Cyclaneusma Needlecast and Needle Retention in Scots Pine

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ABSTRACT

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Portions of two Pennsylvania *Pinus sylvestris* Christmas tree plantations, each of a different provenance, were left untreated or treated repeatedly with fungicide to prevent infection of the 1990, 1991, and 1992 needle complements by *Cyclaneusma minus*. Periodically from July 1990 to August 1992, incidence of infection by *C. minus* was determined by direct isolation from needles of the 1990 and 1991 complements of permanent sample trees within each treatment block. Treatment with fungicide significantly increased retention of third-year needles, but not of second-year needles of these provenances. Fungicide treatment also significantly increased the proportions of trees retaining more than 50% of their third-year needles. Retentions of third-year and second-year needles on individual trees were not correlated and varied greatly among individual trees regardless of infection by *C. minus*. Results indicate a host genetic factor independently affecting needle retention in Scots pine, upon which are superimposed the effects of Cyclaneusma needlecast, and which has confounded all previous evaluations of the impact of this disease.

Needlecast of Scots pine (*Pinus sylvestris* L.), caused by *Cyclaneusma minus* (Butin) DiCosmo, Peredo & Minter, is widespread, having been reported from North and South America, Europe, Asia, Africa, and Australasia (17). The fungus can be isolated from first-year needles, albeit at a low incidence, within 3 weeks of their emergence from the fascicle sheaths (14,22,23). Incidence of infection increases throughout the first and often the second growing seasons, and sometimes into the third growing season, depending on environmental conditions and the provenance of the host (14,22,23; N. G. Wenner and W. Merrill, *unpublished*). It causes a fall yellowing and premature casting of second-year and older needles in some provenances (8).

There is controversy regarding the pathogenicity of this fungus. Although some consider it a pathogen (6,8,9,13,21), some Europeans have stated, based primarily on timing of fruiting body formation or field observations with little or no quantitative data, that the fungus is a weak parasite on "...debilitated needles..." (11), a secondary organism invading needles with "...weakened physiological activities" (10), or a nonparasitic endophyte (19). Rack and Scheidemann (20) stated that the reported completion of Koch's postulates by Kistler and Merrill (8) "...is questionable," ignoring the fact that Koch's postulates also were completed with this pathogen in New Zealand (4) and Scotland (6).

Rack (18) pointed out the difficulty in separating normal fall needle drop in pines from fall needlecasting due to fungal pathogens. This difficulty can be eliminated only by comparison of replicated blocks of trees untreated or treated with a sufficient number of pesticide applications to eliminate fungal infection from at least three needle complements. Rack and Scheidemann (20) later restated Rack's earlier conclusion (19) that *C. minus* was a nonpathogenic endophyte. The difficulty of separating normal fall needle drop from that caused by disease in the absence of a disease-free control, plus the fact that Rack and Scheidemann (20) worked in plantations with mixed infections of *C. minus* and *Lophodermium seditiosum* Minter, Staley & Millar, led them to this questionable conclusion. Moreover, Rack and Scheidmann's (20) definition of an endophyte as a "...fungus detectable in prematurely dying needles only after the death of such needles" contradicted their subsequent definitions and discussion. They accepted and classified *L. seditiosum* as a parasite, but it forms fruiting bodies ONLY after the needles have died prematurely, as is true of other major needlecast fungi. Thus by their definition, *L. seditiosum* and most other needlecast fungi would be endophytes and, based on their subsequent discussion, nonpathogenic. Numerous studies by pathologists, beginning with Hartig (5) over a century ago, have demonstrated otherwise.

Provenance affects both susceptibility to *C. minus* and needle retention (15; W. Merrill and N. G. Wenner, *unpublished*). The fungus causes a casting of third-year needles in some sources and of second-year needles in others. In our initial studies with this disease, we recognized the great variation in susceptibility within and among seed sources and the difficulty in distinguishing the effects of *C. minus* from those due to other factors, such as drought, rooting depth, soil fertility, "tight shearing," insects, and normal needle senescence, all of which were reputed to be the cause of fall yellowing and casting of needles. The within-source variation was so great that the efficacy of fungicides could be evaluated only by comparing incidence of infection in treated and untreated populations, determined by frequent periodic isolation of the fungus from the same individual sample trees over a 2- to 3-year period (22,23).

