AN ABSTRACT OF THE THESIS OF

GEORGE MATHER HARVEY for the DOCTOR OF PHILOSOPHY
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Abstract approved: Redacted for privacy
Lewis F. Roth

In 1967, Lophodermella morbida Staley and Bynum, a recently-described hypodermataceous needle-cast fungus, became destructively epidemic in a knobcone pine (Pinus attenuata Lemm.) plantation in Del Norte County, California, and in several ponderosa pine (P. ponderosa Laws.) plantations in western and southwestern Oregon. This thesis presents information on this currently destructive disease.

The life cycle of L. morbida is completed within 12 months. Mature ascospores are discharged during periods of general rain from early June through mid-July. Infection occurs only on foliage recently emerged from the fasicle sheath. Foliage infected in one year drops from the tree by mid-summer of the next. By mid-summer about one-half of each newly infected needle has become necrotic; thus seriously impairing food production. Growth of repeatedly infected trees is significantly reduced; however, from

1969 through 1973, there has been little mortality in the plantations under study.

Probably L. morbida is a native fungus, catapulted to prominence in populations of a very susceptible host growing on unsuitable sites under climatic conditions favoring spread of the pathogen and disease intensification. To avoid trouble from this disease, planting ponderosa pine on questionable sites should be stopped. When ponderosa pine is planted, ridgetops and natural basins where clouds linger should be avoided. On the eastern slope of the Cascade Mountains, the risk from L. morbida to either natural stands or plantations of ponderosa pine appears minimal because of limited moisture. However, an unusually wet June or July might substantially increase the risk. Pine on the windward (west) slope of interior mountains of the Pacific Northwest may have a high risk factor from infection because of favorable rainfall patterns induced by local topography.

Epidemiology of *Lophodermella morbida* in Plantations of Ponderosa Pine in Western Oregon

by

George Mather Harvey

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Professor of Plant Pathology
in charge of major

Redacted for privacy

Head of Department of Botany and Plant Pathology

Redacted for privacy

Dean of Graduate School

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Typed by Susie Kozlik for George Mather Harvey

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FRONTISPIECE

General view of ponderosa pine plantation heavily infected with *Lophodermella morbida*. Willamette National Forest, Lane County, Oregon, October, 1969.

EPIDEMIOLOGY OF *LOPHODERMELLA MORBIDA* IN PLANTATIONS OF PONDEROSA PINE IN WESTERN OREGON

I. INTRODUCTION

In 1967 an apparently new needle cast organism of alarming pathogenicity was observed causing disease in plantations of ponderosa pine (*Pinus ponderosa* Laws.) in southwestern Oregon and in a knobcone pine (*P. attenuata* Lemm.) plantation in Del Norte County, California (1). Because of the menacing implications of this disease to the interior ponderosa pine forests east of the Cascade Mountains and the need for swift evaluation of the threat, a project was developed in early 1969 to investigate the disease. Responsibilities were divided among three units of the U. S. Forest Service:

(1) The Pacific Northwest Regional Office, Insect and Disease Control Branch of the Division of Timber Management, Portland, Oregon. (Hereafter referred to as Region Six).

(2) The Rocky Mountain Forest and Range Experiment Station, Division of Forest Disease Research, Fort Collins, Colorado. (Hereafter referred to as Rocky Mountain Station).

(3) The Pacific Northwest Forest and Range Experiment Station, Division of Forest Disease Research, Forestry Sciences Laboratory, Corvallis, Oregon. (Hereafter referred to as PNW Station).

The Rocky Mountain and PNW Stations are units of the Research Branch of the U. S. Forest Service, while Region Six is an administrative unit of the National Forest System.

The late Mr. H. H. Bynum, Region Six Zone Plant Pathologist stationed at Medford, Oregon was assigned responsibility to: (a) locate and evaluate occurrences of the disease; (b) determine the host range of the disease; and (c) evaluate opportunities for chemical control of the disease.

Dr. John M. Staley of the Rocky Mountain Station, a recognized authority on the hypodermataceous fungi, agreed to (a) identify the organism if a satisfactory description could be found in the literature; (b) prepare a taxonomic description of the organism should there not be a satisfactory description in the literature; and (c) to work out details of microscopic structure of the fungus as such features might be a basis for the taxonomic description of a new species.

Dr. Keith R. Shea and George M. Harvey of the PNW Station assumed responsibility to: (a) determine the general life history of the organism; (b) study infection of the host; (c) evaluate the role of environment on disease spread and development; (d) determine the impact of the disease on tree growth and mortality; and (e) estimate the threat to native hard pines.

The main concern of this dissertation will be the responsibilities assigned to the PNW Station as just stated. Two hypotheses will be examined.

(1) Lophodermella morbida Staley and Bynum sp. nov. probably is a native organism.

(2) The threat from Lophodermella morbida to plantings and natural stands of ponderosa pine is variable and dependent upon local weather patterns.

II. THE ORGANISM AND IT'S LIFE CYCLE

Staley and Bynum (8) describe Lophodermella morbida as a new species in the genus Lophodermella, family Hypodermataceae. They feel that: (a) color of the ascocarps and position of the ascocarps within the host tissues, (b) dimensions of the asci and ascospores, and (c) characteristics of the applanate subhypodermal pycnidia set thus fungus apart from previously named species.

In western Oregon, the life cycle of L. morbida is completed within 12 months. The mature hysterothecia, typically 1-6 mm. long, (Figures 1 and 2) are borne on one year-old needles. During rainy periods in June and early July, hysterothecia rupture medially to release clavate ascospores (23-53 μ long by 2.5-3.5 μ in diameter, [8] from 8-spored asci (95-162 μ long by 11-14 μ wide [Figure 3]). The ascospores infect the tender needle tips recently emerged from the fasicle sheath (Figure 4).

By mid-summer the distal one-third to one-half of each infected needle has turned a reddish-brown (Figures 5, 6, 7, and 8) and infected needles from the previous year have fallen, leaving the branches tufted and the tree scorched in appearance (Figures 9 and 10). Pycnidia (function unclear) are first visible in October and immature hysterothecia with their developing paraphyses appear shortly thereafter. Developing asci are recognizable the following

April, and by early June mature asci capable of spore discharge are again present--to repeat the cycle.

Figure 1. Mature hysterothecia of L. morbida on one-year old needles of ponderosa pine.

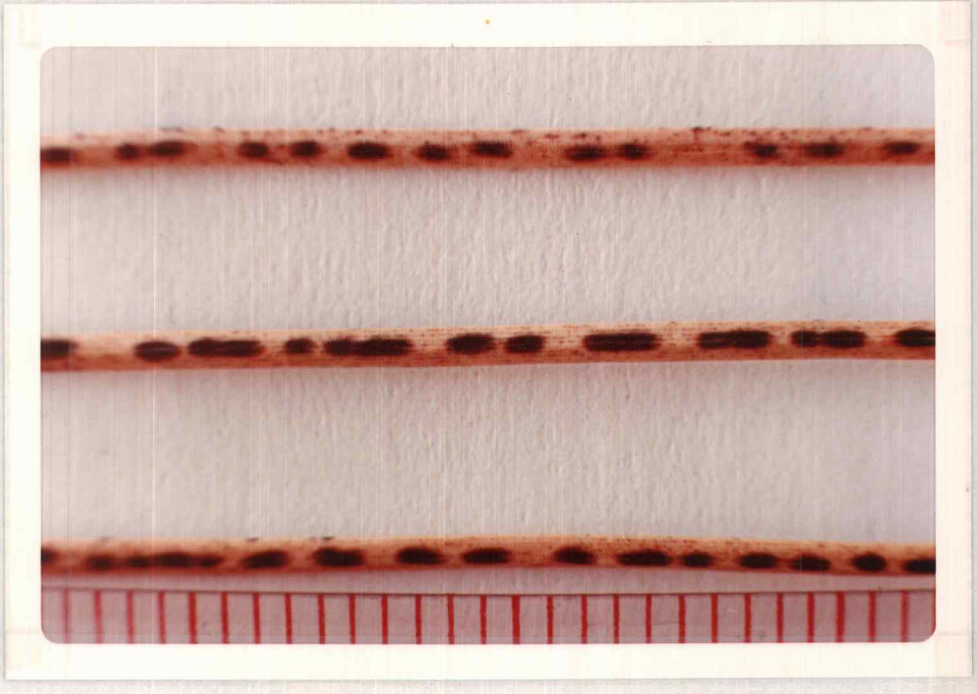


Figure 2. Detail of Figure 1. Ruler divisions are in millimeters.

Figure 3. Mature asci, ascospores, and paraphyses of L. morbida from ponderosa pine. x 400.

Figure 4. Susceptible juvenile foliage of ponderosa pine amongst infected year-old foliage.

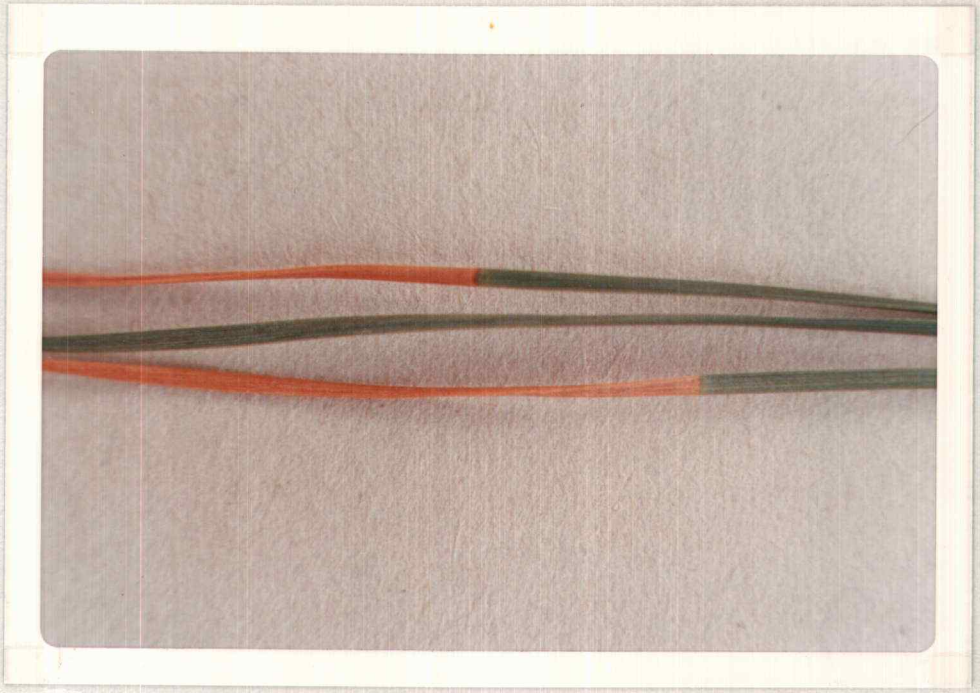


Figure 5. Early necrosis of current season's needles caused by L. morbida infection. September 1972 photograph.

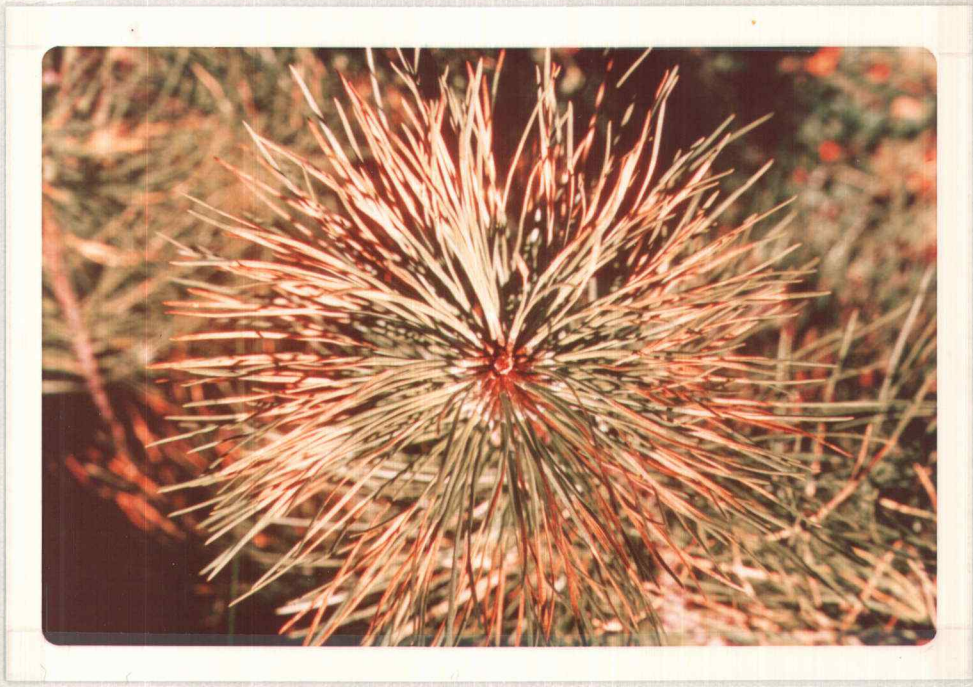


Figure 6. Massed foliage necrosis gives appearance of "tip burn" to branches. September 1969 photograph.

Figure 7. New needle growth "greens up" a heavily diseased plantation to some extent. Willamette high-elevation plantation; July 7, 1969 photograph.

Figure 8. Necrosis of new needles returns plantation to severely diseased appearance. Willamette high-elevation plantation; September 16, 1969 photograph.

Figure 9. Young ponderosa pine retaining considerable vigor after several years of attack by L. morbida.

Figure 10. Young ponderosa pine greatly reduced in vigor by repeated defoliation by L. morbida. October 1969 photograph; tree still alive in 1973.

III. STUDY AREAS AND METHODOLOGY

The 1969 Areas and Methods

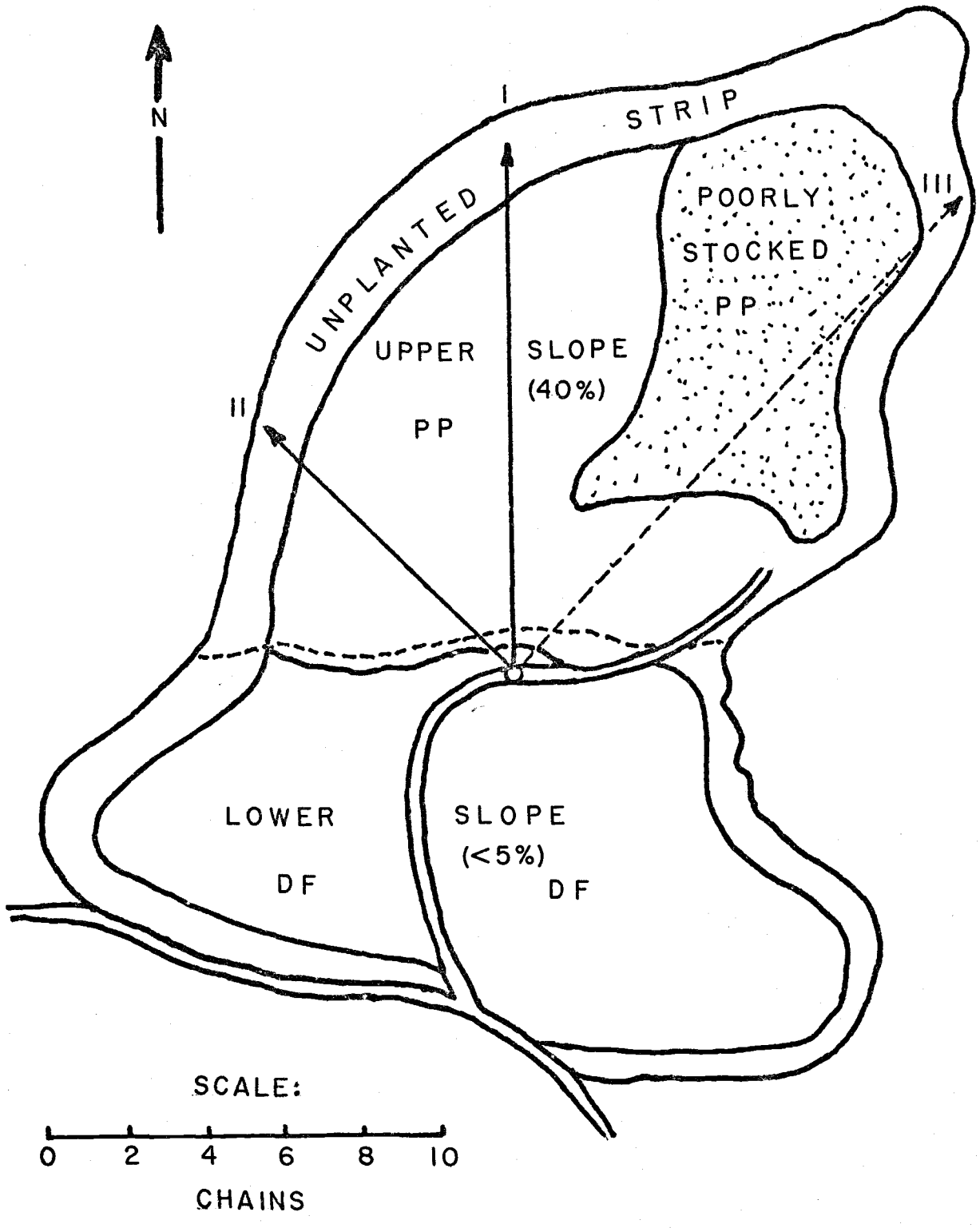
In 1969 two infected ponderosa pine plantations were selected for study. The first is at an elevation of 3150 feet on the Willamette National Forest, Rigdon Ranger District, in the Little Willow Creek drainage (Township 22 South, Range 3 East, Section 24, Willamette Meridian). The second, about 54 miles distant from the first plantation, is at 4150 feet on the Umpqua National Forest, Tiller Ranger District (Township 31 South, Range 1 West, Section 15, Willamette Meridian).

