Resistance of *Pinus ponderosa* to *Endocronartium harknessii* in Pennsylvania

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ABSTRACT

Merrill, W., Wenner, N., and Towers, B. 1986. Resistance of *Pinus ponderosa* to *Endocronartium harknessii* in Pennsylvania. Plant Disease 70: 317-320.

Incidence and severity of infection by *Endocronartium harknessii* on *Pinus ponderosa* from 49 seed sources were measured in central Pennsylvania. Levels of infection varied more within than among seed sources. The greatest variation in resistance was among seed sources from the northern portions of the range of *P. ponderosa* in Montana, Wyoming, South Dakota, and Nebraska. Some seed sources recommended for reforestation of strip mine spoil banks contained high percentages of susceptible individuals and should not be used where this pathogen occurs.

In 1969, the USDA Forest Service initiated a study to determine the suitability of various seed sources and ecotypes of *Pinus ponderosa* Laws. for reforestation of spoil banks of coal strip mines in Pennsylvania (2). The 4-yr-old plants used in this study were remnants from a large provenance study. They had been grown for 2 yr in seedbeds at the USDA Forest Service Bessey Nursery at Halsey, NE, from seed collected from various sites within the range of *P. ponderosa* (Fig. 1) and had been transplanted twice before being planted on a spoil bank in Clearfield County, PA (2). Forty-eight of the seed sources were *P. ponderosa* var. *scopulorum* Engelm. (*P. p. scopulorum*), and one was *P. ponderosa* var. *ponderosa* (*P. p. ponderosa*) (2,8). The average percentage of survival and height growth of seedlings from each source were determined after four and six growing seasons, and eight seed sources were recommended as superior for spoil bank reclamation (2). Three other sources also appeared superior, but the data were based on incomplete replicates (2).

The Bessey Nursery lies within the natural range of *Endocronartium harknessii* (J. P. Moore) Y. Hiratsuka, the autoecious causal agent (3) of pine-pine gall rust (western gall rust). Some of the seedlings used in this study were infected while in the nursery seedbeds or transplant beds (5,6). Thus by 1981, the rust had become well established within the Pennsylvania plantation. Some trees bore more than 300 galls; many were incurring extensive branch mortality and were being stunted or killed. The number of diseased individuals appeared to vary among the seed sources, affording the opportunity to evaluate the relative resistance of the various provenances and ecotypes to this pathogen under the climatic regime of central Pennsylvania. A preliminary report has been published (10).

MATERIALS AND METHODS

The initial plantation consisted of six randomized blocks, each containing rows of 10 or 11 individuals from each of 40 seed sources. Some blocks also contained sets of 10 or 11 individuals from some of the other nine sources (2). All trees were planted 1.83 × 1.83 m apart on a flat to gently south-sloping black calcareous

