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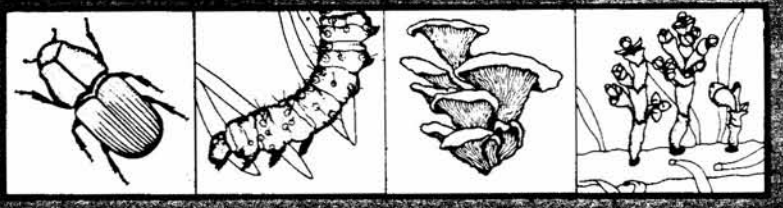

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EFFECTS OF BRASSICA COVER CROP, ORGANIC AMENDMENT, FALLOWING, AND SOIL FUMIGATION ON PRODUCTION OF BAREROOT DOUGLAS-FIR SEEDLINGS - USDA FOREST SERVICE NURSERY, COEUR D'ALENE, IDAHO

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ABSTRACT

Effects of incorporating a *Brassica hirta* cover crop and composted municipal sewage sludge into soil were compared with fallowing soil and dazomet fumigation on production of Douglas-fir seedlings at the USDA Forest Service Nursery in Coeur d'Alene, Idaho. Soil was treated one growing season before sowing. Incorporating *Brassica* into soil was ineffective in controlling root disease and resulted in higher numbers of potentially pathogenic fungi, greater disease, and reduced seedling density and quality. Seedling production with fumigation was similar to fallowing and composted sewage sludge treatments. Sludge treatments added more organic matter to soil without resulting in higher disease levels or reduced seedling quality. Fallowing reduced soil populations of potentially pathogenic fungi; seedlings produced in fallowed fields were of similar quality to those grown in fumigated soil. *Fusarium oxysporum* was the most commonly isolated *Fusarium* spp. from soil and roots of diseased and healthy seedlings. Producing high-quality Douglas-fir seedlings is possible without chemical soil fumigation.

INTRODUCTION

Root diseases are important limiting factors in the production of bareroot conifer seedlings at the USDA Forest Service Nursery in Coeur d'Alene, Idaho (James 1983, 1989c; James and others 1990). Population densities of fungi capable of eliciting root diseases vary with season of year, cropping history, presence of cover crops, and cultivation practices (James and Gilligan 1985, 1986, 1990; James and others 1990). Formerly, soil-borne pathogenic fungi were adequately controlled by chemical fumigation (James 1989a; James and others 1990). Initially, methyl-bromide/chloropicrin (MBC) fumigation was applied, usually in late summer preceding sowing the following spring (James and Gilligan 1985; James and others 1990). Although quite effective in controlling soil-borne pathogens, MBC use was terminated recently because of its extreme toxicity and potential danger to humans within and near the nursery. In its place, the granular fumigant dazomet (Basamid®) was used the past several years. Like MBC, dazoment is applied in late summer and is usually effective in reducing levels of soil-borne pathogenic fungi (Campbell and Kelpsas 1988; Chapman 1992; James and others 1990; Shugert 1989).

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Besides controlling soil-borne pathogenic fungi, fumigation may sometimes increase disease problems because the chemicals used are broad-spectrum biocides that also kill desirable organisms (James 1989a). If pathogens are reintroduced into fumigated soil, particularly on conifer seed, disease may be greater than if soil was never fumigated. In addition, application of chemical soil fumigants is very expensive (Chapman 1992; James 1989a; James and others 1990). Another concern for growers is that soil fumigants may become more difficult to use in the future because of increasing environmental restrictions on chemical pesticide use (James 1989a). For example, methyl bromide use will be illegal after January 1, 2001 because of restrictions imposed by the amended Clean Air Act which responded to the international Montreal Protocol (Barnard and others 1994; EPA 1993). This agreement will ban use of chemicals deemed important in destroying stratospheric ozone.