The Willamette plantation is on a steep (40%) south slope and bench (< 5%) with a few widely scattered rock outcroppings near the upper edge. For ease in discussion, parts of the 38-acre Willamette site are described under five classifications (Figure 11):

Upper slope	12.5 acres
Lower slope	11.8 acres
Unplanted strip	5.5 acres
Poorly stocked area	3.5 acres
Road and landing	4.7 acres

A systematic line-plot survey made in 1970 indicated that the steep (upper) slope portion of the Willamette plantation consists of an uneven mixture of three age classes of ponderosa pine (7, 12, and

Figure 11. Willamette high-elevation plantation; Rigdon Ranger District, Willamette National Forest, Oakridge, Oregon. Transect locations (indicated by arrows) and ponderosa pine and Douglas-fir planting areas.


N
I
STRIP
UNPLANTED
POORLY
STOCKED
PP
III
UPPER
PP
SLOPE
(40%)
II
LOWER
DF
SLOPE
(<5%)
DF
SCALE:
0 2 4 6 8 10
CHAINS

18 years) with a small admixture of naturally regenerated Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) (Figure 11 and Table 1).

Table 1. Stocking distribution per acre by species on the Willamette plantation, 1970.

Plantation Portion	Area Acres	Trees Per Acre Number				Present Stocking Ratio[1] %
		Ponderosa Pine	Douglas-fir	Other Conifers	All Trees	
Upper Slope	12.5	20.8	1.0	0.0	21.8	7.2
Lower Slope	11.8	0.0	3.1	0.4	3.5	1.1
Unplanted Strip	5.5	0.0	10.9	0.0	10.9	3.6
Poorly Stocked	3.5	0.8	16.3	0.0	17.1	5.7
Entire Plantation	33.3	7.9	5.0	0.1	13.0	4.3

[1] Ratio based on a stand of 300 trees per acre, or a plantation spacing of 12 x 12 feet.

The stand of 200 year-old Douglas-fir originally occupying the site was clearcut in the summer of 1949. The slash was burned in the fall of 1950. In December 1951, 8,000 2-0 ponderosa pine seedlings were planted on the upper slope and 7,000 2-0 Douglas-fir seedlings were planted on the bench. Sources of the stock were not recorded. Over the next 11 years the area was partially replanted three times (1957 = ponderosa pine and Douglas-fir; 1960 = Douglas-fir; 1962 = ponderosa pine) in an effort to achieve satisfactory stocking. Even

though the overall stocking was poor (13 trees per acre in 1970: Table 1), regeneration efforts covering 12 years were terminated in 1962.

The Umpqua plantation is located on a gentle to moderate (10-20%) northeasterly slope about 1000 feet higher in elevation than the Willamette plantation. The 28-acre unit was clearcut and burned in 1954 and planted in 1955 with 2-0 ponderosa pine seedlings, Deschutes National Forest seed source from the Bend, Oregon Nursery. Unlike the Willamette plantation, the Umpqua plantation was immediately successful and required no further regeneration attention.

Methods for studying the disease in 1969 were identical on both plantations. The spore cast was monitored weekly by grease-coated microscope slides hung in randomly selected infected trees (Figure 12). Five vertical and five horizontal slides were exposed in each plantation. Slides were collected weekly.

To count the spores, a 22 millimeter square cover slip was put over a drop of cotton blue in lactophenol and the slide examined at a magnification of 400 diameters. Six systematically-chosen parallel bands (band width equalled the diameter of the microscope field) across each cover slip were examined per slide. If more than half a spore was included in the band, it was tallied. Depending on the microscope used, the area examined per six bands ranged from 46.2 to 59.4 square millimeters. Because of these area differences the

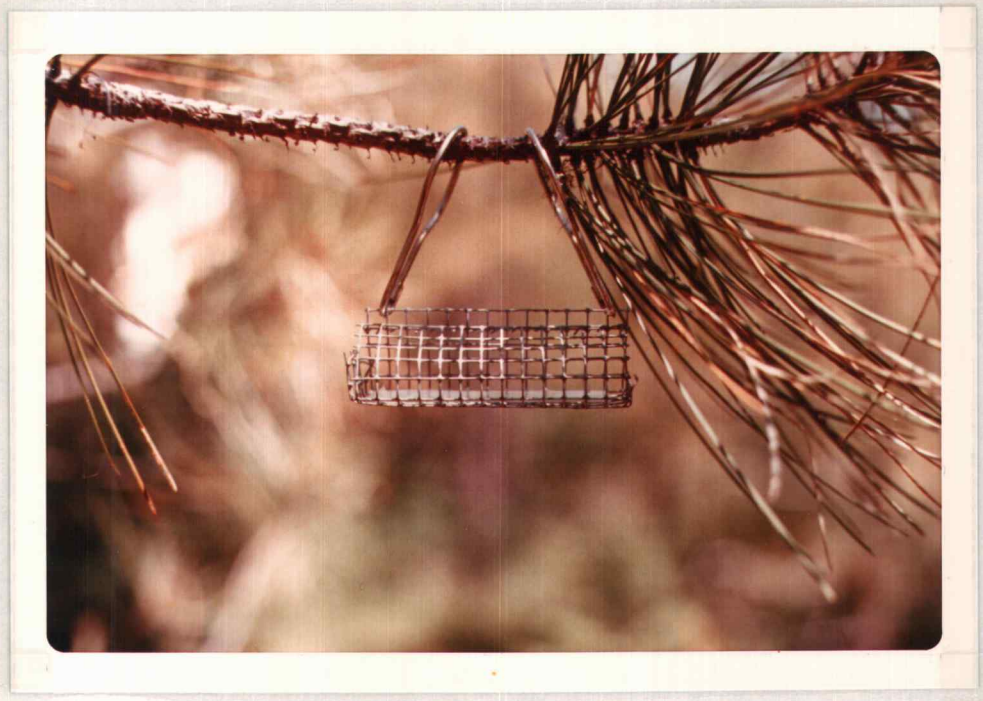


Figure 12. Hardware cloth cage exposing spore trap slide.

microscope used was identified for each slide so that later spore cast computations would be accurate.

To determine the time and conditions necessary for infection in the field, new foliage was protected from spores of the pathogen by "Pollen Tector"[1] bags from mid May through October. The bags were removed for two week intervals of exposure during this time according to two schedules. In Schedule I (Tables 7 and 8, pp. 58 and 59), 39 branches were bagged, each on a separate infected tree. At two week intervals, including the first two weeks, bags were removed from three randomly selected branches for two weeks and then replaced for the remaining time. Three branches (one per tree) from which the bags were never removed throughout the test period (May to October) served as "untreated" controls. In Schedule II (Tables 7 and 8, pp. 58 and 59) the procedure was reversed--three randomly selected branches were bagged for two weeks and then the bags were removed for the remaining time. Three branches (one per tree) which were never bagged served as "untreated" controls. To summarize, when one set of unprotected branches was bagged and protected from infection (Schedule I), an opposite set of protected branches was unbagged and exposed to infection for the same period (Schedule II).

---

[1]No. 1140/OT "Pollen Tector," special kraft bags, manufactured by the Carpenter Paper Co., 106 SW 7th St. Des Moines, Iowa 50302.

Test branches were selected from the north side of the tree. To be suitable for the experiment a selected branch had to have a vigorous-appearing terminal bud and the foliage from the previous year had to have abundant L. morbida hysterothecia. All foliage from previous years was carefully stripped away. A two-inch band of non-absorbent cotton was wrapped around the branch about three inches back from the bud. An open "Pollen-Tector" bag was then slid over the branch tip and securely tied, binding the opening of the bag over the cotton band which served as an air filter (Figure 13). "Pollen-Tector" bags are resin-impregnated, wet-strength kraft paper bags which will last up to six months in the field unless mechanically damaged. To insure against loss from damage to the bags, several additional trees were selected and bagged (or left unbagged) to provide reserve test material.

At two week intervals, on five trees in each plantation, phenological development of the host and parasite were observed. Observations included budbreak, needle and shoot elongation and evidence of fungus activity in new needle tissue. Corollary phenological observations were made at the same time on totally unrelated vegetation in the hope of finding an "indicator plant" of use to the lay person to predict the heavy sporulation period of L. morbida.

A rain gauge located within each plantation obtained the weekly rainfall. Evaporation from any accumulated rainfall was slowed by

Figure 13. Intact "Pollen-Tector" kraft paper bag after five months in place.

several drops of light transformer oil placed in the gauge after each reading. Daily fluctuations in temperature and relative humidity were obtained with a recording hygrothermograph in each plantation.

In both the Willamette and Umpqua study plantations staff workers of Region Six installed a test of the relative susceptibility of ponderosa pine, Jeffrey pine (P. jeffreyi Grev. & Balf.), lodgepole pine (P. contorta Dougl.), and knobcone pine to L. morbida. Trees were planted bare-rooted in auger-drilled planting holes and in pulp pots sunk in a ditch. The species, seed source, and number of seedlings for each method of planting are given in Table 2. The outplantings were examined in October 1972. Details are in Appendix B.

Region Six people also installed chemical control tests in 1969. For these tests twenty infected trees were selected on each of the study plantations. Chemicals were applied by dipping the needles into the chemical six times during the needle and shoot elongation period. Treatments began at bud break in the spring (May 19, 1969) and continued at approximately two week intervals until full needle length was reached (July 30, 1969). Four chemicals (Daconil 2787, Zineb, Difolatan flowable, Bordeaux 8-8-10) at two concentrations (2.0% and 0.2%) and water controls were used. Details are in Appendix A.

Table 2. Species, planting method, and seed source employed in testing relative susceptibility of pines to L. morbida; Willamette and Umpqua plantations, 1969.

Species	Planting Method Number		Age Yrs.	Seed Source National Forest	Nursery Designation
	Ground[1]	Pot[1]			
Ponderosa pine	10	15	2/	Deschutes	122-01-682-010-4.0 6011
Ponderosa pine	5	10	2-0	Willamette	122-18-472-030-4.5
Ponderosa pine	5	10	3-0	Umpqua	122-15-492-020-4.5
Jeffrey pine	5	25	2-0	Rogue River	116-10-502-010-4.5
Lodgepole pine	5	25	2-0	Willamette	108-18-462-030-4.5
Knobcone pine	5	25	1-0	Rogue River	124-10-511-020-4.0

[1] Bare-rooted in auger holes and in sunken pulp pots.

[2] Not available.

The 1970 Areas and Methods

No work was done in 1970 on the more distant Umpqua plantation by the PNW Station because of limited resources. However, Forest Service staff of Region Six installed chemical control tests on both the Willamette and Umpqua plantations as in 1969. Unfortunately, most of the details of these second-year tests are lacking. Effort of the PNW Station concerning empidemiology on the Willamette site was enlarged. Two additional ponderosa pine plantations at lower elevations in the Little Willow Creek drainage were added: (a) a mid-elevation plantation at 2650 feet with very light L. morbida infection, and (b) a low-elevation plantation at 1925 feet with no visible L. morbida infection.

The mid-elevation plantation is very similar to the high-elevation plantation in aspect, slope, cutting history, and regeneration problems. It differs in that ponderosa pine was present in the harvested timber in sufficient quantity to have been classified as Douglas-fir-ponderosa pine timber type in the unit records.

The original 200-year-old mixed stand of Douglas-fir and ponderosa pine was clearcut from the 82-acre site in 1948 and 1949. The logging debris was broadcast burned in 1949 and 1950. In 1951, the unit was planted with 19,000 2-0 Douglas-fir seedlings from the Wind River, Washington, Forest Service Nursery. The seed source

was not recorded. By 1955, less than 2% of the planted trees were alive and the area was replanted with 9,500 2-0 ponderosa pine seedlings from the Bend, Oregon, Forest Service Nursery, and 200 2-0 Douglas-fir seedlings from the Wind River Nursery. Again, the seed sources were not recorded. The area was replanted three more times (1957, 1961, and 1969) with both ponderosa pine and Douglas-fir. By 1970, the established trees were growing well, although the area was still somewhat understocked. Infected pine needles bearing the hysterothecia of L. morbida were extremely difficult to find (fewer than 10 per tree) and the general appearance of the trees was excellent.

The low-elevation plantation is located on the south side of Little Willow Creek near the confluence of this west-flowing stream and Hill's Creek Reservoir. The stream flows through an alluvial deposit which slopes moderately (< 10%) to the west. The study trees are located on this deposit. Away from the alluvium north and south-facing slopes rise steeply (60%) and epitomize the influence of aspect on establishment of a new stand following clear-cutting at this latitude and under prevailing climatic conditions. Following harvest and broadcast burning in 1949 the north-facing slope promptly reseeded to Douglas-fir (Figure 14). Planting of the south slope began in 1951 with 15,000 2-0 Douglas-fir seedlings. By 1966, 51,000 trees, mostly ponderosa pine, had been planted and in 1962 12 pounds of

Douglas-fir seed was aerially spread by helicopter. The south slope remained essentially unstocked in 1970 (Figure 15). L. morbida has never been found on the few pines established on this unit.

Methods used to study Lophodermella morbida in 1970 resembled those used in 1969. Consequently, only new or modified methods will be discussed here.

Thirty stations for trapping spores on greased microscope slides were established in the high-elevation plantation in 1970. Six stations each were established in the mid- and low-elevation plantations. Horizontal slides only were used from 1970 on because of the poor performance of vertical slides in 1969. The first set of slides was put out on June 8 and the last set collected on September 23, 1970.

The foliage bagging schedule in 1970 also differed from that in 1969. In early May on the high-elevation plantation, 90 infected trees (70 test, 5 check, and 15 reserve trees) were selected and tagged. On each tree one branch was stripped of infected needles and bagged as for the 1969 tests. A second branch was bagged on each tree with the one year-old infected foliage left intact and included within the bag. A greased microscope slide was attached to the lower inner surface of the bag with the infected foliage to monitor any spore discharge within the bag. At the onset of sporulation, as determined

by microscopic examination of spore trap slides, the bags on two randomly selected trees were removed to allow a 48-hour exposure to possible infection and then replaced. Concurrently, a third branch which had never been covered before was bagged on each of the two trees and the bag allowed to remain in place until all the bags were removed in the fall. During the 48-hour exposure period, a greased slide was hung from the exposed branch to monitor incoming spores. The sequence of 48-hour exposure periods commenced on June 8 and continued through July 6. After July 6, the branch exposure periods varied from one to four weeks (depending upon the press of other duties) as spore trap slides indicated that sporulation was complete by July 2.

Five branches (one per tree--five trees per plantation) which remained bagged from May to September comprised the "untreated" controls for each plantation respectively. However, more branches were bagged in the spring than were used during the season. These also served as controls.

On the mid- and low-elevation plantations there were 35 test trees, 5 check trees and 10 reserve trees in each plantation. Only one branch was unbagged and exposed per 48-hour exposure period. At these sites no bagged infected branches could be studied because infected branches were not present.

In another study, two transects were established through the high-elevation plantation to follow trends in tree vigor and mortality over time. Transect No. 1 (Figure 11) originated at an old log landing and ran northerly perpendicular to the slope. Transect No. 2 was at a 45° angle to No. 1 running northwesterly. After limits of the transects were established, five stations were located equally spaced along the transects. At each station five ponderosa pines were selected as sources for future disease severity and mortality information.

A vegetation survey was conducted on the high-elevation plantation in 1970 to assess the composition of the vegetative cover of the area and to get a feeling for what might happen within the plantation should many of the ponderosa pines die from the disease. A line-quadrat cruise system with ocular estimation of coverage and stem count for frequency was employed. Three cruise lines five chains apart and perpendicular to the main slope were established. Mil-acre plots (6.6 feet square) for the larger vegetation were established along each survey line at two chain intervals. The larger 1/10-acre plots at the described frequency constituted a 10% survey.

The 1971 Areas and Methods

Data collected in 1971 were from the same areas as studied in 1970. In 1971 a third transect evaluating severity of infection and

host response was installed on the high-elevation plantation (Figure 11). This was done after termination of the Region Six fungicide tests which previously occupied this portion of the site. A few additional test trees were selected on each of the three plantations for the 1971 foliage exposure experiment.

On the basis of the 1969 and 1970 sporulation patterns, a six-week foliage exposure period, from June 2 through July 14, was selected for the 1971 foliage infection experiments. Three different schedules of exposing branches were used. Schedule I called for successive one-week exposures, with a different group of branches exposed each of the six weeks (Table 3). Schedule II called for a series of six exposure periods increasing in duration by weekly increments. The first group of branches was exposed one week; the second two weeks; the third three weeks; and so on up to the sixth group being exposed six weeks. Schedule III, the opposite of Schedule II, called for a weekly increment of protection for six groups of branches providing bagged periods of one week, two weeks, and on up to six weeks.

For the high-elevation plantation, five branches on five randomly selected test trees constituted the sample per exposure period. The sample was reduced to three branches on three trees for the mid- and low-elevation plantations.

Table 3. Schedule of periods during which bagged branches were exposed to infection by temporarily removing protective bags. Willamette high-, mid , and low-elevation plantations, 1971.

	Week Number & Dates Exposed						
	0	1	2	3	4	5	6
Exposure Schedule	Checks	6/2-6/9	6/9-6/16	6/16-6/23	6/23 6/30	6/30-7/7	7/7-7/14
I	*[1]	———					
			———				
				———			
					———		
						———	
							———
II	*[1]	———					
		———					
		———					
		———					
		———					
		———					
III	*[1]	———					
			———				
				———			
					———		
						———	
							———

[1] Check branches were bagged throughout the periods that any other branches were exposed.

