Soil Fumigation, Cover Cropping, and Organic Soil Amendments: Their Effect on Soil-Borne Pathogens and the Target Seedling[1]

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Abstract. --Results of two studies are reported dealing with the impact of three common cultural nursery practices (fumigation, cover cropping and organic soil amendments) on soilborne populations of Fusarium and Pythium. The influence of these practices on seedling quality, mortality, and number of seedlings meeting packing standards is included. The potential use of Brassica sp. as a cover crop to lower propagule counts of soilborne pathogens is discussed.

INTRODUCTION

Soil fumigation and cover cropping are common cultural practices in Pacific Northwest bare root forest nurseries. Soil fumigation in the fall, using metam-sodium, methyl bromide (MC33) or dazomet, kill weed seeds and reduce pathogen populations. These chemicals are very toxic and kill both wanted and unwanted organisms alike. Typically, fumigation is used in blocks that will be used as seed beds the following spring.

Cover crops are grown to replace or build soil organic matter levels, increasing soil aggregation, structure, and water-holding capacity. In addition, cover crops can help in soil stabilization, reclaim nutrients that have moved to lower soil levels, and break up hard pans when their roots penetrate these layers (McGuire and Hannaway 1984). Incorporation of soil amendments, such as sawdust, can have some of the same effects produced by cover cropping.

While these cultural practices are widely used, their impacts on seedling quality and soil borne pathogens have not been adequately documented. Spring fumigation has been extensively studied in forest nursery production but a single report by Tanaka et al. (1986) describes the impact of fall fumigation, the method of choice in the Northwest. Likewise, the influence of cover crops and other organic amendments has been addressed in other crop systems but not in Douglas fir nurseries (Wright et al. 1963, Lu 1967, Johnston and Zak 1977). For these reasons, work was initiated to better understand the interactive effects of these practices on soil borne populations of Fusarium and Pythium in nurseries that grow Douglas-fir. In addition, the influence of these practices on seedling mortality and quality of seedlings at lifting was determined. A second study was initiated to confirm the results of the first study and look further at how cover crops influence soilborne pathogen levels. This paper reports some of the information obtained during these two studies; a more complete description of the first study can be found elsewhere (Hansen et al. 1990).

MATERIALS AND METHODS

Study 1. Plots were established in three bare root nurseries; two in Oregon and one in Washington. Three or four cover crops (legume, grass, legume and grass combination, and fallow) and two fumigation treatments (with and without) each with four replications were installed in each nursery. The legume was either peas or beans, the grass either sudan or oats. Cover

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crops were sown in the spring and plowed under in August. Soil fumigation was done soon after and the area remained fallow until the following spring. Douglas-fir seed was sown in May. Seedling inventories (both alive and dead) were done in mid-summer and late fall as 1+0's and at lifting as 2+0's. Soil samples from five composited subsamples were taken at ten separate times from the center of each replication. Sample times were as follows: (1) immediately before fumigation in the fall, (2) immediately after the tarps were removed following fumigation, (3) mid-winter, (4) immediately before beds were formed prior to sowing, (5) immediately after sowing, (6) late summer, (7) late fall, (8) spring as 2+0's, (9) summer as 2+0's and, (10) just before lifting.

Soils were processed in the laboratory to determine the levels of Fusarium and Pythium. Populations were determined using a modified Komada's medium (Komada 1975) amended with 1 µg/ml Benlate for Fusarium and a V-8 agar medium for Pythium developed by Peninsu-Labs (Hansen et al. 1990). Harvest information determined for each treatment included: numbers of packable seedlings; shoot/root ratios; and Fusarium colonization of roots. All seedlings from the sample plots were graded at lifting to determine numbers of packable seedlings. Shoot/root ratios were determined by comparing dry weights of ten seedling shoots and roots per plot, 40 per treatment. Subsamples of ten seedlings from each plot (40/treatment) were selected at lifting for colonization data. Ten, 1 cm root segments from each seedling's tap root were placed on Komada's medium with Benlate.