Ideally, it would be best if soil-borne pathogens were controlled without using chemical soil fumigation. Indeed, several nurseries routinely grow high-quality crops of bareroot conifer seedlings without soil fumigation (James 1989a). These nurseries use several approaches for disease control; in most cases, their cultural practices stimulate soil suppressiveness to pathogenic fungi. This implies that, although pathogens are present, their impact is minimal because of presence of high numbers of other competing organisms (Baker and Cook 1974). The "buffering" quality of these organisms along with restricting amounts of nutrients available to pathogens helps establish soil suppressiveness (Papavizas and Lumsden 1980). Suppressiveness may take time to develop, requiring several crop rotations, and can be destroyed quickly by chemical fumigation (Baker and Cook 1974; James 1989a). Induction of suppressiveness may be challenging. Approaches include soil amendments with organic matter that stimulates non-pathogenic microorganisms rather than pathogens (Chen and others 1988; Chesters 1949; Wall 1984), fallowing soil with periodic cultivation which depletes nutrients available to pathogens and helps reduce viability of pathogen resting structures (Stone 1991; Sutherland 1984; Wall 1984), and growth and incorporation of cover crops which stimulates competing organisms or represses pathogen development (Lewis and Papavizas 1974; Papavizas and Davey 1960).

Brassica species contain secondary metabolites, glucosinalates, that release volatile isothiocyanates when decomposed; these are similar in activity to chemical fumigants (Bailey and others 1961; Clapp and others 1959; Davis 1988; Gamliel and Stapleton 1993a; Stone 1991). In theory, by optimizing conditions for glucosinalate production in cover crops, and the liberation of isothiocyanates upon incorporation of crops in soils, reduction of soil pathogen populations occurs (Angus and others 1994; Lewis and Papavizas 1974). Different *Brassica* cultivars contain different glucosinalate levels (Ramirez- Villapudua and Munnecke 1987, 1988); by incorporating varieties high in these chemicals, soil fumigation might be accomplished without applying toxic chemicals (Stone 1991).

To determine efficacy of alternative means of controlling soil-borne pathogens, an evaluation was conducted at the USDA Forest Service Nursery in Coeur d'Alene, Idaho. The goal was to compare production of bareroot Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco) seedlings in fields treated with an organic amendment, incorporated *Brassica* cover crop, fallowing, and standard chemical soil fumigation.

MATERIALS AND METHODS

Field locations were established in June 1992 and initial (pre-treatment) soil samples collected. All soil samples were collected from six, approximately equidistant, locations within the center of each of four treatment areas. Each sample consisted of a composite of five soil cores about 15 cm deep. Standard soil dilution techniques were used to determine populations of two groups of potential plant pathogenic fungi: *Fusarium* and *Pythium* spp. (James and Gilligan 1985, 1986, 1990; James and others 1990, 1991a). In addition, populations of *Trichoderma* were estimated when *Fusarium* populations were determined. Soil was initially sieved (2 mm sieve) to remove rocks, pieces of undecomposed organic matter, and soil aggregations. From each sample, a 5 gm subsample was dried at about 100°C for at least 24 hours or until sample weight had stabilized (all excess moisture removed). Oven-dry weight was then calculated to provide a standard for comparison. For assay of *Fusarium* and *Trichoderma* populations, 0.5g of field-moist soil was combined with 100 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 (Ko-

mada 1975) and spread uniformly. Plates were incubated five days at about 24°C under diurnal cycles of cool, fluorescent light. *Fusarium* and *Trichoderma* colonies were identified by their morphology on the selective medium and populations determined. Ratios of *Trichoderma* to *Fusarium* propagules were calculated for a rough estimate of potential soil suppressiveness to root pathogens. For assay of *Pythium* populations, 5.0g of soil was combined with 100 ml of 0.3 percent water agar. One ml of solution was placed on each of three plates of another selective medium consisting of V-8 juice agar amended with pimaricin, rifamycin, ampicillin, and pentachloronitrobenzene (James and others 1990). Plates were incubated three days in the dark at about 24°C. *Pythium* colonies were identified based on their diameter after 3 days (15-20 mm), their feathery margin, and whether they grew within rather than superficially on the agar surface. Populations of *Fusarium*, *Trichoderma*, and *Pythium* were expressed as colony-forming units per gm of soil.