Kistler and Merrill (7) first reported high incidence of infection by *C. minus* in symptomless needles. However, that in itself is not an indication that the fungus is a nonpathogenic endophyte. Likewise, a prolonged incubation period is no measure of the lack of pathogenicity of a needlecast fungus. For example, it has been known for over a half century that needlecasts of true firs form hysterothecia only 23 months after infection (3,12).

Over the past 17 years, we have followed incidence of *C. minus* infection in hundreds of individual Scots pines, periodically isolating the fungus from individual needle complements on the same sample trees from needle emergence until casting more than 2 years later (14–16,22,23). To date, these studies have involved nearly 900,000 individual needles. This work has been done in commercial Scots pine Christmas tree plantations involving primarily different Spanish seed sources but also some French and East Anglian sources, different cultural practices including planting density, shearing practices, and weed and pest control, and in environmental regimes spanning years of severe drought as well as years of excessive rainfall. These studies have been done in various climatic zones within Pennsylvania, ranging from

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the Ridge and Valley Province across the Allegheny Plateau and into the High Poconos. Most importantly, we have worked in stands devoid of *L. seditiosum* to avoid its confounding influences. We repeatedly observed that some trees with very low levels of *C. minus* infection dropped their third-year needles, while some also dropped portions or all of their second-year needles. This suggested a host genetic factor independently affecting needle retention, upon which were superimposed the effects of Cyclaneusma needlecast, but there was no way to separate the impact of the fungus on needle retention from the influence of this host genetic component. Finally, we found that five properly timed applications of flowable chlorothalonil per "needle-year," that is, from the time of emergence of one needle complement until emergence of the following needle complement, could almost eliminate Cyclaneusma needlecast infection (23). This provided a means of maintaining trees with three needle complements with low levels of disease incidence, which allowed us to examine the relative importance of Cyclaneusma needlecast versus the host genetic component upon needle retention in Scots pine.

MATERIALS AND METHODS

The study was carried out in two locations in Pennsylvania. One was a commercial Christmas tree plantation on the Allegheny Plateau in Clearfield County, established on a west-facing recontoured strip mine spoil bank with "soil" consisting primarily of loose, fine shale that supported little weed growth. The plantation was established in 1983 with seedlings of the "Pike Lake" strain of Scots pine purchased from a Michigan nursery, planted at approximately 1.83 × 1.83 m spacing, and loosely sheared (30.5 to 35.6 cm between branch whorls) with an average 76° taper. (Taper is defined here as the angle between a horizontal line at the base of the tree and the hypotenuse of a right triangle formed by the side of the tree.) The second plantation was in the Ridge and Valley Province in Centre County, established on a level agricultural field with limestone soil. The planting was made in 1983 with Spanish "Guadarrama" seedlings obtained from a Pennsylvania nursery, planted at approximately 1.52 × 1.83 m spacing, and tightly sheared (20.3 to 28 cm between branch whorls) with an average 71° taper.

Approximately 120 trees were included in each of the treatment and check blocks at the Clearfield Co. site and 50 trees in each block at the Centre Co. site. Within each block, 10 permanent sample trees were randomly selected in May 1990 and tagged. At each site, fungicide applications were made beginning in 1990 to protect the 1990, 1991, and 1992 needle complements. Spray dates were 28 June, 15 August, and 16 October 1990; 3 April, 7 May, 12 June, 12 August, and 16 October 1991; and 10 April, 12 May, 16 June, and 14 August 1992 in Clearfield Co.; and 16 July, 28 August, and 17 October 1990; 4 April, 10 May, 20 June, 13 August, and 17 October 1991; and 14 April, 13 May, 23 June, and 12 August 1992 in Centre Co. Chlorothalonil (Bravo 720F) was applied with a Solo backpack mist blower at a concentration of 2.20 g a.i./liter. For reasons discussed later, the volume of tank mix applied was 378.5 liters/ha in 1990, 442.9 liters/ha in 1991, and 501.2 liters/ha in 1992.

