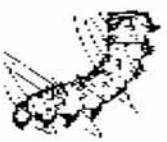
Forest Health Protection

`Report 02-9 May 2002

EFFECTS OF SPRING APPLICATIONS OF DAZOMET ON ROOT DISEASES AND PERFORMANCE OF DOUGLAS-FIR AND WESTERN WHITE PINE TRANSPLANTS USDA FOREST SERVICE NURSERY, COEUR D'ALENE, IDAHO

R.L. James
Plant Pathologist

ABSTRACT

Tests were conducted at the USDA Forest Service Nursery, Coeur d'Alene, Idaho to evaluate effectiveness of spring fumigation with dazomet to improve survival and performance of Douglas-fir and western white pine transplants. Spring fumigation greatly reduced populations of potentially pathogenic *Fusarium* and *Pythium* spp. Disease levels of container (plug+1) and bare root (2+1) Douglas-fir transplants were very low, regardless of soil fumigation. Fumigation reduced disease on bare root (2+1) white pine transplants, but did not improve survival of container (plug+1) white pine transplants. Seedling height growth during the first year after transplanting was significantly improved by soil fumigation. *Fusarium oxysporum* was commonly isolated from soil and roots of diseased bare root transplants. *Fusarium proliferatum* was commonly isolated from the roots of container transplants. Soil fumigation may not necessarily improve survival and performance of all types of conifer transplants in nurseries.

INTRODUCTION

Several different types of conifer seedling stock are produced for reforestation at the USDA Forest Service Nursery, Coeur d'Alene, Idaho. Both container and bare root stock have specific advantages when planted on different forest sites. In some cases, foresters require larger stock with more fibrous root systems for reforesting especially harsh sites. Such stock can be produced as transplants from either container-grown or bare root seedlings. Normally, container transplants are designated "plug+1" indicating that the stock was initially grown in containers and then transplanted outside in the field for one year as bare root stock. Bare root transplants are designated "2+1" indicating that the plants were initially grown for two years as standard bare root stock, lifted and then transplanted for one more growing season prior to shipment for outplanting. Transplants are much more expensive and take longer to produce and are more labor intensive. However, transplants may be superior for certain forest planting sites.

Field soil is normally fumigated with dazomet (Basamid® granular) prior to sowing bare root seedling crops at the Coeur d'Alene Nursery. Fumigation is primarily designed to eliminate or greatly reduce soil populations of potentially pathogenic fungi and weed seeds. Experience has shown that seedlings produced in

United States Department of Agriculture
Forest Service
Northern Region
200 East Broadway
P.O. Box 7669
Missoula, MT 59807

dazomet-fumigated soil are larger, more healthy, and are not usually adversely affected by root diseases (James et al. 1990, 1996; Stone et al. 1995). Costs of fumigation are more than outweighed by the improvement in seedling numbers and quality. For bare root seedling production, dazomet is normally applied in late August or early September of the year prior to sowing (James et al. 1990, 1996). This is usually when the soil is at its optimum temperature for penetration and effectiveness of the fumigant; soil moisture can also be manipulated in late summer for optimum fumigation effectiveness (James 1989; Shugert 1989). In some isolated cases, growers have attempted to fumigate soil in the early spring prior to sowing (Hoffman and Williams 1988) The main problems with spring fumigation include cold soil temperatures, higher than optimum soil moisture, and potential residual effects of the fumigant on seed and young germinants. Also, populations of potential pathogens, although initially reduced, may recover quickly following spring fumigation (Hoffman and Williams 1988). Regardless of these potential problems, spring fumigation may be required when there is insufficient summer-fumigated ground available for seedling production.

Transplants at the Coeur d'Alene Nursery have not historically comprised a large portion of reforestation stock production. In cases where transplants were previously produced, stock was normally placed in soil that had been fallowed for at least a year prior to transplanting (James 1985c, 1995; James and Gilligan 1986). However, performance of transplants in such soils was variable. Transplant losses were sometimes extensive. Therefore, growers wondered whether transplant vigor and performance might be significantly improved by fumigating soil prior to transplanting. To answer this question, an evaluation was established to compare transplant performance and disease in fumigated vs. nonfumigated soil.

MATERIALS AND METHODS

Tests were installed in several sections of Field 3 at the Coeur d'Alene Nursery. Portions of the field were fumigated in mid-April with dazomet at 350 lbs/acre (392 kg/ha). The fumigant was applied topically, cultivated into the soil, sealed and activated with overhead irrigation (Boone 1988; Chapman 1992; Hoffman and Williams 1988). Approximately 1 month following fumigation four types of seedling stock were transplanted into either the fumigated or adjacent nonfumigated soil. The stock types included in the test were Douglas-fir (*Pseudotsuga menziesii* Franco var. *glauca* [Mayr] Sudw.) container-grown seedlings (plug+1: designated DF1), Douglas-fir bare root seedlings (2+1: designated DF2), western white pine (*Pinus monticola* Dougl.) container-grown seedlings (plug+1: designated WP1), and western white pine bare root seedlings (2+1: designated WP2).