Four treatments were installed in blocks approximately 50 ft. wide and 150 ft. long (15.2 m x 45.7 m) (table 1). The second soil sample was collected and analyzed in November 1992 following fumigation, organic matter application, and incorporation of the *Brassica hirta* Moench var. *humus* cover crop. Treatment blocks were sown with the same Douglas-fir seedlot in early May 1993. A third soil sample was collected just before bed formation preceeding sowing.

Five weeks after sowing (June 1993), seedling establishment and post-emergence damping-off were monitored. Five subplots (each 1.0 x 1.5 ft = 1.5 ft^2; 3.0 x 4.6 dm = 14.0 dm^2) were established in the center of treatment blocks approximately where soil samples were collected. Plot centers were located with a wooden stake. Number of healthy (non-symptomatic) and diseased (chlorotic or necrotic) seedlings within each plot were counted. Diseased seedlings were removed from plots for isolation of associated fungi on roots. Five months after sowing (September 1993), number of healthy and diseased seedlings within subplots were again determined. In addition, heights of 10 randomly selected seedlings per subplot were measured. Diseased seedlings were removed for isolation of associated fungi.

Table 1. Treatments evaluated to determine effects on production of bareroot Douglas-fir seedlings at the USDA Forest Service Nursery, Coeur d'Alene, Idaho.

Treatment	Description
Fallow	Field left fallow with periodic cultivation during 1992; seedling crop sown May 1993.
Brassica*	*Brassica hirta* (variety *humus*) sown July 1992 and incorporated September 1992; seedling crop sown May 1993.
Fumigation	Field fumigated with dazomet (350 lbs/A; 392.3 kg/ha) August 1992; seedling crop sown May 1993.
Amendment	Composted municipal sewage sludge applied (1 in.; 2.54 cm thick) August 1992; seedling crop sown May 1993.

* See figure 1 for appearance of *Brassica* cover crop approximately one month after sowing and figure 2 for appearance of the crop being incorporated into soil.

Figure 1. One-month old *Brassica hirta* (variety *humus*) cover crop - USDA Forest Service Nursery, Coeur d'Alene, Idaho.

Figure 2. Three-month old *Brassica hirta* (variety *humus*) cover crop being chopped prior to incorporation Forest Service Nursery, Coeur d'Alene, Idaho.

The fourth soil sample was collected and analyzed after the first growing season (October 1993); the fifth sample was collected in spring of the second growing season (May 1994) and the sixth and final sample collected after the second growing season (October 1994). All soil samples were collected and analyzed as described above.

Soil samples for chemical analysis were systematically collected to a depth of 15 cm from each treatment block in October 1992 to estimate nitrogen (N), carbon (C), and organic matter inputs. Five composite samples were collected in each treatment replication. Soil samples were passed through a 2 mm sieve and dried at 105°C for 24 hours. Organic matter was determined by weight loss after combustion at 375°C for 16 hours (Ball 1964). Total N and C were analyzed on a LECO CHN-600 analyzer. Nitrate and ammonium were determined on undried samples in a 1*N* KCl extract using an Alpkem Rapid Flow Analyzer (Keeney and Nelson 1982). Potential mineralizable N was estimated using the anaerobic incubation technique on undried samples (Powers 1980).

Seedlings were lifted in April 1995 from treatment blocks. One hundred 2-0 seedlings were randomly collected from the center of treatment blocks during lifting. Seedling roots were thoroughly washed to remove adhering soil and measured (height and caliper). Root volume was estimated using Burdett's (1979) water displacement technique. Fifty seedlings from each treatment were sampled for presence of *Fusarium* spp. on their roots. Ten root tips from each sampled seedling were excised, surface sterilized for 1 minute in a 10 percent bleach solution (5.25 percent aqueous sodium hypochlorite), rinsed in sterile water, and placed on a selective agar medium (Komada 1975). Plates were incubated 7-10 days at about 24°C; emerging fusaria were transferred to potato dextrose agar and carnation leaf agar (Fisher and others 1982) for identification using the taxonomic methods of Nelson and others (1983). Selected fusaria from soil samples were likewise identified.