Prior to spraying on each treatment date, four twigs were removed from each sample tree in each block, one twig at each cardinal direction at 0.5-m height, bagged, and taken to the lab. From each twig, 10 needles were randomly selected from each complement to be examined, surface sterilized for 90 s in 0.52% aqueous sodium hypochlorite (household bleach), rinsed three times with distilled water, cut into three sections, and plated onto acidified malt agar (20 g of Difco malt extract and 15 g of Difco flake agar per liter of water, acidified after autoclaving by adding 1 ml of 88.3% lactic acid per liter of medium). The cultures were incubated at room temperature in diffuse light in the laboratory for 3 weeks, and results were recorded as the proportion of needles yielding *C. minus*. Isolations were made from a total of 40,000 needles from the 1990 and 1991 complements.

In late October 1992, after symptom development and needlecasting had occurred in the 1991 complement, four twigs were removed from each of the permanent sample trees plus 10 other randomly selected trees within each block, one twig from each cardinal direction at 0.5 m from the ground. The 1990 and 1991 internodes were separated, and on each the number of fascicle scars from which needles had been cast were marked and counted; then the remaining needle fascicles were removed and counted. The number of fascicles and fascicle scars were totaled to obtain the original number of fascicles on each internode, and the proportion of fascicles retained on each was calculated. The data for each complement on the four shoots of each tree were averaged. Approximately 96,000 needle fascicles and fascicle scars were counted.

RESULTS AND DISCUSSION

Incidence of infection in treated and nontreated blocks at both sites are shown in Figure 1. In August 1992, infection levels in the nontreated blocks were 92.0 and 75.3% in the Centre Co. plots and 99.0 and 89.5% in the Clearfield Co. plots in the 1990 and 1991 complements, respectively. In comparison, the fungicide applications limited infection to 19.8 and 0.3% in the Centre Co. plots and to 10.0 and 0.3% in the Clearfield Co. plots in the 1990 and 1991 complements, respectively.

Although in 1990 the fungicide applications began before the new needles had fully elongated, infection levels in individual trees ranged from 8 to 15% in the Centre Co. plots and from 4 to 6% in the Clearfield Co. plots, once again demon-

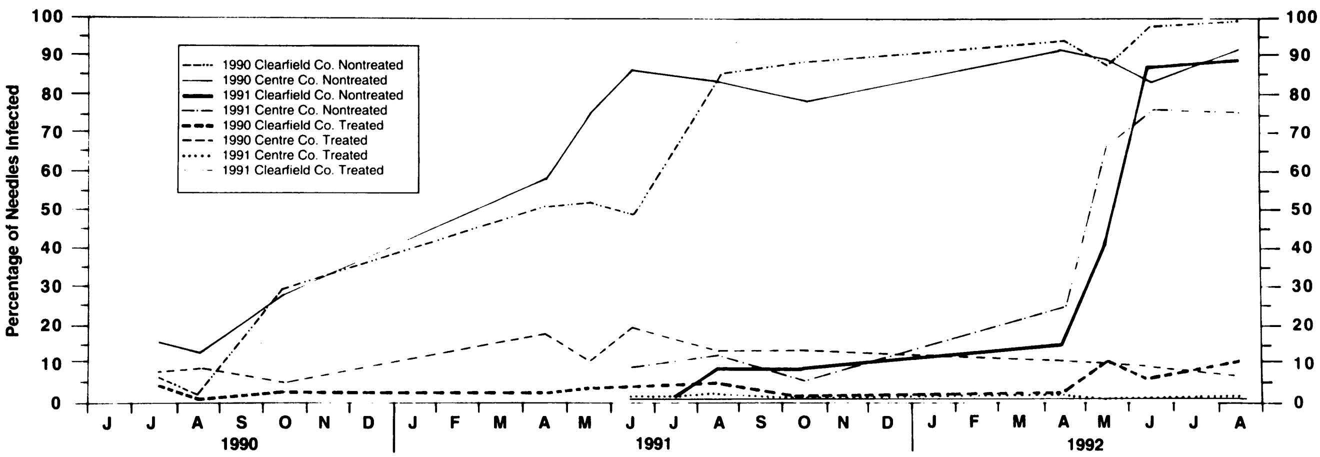

Fig. 1. Percentages of the 1990 and 1991 complements of Scots pine needles infected by *Cyclaneusma minus* in untreated and fungicide-treated plots in Centre and Clearfield Counties, PA.

strating that infection begins as soon as needles emerge from the fascicle sheaths. Infection does not require that needles be "debilitated" or "physiologically weakened."