A few days prior to fumigation, soil in portions of the field destined for fumigation and non-fumigation was sampled for background populations of potentially pathogenic *Fusarium* and *Pythium* spp. Twenty-five samples were collected along a transect within areas to be transplanted; 5 of the samples were in soil that would not be fumigated and 20 of the samples in soil were destined for fumigation. At each sample point a soil core was taken to a depth of about 8 inches (20 cm). Soil was placed in plastic bags, kept refrigerated, and transported to the laboratory for analysis.

Standard soil dilutions (Hildebrand and Dinkel 1988; James et al. 1990, 1996; Stone et al. 1995) were conducted to estimate populations of *Fusarium* and *Pythium* spp. Soil from each sample was initially sieved (2 mm sieve) to remove rocks, pieces of organic matter, and soil aggregates. From each sample, an approximate 5 g subsample was oven-dried at about 100°C for at least 24 hours until sample weight had stabilized. Oven-dry weight was

then calculated to provide a standard for sample comparison. For assays of *Fusarium* populations, 0.05 g of field-moist soil was combined with 10 ml of 0.3 percent water agar and thoroughly mixed. One ml of solution was placed on each of three plates of selective agar medium (Komada 1975) and spread uniformly. Plates were incubated at least 7 days at about 24°C under diurnal cycles of cool, fluorescent light. *Fusarium* colonies were identified by their morphology on the selective medium; populations, expressed as number of colony-forming units (cfu) per g of oven-dried soil, were calculated. Selected *Fusarium* isolates were transferred to carnation leaf agar (Fisher et al. 1982) and potato dextrose agar (PDA) for identification using the taxonomy of Nelson et al. (1983). For assay of *Pythium* populations, 0.5 g of soil was combined with 10 ml of 0.3 percent water agar. One ml of solution was placed on each of three plates containing another selective medium consisting of V-8 juice agar amended with pimaricin, rifamycin, ampicillin, and pentachloronitrobenzene (James et al. 1990, 1996; Stone et al. 1995). Plates were incubated in the dark at about 24°C for 3 days. *Pythium* colonies were identified on the basis of their diameter after 3 days (15-20 mm), feathery margin, and growth within rather than superficially on the agar surface. Selected isolates were transferred to PDA for identification using the taxonomy of Waterhouse (1968). It was assumed that each fungal colony originated from one propagule.

At the time of transplanting (1 month after fumigation), a second set of soil samples were collected. This second set consisted of 24 samples (12 each from fumigated and nonfumigated soil) collected along a transect within the field. Samples were collected and processed as described above. Pre- and post-fumigation populations were compared using a paired "T" Test. Significant differences were established at P=0.05.

Seedlings were transplanted into parallel rows within each bed (figure 1). Two assessments of disease were undertaken during the first growing season following transplantation. The first was made about 1 month after transplanting (mid-June); the second was made at the end of the growing season (October). Three monitoring plots were located equidistant from each other within beds of each transplant type in both fumigated and nonfumigated areas. Plots were 10 linear feet (3.05 m) in length; sampling within plots was restricted to the inner three rows of transplants. All transplants within plots were counted and categorized as healthy (no above-ground disease symptoms), fading (some level of chlorotic foliage) or dead (primarily necrotic foliage). Numbers of fading and dead transplants were combined to comprise the "diseased" category. At the end of the growing season (October), 20 healthy-appearing transplants in each plot were measured for height from ground level to the tip of the terminal bud on the main stem. At this time, five fading transplants per plot were carefully extracted from the soil and transported to the laboratory for analysis of root colonization by potentially pathogenic *Fusarium* and *Pythium* spp. Roots of sampled transplants were washed thoroughly to remove soil particles; lateral roots from the five transplants per plot were clipped from taproots, combined and chopped in a blender. Fifty root pieces (each approximately 5 mm in length) per plot were surface sterilized in 0.525 percent aqueous sodium hypochlorite (10 percent commercial bleach), rinsed in sterile water, and placed on the selective agar medium for *Fusarium* spp. Plates were incubated and selected *Fusarium* isolates identified as described above. The same procedure was done for isolation of *Pythium* spp. except 25 root pieces were sampled per plot and these were incubated on the selective V-8 juice agar medium. Percent sampled root pieces colonized by *Fusarium* and/or *Pythium* spp. was calculated for each transplant type.

Fusarium and *Pythium* isolates were identified to species and compared with those obtained from soil samples.

Percent diseased transplants (each transplant type tallied separately) growing within either fumigated or nonfumigated soil were compared statistically using a paired "T" Test. Percentages underwent arc-sin transformation prior to analysis. Average transplant heights were likewise compared with the "T" Test. Statistical differences were set at P=0.05.

RESULTS

Spring applications of dazomet significantly reduced populations of both *Fusarium* and *Pythium* spp. at the Coeur d'Alene Nursery (table 1). Soil populations of these organisms varied widely among sampling locations as indicated by relatively large standard deviations among the samples. *Fusarium* populations in nonfumigated soil did not change much between the two sampling periods and were generally below threshold levels commonly associated with disease problems (Hildebrand and Dinkel 1988). Populations of *Pythium* were significantly less in the nonfumigated portion of the field during the second sampling period. This difference may be related to decreasing soil moisture content as the spring progressed. Pretreatment *Pythium* levels generally exceeded disease thresholds (Hildebrand and Dinkel 1988) in many samples.