Data were analyzed using ANOVA. Because replications within treatments were not randomized, to obtain an estimate of error it was necessary to assume that interaction effects were not present. If this assumption was correct, contrasts normally used to estimate interaction effects estimated error. They were used in place of the error estimates usually used as denominators of F-tests. ANOVAs were performed separately for each variable measured. Mean comparisons were calculated using Tukeys HSD. Significant differences were detected at the $P=0.05$ level.

RESULTS

Treatment effects on soil populations of potentially pathogenic *Fusarium* and *Pythium* spp. and saprophytic (potentially antagonistic) *Trichoderma* spp. are summarized in table 2. Soil fungal populations varied greatly within individual fields and also responded to seasonal changes. Because of this variation, statistically significant differences in soil fungal populations were lacking, even though fungi may have responded to the different soil treatments. Data in table 1 indicated trend increases in overall *Fusarium* populations after amending soil with composted sewage sludge or incorporating *Brassica* residues. In contrast, dazomet fumigation eliminated *Fusarium* and *Pythium* spp.; levels were nondetectable or low throughout the rest of the study.

Table 2. Treatment effects on soil populations of *Fusarium*, *Trichoderma* and *Pythium* species and *Trichoderma/Fusarium* (T/F) ratios - USDA Forest Service Nursery, Coeur d'Alene, Idaho[1].

		Treatment[3]			
	Sample Number[2]	Fallow	Brassica	Fumigation	Amendment
1	*Fusarium*	314A	189A	414A	268A
	Trichoderma	1189A	986A	739A	659A
	Pythium	147A	97A	136A	37B
	T/F	4.24A	5.44A	3.00A	4.00A
2	*Fusarium*	156AB	433A	0B	456A
	Trichoderma	167A	256A	0B	344A
	Pythium	100B	512A	0C	262B
	T/F	0.97A	0.69A	0A	1.29A
3	*Fusarium*	136B	406AB	0B	934A
	Trichoderma	805A	214B	0C	592AB
	Pythium	175B	417A	1C	353AB
	T/F	5.49A	0.49B	0B	0.90B
4	*Fusarium*	620A	754A	13B	673A
	Trichoderma	121A	350A	81A	512A
	Pythium	115AB	218A	7B	178AB
	T/F	0.22A	0.31A	0B	1.09A
5	*Fusarium*	204A	325A	0B	232A
	Trichoderma	95B	54B	13B	436A
	Pythium	8B	11B	0B	52A
	T/F	0.67B	0.16B	0B	2.13A
6	*Fusarium*	135A	27B	0B	54AB
	Trichoderma	94A	13A	0A	0A
	Pythium	4B	21A	4B	35A
	T/F	0.47A	0.48A	0A	0A

[1] Within each row, means followed by the same letter are not significantly different (P=0.05) using Tukeys HSD.

[2] Samples: 1 = pre-treatment (6/92); 2 = post-fumigation, soil treatment (11/92); 3 = at sowing (4/93); 4 = end of first growing season (10/93); 5 = prior to second growing season (5/94); 6 = end of second growing season (10/94).

[3] See table 1 for description of treatments.

Seasonal changes in *Fusarium* populations were best estimated by comparing data in untreated fallow plots, since these were not subjected to additions of organic matter or chemical toxicity. Natural over-winter losses in viable propagules occurred. Populations increased during the first growing season after sowing the susceptible Douglas-fir crop; however, during the second growing season, populations stabilized.

Pythium spp. occurred at levels lower than *Fusarium* throughout the study (table 2). However, fewer *Pythium* propagules per gm of soil are required to elicit root disease (James 1982; James and others 1991a). Similar to *Fusarium* spp, *Pythium* spp. increased in response to organic amendments and were very sensitive to fumigation.