Solid lines denote periods of continuous exposure.

Forty spore trap slide stations were installed on the high-elevation plantation and five each on the mid- and low-elevation plantations in 1971. The first slides were exposed on May 26 and the final slides collected on September 29, 1971. The slides were collected three times weekly during the sporulation period (June 9 through July 14) and at weekly or longer intervals before and after the sporulation period.

Other activities continued as already described except such one-time efforts as the vegetation survey done in 1970.

The 1972 Areas and Methods

In 1972 the bagging studies were discontinued, a new study site was added farther up the Little Willow Creek drainage, dew duration records were obtained at three of the four Little Willow Creek study locations, and an attempt was made to artificially inoculate several healthy ponderosa pines with L. morbida under field conditions. The foregoing items will be discussed in turn.

The new study area was clearcut in 1949 by Pope and Talbot and transferred to the Forest Service in a 1968 land exchange. There are no records of regeneration treatment prior to 1968. The site now supports a fair stand of Douglas-fir. No ponderosa pine was planted. The site is about 1000 feet higher than the original high-elevation plantation and one-half air mile distant. Topography and aspect

resemble the nearby high-elevation plantation as did the original stand of timber. The new site was used to obtain dew duration information and for artificial inoculation attempts.

Dew duration records during the sporulation period were made on the low-, mid-, high-, and the new supplementary high-elevation plantations. The records were made on a Taylor-type dew duration recorder adapted by R. L. Powelson of Oregon State University. The instrument is a clockwork-driven frosted plate glass disc which makes one revolution per 24-hour period (Figure 16). When the plate glass surface is moist from rain or dew, an indelible pencil lead makes a continuous mark. Unfortunately, machine breakdowns and malfunctions prevented our getting any record at all on the high-elevation plantation and obtaining only intermittent records on the low-, mid-, and supplementary high-elevation plantations during the sporulation period from May 31 to July 16, 1972.

The attempt to artificially inoculate trees was carried out on three potted, sapling-sized ponderosa pines which had been growing in the Corvallis area as reserve stock. They were taken to the Willamette supplementary high-elevation plantation on May 23, 1972, placed in the ground, container and all, thoroughly watered at the time of outplanting and intermittently throughout the dry summer months.

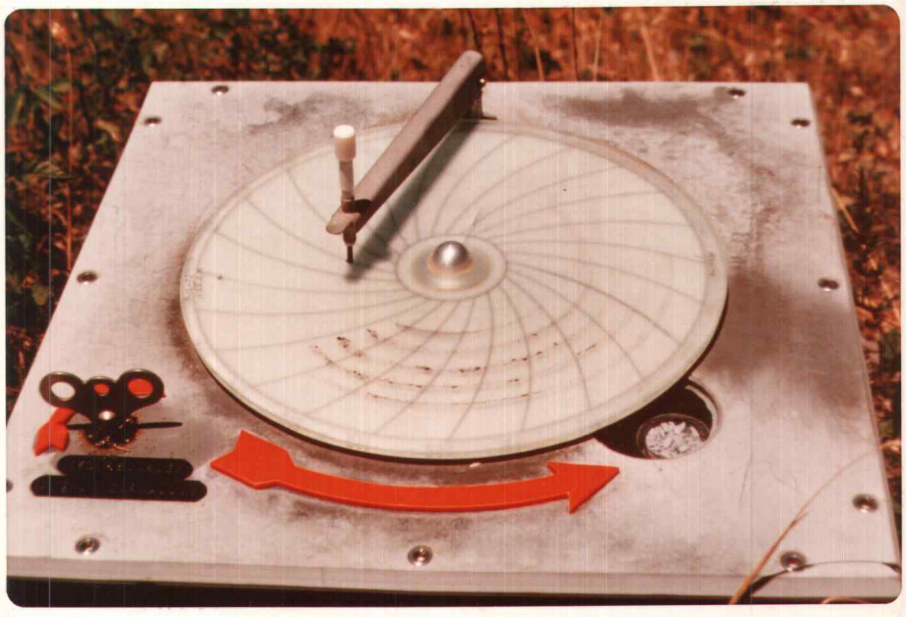


Figure 16. Powelson's adaptation of the dew duration recorder. Note five periods of nighttime dew on the plate.

On June 7, 1972, during a period of shower activity, a laboratory-prepared spore suspension containing 72.2 spores per ml. was used to inoculate four randomly selected branches on each of the three potted trees. Each branch was dipped into the spore suspension for a few moments and then shaken gently over the dipping container to remove excess solution and reduce dripping on foliage below the branch. Two of the four dipped branches on each tree were immediately bagged with Pollen-Tector bags and two branches were left exposed. Four randomly selected branches per tree served as untreated controls--two of these four were bagged at the same time as the inoculated branches and two remained exposed. Additionally, a maximum-minimum thermometer was bagged on an extra branch to give an idea of the maximum temperatures within the bags during the summer months.

The same inoculation procedure as outlined above was repeated on June 28, 1972 during a period of warm, dry weather. However, the spore suspension prepared for this inoculation attempt had only 27.2 L. morbida ascospores per ml.

The 1973 Areas and Methods

Data collected in 1973 were from the same Willamette areas studied since 1970.

In 1973, the impact of L. morbida on tree growth was assessed in terms of height and radial growth. On the high-elevation plantation only, 25 pairs of trees were randomly selected from throughout the plantation. The first tree of a pair was selected as being distinctly healthier in appearance than any of its immediate neighbors. The second tree of a pair was heavily infected with L. morbida (Figure 17). Annual height growth since 1964 was based on measurements to the nearest inch of annual growth between branch whorls (Figure 18). Radial growth to the nearest one-hundredth inch for the past 12 years was determined from increment cores from each tree at 4.5 feet above average ground level. Height growth only was measured on the mid-, and low-elevation plantations.

Five widely-scattered infected trees on the high-elevation plantation were selected to serve as recurring sample trees for laboratory study of the organism. At weekly intervals for ten weeks from June 1 through August 2, infected 1972 foliage samples were taken from the upper crowns of these trees. In the field, a portion of each foliage collection was placed in a small nylon mesh bag and hung from a lower branch of the last sample-collection tree. These bags of foliage remained in place from the day of collection through September 13, 1973.

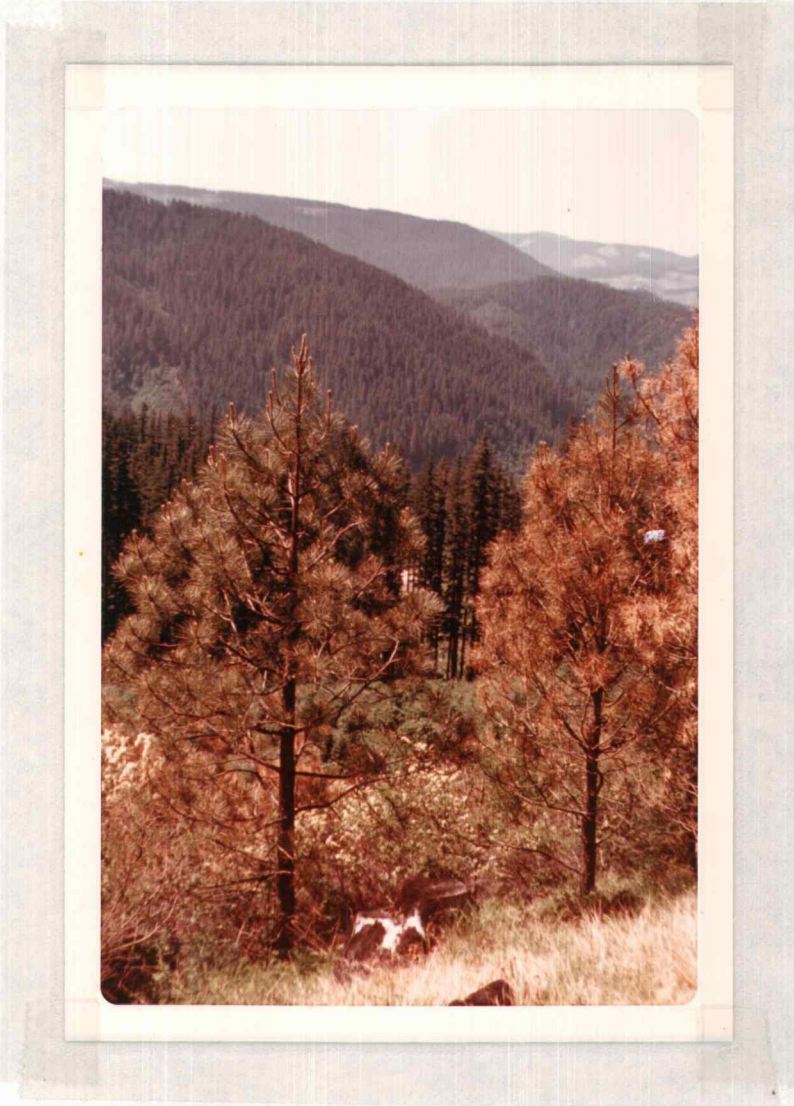


Figure 17. Typical pair of moderately diseased and diseased trees to compare impact of L. morbida on height and radial growth. Willamette high-elevation plantation.

Figure 18. Measuring annual increments of height growth of a study tree.

At the laboratory, each weekly infected foliage sample was subdivided for further study. One sub-sample was placed in a paper envelope and put in refrigerated storage (40° F.); a second sub-sample was also placed in a paper envelope, put in a vapor-proof container to slow dehydration and placed in sub-freezing storage (0° F.); and a third sub-sample was placed in a paper envelope and stored on an open bookshelf in the laboratory. Spores from these three storage methods were sampled periodically and tested for viability. The residual infected foliage not apportioned into sub-sample storage was used at once for laboratory observations on phenology of the organism and spore discharge and germination studies as described below.

Squash mounts and freehand cross sections for microscopic examination were made of hysterothecia from the weekly foliage collections to follow the development of L. morbida before, during, and after the general sporulation period. Examinations were made to estimate whether the asci were full, partially full, or empty of ascospores; whether there were loose spores within the hysterothecium; and whether spore germination had occurred within the asci and/or the hysterothecium.

To determine whether hysterotecia can imbibe sufficient moisture from a saturated atmosphere or require free water to open and discharge ascospores, 30 matched hysterotecia-bearing needle

segments on 2% water agar in five petri plates were used. Two segments were cut from each needle. One segment was placed directly on the agar surface and the other matching segment was placed in the center of a 22 mm. square glass cover slip. Periodic examinations were made with a dissecting microscope to observe opening of the hysterothecia and onset of ascospore discharge.

Extra deep cavity hanging drop microscope slides with a few drops of water agar in the cavity and sealed with vaseline-ringed cover slips were used as miniature moist chambers to observe onset of ascospore discharge and spore germination under the compound microscope. A segment of mature hysterothecia-bearing needle was gently pressed into the hardened agar, the cover slip put in place, the assembly inverted and then incubated within a larger moist chamber for the selected time interval. Usually within an hour of cover slip placement, a uniform layer of small water droplets has condensed on the cover slip.

To obtain the deposition of L. morbida ascospores on a glass surface for subsequent study, 35-40 50-millimeter segments of mature hysterothecia-bearing needles were gently arranged on 2% water agar in a petri dish bottom. Seven 22-millimeter square cover slips were arranged in the petri dish cover. The bottom was then inverted and very gently eased into the petri dish top so as to dislodge as few

needle segments from the upside down agar surface as possible. The entire assembly was incubated at room temperature within a larger moist chamber.

This petri dish sporulation technique of suspending mature hysterothecia over the surface to be studied permitted several options: the cover slips could be omitted and the dish cover washed to make a spore suspension; the cover slips could be exchanged with fresh ones at periodic intervals to observe sporulation duration and intensity; the seeded cover slips could be air dried for varying periods and then returned to moist conditions to observe the effect on subsequent spore germination; and finally, the seeded cover slips could be mounted on microscope slides and exposed to outdoor conditions for varying periods to observe the effect on subsequent spore germination.

To study the germination of L. morbida ascospores on ponderosa pine needles under laboratory conditions, the above-described petri dish technique was used to deposit spores on 30-millimeter segments of juvenile needles. After 72 hours exposure to the spore cast, a flexible collodion spore print was made as described by Delp (3). Each needle segment was dipped briefly in liquid flexible collodion, thoroughly air-dried, the coating with imbedded spores gently slit and peeled from the needle, the coating mounted on a

microscope slide stained with cotton blue in lactophenol, and examined under the microscope for germination and penetration of the spores.

IV. RESULTS

Spore Phenology and Germination

The following summary is based upon five years of weather observations, spore trap slide counts, and foliage bagging experiments. However, the microscopic details of spore phenology and germination were observed in 1973 only.

In a typical year on the Willamette high-elevation plantation, the first week in June is a time of expectant waiting for the investigator. The development of the hysterothecial contents is essentially complete and the next rain will surely result in longitudinal rupture of the hysterothecia and discharge of viable ascospores.

In mid-June (third week) we are in the midst of the usual late spring or early summer rainy period. The hysterothecia have ruptured and spore discharge is at its peak as evidenced by the large number of spores on spore trap slides (Table 4). Almost all the asci are full of spores or partially so--only a few empty asci are evident. A few loose germinated and ungerminated spores are evident within the hysterothecia (Figure 19); however, germinated spores within the asci are still rare.

In mid-July (sixth week) the typical northwestern summer dry period has been in progress from two to three weeks and the infective spore cast is complete. Within the reclosed hysterothecia only a few

Table 4. Phenology of L. morbida on ponderosa pine, June 1 to August 2, 1973, as determined by weekly observations of independent samples from five sampling points; Willamette high-elevation plantation.

Week No.	Date 1973	Rainfall Inches	Avg.[1] Spores per Sq. Mm. Number	Hystero-thecia Ruptured	Asci Contents (Estimated Percent) Full	Partial	Empty	Loose Spores in Hyst. ?	Spore Germination: Intra-ascus	Intra-hyst.	Labora-tory	Remarks
0	6/1	0.00	---	No	100	0	0	No	No	No	Viable	Start of observations
1	6/7	0.00	0.02	No	100	0	0	None to few	No	No	Viable	No rain
2	6/14	0.35	0.61	Yes	70	25	5	None to Many	No	No	Viable	Rain during week
3	6/21	1.00	1.16	Yes	50	40	10	None to Many	Few	No	Viable	Rain during week
4	6/28	0.70	1.16	Yes	30	40	30	Many	Com-mon	No	Viable	Rain during week Some intra-ascus spore degeneration
5	7/5	0.00	0.08	Yes	15	50	35	Many	Com-mon	Few	Viable	Many spores degenerating within asci
6	7/12	0.00	0.02	Yes	15	50	35	Many	Com-mon	Com-mon	Viable	Many spores degenerating within asci. Spores enlarged.
7	7/19	0.00	0.00	Yes	10	65	25	Many	Com-mon	Com-mon	Not Viable	Most spores within asci degenerating. Spores enlarged.
8	7/26	0.05	0.02	Yes	5	30	65	Some	Com-mon	Com-mon	Not Viable	Ditto. Brief shower.
9	8/2	0.00	0.03	Yes	5	35	60	Some	Com-mon	Few mon	Not Viable	Almost all spores within asci degenerated. Spores enlarged.

[1]From spore trap slides.

Figure 19. Ungerminated L. morbida spore exiting from ascus. x800.

Figure 20. Empty asci of L. morbida. x 800.

completely full asci remain--partially full and empty asci predominate (Figure 20). It appears that some spores continue to enlarge within the asci and perhaps cannot exit through the pore. The contents of such asci are beginning to degenerate into an undifferentiated mass (Figure 21). Germinated spores within the asci and loose within the hysterothecia are fairly common. Ungerminated spores are still viable under favorable conditions.

By the first week of August (ninth week), the summer dry period has continued for three more weeks without a trace of precipitation. Daytime temperatures are high (80-90° F.), and daytime relative humidity can be extremely low (10-30%). Within the now effete hysterothecia there are no important changes except that the ungerminated spores are no longer viable under optimum laboratory conditions. Most of the infected needles have fallen from the trees by now and no longer pose a serious infective threat should favorable weather conditions for sporulation return.

The foregoing phenology is expanded to weekly observations and is presented for the period of June 1 through August 2, 1973 in Table 4.

Multiple observations of petri plate-water agar and sealed deep cavity hanging drop moist chambers indicate that most fresh, mature L. morbida hysterothecia will imbibe sufficient moisture from a saturated atmosphere to open and discharge ascospores. Without contact

Figure 21. Enlarged L. morbida spores and degenerating asci contents. x 440.

with the agar surface, opening of the hysterothecia requires from two to three hours and spore discharge customarily follows within an hour. On water agar, hysterothecia open fully within an hour and spore discharge is observed within one to two hours of placement on the agar surface. In both cases, spore germination is usually in progress within an hour of the initial spore discharge.

Free water applied directly to a hysterothecium dramatically reduces the time necessary for the structure to open. The hysterothecium will open within 15 minutes (Figure 22 and 23). Ascospores are discharged into the free water almost simultaneously.

Laboratory spore germination tests comparing spores from hysterothecia on freshly-collected foliage with spores from hysterothecia on foliage which had been stored on the laboratory shelf, under refrigeration (40° F.), frozen (0° F.), and hung outdoors, indicate that fresh foliage is superior for a viable spore cast (Table 5). However, if storage is necessary, refrigerated storage is preferable to frozen storage. Neither shelf storage nor outdoor storage are acceptable methods of storing infected foliage for the delayed production of viable spores.