The data in Figure 1 show that levels of infection in the 1990 complement in the Centre Co. treated plot gradually increased during 1990 and early 1991. These trees averaged about 23 cm shorter and 61 cm wider in diameter and had longer, denser needles than trees in the Clearfield Co. plots. We concluded that the volumes of these trees had increased sufficiently so that we were not obtaining adequate coverage with the volume of fungicide mix being applied. We had noted similar trends in previous spray trials on larger and denser trees.

On Christmas trees, pesticide efficacy trials usually are carried out using trees 0.92 to 1.22 m tall for ease of application and coverage. A pesticide application rate that will give minimum effective coverage

Table 1. Retention in October 1992 of the 1990 and 1991 needle complements of Scots pine and proportion of those needles infected by *Cyclaneusma minus* in untreated and fungicide-treated plots in Centre County, PA

	1990 Complement				1991 Complement			
	Untreated		Treated		Untreated		Treated	
Tree no.	Infected[a] (%)	Retained (%)	Infected[a] (%)	Retained (%)	Infected[a] (%)	Retained (%)	Infected[a] (%)	Retained (%)
1	78	13	5	17	65	88	0	67
2	100	0	18	4	93	92	0	90
3	93	12	5	80	75	91	0	98
4	95	4	3	13	98	92	0	94
5	95	0	8	0	78	93	0	74
6	88	6	3	0	28	82	0	4
7	98	0	3	24	90	72	0	77
8	98	37	8	54	88	82	3	94
9	90	47	15	69	68	85	3	94
10	88	0	5	11	73	66	0	90
11		70		74		96		95
12		58		80		93		99
13		29		56		92		95
14		0		84		69		97
15		13		66		85		94
16		36		37		93		98
17		68		59		94		93
18		6		25		80		89
19		10		63		89		95
20		37		59		82		94
X		22.3		43.8		85.8		86.6
P[b]			0.015				0.884	

[a] Maximum incidence of infection encountered during the duration of the study, usually on one of the last two sampling dates (Fig. 1).
[b] Level of significance between means of paired columns, Student's *t* test.

Table 2. Retention in October 1992 of the 1990 and 1991 needle complements of Scots pine and proportion of those needles infected by *Cyclaneusma minus* in untreated and fungicide-treated plots in Clearfield County, PA

	1990 Complement				1991 Complement			
	Untreated		Treated		Untreated		Treated	
Tree no.	Infected[a] (%)	Retained (%)	Infected[a] (%)	Retained (%)	Infected[a] (%)	Retained (%)	Infected[a] (%)	Retained (%)
1	100	60	25	49	39	97	0	92
2	100	64	28	83	93	83	0	92
3	100	93	3	72	78	99	0	98
4	93	42	3	9	68	97	3	53
5	100	91	5	66	85	99	0	94
6	100	85	3	3	78	91	3	23
7	100	88	15	9	100	94	0	98
8	100	31	0	57	93	76	0	95
9	98	48	8	96	100	65	0	99
10	100	0	3	77	85	58	0	98
11		14		86		94		99
12		28		46		96		95
13		33		77		83		100
14		29		59		84		96
15		5		71		76		97
16		25		80		97		100
17		0		82		88		99
18		14		46		92		100
19		17		42		91		92
20		41		67		93		95
X		40.4		58.8		87.7		90.8
P[b]			0.049				0.533	

[a] Maximum incidence of infection encountered during the duration of the study, usually on one of the last two sampling dates (Fig. 1).
[b] Level of significance between means of paired columns, Student's *t* test.

to a 0.9-m-tall tree will not provide adequate coverage to a 2.3-m-tall tree. The outer surface area of the 2.3-m-tall tree, calculated as a cone with a 70° taper, is 5.48 times that of the 0.9-m-tall tree, and the actual surface area of the multiple needle complements must be several times greater than that. Therefore, in June 1991 and again in June 1992, we increased the volume of fungicide mix applied, as described earlier, to compensate for this increase in crown volume. With this increase in volume of spray mix applied, we were able to hold infection of the 1991 needle complement to 0.3% in both plots.