Table 1. Effects of dazomet soil treatment on populations of *Fusarium* and *Pythium* in fields with Douglas-fir and western white pine transplants – USDA Forest Service Nursery, Coeur d'Alene, Idaho.[1]

Treatment[2]	Fusarium		Pythium	
Fumigated	Pre-Treatment	Post-Treatment	Pre-Treatment	Post-Treatment
Average[3]	434*	8*	100*	5*
Std. Dev.	2164	20	101	9
Not Fumigated	Pre-Treatment	Post-Treatment	Pre-Treatment	Post-Treatment
Average[3]	630	703	271*	49*
Std. Dev.	378	358	117	37

[1]Values in table are colony-forming units per gram of oven-dried soil.

[2]Fumigated soil was treated with dazomet at 350 lbs/acre (392 kg/ha).

[3]Comparing pre- and post-treatment populations for each group of fungi, averages followed by an asterisk are significantly different (P=0.05) using a paired "T" Test.

Some seedlings began dying shortly after being transplanted. This was especially apparent in container-grown white pine (figures 1 and 2). Foliage of affected pine seedlings quickly turned chlorotic; shortly all foliage became necrotic (red-brown) and needles became twisted and hung down from the main stem (figure 2). Dead seedlings appeared wilted. Similar symptoms were evident in diseased bare root white pine transplants (2+1). Much less disease or mortality occurred in Douglas-fir transplants. The few that were affected were generally grouped and surrounded by mostly healthy-appearing plants (figure 3).

Figure 1. Container-grown western white pine transplants (plug+1) growing in nonfumigated beds – USDA Forest Service Nursery, Coeur d'Alene, Idaho.

Figure 2. Container-grown western white pine transplants (plug+1) displaying typical root disease symptoms following transplanting at the USDA Forest Service Nursery, Coeur d'Alene, Idaho.

Figure 3. Bareroot Douglas-fir transplants (2+1) displaying root disease symptoms at the end of the first growing season following transplanting – USDA Forest Service Nursery, Coeur d'Alene, Idaho.

In general, dazomet soil fumigation improved survivability of transplants (table 2). Significantly less disease occurred in fumigated beds transplanted with container-grown Douglas-fir (plug+1) and bare root white pine (2+1). Disease levels of container-grown white pine (plug+1) grown in fumigated or nonfumigated soil were not significantly different. Disease was too low in bare root Douglas-fir transplants (2+1) for detection of any potential fumigation effects.

Table 2. Effects of dazomet soil treatment on root disease of Douglas-fir and western white pine transplants - USDA Forest Service Nursery, Coeur d'Alene, Idaho[1].

Sample 1[2]								
Replicate	DF1[3]		DF2		WP1		WP2	
	Fum	NoFum	Fum	NoFum	Fum	NoFum	Fum	NoFum
1	0	2.3	0	0	8.3	8.4	0	8.7
2	0	1.9	0	0	6.2	14.1	0	15.3
3	0	0	0	0	8.8	14.2	0.5	15.7
Ave.[5]	0*	1.4*	0	0	7.8	12.2	0.2*	13.2*
Sample 2[4]								
Replicate	DF1[3]		DF2		WP1		WP2	
	Fum	NoFum	Fum	NoFum	Fum	NoFum	Fum	NoFum
1	0.5	1.3	0	0	25.6	22.6	0	15.0
2	0.9	1.4	0	0.4	22.0	34.9	0	31.6
3	0.4	0.5	0	0.4	22.5	28.2	0.5	33.2
Ave.[5]	0.6	1.1	0	0.3	23.4	28.6	0.2*	26.6*

[1] Values in table are percent of sampled transplants with above-ground root disease symptoms.

[2] Sample 1 taken about 1 month after transplanting.

[3] DF1 = Douglas-fir container-grown transplants (plug + 1); DF2 = Douglas-fir bare root transplants (2 + 1); WP1 = white pine container-grown transplants (plug + 1); WP2 = white pine bare root transplants (2+1).

[4] Sample 2 taken at the end of the first growing season (October) after transplanting.

In addition to effects on disease, dazomet fumigation improved first-year growth of most transplants (table 3). Significantly larger transplants were found in fumigated beds for bare root Douglas-fir (2+1) and both container-grown (plug+1) and bare root (2+1) white pine. White pine transplants were nearly one-fourth taller in fumigated beds (table 3).

Most diseased seedlings sampled at the end of the first growing season after transplanting had roots that were extensively colonized by *Fusarium* spp. (table 4). The one exception was bare root Douglas-fir transplants (2+1) that had much less of their root systems colonized by *Fusarium* spp. than expected. *Pythium* root colonization was generally low compared to *Fusarium* on diseased transplants (table 4).

Table 3. Effects of dazomet soil treatment on height growth of Douglas-fir and western white pine transplants - USDA Forest Service Nursery, Coeur d'Alene, Idaho[1].

