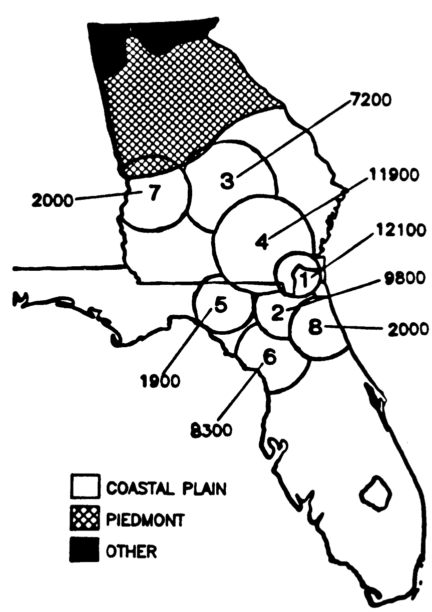

Fig. 1. Hectares of plantations in eight forest management areas in the Florida and Georgia coastal plain, where fusiform rust and site data were collected in young plantations of slash and loblolly pine.

nearest the center of a 78.4-m^2 sample plot. Sample plots were evenly spaced, and their numbers varied with plantation size. For example, averages of 27 (6.75% sample) and 144 (0.50% sample) plots were measured in plantations of 2.43–4.05 ha and 223–243 ha, respectively. Fusiform rust categories were 1) stem and branch infections, or stem only, and 2) branch infections only. Combining these categories provided an estimate of cumulative percentage of rust at age 5 years. Rust incidence (percentage of trees with rust) for each plantation was calculated as a total for all sample plots, i.e., the total number of living trees with rust divided by the total number of living trees. This value underestimates the amount of rust, because trees killed by rust were not included.

Soil drainage and texture. Soil drainage is influenced by soil texture and topography with seven classes defined (21), ranging from excessively drained to very poorly drained. Four of these classes are well represented in the data set: 1) well drained, 2) moderately well drained, 3) somewhat poorly drained, and 4) poorly drained. Average depths to the water table are 152.4–203.2, 101.6–152.4, 50.8–101.6, and 0–50.8 cm for the above drainage classes, respectively.

Soil texture is a physical characteristic associated with the relative proportion of sand, silt, and clay-sized particles (21). Three types of surface soil textures (0–15.2 cm depth) are well represented in the data: 1) sand, 2) loamy sand, and 3) sandy loam. The sandy textured soils are primarily poorly drained and of low topographic position ("flatwoods" soils), often with an underlying spodic horizon (Ultic Haplaquads). Loamy sands are moderately well to well drained, with most possessing an argillic horizon and a few with a spodic horizon. Sandy loam soils are mostly moderately well to well drained. These three soil textural classes are represented within each of the four drainage classes.

In many instances, plantations exhibited more than one drainage and/or textural class. When this occurred, each plantation was assigned a predominant drainage or texture, based on a visual estimation of the areas involved.

Site preparation. Four methods of site preparation are well represented: 1) old field—abandoned agricultural land that required only harrowing or disking before planting, 2) chopped—sites on which the residual vegetation and debris was chopped using a large, tractor-drawn roller drum with cutting blades, followed by burning, 3) chopped and bedded—sites were chopped and burned and the soil was pulled into elevated beds, and 4) harrowed—sites were treated twice with a disk-type harrow and burned.

These categories are not mutually exclusive, however, since some old field sites were chopped or chopped and bedded. Although most site-preparation methods are represented on most soil drainage and textural classes, the actual method used was a management decision based on previous land use, vegetation, and soil factors, especially drainage class. For example, most of the former agricultural land (old fields) are moderately well to well drained, whereas most of the sites that were bedded or harrowed are somewhat poorly or poorly drained.

Site index. The method used to determine site index was that of Coile (4,5), which uses soil characteristics such as soil drainage and texture to estimate the mean total height of dominant and codominant trees on a site at age 25 years.