Study 2. Following the conclusion of study 1, plots were established in two bare root nurseries (one each in Oregon and Washington) to further test the effects of cover crops, fumigation, and soil amendments. Each nursery had four blocks (replications), each including two main plots (sawdust added or no sawdust) and eight subplots. The subplots were (1) grass (Sudan or Rye) cover crop, soil fumigated and tarped, (2) grass, soil not fumigated and not tarped, (3) grass, soil not fumigated and tarped, (4) fallow, soil not fumigated, not tarped, (5) fallow, soil not fumigated, not tarped; (6) mustard, soil not fumigated, not tarped, (7) mustard, soil not fumigated, not tarped; (8) mustard, soil fumigated, tarped. Cover crop treatments were chopped and dried for two weeks before soil incorporation. Soil samples were collected to determine propagule levels of Fusarium and Pythium at three times: (1) just prior to incorporation of cover crops; (2) eight weeks following incorporation of cover crops, and (3) the following spring prior to sowing. Mustard (variety "Tellney") was grown because of recent reports that Brassica sp. had a potential to control Fusarium levels in soil (Ramirez-Villapudua and Munnecke 1987, 1988) through the break down of glycosinulate to form methyl-isothiocyanate gas (Davis 1988). Propagule levels of Fusarium and Pythium were determined as before. Data analysis for both studies use a Fischer's protected LSD, P = 0.05.

RESULTS

Study 1. For the sake of brevity, only results from two nurseries, A and B, are reported. Populations of Fusarium and Pythium before fumigation were high in all nursery soils (Table 1). Fumigation dramatically reduced populations of both fungi at all nurseries and they remained significantly lower than the unfumigated treatments through the two-year crop cycle (Table 1 and 2).

Cover cropping affected populations of both Fusarium and Pythium at Nurseries A and B. Differences in Fusarium levels due to cover cropping were significant before fumigation at both nurseries and at eight of nine (only 5 sample times listed in Table) subsequent sample times in unfumigated plots. In fumigated plots, the effects of cover cropping were significant for two of nine sample times at Nursery A and seven of nine at Nursery B. Populations of Fusarium were generally lowest in the fallow areas and highest with the legume cover crop. Differences due to cover crops persisted in the unfumigated treatments through lifting.

Pythium populations were also affected by cover cropping. Again, as with Fusarium, fallowing had the lowest number of propagules per gram of soil while the beans or pea cover crop supported the highest. Fumigation nearly eliminated Pythium propagules in the soil so cover crop effects within the fumigated areas could not be determined.

Number and quality of seedlings harvested at the end of the two-year crop cycle differed significantly among treatments only at Nursery B (Table 3). More live trees, and more trees meeting nursery size standards (packable), were present in fumigated plots than in unfumigated plots at both nurseries. On fumigated plots, the trees had greater shoot-to-root ratios. All differences were significant ($p = 0.05$) except for shoot/root ratio at Nursery B. Fusarium oxysporum was recovered significantly less frequently from roots of seedlings harvested from fumigated plots than from nonfumigated plots at Nurseries A and B. Very little Pythium was recovered from seedlings of any treatment at any nursery.

Little, if any, disease was evident at Nursery A during the first growing season regardless of whether the plots were fumigated. Fusarium hypocotyl rot caused serious losses at Nursery B, however, as evidenced by differences in seedling count between June and August (Table 3). Mortality in unfumigated beds (45%) was significantly greater than that in fumigated beds (25%).

At Nursery B, more packable trees, with less Fusarium infection, were produced with fallowing than with either cover crop, regardless of whether the plots were fumigated. There was also less hypocotyl rot after fallowing than after either type of cover-cropping.

Study 2. Fusarium and Pythium levels before fumigation were high (Table 4) at both nurseries, as they were in Study 1. Fumigation (Rye plus Fumigation) significantly reduced propagule counts when measured 12 weeks later (Table 5) and these levels remained low through eight months (Table 6).