Replicate	Transplant Type[2]							
	DF1		DF2		WP1		WP2	
	Fum	NoFum	Fum	NoFum	Fum	NoFum	Fum	NoFum
1	235.5	213.5	295.5	270.6	96.5	77.8	162.1	137.8
2	173.2	186.2	286.3	232.8	101.2	89.1	165.3	131.0
3	238.8	223.8	281.7	225.5	95.5	68.2	173.1	133.1
Ave.[3]	215.8	214.8	288.0*	242.9*	97.7*	78.4*	166.8*	133.9*
Change[4]	+0.5%		+18.5%		+24.7%		+24.5%	

[1] Values in table are average height (mm) of transplants at the end of the first growing season (October) following transplanting; each replicate sampled 20 healthy-appearing transplants.

[2] DF1 = Douglas-fir container-grown transplants (plug + 1); DF2 = Douglas-fir bare root transplants (2+1); WP1 = white pine container-grown transplants (plug + 1); WP2 = white pine bare root transplants (2+1).

[3] Comparing fumigated vs. nonfumigated for each transplant type, means followed by an asterisk are significantly different (P=0.05) using a paired "T" Test.

4 Change in average transplant height between nonfumigated and fumigated soil.

Table 4. Root colonization of diseased Douglas-fir and western white pine transplants by *Fusarium* and *Pythium* spp. - USDA Forest Service Nursery, Coeur d'Alene, Idaho.

Transplant Type[1]	Percent Root Colonization[2]	
	Fusarium	**Pythium**
DF1	84	12
DF2	32	16
WP1	80	16
WP2	96	12

[1] DF1 = Douglas-fir container-grown transplants (plug+1); DF2 = Douglas-fir bare root transplants (2+1); WP1 = white pine container-grown transplants (plug+1); WP2 = white pine bare root transplants (2+1).

[2] Percent of root pieces from five randomly-selected transplants displaying chlorotic foliage (root disease symptoms) sampled at the end of the first growing season (October) following transplanting. 50 root pieces from each transplant type sampled for *Fusarium*; 25 sampled for *Pythium*.

The major *Fusarium* and *Pythium* spp. isolated from both soil and roots of diseased transplants are listed in table 5. By far the most common *Fusarium* species encountered was *F. oxysporum* Schlecht., which comprised almost 90 percent of the soil *Fusarium* isolates and most isolates recovered from diseased bare root transplant roots. *Fusarium proliferatum* (Matsushima) Nirenberg was commonly isolated from roots of diseased container transplants, but was not isolated from nursery soil. Other *Fusarium* species were isolated at much lower levels; *F. solani* (Mart.) Wollenw. & Appel was a fairly common soil inhabitant, but did not often colonize transplant roots. The most common *Pythium* spp. isolated from both soil and transplant roots was *P. irregulare* Buisman (table 5); this species comprised about 80 percent of the soil *Pythium* isolates and three-fourths of these *Pythium* isolates obtained from diseased transplants. *Pythium ultimum* Trow was isolated much less frequently from both soil and plant roots and the other *Pythium* species (*P. aphanidermatum* [Edson] Fitzpatrick) was only isolated at low levels from soil.

Table 5 *Fusarium* and *Pythium* spp. isolated from nursery soil and roots of diseased Douglas-fir and western white pine transplants - USDA Forest Service Nursery, Coeur d'Alene, Idaho.

Fungal Species	Percent of Isolates	
	Fusarium	
	Soil	Roots
F. oxysporum	88.5	59.7
F. proliferatum[1]	0	38.2
F. solani	6.8	0.3
F. acuminatum	2.1	1.2
F. avenaceum	1.2	0
F. culmorum	0.5	0
F. sporotrichioides	0.3	0.3
F. equiseti	0.3	0
F. sambucinum	0.3	0.3
	Pythium	
P. irregulare	80.5	75.0
P. ultimum	15.5	25.0
P. aphanidermatum	4.0	0

[1] Limited to container-grown Douglas-fir and white pine (plug+1) transplants.

DISCUSSION

Preplant soil fumigation is a standard practice at the Coeur d'Alene Nursery. The primary goal of fumigation is to eliminate or greatly reduce populations of soilborne organisms capable of eliciting diseases on seedling crops and reducing levels of viable weed seeds (James 1989; James et al. 1990, 1996). For many years methyl bromide/chloropicrin (MBC) was the standard soil fumigant at the Nursery. However, several years ago, growers adopted dazomet as the fumigant of choice primarily because it was less environmentally hazardous and seemed nearly as effective as MBC (James et al. 1990) Whenever possible, fields are fumigated with dazomet during late summer when soil conditions are ideal for penetration of the fumigant (James 1989). However, occasionally, spring fumigation is required, particularly if increased seedling production is required (Hoffman and Williams 1988). In such cases, it is important that fumigation occurs sufficiently in advance of sowing so that seeds and young germinants are not damaged by residual fumigant. Usually 1 month in advance of sowing suffices, although this can vary depending on soil and ambient temperature and moisture conditions (Hoffman and Williams 1988).