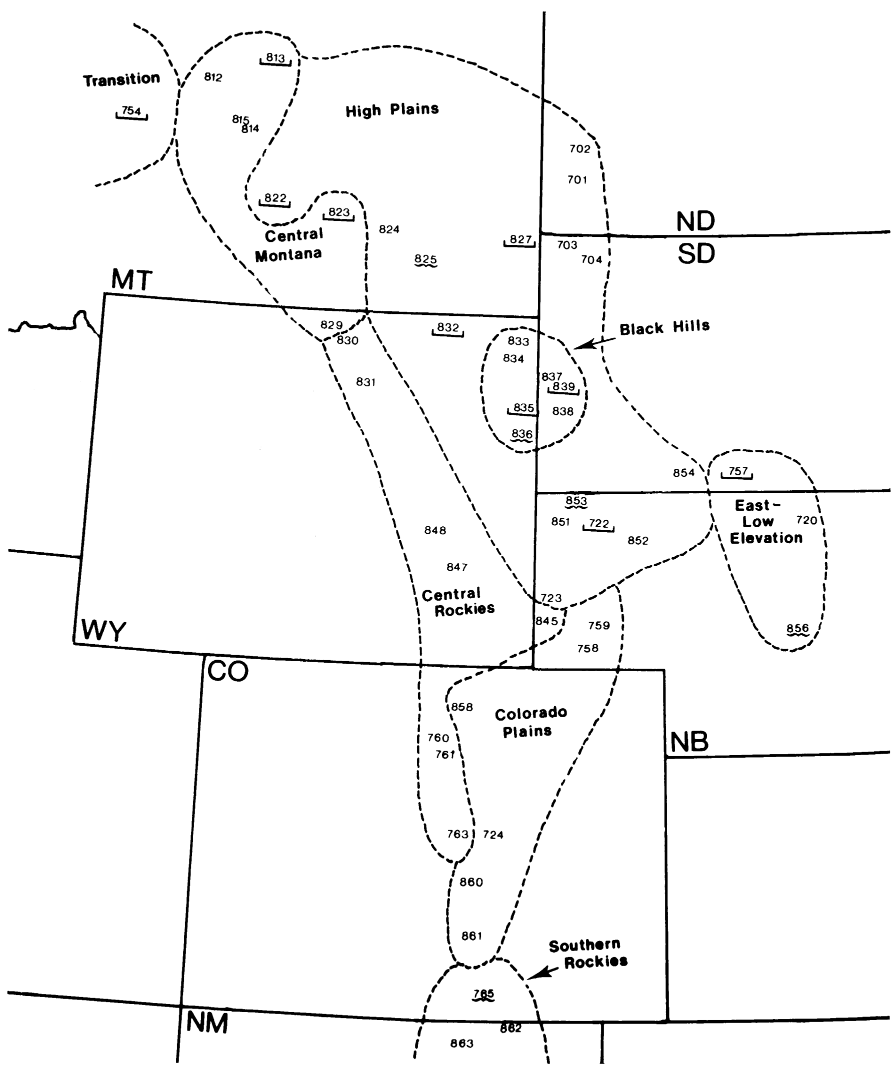

Fig. 1. Geographical origins and ecotypes of the seed sources of *Pinus ponderosa* used in this study. The 10 most resistant sources are underlined with brackets; the five most susceptible sources are underlined with wavy lines.

Contribution 1448, Department of Plant Pathology, Pennsylvania Agricultural Experiment Station. Approved for publication as Journal Series Paper 6905.

Accepted for publication 5 September 1985.

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shale spoil bank. Descriptions of the site (2) and the geographic location and climatological data for each seed source have been published (2,8).

The plantation was examined in February 1982 and the galls on each tree counted. These data were summarized by seed source and block, and the average incidence (percentage of trees infected) and average severity (number of galls per infected tree) were calculated. Data were subjected to analysis of variance and Duncan's new multiple range test to detect significant differences in levels of infection among the various seed sources and ecotypes. Because of missing replications, nine sources were excluded from these analyses.

RESULTS AND DISCUSSION

The results are summarized in Table 1 and Figure 2. Statistical analysis of the data was difficult because of variations (0–11) in the number of surviving trees in some replicates and the variations in both incidence and severity of disease within sources and among replicates. A significant ($P = 0.001$) gradient of increasing infection occurred from west to east across the six blocks. Disease incidence within each block depended on the planting sites of the rows of the more susceptible sources. We were unable to detect discrete infection centers.

We were unable to obtain a significant separation of means when we used the gall rating system of Thomas et al (9). Gall rating was poorly correlated with latitude ($r^2 = 0.04$) and length of growing season (a function of latitude and elevation) of the seed source ($r^2 = 0.06$).

Analysis of variance showed significant ($P = 0.001$) differences among seed sources with respect to average number of galls per diseased tree and also to average percentage of trees infected. Duncan's multiple range test ($P = 0.05$) separated seed sources into three groups according to the average number of galls per infected tree. The first group contained two sources with >30 galls per infected tree, the intermediate group contained 14 sources with 12–30 galls per infected tree, and the third group contained 25 sources with <12 galls per infected tree. The same procedure separated seed sources into multiple groupings on the basis of average percentage of trees infected (Table 1). A linear correlation between disease incidence (percentage of trees infected) and disease severity (average number of galls per infected tree) was significant ($r^2 = 0.74$).

Using the above analyses, we placed the seed sources into three groups according to both disease incidence and severity. We classed sources with <15% incidence and with <12 galls per infected tree as mildly susceptible, those with >35% incidence or >30 galls per infected tree as highly susceptible, and all others as moderately susceptible. When we pooled data from all sources within each of these three categories, analysis of variance showed significant differences ($P = 0.01$) between disease incidence and severity of the groups with low and high susceptibility, though neither group differed at $P = 0.05$ from the group with moderate susceptibility.

Of 11 seed sources listed by the USDA Forest Service report (2) as superior or perhaps superior for spoil bank reforestation, nine had ⩾10% susceptible individuals, six had >20% susceptible individuals, and one had >50% susceptible individuals (Fig. 2). On the basis of survival and height growth (1) and resistance to rust (this study), only five of the 49 sources should be used where pine-pine gall rust occurs (823 from central Montana; 827, 832, and 835 from the Black Hills and high plains; and 757 from the low-elevation east plains). The use of two of these (823 and 832) is questionable because only 20 trees (two replicates) were involved and these were planted in the two blocks with the lowest disease incidence.