Viable ascospores cast upon glass surfaces will germinate if a continuously saturated atmosphere is maintained (Figure 24 and 25). If the glass surfaces are removed from the moist chamber and allowed to air dry for as short a time as an hour, germination activity stops

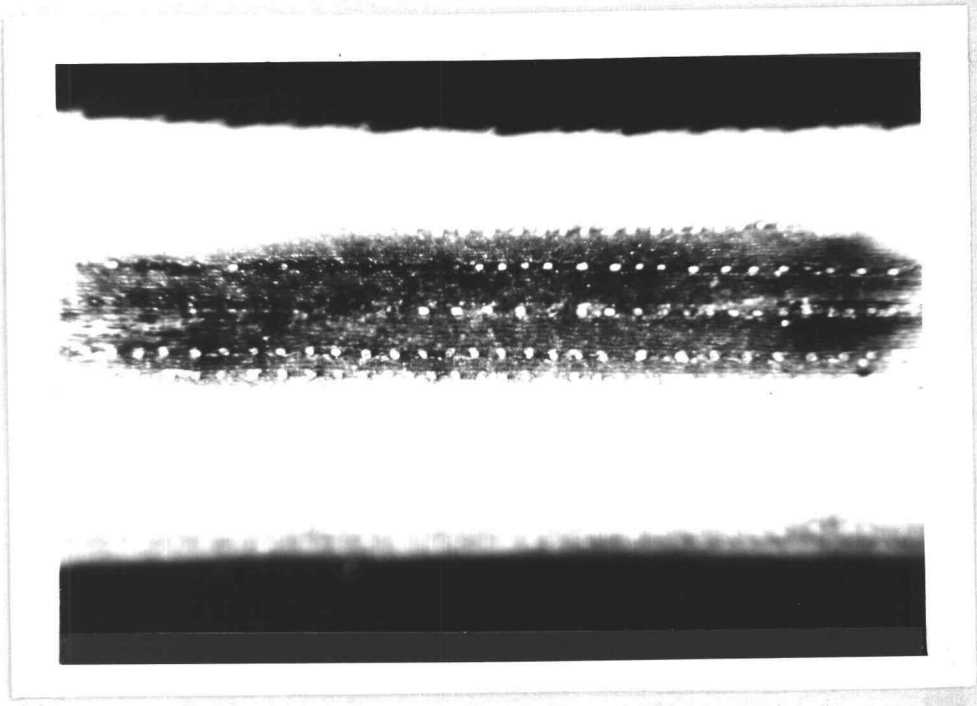


Figure 22. Dry L. morbida hysterothecium. Previous rupture line very faintly visible. x40.

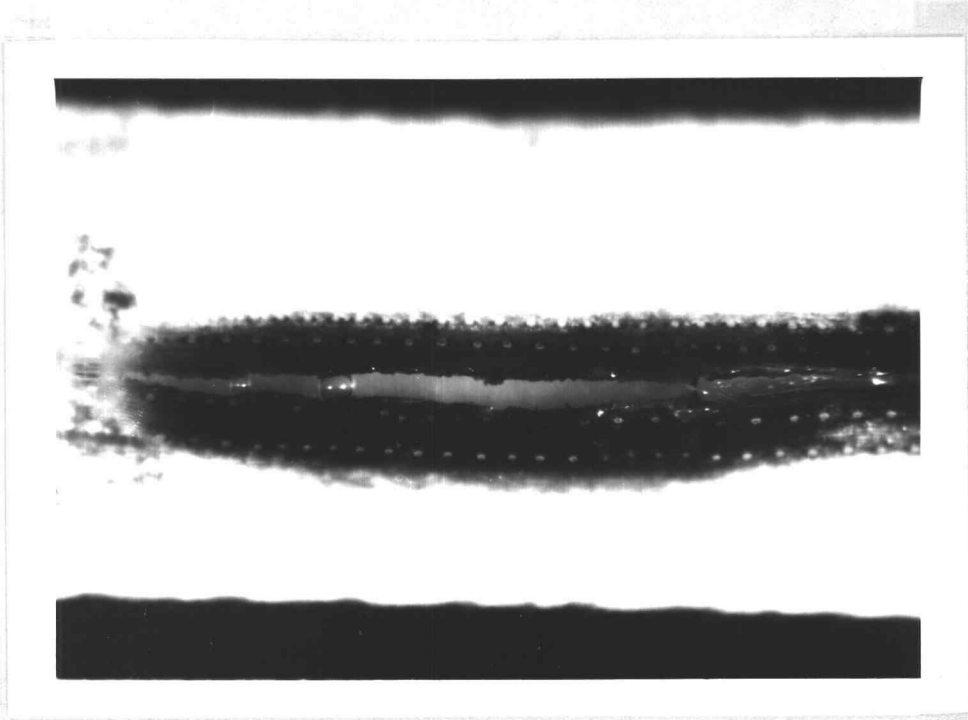


Figure 23. Open L. morbida hysterothecium 15 minutes after wetting. x40.

Table 5. The effect of collection date and storage condition on laboratory germination tests of L. morbida spores from hysterothecia on ponderosa pine foliage collected at the Willamette high-elevation plantation, June 1 to August 2, 1973.

Date Foliage Collected 1973	Unstored	Storage Condition: Laboratory Shelf		Refrigerator 40° F.		Freezer 0° F.		Outdoors	
	Viable	Days Stored Number	Viable	Days Stored Number	Viable	Days Stored Number	Viable	Days Stored Number	Viable
June 1	Yes	69	No	69	No	54	No	--	--
June 7	Yes	62	No	62	No	47	No	56	No
June 14	Yes	47	No	47	No	40	No	49	No
June 21	Yes	40	No	67	Yes	33 54	Yes No	42	No
June 28	Yes	33	No	60	Yes	26	No	35	No
July 5	Yes	34	No	34	No	19	No	--	--
July 12	Yes	27	No	27	No	27 32	Yes No	--	--
July 19	No	--	--	--	--	--	--	--	--
July 26	No	--	--	--	--	--	--	--	--
Aug. 2	No	--	--	--	--	--	--	--	--

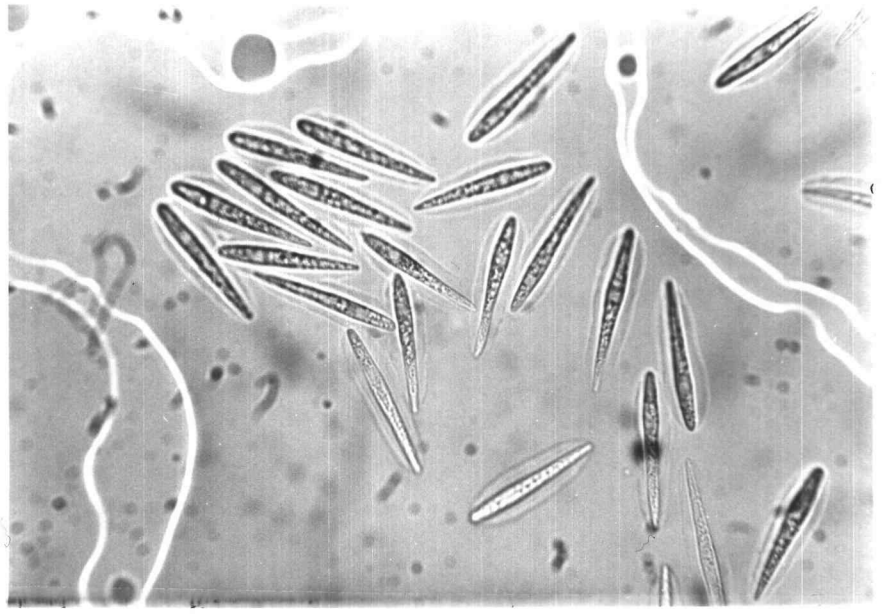


Figure 24. L. morbida ascospores discharged onto glass surface of miniature moist chamber. x400.

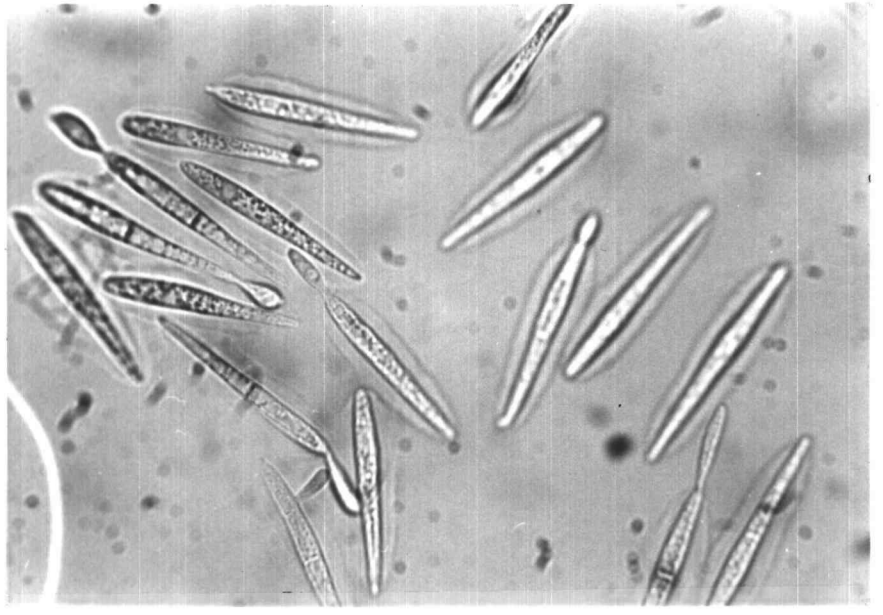


Figure 25. Germinated L. morbida ascospores. Same spores as in Figure 24, 15 hours later. x600.

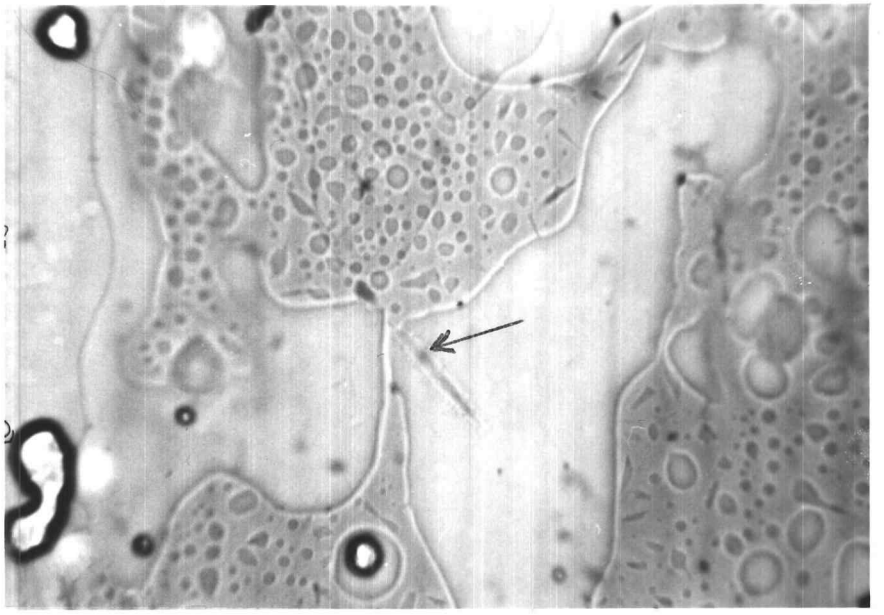


Figure 26. Germinated L. morbida ascospore removed from surface of artificially inoculated ponderosa pine needle in film of flexible collodion. x400.

and will not resume when the surfaces are returned to favorable moist conditions. Shorter exposure periods were not investigated.

Juvenile ponderosa pine needle segments exposed to an artificial inoculation period of 72 hours had germinating spores on the needle surface as determined by flexible collodion spore prints (Figure 26). Careful microscopic search of these spore prints failed to reveal formation of appressoria or the mode of entry of the pathogen into the tissue of the host.

Spore Production Evaluated by Trapping

Spore production on the Willamette high-elevation plantation in 1969 was extraordinarily heavy (35 spores per square millimeter) in comparison with subsequent years. This high spore production was closely associated with 13 rainy days between June 1 and July 14 having a total of 5.56 inches rainfall. In 1970, 1971, 1972, and 1973 one, two, eight, and less than one spore(s) per square millimeter respectively were trapped on this same site. Accompanying precipitation for 1970, 1971, 1972, and 1973 was 1.93, 2.76, 1.29, and 1.05 inches respectively. The number of rainy days for these same four years was 12, 12, 8, and 6 days respectively. These data are presented in Tables 6 and 11.

Spore production on the mid-elevation plantation was monitored only in 1970, 1971, and 1972. The number of spores trapped on this

Table 6. Number of spores trapped on microscope slides on the Willamette plantations during five summers.

Year	Plantation	Inclusive Dates	Days in Sampling Period	Slide Locations	Slides Examined	Target Area Examined	Spores Counted	Average Spores per Sq. Mm.
			Number			Sq. Mm.	Number	
1969	High	6/2-9/29	119	5	84	297.0	10,453	35.20
1970	High	6/8-9/23	107	32	652	1,823.7	1,914	1.05
	Mid	6/8-9/23	107	6	129	326.9	126	0.38
	Low	6/8-9/23	107	6	130	325.3	5	0.02
1971	High	5/26-9/29	126	40	560	2,340.5	4,497	1.92
	Mid	5/26-9/29	126	5	70	289.4	12	0.04
	Low	5/26-9/29	126	5	70	289.4	0	0.00
1972	High	5/31-9/29	121	5	120	297.0	2,524	8.50
	Mid	5/31-9/29	121	2	48	118.8	1	0.01
	Low	Not monitored in 1972						
1973	High	6/1-9/10	102	5	50	297.0	184	0.06
	Mid	Not monitored in 1973						
	Low	Not monitored in 1973						

site these three years was inconsequential (0.38, 0.04, and 0.01 spores per square millimeter respectively) compared to the much heavier production on the high-elevation plantation (Table 6). The low-elevation plantation was monitored only in 1970 and 1971. In 1970 only 0.01 spores per square millimeter were trapped and none in 1971. Possible reasons for these spore production differences between years and among plantations is discussed later under Climatic Factors (page 66).

Infection Periods Identified by Bagging Branches

The use of wet-strength kraft paper bags ("Pollen-Tector") to protect foliage from possible infection allows a direct field evaluation of the infection period(s). Pollen-Tector bags are easy to apply and remove, are weather resistant for up to five months (Figure 13), permit gas and water vapor exchange, transmit sufficient light for near-normal foliage growth (Figure 27), and, if intact, prevent spore entry. On the negative side, maximum temperatures within the bags can be high (126° F. maximum recorded sometime between June 28 and September 13, 1972 on the Willamette supplementary high-elevation plantation) and foliage damage ("bag burn") resembling L. morbida infection can occur. Inquisitive animals (elk, mostly) and birds damaged or destroyed some of the bags, but recourse to the

Figure 27. Near-normal foliage growth and typical "bag burn" of juvenile ponderosa pine foliage which has been within a Pollen-Tector bag for five months.

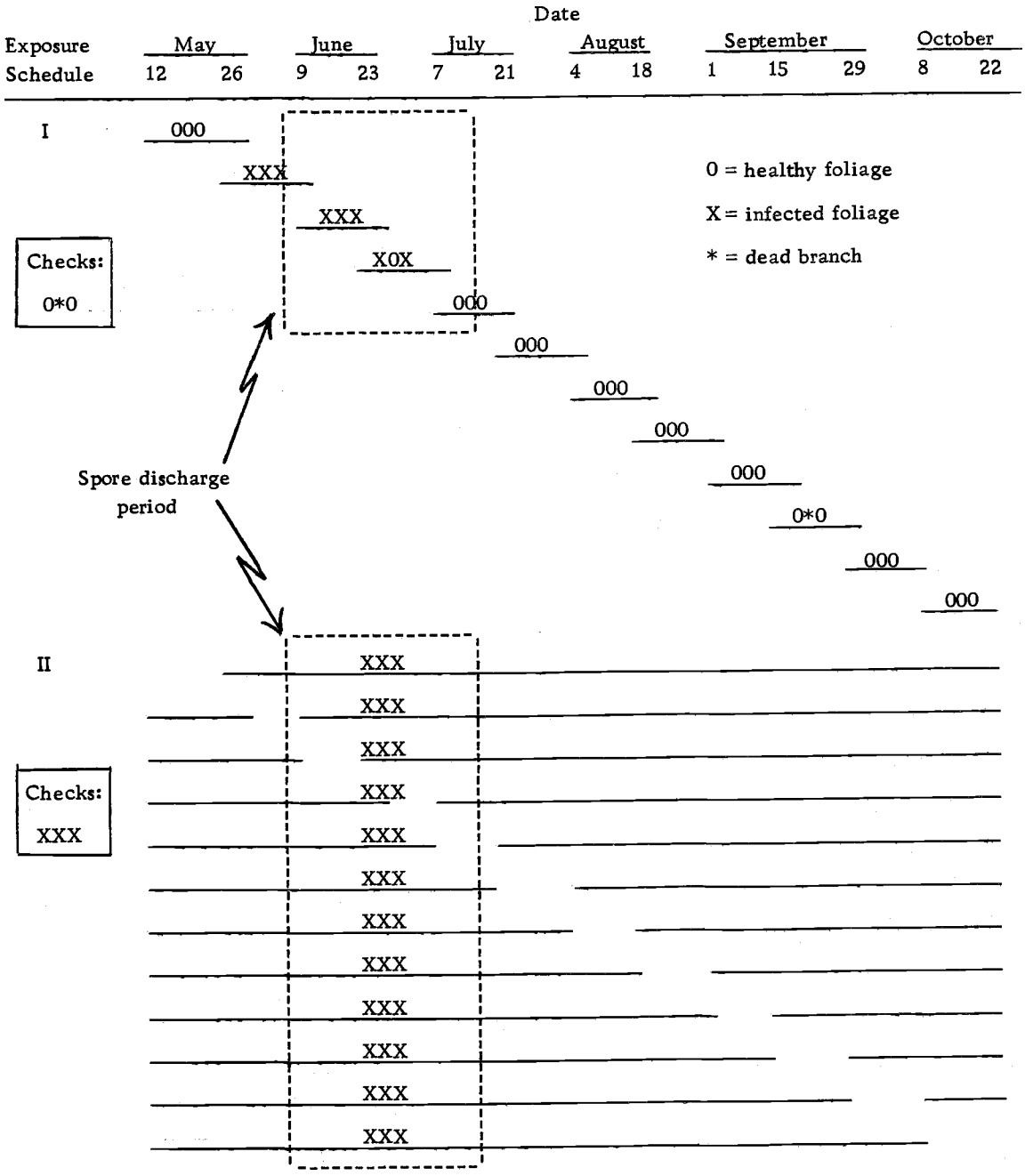
reserve bagged branches allowed scheduled completion of the experiments.