Growers at the Coeur d'Alene Nursery hope eventually to be able to grow high-quality seedling crops without pre-plant chemical soil fumigation. In recent years, several fumigation alternatives have been evaluated. So far, one promising alternative is bare fallowing fields with periodic soil cultivation to keep weed populations low and enhance destruction of soilborne pathogen propagules (James et al. 1996; Stone et al. 1995). The longer fields are fallowed, the better. One problem with fallowing is unpredictability of the technique. In some years, it seems quite effective; in others it is much less effective (James and Beall 2000). This may primarily be due to our ignorance regarding composition and interactions of soil microbiota at different times in different fields. Fallowing is generally not effective following incorporation of a cover/green manure crop (James 2000a; James et al. 1996); in such cases, soil fumigation is required to sufficiently reduce soilborne pathogen populations (James 2000a). Amending fallowed soils with biological control agents may also help control soilborne diseases. Another potential alternative to fumigation is steam treatment of soil. Preliminary tests (James 2002) indicated that, under experimental conditions, steam might effectively penetrate and kill propagules of soilborne pathogens. Operational use of steam has not been forthcoming because of problems with treating large volumes of soil over a wide area in a timely manner. Future modifications of steam-treatment equipment may improve the outlook for this type of soil treatment. Until effective alternatives are developed, growers will probably continue to implement preplant soil fumigation with dazomet. This will particularly be required if fields are amended with cover/green manure crops grown to provide soil tilth and organic matter (James 2000a; James et al. 1996).

All chemical soil fumigants are nonselective in the organisms they kill (James 1989). Following fumigation, microorganisms that initially reinvade treated soil can proliferate without competition (Vaartaja 1967). Therefore, care must be taken to make sure pathogens are not reintroduced into fumigated soil. One problem with introducing seedlings into fumigated soil as transplants is the potential for bringing pathogens into the fumigated environment on seedling roots (James 1985c, 1995; James and Gilligan 1986). Potential pathogens can readily reside

on seedling roots without eliciting disease symptoms and therefore may be inadvertently introduced into fumigated soil (James and Gilligan 1988; James et al. 1991). This was particularly evident in the current evaluation when container-grown white pine (plug+1) stock was transplanted into fumigated soil. Previous evaluations at the Coeur d'Alene Nursery (James 1985, 1995; James and Gilligan 1986) have indicated that container-grown white pine transplants are particularly prone to high levels of disease following transplanting. Tests have shown that many of these seedlings have roots that are extensively colonized by potentially pathogenic fungi when they leave the container nursery (James 1985a, 1988, 1991a; Dumroese et al. 2000). In most cases, these pathogens die out once seedlings are outplanted in forest soil (Dumroese et al. 2000). However, occasionally pathogens carried on roots of container white pine are sufficient to adversely affect establishment and performance on outplanted forest sites (James 1985a, 1988, 1991a). In the current evaluation, disease problems were not encountered with container-grown Douglas-fir transplants, although these may also have roots that are extensively colonized by potential pathogens (James et al. 1987). Likewise, neither bare root Douglas-fir or white pine transplanted into fumigated soil exhibited high levels of disease.

Many affected container white pine seedlings died shortly after being transplanted into fumigated soil. Although this mortality may have been due primarily to the action of pathogens carried on seedling roots, it is also possible that residual phytotoxic effects of dazomet may have been involved. White pine is very susceptible to damage by dazomet and care must be taken to keep the fumigant away from established seedlings or trees (Chapman 1992; James et al. 1990; Shugert 1989). If volatilized dazomet escapes fumigated fields, it can cause serious damage to nearby white pine. Because of this potential, it is probably safer to transplant white pine only into fields that have been fumigated several months previously.

In general, soil fumigation greatly improved first-season growth of surviving transplants. This was undoubtedly due to reduced levels of soilborne pathogens in fumigated soil. Reduced pathogen pressure probably improved root and corresponding height growth.

Fusarium spp. are the most important soilborne pathogens at the Coeur d'Alene Nursery (James 1983, 1985b, 1987; James et al. 1987). These pathogens cause important damping-off and root diseases in both container and bare root conifer seedlings. In general, the most important *Fusarium* species in bare root seedling production is *F. oxysporum* (James et al. 1989, 1990, 1996). This species is a common soil inhabitant and readily infects and colonizes seedling root cortical cells, although it does not always cause disease (James and Gilligan 1988; James et al. 1991). *Fusarium. oxysporum* actually, comprises a large species complex of morphologically similar fungi (Gordon and Martyn 1997; Kistler 1997). Some isolates may be aggressive pathogens; others are strictly saprophytic or may be potential biological control agents against pathogenic isolates (Gordon and Okamoto 1992; James et al. 1991). Unfortunately, sophisticated molecular techniques are required to differentiate pathogenic from nonpathogenic *F. oxysporum* isolates unless costly, time-consuming pathogenicity tests are used (Gordon and Martyn 1997; Gordon and Okamoto 1992; Kistler et al. 1991). Standard soil and root assays reveal a wide range of *F. oxysporum* isolates, only a portion of which

are probably pathogenic (James et al. 1990, 1996). This makes disease prediction based on soil or root colonization populations difficult. However, based on experience, if populations of *F. oxysporum* are high there is a good chance that some disease will occur if susceptible seedling crops are present (James et al. 1990, 1996; Stone et al. 1995).