There is a caveat even in this recommendation. There is great variation among individuals within a single seed source. For example, the tree in the foreground in Figure 3 had more than 300 galls and was killed by the fungus in 1983. The tree immediately behind, from the same seed source, is rustfree. The progeny from the same mother tree probably will vary in disease resistance from year to year because of open pollination, as is true for other characteristics (1).

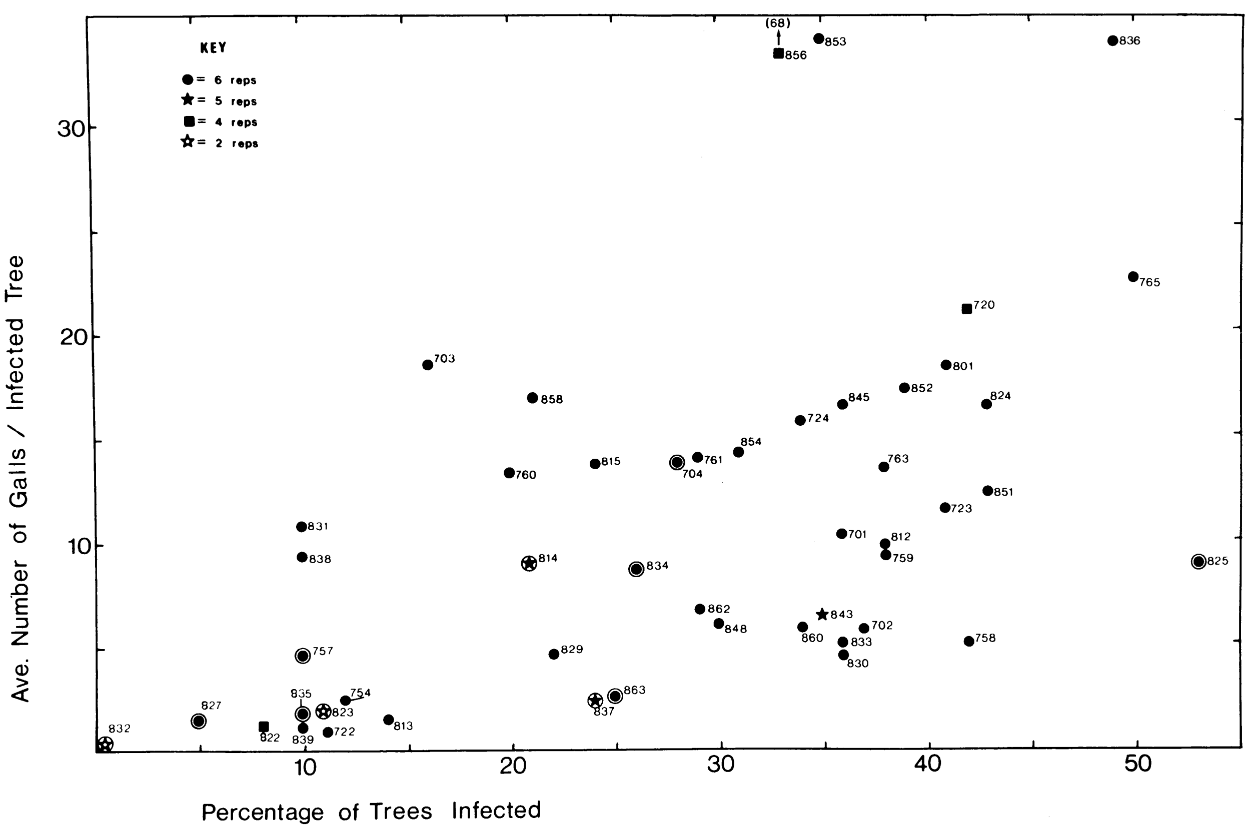

Fig. 2. Incidence and severity of *Endocronartium harknessii* on *Pinus ponderosa* from 49 seed sources. Seed sources recommended by the USDA Forest Service for reforestation of strip mine spoil banks are circled.

Thomas et al (9), working with two plantings of the same seed sources and same nursery seedling lots in Michigan, found significant differences in disease resistance among ecotypes of *P. p. scopulorum*, with a gradient of decreasing resistance from north to south. A somewhat similar trend, though not statistically significant, existed among ecotypes of *P. p. scopulorum* planted in Pennsylvania, with disease incidence in central Montana < Black Hills < central Rockies < high plains < southern Rockies < Colorado plains. When data were pooled, average disease incidence differed significantly ($P = 0.05$) between sources north or south of 43° N latitude.