Ratios of *Trichoderma* to *Fusarium* populations (T/F) may only approximate soil suppressiveness to disease (James 1996) because not all *Trichoderma* spp. are antagonists and not all *Fusarium* spp. are pathogens. Theoretically, soils with more *Trichoderma* relative to *Fusarium* may be less conducive to disease because of increased buffering by potentially antagonistic *Trichoderma*. Developing soils with higher T/F ratios may be an important goal of soil management. In the study area, all soils had similar T/F ratios before treatment (table 2). Fumigation eliminated all fungi and any potential disease suppressiveness. Amending soils with composted sewage sludge and *Brassica* residues greatly reduced T/F ratios, indicating that *Fusarium* spp. responded to organic amendments more than *Trichoderma* spp. However, natural reductions of *Trichoderma* populations also occurred in the untreated fallow field. In that field, *Trichoderma* populations slightly increased before sowing (sample 3 - table 2), but low T/F ratios generally prevailed throughout the two growing seasons. Apparently, introducing a susceptible conifer crop increased *Fusarium* populations with a corresponding decrease in *Trichoderma* spp.

Incorporating *Brassica* residues adversely affected establishment of Douglas-fir seedlings; seedling density at five weeks and five months after sowing was less than in other treatments (table 3). No differences in density of healthy-appearing seedlings were found in the other three treatments when assayed during the first growing season. Many more root diseased seedlings were also found in *Brassica* residue plots assayed five months after sowing. First year seedling height was greatest in the fumigation plots, but much reduced in *Brassica* residue plots (table 3).

Perhaps the most important measure of treatment effects in this study involved seedling biomass production after two growing seasons. Seedlings were significantly shorter in the *Brassica* residue plots (table 4), but calipers and root volumes were similar to the other treatments. Seedlings in fumigated plots were taller than those in other treatment plots. However, seedling calipers and root volumes were generally less.

After two growing seasons, roots from most healthy seedlings in all areas were colonized with *Fusarium* spp. (table 5). The most common species found on roots of healthy and diseased Douglas-fir seedlings was *F. oxysporum* Schlecht.; this species was also commonly isolated from soil throughout the study, comprising about 85 percent of all fusaria. Other species isolated from roots included *F. solani* (Mart.) Appel & Wollenw., *F. acuminatum* Ell. & Ev., *F. sambucinum* Fuckel, and *F. avenaceum* (Fr.) Sacc. *Fusarium equiseti* (Corda) Sacc. and *F. culmorum* (W. G. Smith) Sacc. were isolated from soil but not from seedling roots. Differences in percent seedling infection among treatments were not apparent. However, seedlings grown in *Brassica* residue plots were colonized with *Fusarium* to a significantly greater extent than seedlings from other treatments.

Table 3. Effects of fallowing, *Brassica* cover crop incorporation, soil fumigation and organic amendment on Douglas-fir seedling establishment, disease and height five weeks and five months after sowing - USDA Forest Service Nursery, Coeur d'Alene, Idaho[1].

	Five Weeks After Sowing		Five Months After Sowing[3]		
Treatment[2]	No. Healthy Seedlings	No. Diseased Seedlings	No. Healthy Seedlings	No. Diseased Seedlings	Average Height(mm)
Fallow	40.5A	7.3A	37.0A	2.0B	50.9B
Brassica	33.6A	7.0A	25.6B	5.0A	25.4C
Fumigation	37.2A	6.4A	38.0A	0C	73.1A
Amendment	41.2A	6.4A	39.6A	1.6B	56.1B

[1] Within each column, means followed by the same letter are not significantly different (P=0.05) using Tukeys HSD test.

[2] See table 1 for treatment descriptions.

[3] Ten seedlings randomly selected for height measurement in each of 5 plots established within each treatment area.

Table 4. Effects of fallowing, *Brassica* cover crop incorporation, soil fumigation and organic amendment on morphological characteristics of 2-0 bareroot Douglas-fir seedlings, USDA Forest Service Nursery, Coeur d'Alene, Idaho[1].

Treatment[2]	Avg. Seedling Height (cm)	Avg. Seedling Caliper (mm)	Avg. Seedling Root Volume(g)
Fallow	30.1C	6.8A	10.6A
Brassica	20.3D	5.8AB	12.1A
Fumigation	37.6A	5.2B	8.5B
Amendment	33.0B	6.5A	11.4A

[1] Averages of 100 sampled seedlings per treatment. Within each column, means followed by the same letter are not significantly different (P=0.05) using Tukeys HSD test.

[2] See table 1 for treatment descriptions.