The most important *Fusarium* pathogen of container-grown conifer seedlings at the Coeur d'Alene Nursery is *F. proliferatum* (James et al. 1987, 1995). This species may be associated with *F. oxysporum* on container stock but usually becomes dominant as the crop develops and may be a major root inhabitant by the time seedlings are lifted from containers (James 1985b, 1987, 1991b, 1991c; James et al. 1987). This species produces long chains of microconidia that probably facilitate rapid dissemination of the fungus throughout greenhouses. Tests indicated that there was much less pathogenic variation in isolates of *F. proliferatum* compared to *F. oxysporum*; most isolates obtained from conifer seedling nurseries were extremely virulent under conducive test conditions (James 1997; James et al. 1995). Although *F. proliferatum* is routinely associated with container seedling roots, it is rarely isolated from nursery soil (James 1997). This species does not produce long-lived resting spores that are characteristically produced by several other *Fusarium* spp., including *F. oxysporum*. However, it can persist between seedling crops within greenhouses so that infection occurs on most container seedling crops (James 1997).

Fusarium solani was also commonly detected within nursery soil. This species is well adapted as a soilborne pathogen and can cause important diseases on a wide range of agricultural crops (Adams et al. 1968; Baker and Nash 1965). However, its importance in forest nurseries is variable (James et al. 1989). Some isolates are capable of eliciting disease on conifer seedlings, but many others are saprophytic (James and Perez 2000). Like *F. oxysporum*, pathogenic and nonpathogenic isolates appear morphologically similar (James et al. 1989). Most other *Fusarium* spp. isolated from either soil or transplant roots are common saprophytes readily isolated in forest tree nurseries. Tests (James 2000b; James and Perez 1999) indicated that some isolates of *F. acuminatum* Ell. & Ev. and *F. sporotrichioides* Sherb. were virulent on young conifer seedlings, but most were saprophytic, subsisting on soil organic matter or becoming secondary invaders of diseased root tissues

Pythium spp. have periodically been important causes of root diseases at the Coeur d'Alene Nursery (James 1982; James et al. 1990, 1996). Usually these fungi are associated with chlorotic or declining seedlings in bare root beds located within low lying or poorly drained areas (James 1982). When water accumulates for relatively long time periods, *Pythium* spp. can become important because they readily reproduce with spores that are motile in wet soil (Waterhouse 1968). They are also able to elicit greater disease when host plants are stressed in wet soils with little oxygen availability. By far the most important *Pythium* spp. at the Coeur d'Alene Nursery is *P. irregulare* (James 2000a). This fungus is a common soil inhabitant and often isolated from conifer seedling roots (James 2000a; Waterhouse 1968). The second most common species is *P. ultimum*. The other species identified in this evaluation, *P. aphanidermatum*, is rare. All *Pythium* spp. are mostly bare root seedling pathogens and rarely cause diseases on container seedlings (James 1984). When *Pythium* diseases are diagnosed in bare root beds, they may often be adequately controlled with fungicide drenches

(James 1982, 2000a). Unfortunately, fungicides are not nearly as effective in controlling *Fusarium* diseases under similar conditions (James et al. 1987, 1991).

Results from this evaluation indicated that soil fumigation prior to transplanting seedlings may be effective in improving survivability and performance of Douglas-fir (both container and bare root seedlings) and bare root white pine seedlings. However, fumigation was not effective for container-grown white pine seedlings. For this type of transplant, soil fumigation conferred no advantage. If fact, it was possible that residual fumigant stresssed container white pine transplants. Late summer (instead of spring) fumigation may have improved container white pine performance but further tests are needed to confirm this. If fields are fallowed for several years without introduction of large amounts of organic matter provided by cover crop residues, it is possible to obtain soil with a balanced microbial community that would be less disease conducive and could produce high-quality seedlings and transplants without fumigation (James 2000a; Stone et al. 1995). Disease suppressiveness might be enhanced by periodic introductions of biological control agents into fallowed fields. If particular fields are destined to produce container white pine (plug+1) transplants, it is recommended that these not be fumigated, but kept fallow with periodic cultivation and without cover crops. Under such conditions, it is likely that these transplants will survive and perform better than in fumigated fields.

LITERATURE CITED

Adams, P.B., J.A. Lewis and G.C. Papavizas. 1968. Survival of root-infecting fungi in soil. IX. Mechanisms of control of Fusarium root rot of bean with spent coffee grounds. Phytopathology 58:1603-1608.

Baker, R. and S.M. Nash. 1965. Ecology of plant pathogens in soil. VI. Inoculum density of *Fusarium solani* f.sp. *phaseoli* in bean rhizosphere as affected by cellulose and supplemental nitrogen. Phytopathology 55:1381-1382.

Boone, A.J. 1988. Soil fumigation in forest tree nurseries. Proceedings of the Southern Forest Nursery Association – 1988. pp. 33-38.

Dumroese, R.K., R.L. James and D.L. Wenny. 2000. An assessment of *Cylindrocarpon* on container western white pine seedlings after outplanting. Western Journal of Applied Forestry 15(1):5-7.

Chapman, W. 1992. Alternative treatments to methyl bromide. Proceedings of the Southern Forest Nursery Association – 1992. pp. 96-103.

Fisher, N.L., L.W. Burgess, T.A. Toussoun and P.E. Nelson. 1982. Carnation leaves as a substrate and for preserving cultures of *Fusarium* species. Phytopathology 72:151-153.