The 10 seed sources with lowest percentages of infected individuals occurred in and around the Black Hills-high plains region of Nebraska, South Dakota, Wyoming, and Montana (Fig. 1). Four of the five most susceptible sources also occurred in the same area (Fig. 1). Thus this appears to be the region with greatest genetic variation in rust resistance in *P. p. scopulorum* and is perhaps the area where host and parasite have been associated longest. This area is separated by the open plains from the range of *P. banksiana* Lamb., a major host; *E. harknessii* occurs on *P. banksiana* virtually throughout its entire range in Canada (4) and the northeastern United States (5).

Thomas et al (9) discussed the possible evolution of *E. harknessii* in relation to susceptibility of *P. ponderosa*, with *E. harknessii* evolving early from *Cronartium quercuum* (Berk.) Miyabe ex Shirai and the two fungi then being separated by the plains and late glaciation. Another possibility is that *E. harknessii* evolved from *C. quercuum* in eastern North America. After the retreat of the glaciers and the northward migration of coniferous species, *E. harknessii* could have spread west on *P. banksiana* to *P. contorta* Dougl., then to *P. p. ponderosa*, and then south to *P. p. scopulorum* and other western host species. This would explain the variations in rust resistance found with *P. ponderosa* by Thomas et al (9) and in this study. Other hard pine species native to the mid-Atlantic states and the Northeast are highly resistant if not immune, whereas pines now native to the deep South and hence probably more recent arrivals to the area (e.g., *P. elliottii* Engelm.) appear to be as susceptible as western species (5). A study of the rust resistance of various seed sources and ecotypes of *P. banksiana* would be most interesting.

The growth and survival data summarized in the USDA Forest Service report (2) are questionable. That study did not acknowledge the presence of rust within the plantation, even though branch and stem galls would have been clearly visible when this plantation was examined before the 1973 and 1975 growing seasons. Because basal galls frequently girdle and kill seedlings, the low survival of seedlings from some sources may be due in part to infection that occurred in seedling or transplant beds. Furthermore, multiple branch infections and infection of the main stem stunt the tree (5), thus confounding growth measurements (Fig. 3).

Fig. 3. Two ponderosa pines from the same seed source, showing variation in susceptibility to *Endocronartium harknessii*. The tree in foreground had more than 300 galls and died during the 1983 growing season; the tree immediately behind it is rustfree.

This again demonstrates the danger of the indiscriminate shipment of plants from areas where known dangerous pathogens occur into areas where such pathogens have not yet been introduced. The seedlings used in this study were brought from within the known natural range of *E. harknessii* and from a nursery with a history of seedbed infection by this pathogen (5–7) into central Pennsylvania where at that time, the pathogen was not known to occur. Since the establishment of this plantation, the pathogen also has been found in several other plantations in Pennsylvania and adjoining states. These infection centers were traced to a single commercial nursery in Pennsylvania that transshipped shipments of seedlings from within the natural range of the pathogen in northern Michigan (5). Although one can perhaps excuse commercial nursery workers for such mistakes, the introduction of an important plant pathogen into a new location and the subsequent failure to recognize its presence and effect on a research project demonstrate the necessity of a multidisciplinary approach in the planning, execution, and evaluation of all such research.

Resistance to *E. harknessii* occurs within all seed sources and ecotypes of *P. ponderosa* examined in Pennsylvania. This resistance could be used, via controlled pollination, to produce populations with relatively high levels of resistance as has been done with the southern pines and fusiform rust. The best sources of resistance in *P. p. scopulorum* appear to occur in or near the Black Hills area of South Dakota and Wyoming.

Table 1. Mean incidence of infection of various seed sources of *Pinus ponderosa* by *Endocronartium harknessii*

Seed source no.	Mean disease incidence[a]
825	0.525 a
765	0.503 ab
836	0.492 ab
824	0.430 abc
851	0.425 abcd
758	0.416 abcde
861	0.409 abcdef
723	0.409 abcdef
852	0.389 abcdef
759	0.382 abcdef
812	0.381 abcdef
763	0.378 abcdef
702	0.365 abcdefg
845	0.362 abcdefg
833	0.361 abcdefg
701	0.358 abcdefg
830	0.357 abcdefg
853	0.354 abcdefg
860	0.344 abcdefg
724	0.335 abcdefg
854	0.314 abcdefg
848	0.302 abcdefg
862	0.294 abcdefg
761	0.286 abcdefg
704	0.280 abcdefg
834	0.257 abcdefg
863	0.247 abcdefg
815	0.236 abcdefg
829	0.217 abcdefg
858	0.213 abcdefg
760	0.197 bcdefg
703	0.155 cdefg
813	0.142 cdefg
754	0.122 cdefg
722	0.111 cdefg
838	0.102 defg
831	0.098 efg
835	0.097 efg
757	0.088 fg
827	0.049 g

[a] Means followed by the same letter do not differ significantly ($P = 0.05$) according to Duncan's multiple range test.

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