Table 5. Effects of fallowing, *Brassica* cover crop incorporation, soil fumigation and organic amendment on infection and colonization of healthy 2-0 Douglas-fir seedlings by *Fusarium* spp. - USDA Forest Service Nursery, Coeur d'Alene, Idaho[1].

Fusarium Species[2]	Fallow	Treatment [3] Brassica	Fumigation	Amendment
FOXY				
Infection[4]	96A	100A	94A	100A
Colonization[5]	45.5B	61.6A	35.0B	37.6B
FSOL				
Infection	6A	10A	2A	10A
Colonization	0.8A	1.2A	0.2A	1.0A
FACU				
Infection	7A	4A	2A	8A
Colonization	1.2A	0.4A	0.2A	0.8A
FSAM				
Infection	6B	2B	34A	6B
Colonization	0.6B	0.2B	4.8A	0.6B
FAVE				
Infection	0B	2B	20A	6AB
Colonization	0B	0.4B	2.4A	0.6B
All Species				
Infection	96A	100A	98A	100A
Colonization	47.0B	62.2A	42.2B	39.8B

[1] Within each row, means followed by the same letter are not significantly different (P=0.05) using Tukeys HSD test.

[2] FOXY = *F. oxysporum*; FSOL = *F. solani*; FACU = *F. acuminatum*; FSAM = *F. sambucinum*; FAVE = *F. avenaceum*.

[3] See table 1 for treatment descriptions.

[4] Percent of seedlings sampled (50 per treatment) infected with the appropriate *Fusarium* species.

[5] Average percent of root tips (10 sampled per seedling) colonized by the appropriate *Fusarium* species.

Treatment effects on selected soil characteristics are outlined in table 6. Extreme variability among samples resulted in few statistical differences among treatments. However, composted sewage sludge amendments increased carbon, nitrogen, and organic matter percentage when compared to other treatments. Interestingly, similar increases were not detected in *Brassica* residue plots.

Table 6. Effects of fallowing, *Brassica* cover crop incorporation, soil fumigation, and organic amendment of soil characteristics - USDA Forest Service Nursry, Coeur d'Alene, Idaho[1].

	Percent			mg/kg		
Treatment[2]	Carbon	Nitrogen	Organic Matter	Nitrogen Mineralization	Ammonium	Nitrate
Fallow	0.68A	0.002A	2.75A	31.56A	18.84A	1.02B
Brassica	0.59A	0.002A	2.75A	5.52B	0.65B	3.89B
Fumigation	0.59A	0.006A	2.50A	12.51AB	1.26B	5.26A
Amendment	1.89A	0.749A	5.90B	17.09A	0.89B	2.09B

[1] Within each column, means followed by the same letter are not significantly different (P=0.05) using Tukeys HSD test.

[2] See table 1 for treatment descriptions.

DISCUSSION

Root diseases may be important limiting factors in the production of bareroot conifer seedlings in many nurseries, including the USDA Forest Service Nursery in Coeur d'Alene (James 1982, 1983, 1989c; James and others 1990, 1991b). Although these diseases have traditionally been controlled by soil fumigation (James 1989a; James and others 1990, 1991a), growers need alternatives to chemical applications.

Undecomposed plant residues are normally incorporated into nursery soil to improve tilth, aeration, moisture-holding capacity and improved root penetration by crop plants (Jarvis and Thorpe 1981; Papavizas and Davey 1960; Sequeira 1962). Immediately after incorporating plant residues, microbial activity usually increases greatly (Papavizas and Lumsden 1980; Sequeira 1962). However, incorporating undecomposed plant residues into soil may also stimulate populations of microorganisms capable of eliciting disease (Bloomberg 1963; Redfern 1970; Wycoff 1952) and produce decomposition products possibly phytotoxic to crop plants (Beach 1946; Patrick and Koch 1958; Patrick and others 1964). Because soil microorganisms are stimulated by incorporating a green manure crop, it is important that a fallow period of several weeks or months be used to allow reductions of pathogen populations before sowing conifer crops into treated fields (Papavizas and Davey 1960; Wall 1984).