Gordon, T.R. and R.D. Martyn. 1997. The evolutionary biology of *Fusarium oxysporum*. Annual Review of Phytopathology 35:111-128.

Gordon, T.R. and D. Okamoto. 1992. Population structure and the relationship between pathogenic and nonpathogenic strains of *Fusarium oxysporum*. Phytopathology 82:73-77.

Hildebrand, D.M. and G.B. Dinkel. 1988. Evaluation of methyl bromide, Basamid granular, and solar heating for pre-plant pest control for fall-sown eastern redcedar at Bessey Nursery. USDA Forest Service, Rocky Mountain Region, Timber, Forest Pest, and Cooperative Forestry Management. Technical Report R2-41. 13p.

Hoffman, J.T. and R.E. Williams. 1988. Evaluation of spring-applied Basamid to control soil-borne root pathogens at Lucky Peak Nursery, Idaho. USDA Forest Service, Intermountain Region, Forest Pest Management. Report R4-88-11. 7p.

James, R.L. 1982. Pythium root disease of Douglas-fir and grand fir seedlings at the Coeur d'Alene Nursery, Idaho. USDA Forest Service, Northern Region, Forest Pest Management. Report 82-10. 10p.

James, R.L. 1983. Fusarium root disease of western white pine seedlings at the Coeur d'Alene Nursery, Idaho. USDA Forest Service, Northern Region, Forest Pest Management. Report 83-19. 5p.

James, R.L. 1984. Diseases of containerized conifer seedlings. In: Dubreuil, S.H. (compiler). Proceedings of the 31st Western International Forest Disease Work Conference, Coeur d'Alene, Idaho. pp. 17-23.

James, R.L. 1985a. Containerized western white pine seedling mortality at the Bonners Ferry Ranger District, Idaho Panhandle National Forests. USDA Forest Service, Northern Region, Forest Pest Management. Report 85-18. 7p.

James, R.L. 1985b. Decline of containerized western white pine seedlings at the USDA Forest Service Nursery, Coeur d'Alene, Idaho. USDA Forest Service, Northern Region, Forest Pest Management. Nursery Disease Notes No. 24. 4p.

James, R.L. 1985c. Root diseases of transplanted western white pine seedlings at the USDA Forest Service Nursery, Coeur d'Alene, Idaho. USDA Forest Service, Northern Region, Forest Pest Management. Nursery Disease Notes No. 21. 4p.

James, R.L. 1987. Containerized western white pine seedling root disease - USDA Forest Service Nursery, Coeur d'Alene, Idaho. USDA Forest Service, Northern Region, Forest Pest Management. Nursery Disease Notes No. 66. 4p.

James, R.L. 1988. Field mortality of western white pine transplants – Kootenai National Forest. USDA Forest Service, Northern Region, Forest Pest Management. Nursery Disease Notes No. 71. 3p.

James, R.L. 1989. Effects of fumigation on soil pathogens and beneficial microorganisms. *In*: Landis, T.D. (tech. coord.). Proceedings: Intermountain Forest Nursery Association Meeting. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. General Technical Report GTR-184. pp. 29-34.

James, R.L. 1991a. Fungal colonization of roots from western white pine transplant seedlings outplanted on the Wallace Ranger District, Idaho Panhandle National Forests, Idaho. USDA Forest Service, Northern Region, Forest Pest Management. Nursery Disease Notes No. 120. 10p.

James, R.L. 1991b. Root decay of container-grown lodgepole pine and western white pine seedlings - USDA Forest Service Nursery, Coeur d'Alene, Idaho. USDA Forest Service, Northern Region, Forest Pest Management. Nursery Disease Notes No. 116. 4p.

James, R.L. 1991c. Wilting of container-grown western white pine seedlings - USDA Forest Service Nursery, Coeur d'Alene, Idaho. USDA Forest Service, Northern Region, Forest Pest Management. Nursery Disease Notes No. 123. 5p.

James, R.L. 1995. Root diseases of western white pine transplants - USDA Forest Service Nursery, Coeur d'Alene, Idaho. USDA Forest Service, Northern Region, Insect and Disease Management. Report 95-8. 10p.

James, R.L. 1997. A short review of *Fusarium* section *Liseola*: implications for conifer seedling production. *In*: James, R.L. (ed.). Proceedings of the Third Meeting of IUFRO Working Party S7.03-04 (Diseases and Insects in Forest Nurseries). USDA Forest Service, Northern Region, Forest Health Protection. Report 97-4. pp. 34-41.

James, R.L. 2000a. Effects of a 2-year fallow period on soil populations of *Fusarium*, *Trichoderma* and *Pythium* species after incorporating corn plant residues - USDA Forest Service Nursery, Coeur d'Alene, Idaho. USDA Forest Service, Northern Region, Forest Health Protection. Report 00-17. 11p.

James, R.L. 2000b. Pathogenic characteristics of *Fusarium acuminatum* from inland Pacific Northwest nurseries. USDA Forest Service, Northern Region, Forest Health Protection. Report 00-16. 8p.

James, R.L. 2002. Effects of pre-plant soil treatments on *Fusarium* and *Trichoderma* populations and fungal root colonization of 2-0 non-diseased western white pine seedlings - USDA Forest Service Nursery, Coeur d'Alene, Idaho. USDA Forest Service, Northern Region, Forest Health Protection. (In Press). 11p.