Fungicide treatment significantly increased the retention of third-year (1990) needles but not second-year (1991) needles at both sites (Tables 1 and 2). More importantly, fungicide treatment significantly increased the proportions of trees maintaining more than 50% of their third-year needles and also increased, although not significantly at $P = 0.05$, the proportion retaining more than 70% of their third-year needles (Table 3), thus increasing the "fullness" of the trees. These data demonstrate indirectly that infection by *C. minus* does cause premature needle loss.

Within both seed sources, however, retention of second-year and third-year needles varied greatly among individual trees, frequently unrelated to incidence of infection (Tables 1 and 2). For example, tree 3 in the Centre Co. treated block (Table 1) maintained 80 and 98% of its third- and second-year needles with maximum infection incidence of 5 and 0%, respectively; whereas tree 6 retained 0 and 4% of its third- and second-year needles with maximum infection incidence of 3 and 0%, respectively. Similarly, tree 5 in the treated block retained 0% of its third-year needles and 74% of its second-year needles, with maximum infection levels of 8 and 0%, respectively. Obviously, needle loss in trees 5 and 6 was unrelated to infection by *C. minus*.

Similar variation occurred in the Clearfield Co. plot (Table 2). For example, trees 4, 6, and 7 in the treated block retained 9, 3, and 9% of their third-year needles, with maximum levels of infection of 3, 3, and 15%, respectively. Trees 4 and 6 in this block retained 53 and 23% of their second-year needles, with maximum infection levels of 3%. Again, it is obvious that needle loss in these trees was unrelated to infection by *C. minus*.

In marked contrast, in the untreated Clearfield Co. block (Table 2), trees 3, 5, 6, and 7 retained 93, 91, 85, and 88% of their third-year needles, respectively, with infection levels of 100% in all four trees. Infection by *C. minus* had little if any effect on needle retention in these four trees.

These data show the existence of a host genetic factor that affects needle retention and that acts independently of infection by *C. minus*. At present, it is impossible to state how this factor interacts with or affects the fungus and its ability to cause needlecasting. This host genetic factor has confounded all previous attempts to quantify the relationship between needle loss and incidence of infection by this fungus. It follows, therefore, that this factor undoubtedly has confounded all previous studies to relate needle loss to activities of insects such as the two-spotted pine aphid, *Eulachnus agilis* (Kaltenbach), and to the effects of drought, fertilization, shearing practices, and site. This finding should provide a better understanding of the procedures necessary to develop improved strains of Scots pine for use as Christmas trees.

For example, trees 3, 5, 6, and 7 in the Clearfield Co. untreated block (Table 2) are the types of trees that breeders should select for "superior" Christmas trees. Indeed, these were the only four trees in this entire study that should have been kept in such a program. These trees retained from 85 to 93% of their third-year needles, 100% of which were infected. Any Scots pine that can maintain 85% or more of its third-year needles is valuable breeding material for Christmas trees, regardless of its other characteristics. Trees with such needle retention can be sheared more loosely while still appearing dense, and hence can produce a salable tree more quickly, all other factors being equal. Unfortunately, in Christmas tree development programs thus far, no attention has been given to quantifying needle retention; all efforts have been concerned with growth rate, color, and form. However, needle retention is of paramount importance: any tree that cannot maintain its needles is worthless as a Christmas tree regardless of its color, form, or growth rate.

These data also illustrate the great differences in needle retention that exist among sources. Although this study used two different seed sources, each planted on very different sites and in different climatic zones within the state, the epidemic curves (incidence of infection) in the untreated plots were virtually identical in 1990 and 1991 (Fig. 1). Yet untreated trees of the "Pike Lake" strain (Clearfield Co. plots) maintained twice the proportion of third-year needles of the Spanish "Guadarrama" source (Centre Co. plots) (Tables 1 and 2), four times the proportion of trees maintaining more than 70% of their third-year needles and twice the proportion maintaining more than 50% of their third-year needles (Table 3). In field studies spanning nearly 20 years and involving trees of East Anglian, French, Spanish, Greek, and Turkish provenances, similar variations in needle retention have been found in and among all sources (15; W. Merrill, B. R. Kistler, L. Zang, and N. G. Wenner, *unpublished*).