The 1969 foliage bagging results from both the Willamette and Umpqua plantations were remarkably similar. On the Willamette high-elevation plantation, of 12 branches exposed during the sporulation period (indicated by dashed line, Schedule I, Table 7), eight became infected with L. morbida and four remained healthy (Figure 28). On the Umpqua plantation (Table 8), of the 12 Schedule I branches exposed during this same period, 10 became infected and two remained healthy. All other live branches in Schedule I (including checks) on both plantations remained healthy. These infection ratings were confirmed the following year by the development of L. morbida ascocarps on foliage rated as "diseased" in 1969.

Schedule II (Tables 7 and 8) was inadvertently constructed in such a way that all branches in the Schedule were exposed to L. morbida spores at some time during the six week sporulation period in 1969. All live branches in Schedule II on both plantations became infected with L. morbida.

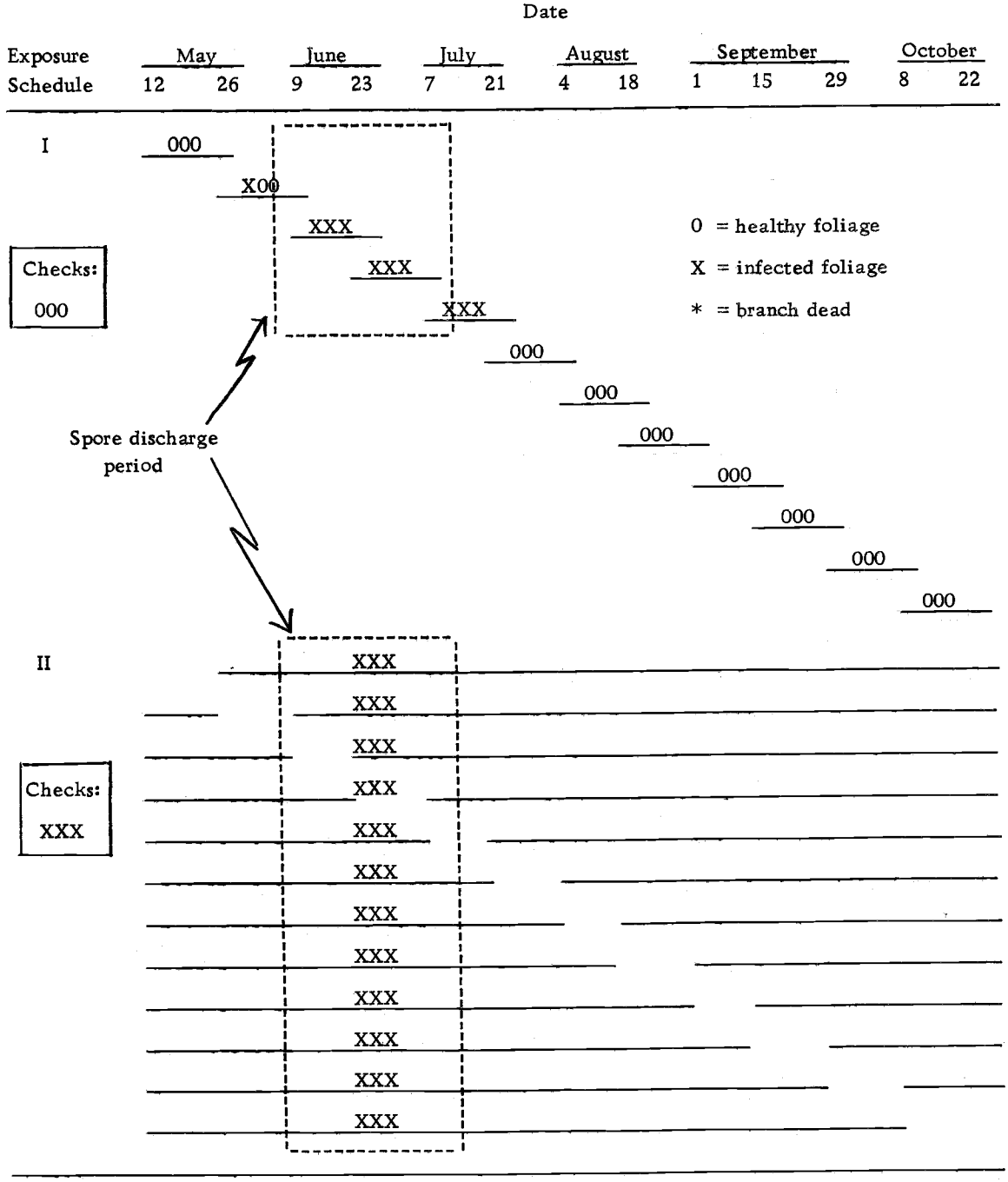
The considerably more complex foliage bagging schedule (described on pages 27 and 28) used in 1970 on the Willamette high-, mid-, and low elevation plantations yielded some unexpected results. I hoped that by means of shorter (48-hour) exposure periods the time of infection could be more closely correlated with critical periods

Table 7. Interval in 1969 during which ponderosa pine branches on the Willamette plantation exposed to inoculum of L. morbida by removal of protective bags became infected.



Solid line denotes period of branch exposure. Unexposed checks for Schedule I bagged from May 12 through October 22; Schedule II checks never bagged. Each character on a line (0, X, or *) denotes the classification for one branch.

Table 8. Interval in 1969 during which ponderosa pine branches on the Umpqua plantation exposed to inoculum of L. morbida by removal of protective bags became infected.



Solid line denotes period of branch exposure. Unexposed checks for Schedule I bagged from May 12 through October 22; Schedule II checks never bagged. Each character on a line (0, X, or *) denotes the classification for one branch.

Figure 28. Typical healthy foliage protected during the sporulation period by a paper bag compared with adjacent heavily infected foliage of an unbagged branch; Willamette plantation, 1969.

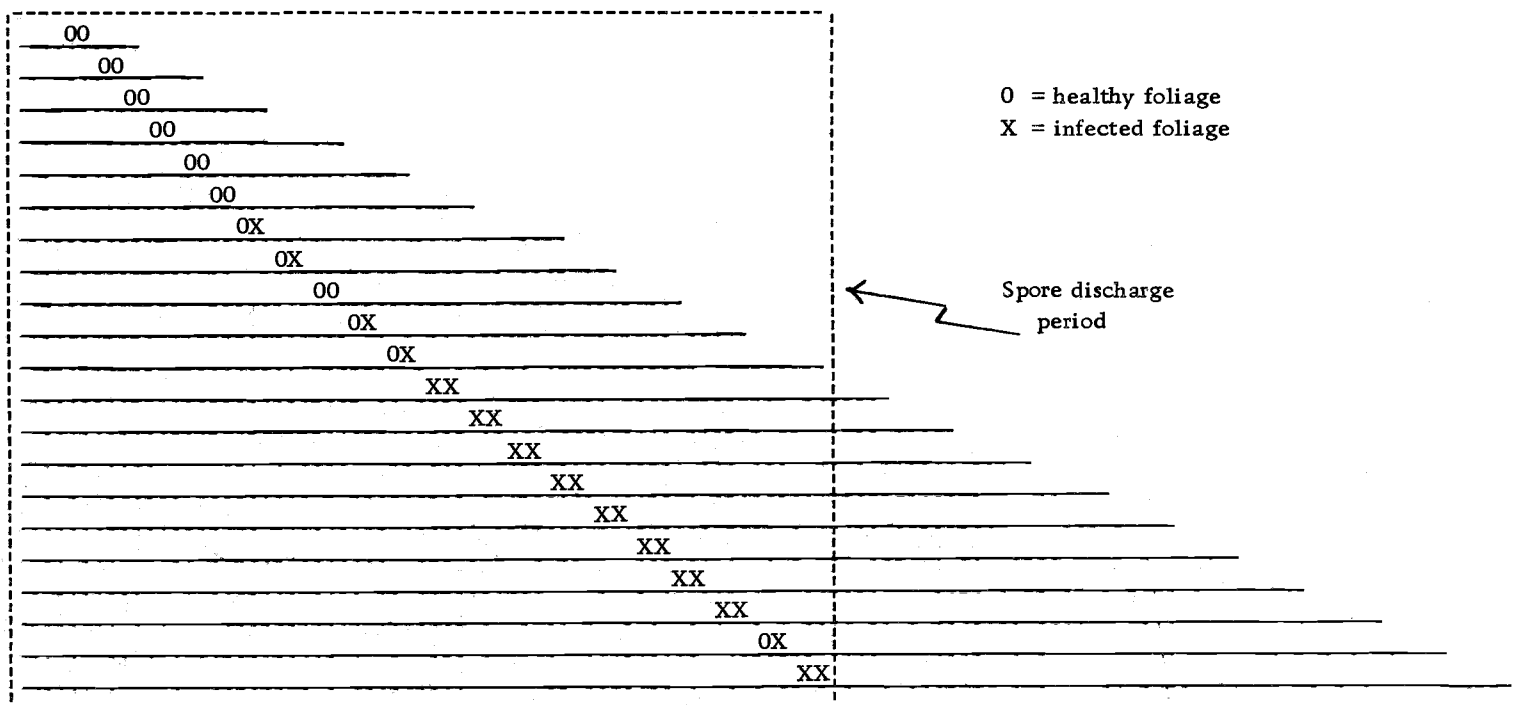
of spore cast and precipitation. No benefit resulted. Not a single branch on the 48-hour exposure schedule (old foliage removed or old foliage intact series) at any of the three study sites (high-, mid-, or low-elevation) developed evidence of L. morbida infection; whereas adjacent non-test branches (on the high-elevation plantation only) became infected with L. morbida. It would seem that either the 48-hour exposure period is not long enough for the infection process or else the environment created by rebagging the foliage so soon after natural infection inhibits any further development of the organism.

The only successful exposure schedule of bagged foliage in 1970 in which infection occurred was the "third branch" per tree described on page 28. These third branches had never been bagged until the start of the 48-hour exposure period for the other two test branches on the tree, at which time they were bagged and remained so until the end of the experimental period in October. Any infection obviously must have occurred before the bags were put in place on this group.

Spore trap slides from the high-elevation plantation indicate that spores were trapped during 11 of the 14 48-hour periods from June 8 through July 6, 1970 (Table 9). Rainfall was recorded during six of these same 14 48-hour periods. The critical rainfall-spore discharge period appears to be the rainy period which began after June 26 and ended on June 30, 1970. Of the 18 branches exposed sometime

Table 9. Interval in 1970 during which ponderosa pine branches on the Willamette high-elevation plantation exposed to L. morbida inoculum became infected.

	DATE																						
	June											July							August		Sept.	
	10	12	14	16	18	20	22	24	26	28	30	2	4	6	13	20	27	30	12	26	9	23
Rainfall in Inches →	0.80	0.04	0.44	0.04	0.00	0.00	0.00	0.00	0.00	0.50	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.45	0.76
Spores per 10 Sq. Mm. →	1.2	0.8	2.1	1.9	0.5	0.1	0.5	0.1	0.0	44.8	11.4	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0



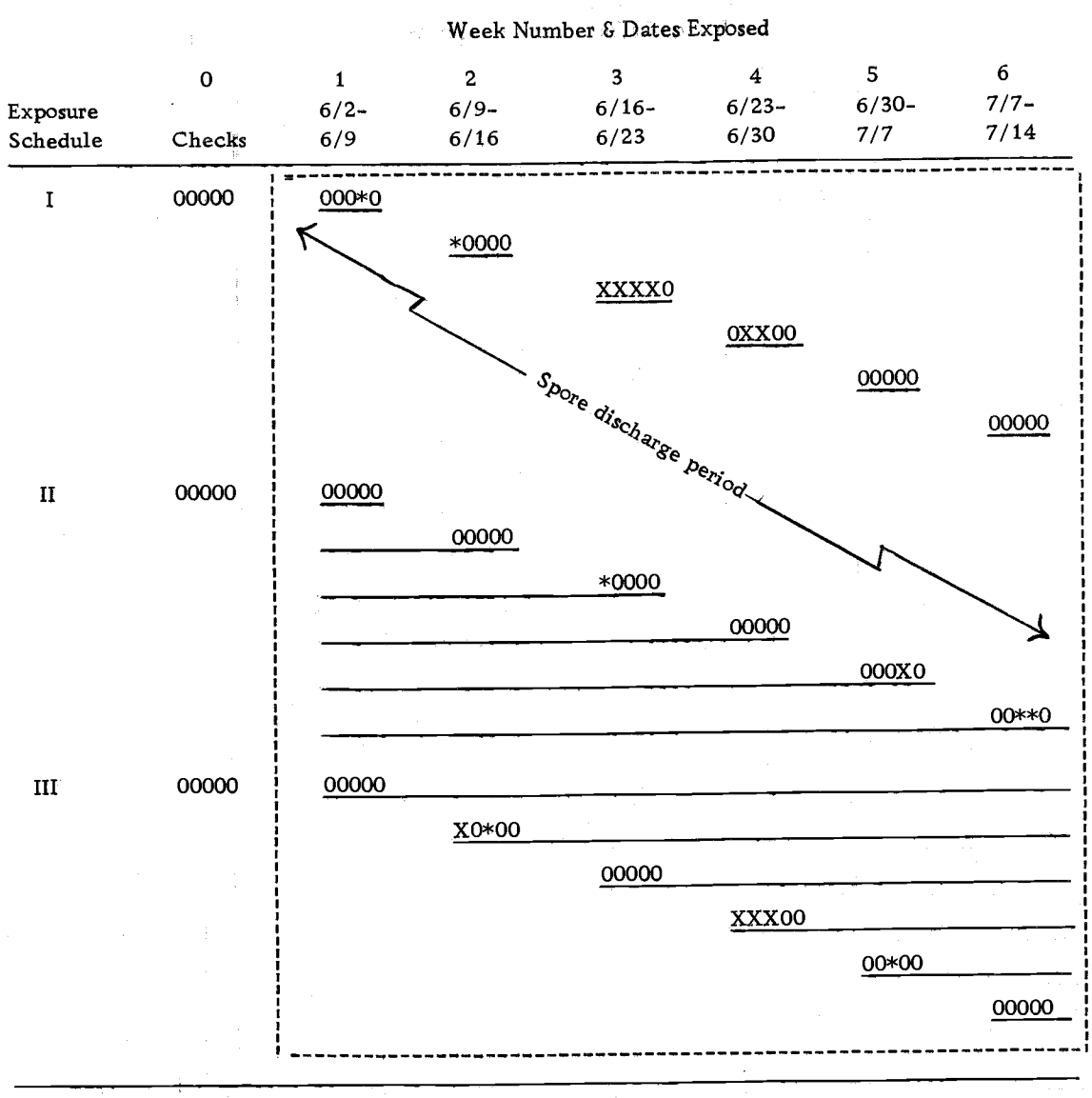
Solid lines denote periods of branch exposure. The first set of branches (2 per set) was bagged on June 10, the second set on June 12, the third set on June 14, etc. Each character on a line (x, 0) denotes the classification of one branch.

between June 10 and June 26, only two (11.1%) became infected; whereas branches exposed from June 10 through the heavy sporulation period of June 28-30 became infected (19 out of 24 = 79.1%).

The infection results from the 1971 foliage bagging schedules are inconclusive and contradictory (Table 10), even though the basic exposure time was extended from 48 hours to one week. There were no detectable infections on either the mid- or low-elevation plantations even though a few spores (0.04 per sq. mm., Table 6) were trapped on the mid-elevation plantation. No spores were trapped at the low-elevation plantation in 1971. The infection pattern on the high-elevation plantation is puzzling and suggests escapes from infection because of a relatively light spore cast. Some foliage which was exposed throughout the sporulation period (six weeks) remained healthy, and other foliage exposed for only one week during the six weeks became heavily infected.

A significant corollary from the foliage bagging experiments is the fact that in all instances where bagged foliage was not infected by L. morbida at the conclusion of the season's experimentation, such healthy foliage remained uninfected by L. morbida in subsequent seasons (Figure 29). This indicates that infection takes place only on juvenile foliage and that L. morbida is not systemic, but recurs each year on the newly developing juvenile foliage.

Table 10. Interval in 1971 during which ponderosa pine branches on Willamette high-elevation plantation exposed to inoculum of L. morbida by removal of protective bags became infected.



Solid line denotes period of branch exposure. Checks bagged from June 2 through July 14. 0 = healthy foliage; X = infected foliage; * = dead bud, branch, or tree -- unable to rate. Each character on a line denotes the classification for one branch.