Analyses. Means were tested for statistical significance by Duncan's multiple range (0.05 level of probability) only when the F values for main effects in an analysis of variance indicated statistical significance.

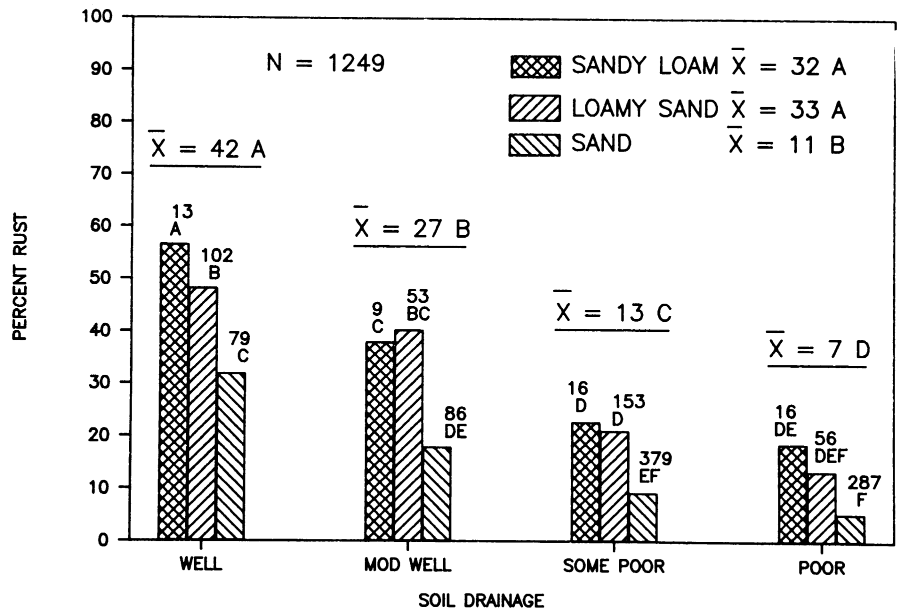

Fig. 2. Association of fusiform rust incidence with soil drainage and texture in young slash pine plantations in eight management areas in the Florida and Georgia coastal plain. Among soil drainage classes, soil textures, and drainage/texture combinations, rust incidence means ($\bar{x}$) or bars with a common letter are not significantly different ($P = 0.05$). The number of plantations (N) is given above the bar, total N = 1,249.

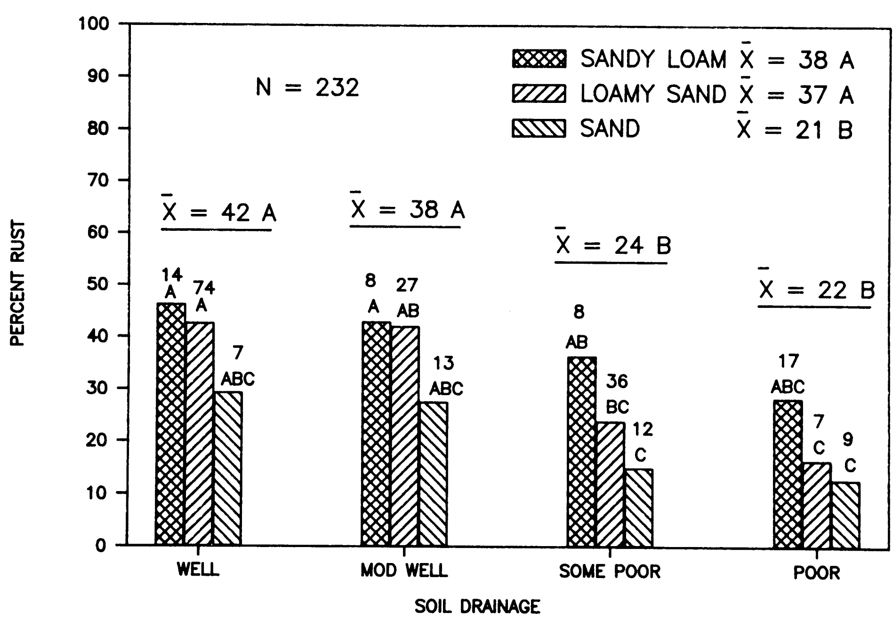

Fig. 3. Association of fusiform rust incidence with soil drainage and texture in young loblolly pine plantations in eight management areas in the Florida and Georgia coastal plain. Among soil drainage classes, soil textures, and drainage/texture combinations, rust incidence means ($\bar{x}$) or bars with a common letter are not significantly different ($P = 0.05$). The number of plantations (N) is given above the bar, total N = 232.