James, R.L. and K. Beall. 2000. Effects of fallowing on *Fusarium*-associated root diseases and production of bare root ponderosa pine seedlings at the USDA Forest Service Lucky Peak Nursery, Boise, Idaho. USDA Forest Service, Northern Region, Forest Health Protection. Report 00-3. 13p.

James, R.L., R.K. Dumroese and D.L. Wenny. 1989. Occurrence, characteristics, and descriptions of *Fusarium* isolates from Douglas-fir seed and seedlings. USDA Forest Service, Northern Region, Forest Pest Management. Report 90-4. 23p.

James, R.L., R.K. Dumroese and D.L. Wenny. 1991. *Fusarium* diseases of conifer seedlings *In*: Sutherland, J.R. and S.G. Glover (eds.). Proceedings of the First Meeting of IUFRO Working Party S2.07-09 (Diseases and Insects in Forest Nurseries). Forestry Canada. Pacific and Yukon Region. Information Report BC-X-331. pp. 181-190.

James, R.L., R.K. Dumroese and D.L. Wenny. 1995. *Fusarium proliferatum* is a common, aggressive pathogen of container-grown conifer seedlings. Phytopathology 85(10):1129.

James, R.L., R.K. Dumroese, D.L. Wenny, J.F. Myers and C.J. Gilligan. 1987. Epidemiology of *Fusarium* on containerized Douglas-fir seedlings. 1. Seed and seedling infection, symptom production, and disease progression. USDA Forest Service, Northern Region, Forest Pest Management. Report 87-13. 22p.

James, R.L. and C.J. Gilligan. 1986. Root diseases of western white pine transplants at the USDA Forest Service Nursery, Coeur d'Alene, Idaho. USDA Forest Service, Northern Region, Forest Pest Management. Report 86-11. 8p.

James, R.L. and C.J. Gilligan. 1988. Occurrence of *Fusarium* on the roots of nondiseased bareroot Douglas-fir seedlings - USDA Forest Service Nursery, Coeur d'Alene, Idaho. USDA Forest Service, Northern Region, Forest Pest Management. Report 88-12. 4p.

James, R.L., S. Metzger and C.J. Gilligan. 1990. Effects of soil fumigation on conifer seedling production at the USDA Forest Service Nursery, Coeur d'Alene, Idaho. USDA Forest Service, Northern Region, Forest Pest Management. Report 90-11. 18p.

James, R.L., D.S. Page-Dumroese, S.K. Kimball and S. Omi. 1996. Effects of *Brassica* cover crop, organic amendment, fallowing, and soil fumigation on production of bareroot Douglas-fir seedlings - USDA Forest Service Nursery, Coeur d'Alene, Idaho. USDA Forest Service, Northern Region, Forest Health Protection. Report 96-6. 10p.

James, R.L. and R. Perez. 1999. Pathogenic characteristics of *Fusarium sporotrichioides* isolated from inland Pacific Northwest forest nurseries. USDA Forest Service, Northern Region, Forest Health Protection. Report 99-8. 11p.

James, R.L. and R. Perez. 2000. Pathogenic characteristics of *Fusarium solani* isolated from inland Pacific Northwest forest nurseries. USDA Forest Service, Northern Region, Forest Health Protection. Report 00-15. 12p.

Kistler, H.C. 1997. Genetic diversity in the plant-pathogenic fungus *Fusarium oxysporum*. Phytopathology 87:474-479.

Kistler, H.C., E.A. Momol and U. Benny. 1991. Repetitive genomic sequences for determining relatedness among strains of *Fusarium oxysporum*. Phytopathology 81:331-336.

Komada, H. 1975. Development of a selective medium for quantitative isolation of *Fusarium oxysporum* from natural soil. Review of Plant Protection Research (Japan) 8:114-125.

Nelson, P.E., T.A. Toussoun and W.F.O. Marasas. 1983. *Fusarium* species: an illustrated manual for identification. The Pennsylvania State University Press, University Park. 193p.

Shugert, R. 1989. Basamid-update. Combined Proceedings of the International Plant Propagators' Society 38:525-526.

Stone, J.K., D.M. Hildebrand, R.L. James, S.M. Frankel and D.S. Gemandt. 1995. Alternatives to methyl bromide for control of soil-borne diseases in bare root forest nurseries. In: Proceedings: Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. November 6-8, 1995, San Diego, CA. Methyl Bromide Alternatives Outreach, U.S. Environmental Protection Agency and U.S. Department of Agriculture. pp. 77-1 – 77.4.

Vaartaja, O. 1967. Reinfestation of sterilized nursery seedbeds by fungi. Canadian Journal of Microbiology 13:771-776.

Waterhouse, G.M. 1968. The genus *Pythium* Pringsheim. Commonwealth Mycological Institute, Kew, Surrey, England. Mycological Papers No. 110. 70p.

R.L. James is Plant Pathologist, USDA Forest Service, Northern Region, Forest Health Protection. Address: USDA Forest Service, 3815 Schreiber Way, Coeur d'Alene, ID 83814; email rjames@fs.fed.us.