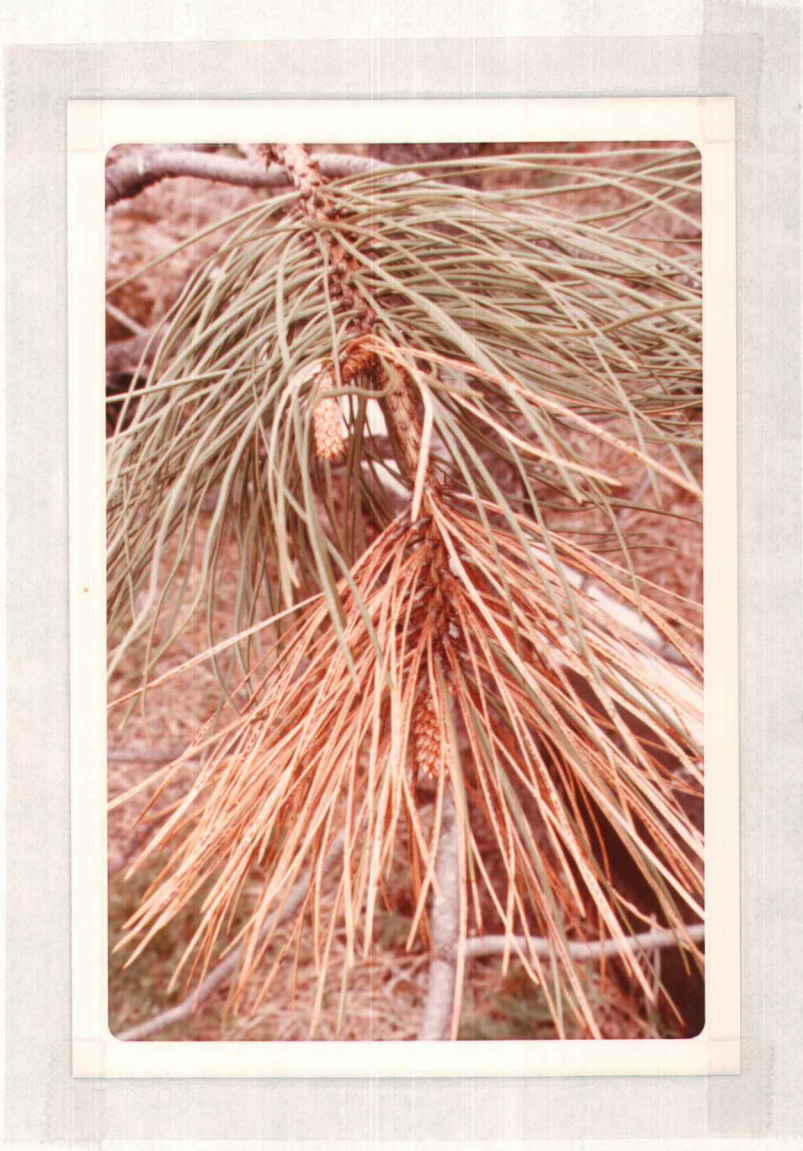


Figure 29. Healthy foliage bagged three years previously, with adjacent one-year younger heavily infected foliage.

Climatic Factors

The behavior of L. morbida in the three ponderosa pine plantations on Little Willow Creek (Willamette) can best be understood by examining the climatic factors monitored on the plantations from 1969 through 1973 (Tables 11 and 12; Figures 30, 31, 32, and 33). During the annual sporulation period of L. morbida (June 1 through July 14), the average of the mean daily temperatures, the average of the mean daily relative humidity, and duration of relative humidity between 90 and 100 percent were found to be statistically non-significant among the three plantations. However, the presence of free water--rainfall and dew duration--was statistically less (1% level) at the low-elevation plantation. Although the high- and mid-elevation plantations may not differ climatically as measured statistically (Table 12) they do differ in that the disease, while present, has failed to intensify on the mid-elevation plantation over a five year period.

One difference which might account for the severe disease conditions on the high-elevation plantation, is the tendency for clouds to linger for hours at about the 3000 foot level after general storm activity has passed (Figure 34). These clouds extend the wet foliage intervals and accordingly the time period favoring infection. If climatic differences exist between the high- and mid-elevation plantations other than the measureable, but statistically non-significant

Table 11. Summary of climatic factors during annual sporulation period of L. morbida extending from June 1 through July 14, 1969-1973; Willamette high-, mid-, and low-elevation plantations.

Year	Plantation			Est.	Temperature			Relative Humidity			Time at	Time	Mean
	Desig-nation	Ele-vation	Rain	days w/rain	Mean Max.	Mean Min.	Mean	Mean Max.	Mean Min.	Mean	90-100% R.H.	below 50°F	hours dew per day
		Feet	Inches	Number	°F			Percent					Number
1969[1]	High	3150	5.56	13	72.4	49.2	60.8	100.0	56.7	78.3	65.6	21.2	2/
1970	High	3150	1.93	12	76.1	47.6	61.8	100.0	58.3	79.2	63.2	28.9	2/
	Mid	2650	1.68	12	82.1	50.4	66.3	99.9	42.4	71.2	46.1	13.3	2/
	Low	1725	1.37	11	82.4	51.2	66.8	99.9	40.4	70.2	36.4	12.5	2/
1971	High	3150	2.76	12	68.1	43.0	55.5	100.0	42.2	71.1	47.4	41.7	2/
	Mid	2650	2.76	12	71.4	43.3	57.4	99.9	42.4	71.2	43.4	36.1	2/
	Low	1725	2.49	12	73.9	45.9	59.9	99.4	32.6	66.0	34.6	26.1	2/
1972	High	3150	1.29	8	75.9	48.5	62.2	100.0	45.9	72.9	55.5	20.1	10.7[3]
	Mid	2650	1.07	8	78.2	47.5	62.8	98.3	33.0	65.6	33.1	24.1	9.5
	Low	1725	0.80	7	80.1	46.8	63.5	100.0	42.8	71.4	50.9	21.4	8.6
1973[1]	High	3150	1.05	6	68.7[4]	46.0[4]	57.4[4]	97.3[4]	40.1[4]	68.7[4]	37.1[4]	36.3[4]	2/

[1]High plantation only in 1969 and 1973; [2]Available only for 1972; [3]Supplementary high-elevation plantation; [4]1973 temperature and relative humidity records: 6/1 through 6/6 and 6/22 through 6/27 missing.

Table 12. Composite results of analyses of variance and multiple range tests of climatic factors, Willamette high-, mid-, and low-elevation plantations; June 1 through July 14, 1970-1972.

Measured variable	Plot	Means	Conclusion
Rainfall	High	1.99 inches	Low plot is highly significantly different
	Mid	1.84 inches	
	Low	1.55 inches**	
Temperature: Average Daily Mean	High	59.8° F.	Not significant
	Mid	62.2° F.	
	Low	63.4° F.	
Average relative humidity	High	74.4%	Not significant
	Mid	69.3%	
	Low	69.2%	
Percentage of time at 90-100% R. H.	High	55.3%	Not significant
	Mid	40.8%	
	Low	40.6%	
Dew duration (hours of 24 hour day)	High	10.7 hours	Low plot is highly significantly different
	Mid	9.5 hours	
	Low	8.6 hours**	

Figure 30. Graphic summary of certain records relating to the epidemiology of L. morbida; Willamette high-elevation plantation, 1969.

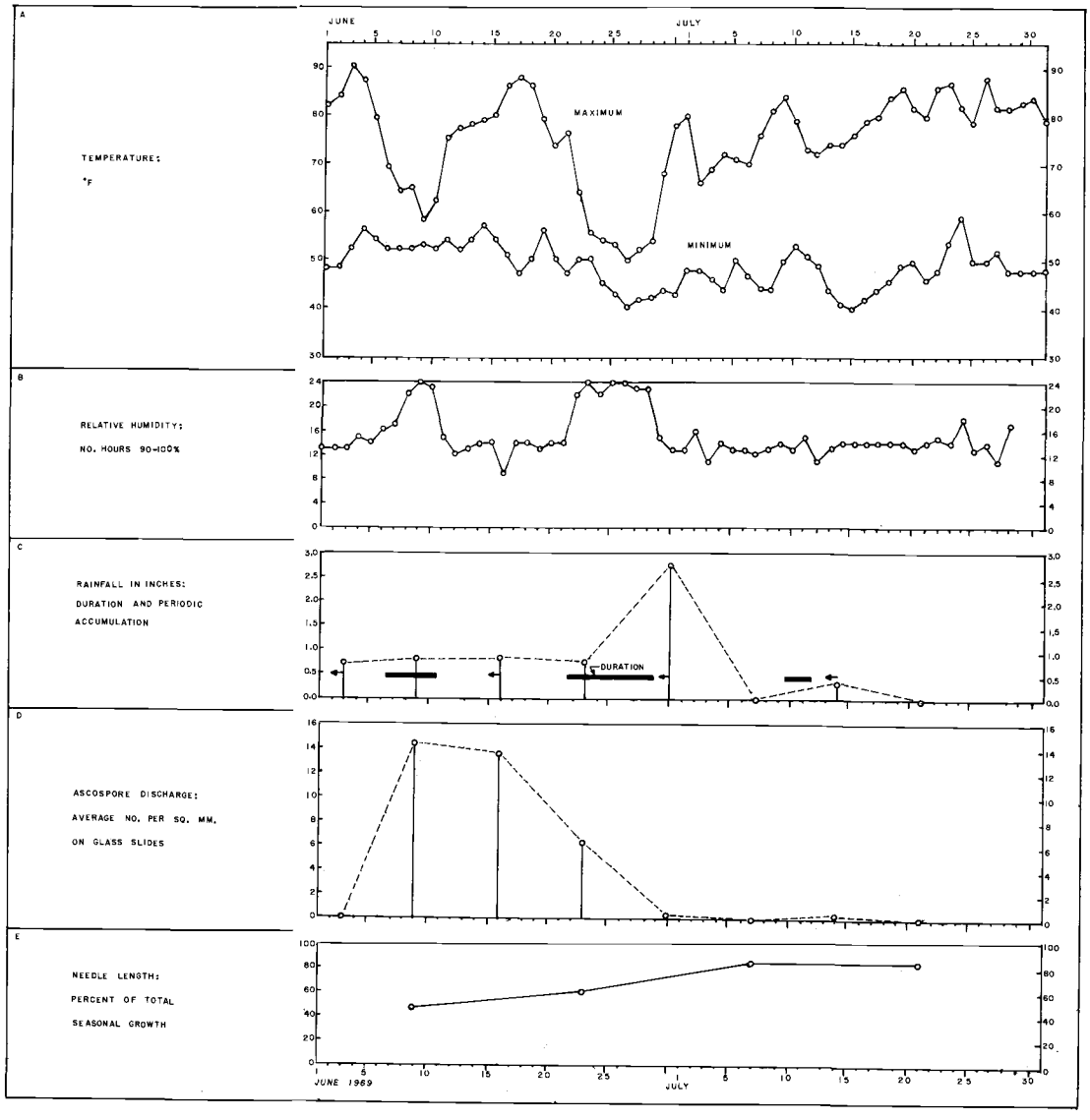

A
TEMPERATURE:
°F
JUNE
JULY
MAXIMUM
MINIMUM
B
RELATIVE HUMIDITY:
NO. HOURS 90-100%
C
RAINFALL IN INCHES:
DURATION AND PERIODIC
ACCUMULATION
DURATION
D
ASCOSPORE DISCHARGE:
AVERAGE NO. PER SQ. MM.
ON GLASS SLIDES
E
NEEDLE LENGTH:
PERCENT OF TOTAL
SEASONAL GROWTH
JUNE 1969
JULY

Figure 31. Graphic summary of certain records relating to the epidemiology of L. morbida; Willamette high-elevation plot, 1970.

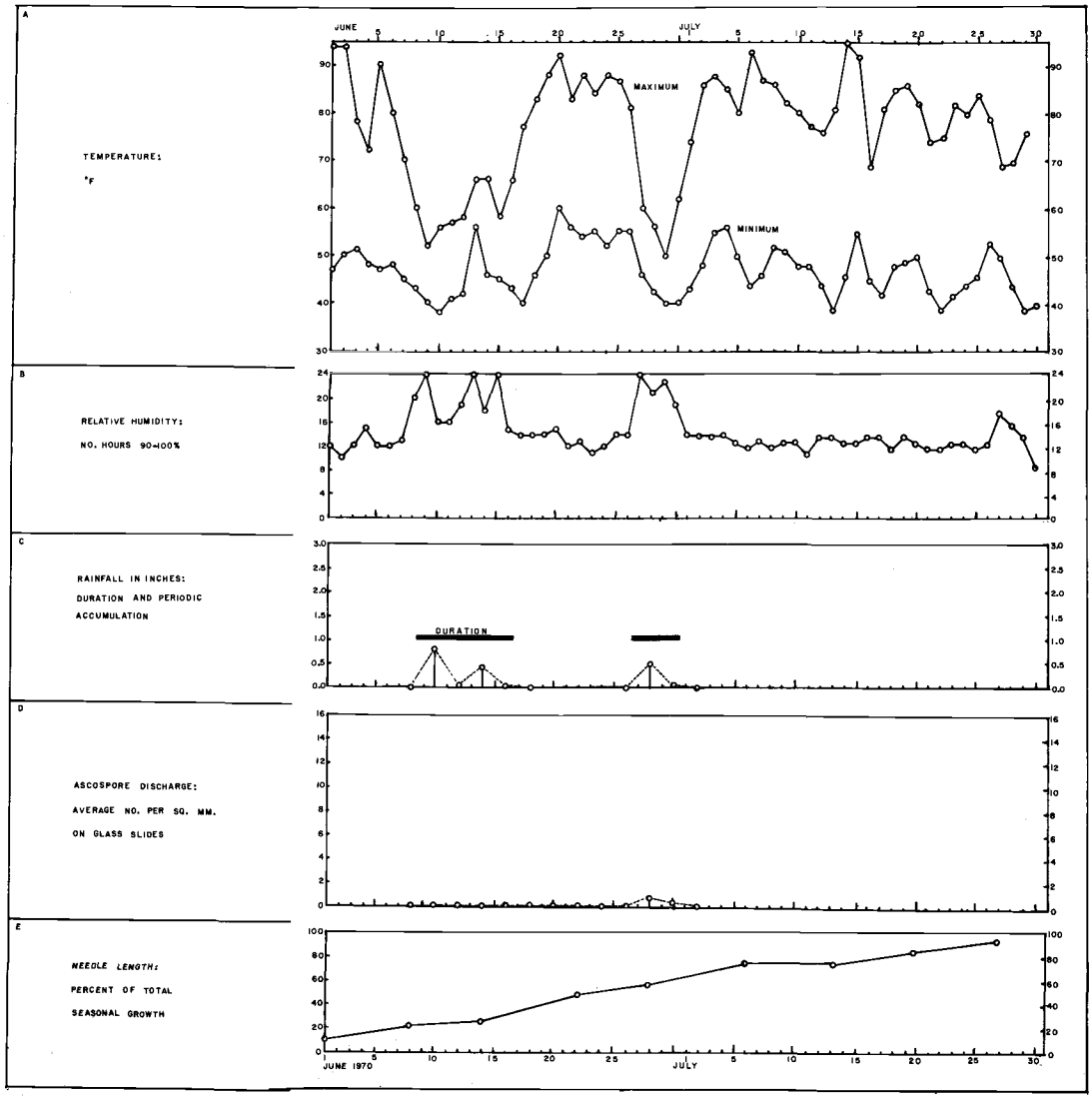

A
TEMPERATURE:
°F
JUNE
JULY
MAXIMUM
MINIMUM
B
RELATIVE HUMIDITY:
NO. HOURS 90-100%
C
RAINFALL IN INCHES:
DURATION AND PERIODIC
ACCUMULATION
DURATION
D
ASCOSPORE DISCHARGE:
AVERAGE NO. PER SQ. MM.
ON GLASS SLIDES
E
NEEDLE LENGTH:
PERCENT OF TOTAL
SEASONAL GROWTH
JUNE 1970
JULY

Figure 32. Graphic summary of certain records relating to the epidemiology of L. morbida; Willamette high-elevation plantation, 1971.