RESULTS

Soil drainage and texture. When data from all management areas were combined into one analysis, there were significant differences in rust incidence among soil drainage and surface textural classes for both pine species. Rust incidence was highest on the moderately well- and well-drained sandy loam soils and lowest on the poorly drained, sandy soils. In 1,249 slash pine plantations (Fig. 2), rust incidence averaged 42, 27, 13, and 7% on well-, moderately well-, somewhat poorly, and poorly drained soils, respectively. Average rust incidence was 32, 33, and 11% on sandy loam, loamy sand, and sand textural classes, respectively.

In 232 loblolly pine plantations (Fig. 3), average rust incidence was 42, 38, 24, and 22% on well-, moderately well-, somewhat poorly, and poorly drained soils, respectively. Average rust incidence was 38, 37, and 21% on sandy loam, loamy sand, and sand textural classes, respectively.

When the data were separated into the eight management areas (each geographically distinct and representing perennially high or low rust incidence) (16), significant differences in rust incidence among soil variables were less consistent. For example, in slash pine (Table 1) rust incidence in low incidence areas 4 and 6 and in high rust incidence area 5 was consistent with the trends of the combined data, i.e., rust incidence increases with increased drainage. However, in the high rust incidence area 3, there were no differences in rust incidence among drainage classes. Of the four areas not shown, area 7 had too few observations and areas 1, 2, and 8, which had few observations in some drainage classes, generally showed increased rust with increased drainage. Results were similar for soil texture (Table 2). In areas 4, 6, and 5, rust incidence was significantly less on the sandy soils. But rust incidence in area 3 showed no differences among soil textures. In the four areas not shown that had few or no observations in some textures, the results were similar to those in Table 2.

When the loblolly pine data were separated into management areas, there were too few observations in many classes and no statistical differences among soil drainage (Table 3) or soil texture (Table 4) classes within areas. However, the trends appear similar to those for slash pine. Rust incidence in areas 3 and 7 was high regardless of soil drainage (Table 3) or texture (Table 4). Rust incidence increased with increased soil drainage in areas 1 and 6 (Table 3). Trends for soil texture in areas 1 and 6 were not evident (Table 4). In the four areas not shown, there were too few observations for comparison in loblolly.

Site preparation. In the combined analysis, rust incidence varied significantly among site preparation methods in both loblolly and slash pine (Fig. 4). Rust incidence was greatest in both species on old field sites. The chopped and bedded sites did not differ significantly from the harrowed sites for either pine species. Chopped sites differed significantly from other methods in both species. Rust incidence on these sites was lowest for slash pine, but intermediate for loblolly pine.

Site index. In the combined data, disregarding geographic location and soil drainage/texture classes, there was a significant negative correlation between rust incidence and Coile-estimated site

Table 1. Association of fusiform rust incidence with soil drainage in young slash pine plantations in four management areas in the Florida and Georgia coastal plain

	Low rust incidence				High rust incidence			
	Area 4[w]		Area 6		Area 3		Area 5	
Soil drainage[v]	Number[x]	Percent[y]	Number	Percent	Number	Percent	Number	Percent
Well	6	28 a[z]	17	11 a	148	45 a	7	60 a
Moderately well	11	23 a	46	8 ab	33	53 a	16	60 a
Somewhat poorly	97	14 b	49	6 b	16	42 a	39	53 a
Poorly	155	6 c	33	2 c	11	46 a	6	36 b
Total	269		145		208		68	
Mean		10		6		46		54

[v] Depth to water table decreases from a range of 152.4 to 203.2 cm to a range of 0 to 50.8 cm as drainage classes change from well to poorly drained.
[w] Area 3 = central Georgia, 4 = southeast Georgia, 5 = northwest Florida, 6 = south central Florida (Fig. 1).
[x] Number of plantations.
[y] Average percent of live trees with a stem or branch gall.
[z] Within columns, means followed by a common letter are not significantly different, according to Duncan's multiple range test ($P = 0.05$).