Our results showed that incorporating *Brassica* residues into soil failed to control soil-borne pathogens and resulting root disease; incorporated residues also increased populations of potential pathogens and decreased seedling production and quality. Although cruciferous plants may contain high levels of sulfur-containing compounds and glucosinalates (Angus and others 1994; Bailey and others 1961; Clapp and others 1959; Gamliel and Stapleton 1993a), in our test the *Brassica* plant material apparently did not suppress *Fusarium* spp. Soil incorporated cruciferous crops may reduce levels of some pathogens (Lewis and Papavizas 1974; Ramirez-Villapudua and Munnecke 1987, 1988), but stimulatory effects have also been reported (Stone 1991), confirming our results. Apparently, some *Brassica* crops produce more toxic isothiocyanates than others (Angus and others 1994; Davis 1988; Ramirez-Villapudua and Munnecke 1987, 1988); to produce toxin levels approaching those applied during standard soil fumigation, much more plant biomass would be necessary than produced in a cover crop (Stone 1991). Although many growers of bareroot

(Stone 1991). Although many growers of bareroot conifer seedlings use cover crops to build soil organic matter, increase soil aggregation, structure, and water-holding capacity (Hamm and Hansen 1990) and help prevent various forms of soil erosion (McGuire and Hannaway 1984), many of these crops potentially stimulate pathogen populations if incorporated into soil (Hamm and Hansen 1990; Sutherland 1984). Therefore, benefits of cover crops must be weighed with potential disadvantages of increased disease.

Increasing soil organic matter usually results in higher total microbial activity (Chesters 1949). Increased microbial activity may decrease pathogenesis by some fungi (Chen and others 1988; Gamliel and Stapleton 1993b; Lu 1968), depending on which organisms are stimulated by organic matter additions (Chen and others 1988; Voland and Epstein 1994). Sewage sludge composts are usually made by mixing effluent with wood chips or sawdust (Gouin 1977). Some sludges may contain potentially toxic metals (McIlveen and Cole 1977) and only those with low metal concentrations can be used as soil amendments for crops (Gouin 1993). Composted sewage sludge may also introduce high levels of soluble salts into soil (Gouin 1977; Gouin and Walker 1977). Therefore, application rates must be monitored to ensure excess salts or metals are not added to soil, resulting in possible seedling phytotoxicity (Gouin 1977). Sludge composts also contain fungi which are normal components of the sewage treatment process (Cooke 1956). Although some of these organisms may be potential plant pathogens (Cooke 1956), a majority may have potential antagonism toward pathogens (McIlveen and Cole 1977: Gouin 1993).

In our test, incorporating composted sewage sludge resulted in higher populations of potential pathogenic fungi, but without adverse effects on seedling density, disease or quality. Apparently, the composted material stimulated organisms antagonistic to the increasing *Fusarium* population. These antagonists were not *Trichoderma* spp., but perhaps bacteria and/or actinomycetes (McIlveen and Cole 1977). One goal in management of soil-borne pathogens is to increase levels of antagonists while decreasing potential pathogens (Baker and Cook 1974). Composted sewage sludge as an organic amendment offers promise as a means of increasing disease suppression in soil.

As expected, the most effective treatment in reducing populations of potentially pathogenic fungi was dazomet fumigation. Seedling density and height were very high. However, calipers and root volumes were lower than other treatments. Larger diameter seedlings have better survival (Duryea 1984; South and others 1993) and grow more vigorously in the field (Ritchie 1984; South and others 1993). Seedling height is often less indicative of outplanting performance than root collar diameter (Chavasse 1977). Therefore, seedlings from fumigated plots were not necessarily the most desirable from an outplanting-performance standpoint.