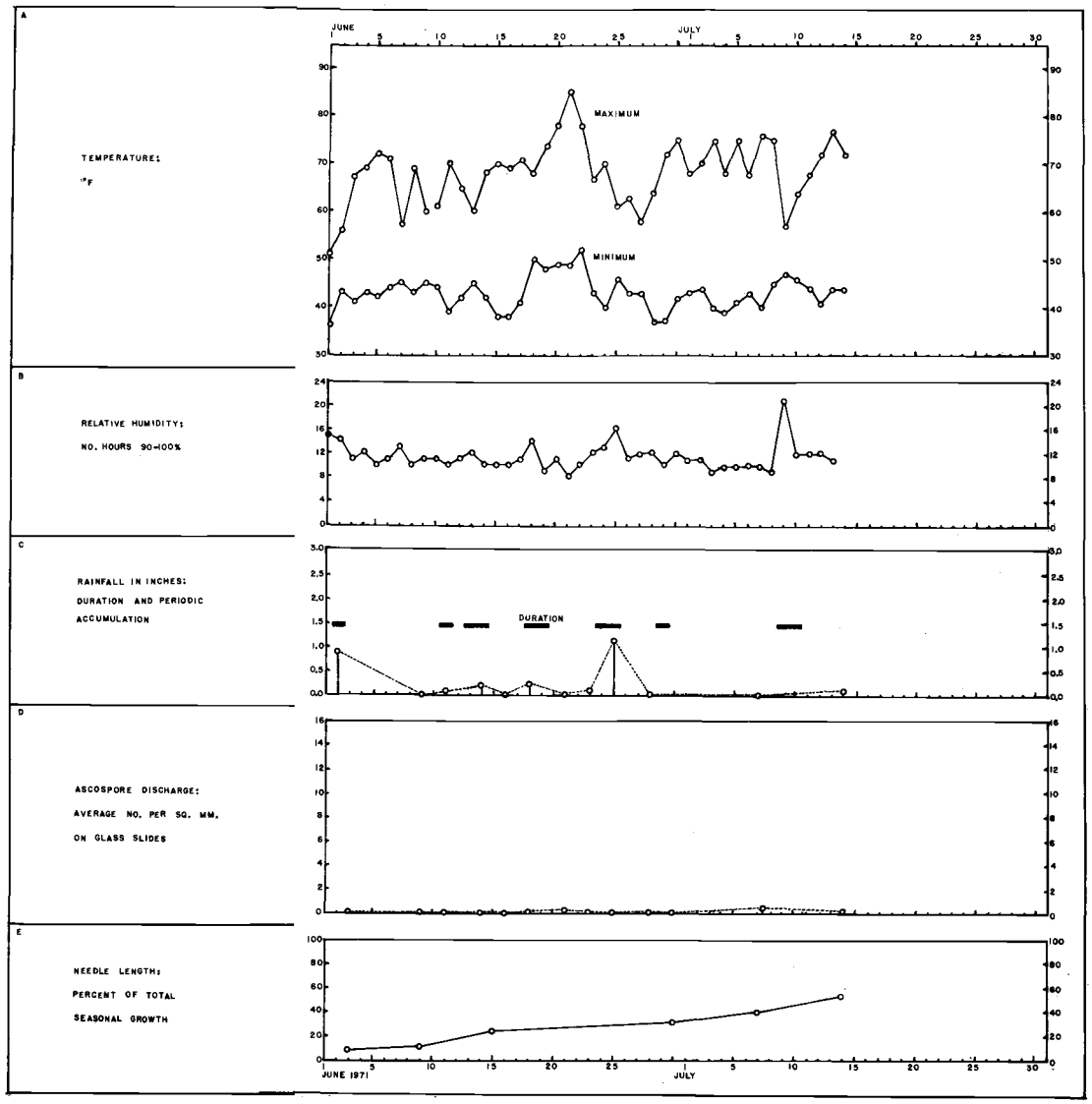

A
TEMPERATURE:
°F
JUNE
JULY
MAXIMUM
MINIMUM
B
RELATIVE HUMIDITY:
NO. HOURS 90-100%
C
RAINFALL IN INCHES:
DURATION AND PERIODIC
ACCUMULATION
DURATION
D
ASCOSPORE DISCHARGE:
AVERAGE NO. PER SQ. MM.
ON GLASS SLIDES
E
NEEDLE LENGTH:
PERCENT OF TOTAL
SEASONAL GROWTH
JUNE 1971
JULY

Figure 33. Graphic summary of certain records relating to the epidemiology of L. morbida; Willamette high-elevation plantation, 1972.

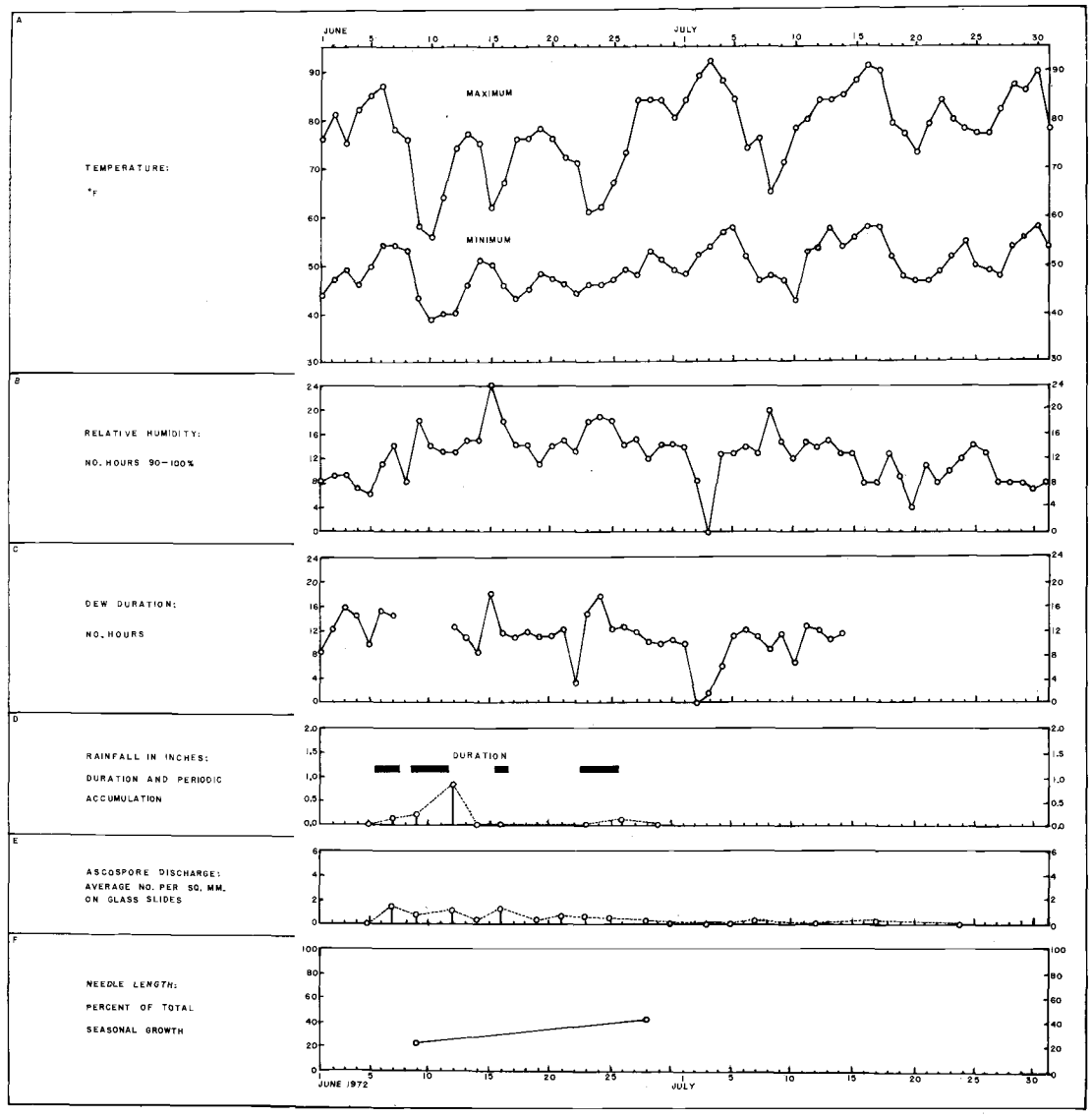

A
TEMPERATURE:
°F
JUNE
JULY
MAXIMUM
MINIMUM
B
RELATIVE HUMIDITY:
NO. HOURS 90–100%
C
DEW DURATION:
NO. HOURS
D
RAINFALL IN INCHES:
DURATION AND PERIODIC
ACCUMULATION
DURATION
E
ASCOSPORE DISCHARGE:
AVERAGE NO. PER SQ. MM.
ON GLASS SLIDES
F
NEEDLE LENGTH:
PERCENT OF TOTAL
SEASONAL GROWTH
JUNE 1972
JULY

Figure 34. Clouds lingering at approximately the 3000-foot level after general storm activity has passed.

Table 13. Average total June and July precipitation and number of days with rain during last three to ten years at selected stations in western and central Oregon compared with the Willamette high-, mid-, and low-elevation plantations.

Reporting Station Location	Average Total June-July Rainfall Inches	Average June July Days With Rain Number	Years Represented in Average Number
Willamette - high plantation	2.52	10	5
Ochoco Ranger Station	2.23	13	10
Oakridge	2.19	12	10
Willamette - mid plantation	1.84	11	3
Eugene	1.62	14	10
Willamette - low plantation	1.55	10	3
Crescent Lake Junction	1.30	11	10
Sisters	1.08	9	10

differences in rainfall, dew duration, etc. --we were unable to detect them with our instrumentation.

The average total precipitation and average total number of days with rain for June and July is compared in Table 13 with two western Oregon reporting stations (Eugene and Oakridge) and three central Oregon stations (Sisters, Crescent Lake Junction, and Ochoco Ranger Station) near natural stands of ponderosa pine. On the basis of total average rainfall and average total number of days with rain, it would seem that ponderosa pine stands in the rain shadow of the Cascade Range are in little danger from L. morbida under normal weather conditions. However, ponderosa pine stands on the western slopes of the Ochoco Mountains (and possibly the Blue Mountains) may be in some danger if the organism is introduced into these areas. Great care must be exercised to insure that this does not happen. It seems unlikely that the disease will spread naturally from the west slope to the east slope of the Cascades as climatic conditions appear to be somewhat inhospitable for the spread and intensification of the organism on the east slope.

Disease Impact

Data were collected on the Willamette plantations from 1969 through 1973 for several of the usual indices of growth. Diameter growth at breast height and basal area analyses may in time provide

an adequate base for comparison of disease impact, but at present are not satisfactory because past growth accumulations are not identifiable by year. Annual height growth and radial growth (increment cores) circumvent this problem.

On the basis of paired (25 healthy vs. 25 diseased trees) annual height growth and radial growth measurements made in 1973, L. morbida has had an apparently significant impact on the growth of ponderosa pine on the Willamette high-elevation plantation. The average annual height growth of the "now diseased" trees was not significantly different ($t_{.05}$ = 0.992 N.S.) from that of "now healthy" trees before the disease appeared in 1967 (Table 14). However, after the disease appeared, the height growth has been significantly reduced in the "now diseased" group of trees ($t_{.01}$ = 7.322**, Table 14).

For these same 50 trees, the situation becomes somewhat more complex when the average annual radial growth is considered. The "now healthy" and "now diseased" groups were statistically different both before and after appearance of the disease in the plantation (before: $t_{.05}$ = 2.345*; after: $t_{.05}$ = 2.245* - Table 14). However, before 1967, the "now diseased" trees had a higher mean annual radial growth rate than the "now healthy" group. After 1967, the "now diseased" group had the expected growth impact and was less than the "now healthy" group. In other words, the radial growth impact is perhaps more significant than the statistical t-test indicates.

Table 14. Comparison of average annual height and radial growth for now healthy and now diseased trees before and after appearance of L. morbida on Willamette high-elevation plantation, 1961-1973.

	Average Annual Height Growth (Inches)				Average Annual Radial Growth (Inches)			
	Pre-disease: 1964-1966		Post-disease: 1967-1973		Pre-disease: 1961-1966		Post-disease: 1967-1973	
Pair Number	Now Healthy	Now Diseased	Now Healthy	Now Diseased	Now Healthy	Now Diseased	Now Healthy	Now Diseased
1	21.0	14.7	17.4	11.1	0.14	0.21	0.08	0.06
2	18.3	13.3	20.6	13.1	0.21	0.19	0.16	0.12
3	9.7	15.7	10.1	6.1	0.14	0.22	0.14	0.18
4	16.7	10.3	20.4	8.3	0.25	0.25	2.21	0.08
5	11.7	9.7	11.4	5.7	0.18	0.12	0.12	0.05
6	12.3	9.7	14.6	7.7	0.19	0.23	0.13	0.16
7	14.3	14.0	16.8	10.7	0.18	0.22	0.10	0.10
8	12.7	13.7	11.7	10.8	0.14	0.20	0.10	0.09
9	18.3	20.0	18.3	14.9	0.20	0.22	0.11	0.11
10	17.7	14.0	15.0	11.7	0.17	0.14	0.14	0.12
11	9.7	13.0	10.7	7.0	0.12	0.13	0.08	0.10
12	14.3	10.7	16.1	4.6	0.09	0.21	0.09	0.14
13	18.7	12.7	18.0	11.6	0.22	0.22	0.13	0.18
14	12.7	15.7	10.4	9.9	0.16	0.20	0.12	0.12
15	8.0	10.0	7.4	8.1	0.14	0.12	0.10	0.10
16	15.7	10.7	11.7	5.8	0.17	0.15	0.16	0.11
17	10.3	12.7	7.0	5.6	0.15	0.22	0.13	0.05
18	10.7	12.7	10.8	5.9	0.14	0.20	0.11	0.08
19	14.0	11.0	17.7	8.3	0.16	0.16	0.15	0.12
20	7.0	8.7	5.6	3.6	0.13	0.15	0.11	0.06
21	7.7	12.3	8.0	7.3	0.10	0.17	0.10	0.08
22	15.7	12.3	13.7	9.7	0.19	0.12	0.16	0.17
23	14.0	10.7	15.3	9.1	0.20	0.17	0.14	0.08
24	10.3	12.7	11.1	8.1	0.15	0.16	0.13	0.08
25	8.3	4.3	5.6	1.4	0.08	0.13	0.16	0.12
Mean	13.2	12.2	13.0	8.2	0.16	0.18	0.13	0.11
t Test	$t_{.05} = 0.992$ N.S.		$t_{.01} = 7.372^{**}$		$t_{.05} = 2.345^{*}$		$t_{.05} = 2.245^{*}$	

Table 15. Chemicals tested on the Willamette high-elevation and Umpqua plantations in 1969 ranked by decreasing effectiveness, 1 to 10.

Chemical	Concentration (Wt./Vol.) Percent	Effectiveness Ranking[1] Visual	Needle Count
Daconil 2787	2.0	1	1
Zineb	2.0	2	2
Manzate D	2.0	3	3
Difolatan flowable	2.0	8	8
Bordeaux 8-8-100	1.0	9	10
Control - water		6	5
Daconil	0.2	4	4
Zineb	0.2	7	7
Manzate D	0.2	5	6
Difolatan flowable	0.2	10	9

[1]Combined rank for both plantations.

Chemical Control

From data in the files of the late H. H. Bynum, the staff of the Insect and Disease Control Section of the Regional Office of the U. S. Forest Service prepared a final report of the 1969 Willamette and Umpqua tests on chemical control of L. morbida (Appendix A). Their failure to mention the 1970 tests suggests that these data are missing, incomplete, or impossible to summarize.

Ratings for both plantations based on a visual effectiveness ranking and a count of infected needles (Table 15) indicated that 2% Daconil 2787, 2% Zineb, and 2% Manzate D gave acceptable protection from infection by L. morbida. Poorest control was achieved by 1% Bordeaux (8-8-100). Authors of Appendix A feel that Bordeaux eliminated fungi antagonistic to L. morbida, while having little or no effect on the pathogen itself.

Species Susceptibility

In October 1972 Region Six staff examined the hard pine susceptibility tests installed by the late H. H. Bynum on the Willamette and Umpqua National Forests in 1969. They feel it to be premature to judge the relative resistance of the various species and various seed sources of hard pines on such a small-scale test and conclude that additional testing will be necessary. Appendix B.

Vegetation Survey

The vegetation survey conducted in 1970 on the Willamette high-elevation plantation indicated that for the plantation as a whole, there were only five Douglas-firs per acre (Table 1). The number of Douglas-firs per acre varied according to the portion of the plantation under consideration--ranging from 1 per acre on the upper slope portion (planted to ponderosa pine) to a high of 16 per acre in the poorly stocked plantation portion. The number of Douglas-firs on the area will doubtlessly increase slowly with time as the area receives the annual seed crop from the adjacent mature Douglas-fir timber and as more Douglas-firs within the plantation reach reproductive age. Even though 42.2% of the plantation area as a whole is classified as "vacant" on a tree and woody plant coverage basis (Table 16), this "vacant" area is usually fully occupied with a heavy cover of grass, sedge, or other low vegetation which might hinder tree seed from reaching the soil or affording too much competition for the survival of new seedlings.

As each of the ponderosa pine stems was tallied for the vegetation survey, an occular estimate of tree health or cause of death was recorded (Table 17). This estimate indicates that almost all the trees (93.6%) are affected to some extent by L. morbida, but that only a very few (0.9%) have apparently died from the disease at this time.

Table 16. Tree and shrub coverage, Willamette high-elevation plantation; 1970.

Plant	Percent				
	Plantation portion				All Areas Combined
	Upper Slope	Lower Slope	Unplanted Strip	Poorly Stocked	
Pinus ponderosa Laws.	30.3	0.2	0.0	0.2	7.6
Pseudotsuga menziesii (Mirb.) Franco	0.4	1.9	1.7	2.0	1.5
Abies grandis (Dougl.) Lindl.	0.0	0.3	0.0	0.0	0.1
Thuja plicata Don	0.0	0.1	0.0	0.1	0.1
Arbutus menziesii Pursh.	0.3	0.0	0.0	0.2	0.1
Salix spp.	0.4	0.3	0.0	0.2	0.2
Cornus nutallii Aud.	0.0	0.1	0.0	0.0	0.1
Alnus rubra Bong.	0.0	0.1	0.0	0.0	0.1
Populus trichocarpa Torr. & Gray	0.0	0.1	0.0	0.0	0.1
Acer macrophyllum Pursh.	0.0	0.1	0.0	1.0	0.3
Ceanothus sanguineus Pursh.	22.8	2.9	55.7	9.6	22.7
Prunus emarginata Dougl.	0.1	2.2	0.2	0.0	0.6
Holodiscus discolor (Pursh.) Maxim.	4.6	0.7	18.9	4.6	7.2
Acer circinatum Pursh.	2.9	7.8	0.0	0.2	2.7
Corylus cornuta Marsh.	0.2	0.0	0.0	0.0	0.1
Arctostaphylos spp.	0.2	1.6	0.0	0.7	0.6
Sambucus cerulea Raf.	0.4	0.1	0.0	0.5	0.2
Ribes sanguineum Pursh.	0.4	0.4	0.0	0.2	0.2
Logging debris	3.4	21.3	0.0	28.7	13.3
Vacant	33.6	59.8	23.5	51.8	42.2
Totals	100.0	100.0	100.0	100.0	100.0

Table 17. Disease conditions and mortality of planted ponderosa pine, Willamette high-elevation plantation; 1970.