Table 2. Association of fusiform rust incidence with soil texture in young slash pine plantations in four management areas in the Florida and Georgia coastal plain

	Low rust incidence				High rust incidence			
	Area 4[w]		Area 6		Area 3		Area 5	
Soil texture[v]	Number[x]	Percent[y]	Number	Percent	Number	Percent	Number	Percent
Sandy loam	7	24 a[z]	4	21 a	9	51 a	6	70 a
Loamy sand	46	11 b	13	11 b	127	48 a	46	58 a
Sand	216	9 b	128	5 b	72	41 a	16	37 b
Total	269		145		208		68	
Mean		10		6		45		54

[v] Surface soil texture 0–15.2 cm.
[w] Area 3 = central Georgia, 4 = southeast Georgia, 5 = northwest Florida, 6 = south central Florida (Fig. 1).
[x] Number of plantations.
[y] Average percent of live trees with a stem or branch gall.
[z] Within columns, means followed by a common letter are not significantly different, according to Duncan's multiple range test ($P = 0.05$).

Table 3. Association of fusiform rust incidence with soil drainage in young loblolly pine plantations in four management areas in the Florida and Georgia coastal plain

	Rust incidence							
	Low		Intermediate				High	
	Area 1[x]		Area 3		Area 6		Area 7	
Soil drainage[w]	Number[y]	Percent[z]	Number	Percent	Number	Percent	Number	Percent
Well			29	31	6	43	58	49
Moderately well	3	18	8	28	14	35	11	55
Somewhat poorly	13	14	18	38	2	20	1	26
Poorly	10	11	19	32				
Total	26		74		22		70	
Mean		13		33		36		49

[w] Depth to water table decreases from a range of 152.4 to 203.2 cm to a range of 0 to 50.8 cm as drainage classes change from well to poorly drained.
[x] Area 1 = northeast Florida, 3 = central Georgia, 6 = south central Florida, 7 = west central Georgia (Fig. 1).
[y] Number of plantations.
[z] Average percent of live trees with a stem or branch gall.

index for both slash and loblolly pine. However, when the slash pine data were partitioned into drainage/texture classes, rust percentage within these classes was positively correlated with site index (Fig. 5).

DISCUSSION

In the overall analyses that combined management areas, fusiform rust incidence on both slash and loblolly pine was significantly greater on the better-drained sites. This relationship was reported by others (8,10,11) for slash pine, was confirmed by our data, and was extended to loblolly pine.

Also, in the combined data, rust incidence on both slash and loblolly pine was significantly greater on the loamy sand and sandy loam soils and least on the sand soils. This specific relationship has not been reported previously, although Smith et al (17) noted that "rust incidence appeared greatest on soils with sandy surface horizons over argillic horizons, which prevent both excessive drying or prolonged saturation of the profile." Our data characterize surface textures (0–15.2 cm) and do not reflect the nature or depth of the subsurface texture, which could be important variables.

When these data were separated into discrete geographic management areas, the differences in rust incidence associated with soil drainage and texture classes evident in the combined analyses were not consistent within individual areas. For example, in area 3 rust incidence was equally high on both species regardless of soil drainage or texture. Apparently, in this area, where well- and moderately well-drained sandy loam and loamy sand soil predominate, abundant, wind-dispersed inoculum infects trees on adjacent sites regardless of soil properties. However, for slash pine in areas 4, 5, and 6, the trends defined in the combined data were present.