Disease was almost non-existent after the initial damping-off stage, although most seedlings were infected with *Fusarium* at the time of lifting. Chemical soil fumigation may be the most effective way to reduce or eliminate populations of potentially pathogenic fungi (James 1989a). Soils properly fumigated may remain low in pathogen populations for many months despite presence of nearby non-fumigated fields and movement of equipment between fields (Hansen and others 1990; James and Gilligan 1985). However, in some cases, fairly high disease levels may occur despite fumigation (James 1983; James and others 1991a). Dazomet has been an effective soil fumigant alternative to MBC in some cases (Barnard and others 1994; Campbell and Kelpsas 1988; Hansen and others 1990; James and others 1990), but less effective in others (Chapman 1992; Hildebrand and Dinkel 1988). Dazomet may not always penetrate soil as effectively as MBC (Chapman 1992; Hildebrand and Dinkel 1988; Kelpsas and Campbell 1994) so that reinvasion of treated fields may be quicker than fumigating with MBC (James and others 1990; 1991a). Regardless of these potential problems, dazomet has been quite effective at the Coeur d'Alene Nursery and is now used operationally.

Bare-fallowing fields before sowing resulted in low levels of disease and production of high-quality seedlings. Populations of potentially pathogenic fungi were kept much lower in fallow fields than those with organic amendments. Fallowing, particularly with periodic cultivation to mix soil, may be an effective, low-cost alternative to chemical soil fumigation for disease control (Hansen and others 1990; Stone 1991; Sutherland 1984; Wall 1984). Populations of pathogenic fungi have little chance to increase with low organic matter available and tend to die out over time (Stone 1991; Sutherland 1984).

The major problems associated with fallowing are soil erosion, low organic matter, and field rotation requirements. However, some of these can probably be ameliorated by establishing windbreaks, applying inert mulches, and amending with disease-suppressive composts.

Infection of roots of apparently healthy Douglas-fir seedlings with *Fusarium* is common (Hansen and others 1990; James 1989b; James and Gilligan 1988). *Fusarium* spp. preferentially colonize cortical tissues of conifer roots, although they may not necessarily elicit disease (James and others 1991b). Whether disease occurs probably depends on presence and extent of pathogenic fungal isolates and stress levels exerted on seedlings (Hansen and others 1990; James and others 1991b). Nursery seedlings are not routinely stressed, although they may become stressed when outplanted. Therefore, disease symptoms may be absent, even though seedlings are extensively colonized by *Fusarium* spp. On outplanted seedlings, *Fusarium* tends to become replaced on roots (Dumroese and others 1993; Smith 1967). Usually, seedlings with low levels of *Fusarium* root infection perform well when outplanted, especially if they are not extensively stressed (Dumroese and others 1993). However, it is possible that non-diseased seedlings with higher levels of root infection may be at risk when outplanted, particularly if a high proportion of the *Fusarium* isolates present on the root system are pathogenic. Seedlings produced in *Brassica* residue plots were colonized more than those in other treatment plots. This may decrease seedling survival and growth when outplanted.

Significantly higher nitrate concentrations in fumigated soil, compared to other treatments, is most likely a result of nitrogen mineralization from microorganisms killed by fumigation (Hansen and others 1990). While total carbon and nitrogen were unaffected by treatment, organic matter by loss-on-ignition was significantly higher in soil amended with composted sewage sludge. We expected an increase in soil organic matter content after incorporation of *Brassica* residues. However, because nursery soil has a low organic matter content compared to local forest soils (Page-Dumroese and others 1986), large amounts of plant biomass may be necessary to raise it significantly. Increased mineralizable nitrogen in the fallow, fumigated, and organic amended treatments may have allowed seedlings to capitalize on N releases (Page-Dumroese and others 1996) and likely contributed to improved seedling growth in these treatments.

CONCLUSIONS

Incorporating a *Brassica hirta* (variety *humus*) cover crop into soil was ineffective in controlling root disease on bareroot Douglas-fir seedlings. Higher populations of potentially pathogenic *Fusarium* and *Pythium* species and reduced seedling density and quality and higher disease resulted from this treatment. Soil fumigation with dazomet, fallow, and composted sewage sludge treatments were similar in Douglas-fir seedling production after two growing seasons, indicating that it is possible to produce high quality Douglas-fir seedlings without chemical soil fumigation. Fallowing may be a viable option, but problems of soil erosion and low soil organic matter must be considered. Composted sewage sludge was an effective treatment in our test, but needs additional evaluation, particularly on other conifer species which may react differently than Douglas-fir. It is possible that the chemical makeup of this compost may varies time, thus affecting response of soil microorganisms and conifer seedlings.

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