Disease classification	Trees Number	Percent
Healthy	3	1.4
Light to moderate	132	59.4
Heavy	76	34.2
Dead - L. morbida	2	0.9
Dead - porcupine	1	0.5
Dead - other causes	8	3.6
Total	222	100.0

Artificial Inoculation

The artificial inoculation attempt on the three potted ponderosa pines transported from Corvallis to the Willamette supplementary high-elevation plantation for inoculation was not successful. The bagged and unbagged branches were first examined for incipient infections on September 13, 1972. At that time there was some needle necrosis as illustrated in Figure 5. However, it is often impossible to distinguish incipient needle infections from bag burn on bagged foliage. Consequently, a final evaluation was made on April 26, 1973. At that time there was no visible evidence of L. morbida infections on any of the inoculated branches.

Temperatures on the bagged maximum-minimum thermometer ranged from a low of 30° F. to a high of 104° F. for the period from June 5 to June 28, 1972. For the period from June 28 through September 13, 1972 the temperature range was from a low of 30° F. to a high of 126° F. With temperatures up to 126° F. within the bags in the sun, it is understandable why some foliage is stressed and has what we came to describe as "bag burn."

Apparent Host Resistance

Several trees on the Willamette plantation and one tree on the Umpqua plantation exhibited varying degrees of apparent resistance to L. morbida infection. The resistant tree on the Umpqua plantation (Figure 35) exhibited its apparent resistance in 1969 only. In subsequent years, this tree was infected and indistinguishable from its neighbors.

On the Willamette plantation, we observed that certain trees were healthier in appearance than their neighbors in May and June, but by August and September symptom expression had progressed to the point where they no longer appeared healthy or much different from their infected neighbors. We can offer no explanation for either of these phenomena.

Figure 35. Ponderosa pine apparently resistant to L. morbida surrounded by heavily infected trees; Umpqua plantation, October 1969.

V. DISCUSSION AND CONCLUSIONS

The appearance of an aggressive foliage disease on plantings of a forest tree species in a monoculture is neither new nor unexpected to the forest pathologist--particularly so if the species is planted on an inappropriate site. This is especially true when a species such as ponderosa pine, which is acclimated to the drier conditions east of the Cascade Mountains, is planted in the moister conditions on the west slope of the Cascades. This action is simply begging for trouble. The surprising factor in the current outbreak of L. morbida is that so far there has been very little mortality and only moderate growth impact on affected trees from a disease of such alarming visual appearance and apparent aggressiveness.

The life cycle and timing of the organism appears to be well adapted to the climatic conditions of the higher portions of the west slope of the Cascade Mountains which strongly suggests that it is a native organism endemic on scattered west-side ponderosa pine. We have been unable to confirm this suspicion. However, it is not unknown in the Willamette Valley, having been collected on the MacDonald Forest near Corvallis, Oregon in 1953 and 1970, and is currently (July 1973) present on the 1972 foliage of a long-established ponderosa pine provenance study. The fact it has been present west of the Cascades for at least 20 years and has not penetrated the

interior ponderosa pine forests east of the Cascades suggests an effective climatic barrier to the spread of the organism. This barrier is probably the climatic difference between the two sides of the mountains. The usual late spring rainy periods and mild winters west of the Cascades would favor the infective dispersal and the year-long growth and development of L. morbida; whereas the hot, dry summers and cold winters could effectively limit sporulation, infection, and development of the pathogen east of the mountains under normal climatic conditions. However, the abnormal and atypical are always possibilities and care must be exercised to keep this pathogen from reaching the interior ponderosa pine forests of the Pacific Northwest by the inadvertent introduction of infected ponderosa pines from the west side of the Cascade Mountains.

In conclusion--

a. L. morbida is probably a native organism, catapulted to prominence by an unusual and unnatural abundance of a very susceptible host growing under climatic conditions favorable for spread and intensification of the pathogen.

b. Heavy ascospore discharge and subsequent foliage infection is correlated with periods of general rain from early June to mid-July.

c. Ascospore infection occurs only on juvenile foliage. Healthy foliage from previous years does not become infected when

exposed to conditions which infect adjacent juvenile foliage.

d. Planting ponderosa pine on the west slope of the Cascade Mountains above 2000 feet elevation should be discouraged. If ponderosa pine is the only feasible species to plant, areas near ridgetops or basins where clouds linger after general storm activity has ceased should be avoided.

e. Native ponderosa pine stands on the east slope of the Cascade Mountains which are in the rain shadow of the Cascades are probably safe from significant L. morbida infection under normal climatic conditions. However, ponderosa pine stands on the west slope of interior mountain ranges in the Pacific Northwest may be in a higher risk category than east slope Cascade stands because of the generally higher rainfall during June and July.

f. Again, care must be exercised to prevent the introduction of L. morbida infected ponderosa pines from the west side of the Cascade Mountains into the interior ponderosa pine forests of the Pacific Northwest.

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APPENDICES

APPENDIX A

U. S. Forest Service
Region 6

Portland, Oregon
December, 1972

A FINAL REPORT ON THE EVALUATION OF POTENTIAL CHEMICALS FOR CONTROL OF LOPHODERMELLA MORBIDA STALEY.

This is a part of "An administrative research study to investigate damage potential and threat to hard pines by a newly discovered needle pathogen," prepared by H. H. Bynum, K. R. Shea, and G. M. Harvey, April 10, 1969. A supplemental report on host range studies is attached.

Objectives

To evaluate potential selected chemicals for foliar application to reduce or prevent field infection by Lophodermella morbida. This is a cooperative project (FS-PNW-2301) involving the Insect and Disease Control Branch (R-6), the Pacific Northwest Forest and Range Experiment Station, and the Rocky Mountain Forest and Range Experiment Station staff.

Methods and Materials

Small scale tests of chemicals involved treating 100 ponderosa pine branches (10 per treatment) with chemicals in each of two plantations in Oregon (Three Cabin Creek, Tiller R. D., Umpqua N. F., T. 31 S., R. 1 W., Sec. 15, Unit 1; and Little Willow Creek, Rigdon R. D., Willamette N. F., T. 22 S., R. 3 E., Sec. 24, subdivision 16). In both plantations, non-local seed sources were used and the ponderosa pine is planted on sites best suited to other species.

For each treatment a single branch per tree was dipped into each chemical containing spreaders and stickers. Each tree received all 10 treatments. Treatments began at bud break in the spring (May 19, 1969) and continued approximately at 2 week intervals until full needle

length was reached. (The last treatment was applied on July 30, 1969.)

Current year needles become infected by L. morbida as they develop.

The chemicals tested and the concentrations used are presented in Table 1.

Two methods of assessing the relative effectiveness of each treatment in preventing needle infection were used. A visual rating of effectiveness was made after collection of 20 twigs per treatment (10 per site) during April 1970. Twigs were collected from the Three Cabin Creek plot on April 7 and 14, and from the Little Willow Creek plot on April 9 and 29. The data were combined for the final analysis. The twigs (representing all treatments) from each tree were arranged in order of increasing amount of infection present. Twigs having the least amount of infection were rated 1; twigs with the most amount of infection were rated 10. This method of rating needle infection was used for each tree.

The effectiveness of each chemical was expressed as the sum of the individual rankings divided by the number of individual rankings. The lowest numbers represented the most effective chemicals.

The amount of infection attributed to secondary fungi, Hendersonia sp., was rated on a scale from 0 to 3 (0 = none, 1 = light, 2 = moderate, 3 = heavy).

Infection by L. morbida was also determined quantitatively by counting the infected and non-infected needles on each twig for each treatment. The percent of infection was expressed as the total number of infected needles divided by the total number of needles. Partially infected needles were counted as infected. Needles that died as a result of feeding by the pine bud mite, Phytoptus pini, were not included in the needle count.

Results and Discussion

The results of both the visual rating and needle count examinations of the treated foliage are presented in Tables 2 and 3. The amount of infection varied in the two test sites. The percent infection of controls as indicated by needle counts at the Little Willow Creek and Three Cabin Creek plots were 42.2 percent and 81.3 percent, respectively. The ranking of the effectiveness provided by the treatments was similar using either the visual or needle count method. Daconil 2787 (2%) provided the best protection, followed by Zineb (2%) and Manzate D

(2%). It is interesting to note that the poorest control was achieved with Bordeaux mixture 1% (8-8-100). It is thought that this chemical eliminated fungi antagonistic to L. morbida while having no or little effect on this pathogen alone (see Table 2 for ranking of secondary fungi). Several other treatments including Zineb and Manzate D at 0.2 percent concentration also resulted in greater amounts of infection by L. morbida than that recorded for the control.

The relative effectiveness of other fungi in reducing infection by L. morbida warrants additional research.

DAVID W. JOHNSON
Plant Pathologist

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Bynum, H. H. and D. R. Miller. 1969. A new needle disease of hard pines in Oregon and Washington. Plant Disease Reporter, 53(3): 232-234.

cc: Geo. Harvey, PNW, Corvallis.

Table 1. Treatments applied to ponderosa pine foliage to prevent infection by Lophodermella morbida.

Treatment No.	Chemical	Conc. (w/v)	Carrier and Additives
1	Daconil 2787	2% (94.6 g/gal)	None
2	Zineb	2% (94.6 g/gal)	1 ml s-s conc. in 10 ml H_2O
3	Manzate D	2% (90.8 g/gal)	1 ml s-s conc. + 10 ml H_2O
4	Difolatan Flowable	2% (151.4 ml/gal)	None
5	Bordeaux	1% (36.29 g/gal) 8-8 100	None
6	Control (Water)		
7	Daconil 2787	0.2% (380 ml of 2%/gal	None
8	Zineb	0.2% (380 ml of 2%/gal)	1 ml s-s in 10 ml H_2O
9	Manzate D	0.2% (380 ml of 2%/gal)	1 ml s-s in 10 ml H_2O
10	Difolatan	0.2% (15.14 ml/gal)	None

Table 2. Visual rankings of effectiveness of treatments applied to ponderosa pine foliage to prevent infection by Lophodermella morbida.

Chemical	Secondary* Fungi (O L-M-H)	Effectiveness** (Lowest Numbers Most Effective) 3-Cabin Plot Umpqua N.F.		Little Willow Plot Willamette N. F.		Com. Total Both Plots
Daconil 2787 2%	0.05	39/20	1.95	20/17	1.2	1.6
Zineb 2%	1.2	46/20	2.3	46/17	2.7	2.5
Manzate D 2%	0.3	55/18	3.1	32/16	2.0	2.6
Difolatan flowable 2%	0.4	131/19	6.9	81/15	5.4	6.2
Bordeaux 8-8-100	2.6	154/20	7.7	117/18	6.5	7.1
Control - water	1.8	99/18	5.5	91/18	5.1	5.3
Daconil 0.2%	2.0	62/18	3.4	30/18	1.7	2.6
Zineb 0.2%	2.7	133/20	6.6	78/18	4.3	5.5
Manzate D 0.2%	2.4	123/20	6.2	71/17	4.2	5.2
Difolatan 0.2%	0.7	149/19	7.8	114/17	6.7	7.3

*Total Rating / No. Live Twigs

Rating
0 = No Secondary Fungi
1 = Light Secondary Fungi
2 = Moderate Secondary Fungi
3 = Heavy Secondary Fungi

** Sum of Individual Rankings / No. of Individual Rankings

Table 3. Needle count infection ratings of treatments applied to ponderosa pine to prevent infection by Lophodermella morbida.

Chemical	3-Cabin Plot Needles Total No. *	3-Cabin Plot Needles % Infected	Little Willow Plot Needles Total No. *	Little Willow Plot Needles % Infected	Both Plots Needles Total No. *	Both Plots Needles % Infected
Daconil 2787 2%	278/2903	9.6	24/1806	1.3	302/4707	6.4
Zineb 2%	412/2798	14.7	128/1805	7.1	540/4603	11.7
Manzate D 2%	454/1795	25.3	41/1578	2.6	495/3373	14.7
Difolatan Flowable 2%	3079/3370	91.4	790/1687	46.8	3869/5057	76.5
Bordeaux 8-8-100	2836/2897	97.9	1394/1984	70.3	4230/4881	86.7
Control - water	1433/1762	81.3	556/1319	42.2	1989/3081	64.6
Daconil 0.2%	587/2340	25.1	87/1646	5.3	674/3986	16.9
Zineb 0.2%	2568/2870	89.5	769/2085	37.6	3337/4955	67.3
Manzate D 0.2%	1867/2076	89.9	618/1700	36.4	2485/3776	65.8
Difolatan 0.2%	2667/2821	94.5	1290/2007	64.3	3957/4828	81.9

* Total Infected / Total Needles

APPENDIX B

U. S. Forest Service
Region 6

5200
Portland, Oregon
December 1972

Host Range Study: EVALUATION OF OUTPLANTED PINE SPECIES SUBJECTED TO INFECTION BY LOPHODERMELLA MORBIDA FOR THREE YEARS.

Objectives

To evaluate several pine species and pine seed sources for relative resistance to infection by the needle cast fungus, Lophodermella morbida Staley.

Materials and Methods

Field studies of the host range of L. morbida were conducted by exposing seedlings in infected ponderosa pine plantations on the Umpqua and Willamette National Forests (Three Cabin Creek and Little Willow Creek plots, respectively). Tree species included ponderosa pine from three seed sources, as well as Jeffrey pine, lodgepole pine and knobcone pine. Potted seedlings (1-3 years old) of each species were placed in trenches during October 1969. Other seedlings were planted with an auger under infected plantation trees. A list of the tree species planted and their seed source are included in Table 1.

Observations on the numbers of live, dead or missing trees in each plot were made and recorded during October 1972. The data are presented in Tables 2, 3, 4, and 5.

Results and Discussion

Ponderosa pine from the Deschutes seed source exhibited the poorest growth of all species and sources tested. Auger-planted trees had poorer growth than potted trees placed in trenches. Survival for all seedlings was poorest on the Little Willow Creek plot. It was noted

that the ponderosa pine in the plantation had a general red cast in October 1972. Only the current year's foliage was present on most of the trees and it was also infected. The cause for the poor survival of the auger-planted seedlings compared to that of the potted seedlings is unknown. Competition from grass and injury from rodents was suspected as contributing to the death of many trees. Also, the auger-planted trees were placed under an overstory of infected trees, whereas, the potted seedlings were placed in trenches in the open.

It would be premature to judge the relative resistance of the tree species and seed sources tested based on such a small-scale experiment. A greater number of replicates would be necessary for a good test, also some control of weeds is needed. Trees should be caged to prevent rodent injury.

Additional field testing is necessary before a conclusion as to the relative resistance of these pines can be made.

DAVID W. JOHNSON
Plant Pathologist

cc: Geo. Harvey, PNW, Corvallis

Table 1. Pine species and seed sources used in host range study.

Tree Code	Nursery Designation	Species	Age	Seed Source
DPP	122-01-682-010-4.0-6011	Ponderosa	(Not available)	Deschutes
UPP	122-15 492-020-4.5	Ponderosa	3-0	Umpqua
WPP	122-18-472-030-4.5	Ponderosa	2-0	Willamette
RJP	116-10 502-010-4.5	Jeffrey	2-0	Rogue River
RKP	124-10 511-020-4.0	Knobcone	1-0	Rogue River
WLP	108-18 462 030-4.5	Lodgepole	2-0	Willamette

Table 2. Potted pine seedling survival after three years. Three Cabin Creek - Umpque N.F.

Tree Code	No. Trees in Sample	Live	Dead and/ or Missing	% Survival After 3 Yrs.	Needles Yrs. Present
DPP	15	14	1	93.3	1-2
UPP	10	10	0	100.0	2
WPP	10	10	0	100.0	2
RJP	25	24	1	96.0	2
RKP	25	23	2	92.0	2
WLP	25	25	0	100.0	3
Totals	110	106	4	96.4	

Table 3. Potted pine seedling survival after three years. Little Willow Creek - Willamette N.F.

Tree Code	No. Trees in Sample	Live	Dead and/ or Missing	% Survival After 3 Yrs.	Needles Yrs. Present
DPP	15	6	9	40.0	1-2
UPP	10	10	0	100.0	1-2
WPP	10	7	3	70.0	2-3
RJP	25	21	4	84.0	2-3
RKP	25	21	4	84.0	3-4
WLP	25	21	4	84.0	3-4
Totals	110	86	24	78.2	

Table 4. Auger-planted pine seedling survival after three years. Three Cabin Creek - Umpqua N. F.

Tree Code	No. Trees in Sample	Live	Dead and/ or Missing	% Survival After 3 Yrs.	Needles Yrs. Present
DPP	10	5	5	50.0	2
UPP	5	3	2	60.0	1
WPP	5	5	0	100.0	2
RJP	5	3	2	60.0	1
RKP	5	4	1	80.0	3
WLP	5	2	3	40.0	2
Totals	35	22	13	62.9	

Table 5. Auger-planted pine seedling survival after three years. Little Willow Creek - Willamette N. F.

Tree Code	No. Trees in Sample	Live	Dead and/ or Missing	% Survival After 3 Yrs.	Needles Yrs. Present
DPP	10	3	7	30.0	1
UPP	5	4	1	80.0	1
WPP	5	5	0	100.0	1
RJP	5	3	2	60.0	2
RKP	5	4	1	80.0	1
WLP	5	1	4	20.0	1
Totals	35	20	15	57.1	