Site preparation or cultural practices influence rust incidence (1,3,11,12), and it is generally believed that in the presence of abundant inoculum, factors that enhance growth of pine can result in increased rust incidence. Overall, our data show significant differences among site preparation methods, with old field sites having the highest rust incidence for both slash and loblolly pine. However, site preparation is confounded with drainage/texture classes. Old field sites are most often well- to moderately well-drained sandy loams or loamy sands, and bedded sites are those in wetter areas. Thus, the association of rust with site preparation is likely due indirectly to drainage and texture (which influence site preparation treatment), and is not directly a consequence of site preparation.

In the combined data, Coile-estimated site index (4,5) was negatively correlated with rust incidence in both slash and loblolly pine. This negative relation is in disagreement with data of others (2,13) and with what is generally accepted, i.e., that rust incidence is positively related to increased growth. We believe that this negative correlation occurs because of the strong relationship between rust incidence and soil drainage coupled with the fact that Coile's estimated site index is based on soil drainage and/or texture. Coile's model predicts lower site indexes on well-drained soils where, in our data, rust was greatest. When data are partitioned into drainage/texture classes, however, a positive relation between rust incidence and site index was evident for slash pine, but not for loblolly pine.

Apparently, other more directly associated factors are influencing rust incidence, e.g., oak abundance (8,9). We hypothesize that in high-rust-incidence areas, where drier sandy loam and loamy sand soils predominate, oaks are abundant and inoculum is wind-dispersed to infect pine on adjacent sites regardless of the soil drainage and texture. In contrast, in areas with predominately wet, sandy soils, oaks are not abundant and high rust incidence is more restricted to those sites with oak, i.e., the drier sites. Snow et al (18) has identified a disease gradient to approximately 200 m from a known source of basidiospore inoculum, and Froelich and Snow (8) define high-rust hazard sites as having abundant on-site oaks or abundant surrounding oaks within 800 m. In our data, there was evidence for a negative correlation between rust incidence and plantation

Table 4. Association of fusiform rust incidence with soil texture in young loblolly pine plantations in four management areas in the Florida and Georgia coastal plain

	Rust incidence							
	Low		Intermediate				High	
	Area 1[x]		Area 3		Area 6		Area 7	
Soil drainage[w]	Number[y]	Percent[z]	Number	Percent	Number	Percent	Number	Percent
Sandy loam	3	12	24	30	1	37	16	51
Loamy sand	14	13	40	33	18	40	54	49
Sand	9	14	10	36	3	12		
Total	26		74		22		70	
Mean		13		33		36		50

[w] Surface soil texture 0–15.2 cm.
[x] Area 1 = northeast Florida, 3 = central Georgia, 6 = south central Florida, 7 = west central Georgia (Fig. 1).
[y] Number of plantations.
[z] Average percent of live trees with a stem or branch gall.