These data also illustrate the dangers of drawing conclusions of fungicide efficacy based on a single time of observation on randomly selected trees without knowing the infection history of those specific trees. For example, if one had inadvertently selected trees 2, 4, 5, 6, and 10 in the Centre Co. treated plot (Table 1) and trees 9, 11, 12, 16, and 17 in the untreated plot, and examined final retention of the 1990 complement, one would have found that the treated trees had an average retention of 5.6%; whereas the untreated trees had an average retention of 55.8%, significantly different at $P =< 0.0005$. One would have been forced to conclude that needlecasting was caused by the application of fungicide! Needlecasting in those 10 trees was unrelated to incidence of infection or to pesticide treatment, but was due to the host genetic factor controlling needle retention.

To adequately evaluate the effects of needlecasts and needle blights on needle retention of Scots pine, one will have to use clonal lines that differ not only in their susceptibility to the pathogen but also in their genetically controlled needle retention. Such clonal materials also should be used to reevaluate the effects of various insect pests, drought, fertilization, and cultural practices on needle retention.

Adams (1) concluded that *C. minus* was not economically harmful to Scots pine Christmas trees because he found no differences between the percentages of no. 1 Christmas trees in sprayed and unsprayed plots. He perhaps made the proper conclusion for the seed sources he examined, but for entirely wrong reasons. The pro-

Table 3. Proportions of fungicide-treated or nontreated Scots pines retaining more than 50% or more than 70% of their third-year needle complement in two study areas

Area	Proportion of trees maintaining needles			
Treatment	>50% of 3rd-yr		>70% of 3rd-yr	
Centre Co.				
Nontreated	0.15	0.007[a]	0.05	0.159[a]
Fungicide-treated	0.55		0.20	
Clearfield Co.				
Nontreated	0.30	0.027[a]	0.20	0.096[a]
Fungicide-treated	0.65		0.45	

[a] Level of significance between paired values within columns, Student's *t* test.

portion of trees in different Christmas tree grades is not a valid criterion upon which to determine the efficacy of spray trials, as those involved in pesticide efficacy testing have known for at least three decades. Christmas tree grade is determined primarily by straightness of the stem, the absence of holes in the side of the tree created by missing or damaged branches, and the degree of taper (2). Foliage density or apparent fullness is of secondary importance. Shearing practices not only control the taper but also affect apparent foliage density and, properly done, may minimize the appearance of holes. Apparent foliage density or fullness of the foliage of a Christmas tree is affected primarily by branching angle, needle length, and tightness of shearing, and usually bears little relationship to the number of complete or partial needle complements present. A loosely sheared tree (35 to 46 cm between branch whorls) with a horizontal branching habit and bearing three complete needle complements will look considerably thinner and hence will be of a lower grade than a tightly sheared tree (20 to 25 cm between branch whorls) with an upright branching habit and bearing only two needle complements. Indeed, some individual trees of long-needled strains of Scots pine with upright branching habits, if tightly sheared, may be salable as no. 1 trees when bearing only a single needle complement. Skilled shearers unconsciously shear thinly needled or flatly branched trees more tightly than densely needled or uprightly branched trees to compensate for the open appearance of the former, to "help fill them in."

Although Cyclaneusma needlecast significantly decreased retention of third-year needles on both seed sources used in this study, whether a control program improves tree quality sufficiently overall to yield an increased net return on that investment still must be answered by and for a specific grower. The economic feasibility of such a control program will depend on the specific provenance or strain of Scots pine being grown, especially its branching habits, its genetically controlled ability to retain multiple needle complements, and its susceptibility to *C. minus*, as well as on the shearing practices of the specific grower. Because as yet we do not know how this genetic factor controlling needle retention interacts with factors affecting the tree's susceptibility to Cyclaneusma needlecast, we cannot recommend an industry-wide control program for this disease. Instead, growers encountering problems with Cyclaneusma needlecast should conduct well-designed cost/benefit analyses in their own plantations using their own specific shearing practices and their customary tree strains or provenances. This determination should be based on a quantitative assessment of retention of second- and third-year needles of randomly selected trees in treated versus untreated blocks.

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