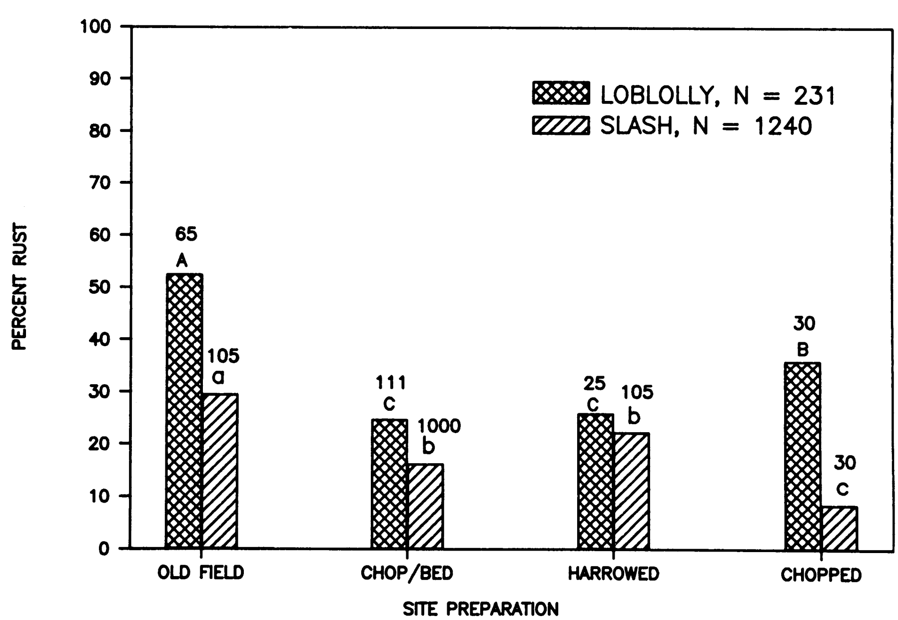

Fig. 4. Association of fusiform rust incidence with site preparation in young slash and loblolly pine plantations in eight management areas in the Florida and Georgia coastal plain. Among site preparation treatments (within species) rust incidence means with a common letter do not differ significantly ($P = 0.05$). The number of plantations (N) is given above the bar, total N for loblolly = 231, slash = 1,240.

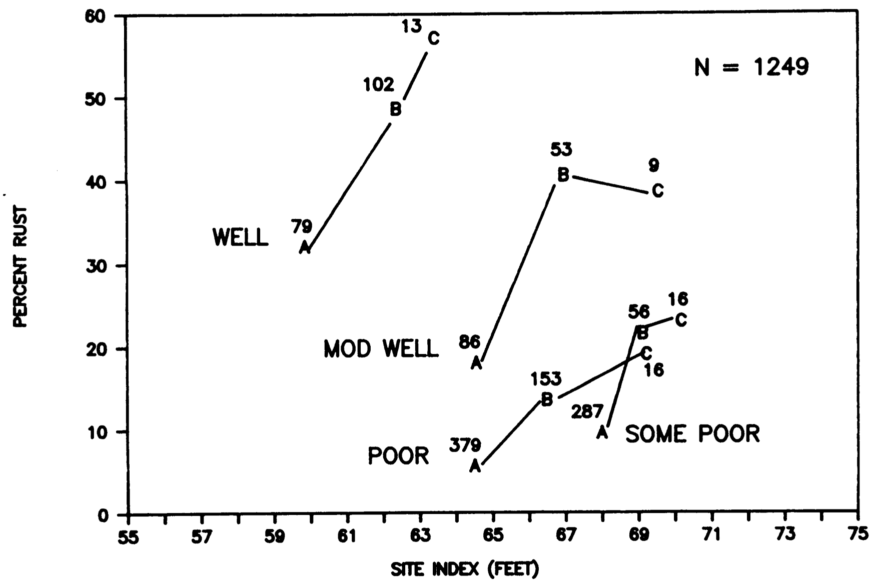

Fig. 5. Association of fusiform rust with average estimated site index (4,5), soil drainage (well, moderately well, somewhat poorly, and poorly drained), and soil texture (A = sand, B = loamy sand, and C = sandy loam) in young slash pine plantations in eight management areas in the Florida and Georgia coastal plain. The number of plantations (N) is given for each datum, total N = 1,249.

size, suggesting that rust incidence is greater in plantations where pines are closer to inoculum on surrounding oak.

These inventory data, sometimes confounded by management practices, are descriptive and correlative. Due to unequal numbers of plantations among site factor categories and geographic areas and perhaps unequal opportunities for rust infection among plantations, cause and effect cannot be established. Nevertheless, these data provide valuable insights into site-rust hazard relations and rust management.

LITERATURE CITED

1. Boggess, W. R., and Stahelin, R. 1948. The incidence of fusiform rust in slash pine plantations receiving cultural treatments. J. For. 46:683-685.
2. Borders, B. E., and Bailey, R. L. 1986. Fusiform rust prediction models for site-prepared slash and loblolly pine plantations in the Southeast. South. J. Appl. For. 10:145-151.
3. Burton, J. D., Shoulders, E., and Snow, G. A. 1985. Incidence and impact of fusiform rust vary with silviculture in slash pine plantations. For. Sci. 31:671-680.
4. Coile, T. S. 1952. Soil productivity for southern pines. Part I. Shortleaf and loblolly pines. For. Farm. 11(7):10-11,13.
5. Coile, T. S. 1952. Soil productivity for southern pines. Part II. Longleaf, slash and pond pines. For. Farm. 11(8):11-12.
6. Dinus, R. J., and Schmidt, R. A., eds. 1977. Management of fusiform rust in southern pines. Symp. Proc. Univ. Fla., Gainesville. 163 pp.
7. Dinus, R. J., and Schmidtling, R. C. 1971. Fusiform rust in loblolly and slash pines after cultivation and fertilization. U.S. Dep. Agric., For. Serv. Res. Pap. SO-68. 10 pp.
8. Froelich, R. C., and Snow, G. A. 1986. Predicting site hazard to fusiform rust. For. Sci. 32:21-35.
9. Hollis, C. A., and Schmidt, R. A. 1977. Site factors related to fusiform rust incidence in north Florida slash pine plantations. For. Sci. 23:69-77.
10. Hollis, C. A., Smith, W. H., Schmidt, R. A., and Pritchett, W. L. 1975. Soil and tissue nutrients, soil drainage, fertilization and tree growth as related to fusiform rust incidence in slash pine. For. Sci. 22:141-148.
11. May, J. T., Rahman, S., and Worst, R. H. 1973. Effects of site preparation and spacing on planted slash pine. J. For. 71:333-335.
12. Miller, T. 1972. Fusiform rust in planted slash pines: Influence of site preparation and spacing. For. Sci. 18:70-75.
13. Nance, W. L., Froelich, R. C., and Shoulders, E. 1981. Effects of fusiform rust on survival and structure of Mississippi and Louisiana slash pine plantations. U.S. Dep. Agric. For. Serv., Res. Pap. SO-172. 11 pp.
14. Powers, H. R., Jr., Schmidt, R. A., and Snow, G. A. 1981. Current status and management of fusiform rust on southern pines. Annu. Rev. Phytopathol. 19:353-371.
15. Schmidt, R. A., Goddard, R. E., and Hollis, C. A. 1974. Incidence and distribution of fusiform rust in slash pine plantations in Florida and Georgia. Fla. Agric. Exp. Stn., IFAS, Univ. Fla., Gainesville. Tech. Bull. 763. 21 pp.
16. Schmidt, R. A., Holley, R. C., Klapproth, M. C., and Miller, T. 1986. Temporal and spatial patterns of fusiform rust epidemics in young plantations of susceptible and resistant slash and loblolly pines. Plant Dis. 70:661-666.
17. Smith, W. H., Hollis, C. A., and Gooding, J. W., III. 1977. Influence of soil factors on fusiform rust incidence. Pages 81-88 in: Management of Fusiform Rust in Southern Pines. R. J. Dinus and R. A. Schmidt, eds. Symp. Proc. Univ. Fla., Gainesville. 163 pp.
18. Snow, G. A., Wells, O. O., and Switzer, G. L. 1986. Fusiform rust gradient in a loblolly pine plantation. For. Sci. 32:372-376.
19. Squillace, A. E. 1976. Geographic patterns of fusiform rust infection in loblolly and slash pine plantations. U.S. Dep. Agric., For. Serv. Res. Note SE-232. 4 pp.
20. Squillace, A. E., Dinus, R. J., Hollis, C. A., and Schmidt, R. A. 1978. Relation of oak abundance, seed source, and temperature to geographic patterns of fusiform rust incidence. U.S. Dep. Agric., For. Serv. Res. Pap. SE-186. Southeast. For. Exp. Stn., Asheville, NC. 20 pp.
21. U.S. Department of Agriculture. 1975. Soil Taxonomy—A Basic System of Soil Classification for Making and Interpreting Soil Surveys. U.S. Dep. Agric. Handb. 436. 754 pp.