The addition of sawdust as a soil amendment reduced soil populations at all sample times but means were not always significantly different. Fusarium numbers before fumigation were halved (26,529 versus 13,044) at Nursery D and reduced by 1/3 (9,260 versus 6,089) at Nursery E (Table 4). Pythium levels were also lower (152 versus 120) at Nursery D and were significantly reduced (P = 0.05) at Nursery E (292 versus 5). These differences persisted for 12 weeks (Table 5) and eight months (Table 6) following fumigation at the two nurseries.

Cover crops also had a significant impact in some cases. As in Study 1. fallow treatments in unfumigated plots had nearly always the fewest propagules of Fusarium at all sample times, and differences were often significant. Pythium numbers were also reduced in fallow areas, but not as dramatic or consistent as that which occurred with Fusarium. Highest levels of Fusarium were generally where mustard was grown before treatment (Table 4). Mustard incorporation, however, reduced Fusarium levels at both nurseries over the rye cover crop, but only significantly so at Nursery E (Table 5). Pythium numbers were variable following incorporation of the mustard cover crop at both nurseries.

DISCUSSION

The dramatic reduction of soil populations of Fusarium oxysporum and Pythium spp. following fall fumigation was not surprising, although it has only been documented in one other study involving western conifer nurseries and current nursery practices. The duration of the effect

Table 1. Fusarium populations (colony-forming units per gram dry weight of soil) at various times during the two-year crop cycle in soils of two Douglas-fir seedling nurseries subjected to various combination of cover crops and fumigation treatments[1]

	Sampling Time				
Nursery and Treatment	Pre-Fumigation Sept. 1985	Post-Fumigation Nov. 1985	Presowing June 1986	Aug. 1986	Aug. 1987
Nursery A					
Fumigated	1670a	15a	40a	1170a	6390a
Fallow	10570b	0a	40a	1130a	2910a
Oats	5700b	0a	20a	820a	3510a
Peas & Oats	3750b	3a	40a	1000a	5400a
Peas					
Unfumigated	1820A	1260A	430A	1260A	17060A
Fallow	6909B	10040B	2460BC	6570B	53440A
Oats	5820B	8270B	3640B	9100B	43340A
Peas & Oats	11420B	9550B	1920B	6720B	39910A
Peas					
Nursery B					
Fumigated					
Fallow	13690a	90a	40a	80a	760a
Sudan	32910b	1a	330b	530b	2710b
Beans	48340b	160a	1170c	1670c	9180b
Unfumigated					
Fallow	1920A	8510A	1370A	3590A	2560A
Sudan	17120B	8710A	4520B	11820B	8990A
Beans	31660B	8680A	13139C	18030C	33780A

[1]Within a column segment for a single nursery and fumigation treatment, populations followed by the same letter (lower case letter = fumigated areas, uppercase letter = unfumigated areas) are not significantly different by Fischer's protected LSD (P = 0.05).

was surprising, however. Not only were populations low at the time of sowing eight months after fumigation (Study 1 and 2), but also they increased very slowly and remained significantly lower than in unfumigated beds through the entire two-year crop cycle (Study 1). Population differences were maintained despite the immediate proximity of unfumigated beds and the repeated movement of tractors and irrigation water across the plots. Not until a new cover crop was plowed under nearly three years later did populations approach prefumigation levels (Hansen *et al*. 1990).

Although more seedlings were produced in fumigated beds during Study 1 than in unfumigated ones, there were no real differences in root growth potential of the trees, as measured by the standard test (data not shown). Seedlings from unfumigated beds were smaller and more variable in size than those from fumigated beds, and more of them did not meet packing standards for this reason.

The effect of the preceding cover crop in determining populations of both *Fusarium* and *Pythium* was evident in the fall of the first year, even before the ground was fumigated (Study 1 and 2). Differences persisted through the entire crop cycle in unfumigated treatments (Study 1). Although legume cover crops tended to support higher populations than did grass cover crops, the most significant differences were between no cover crop (fallowing) and the other treatments. These differences were still present 30 months after the cover crop was plowed under in unfumigated plots. *Fusarium* populations in fallow, unfumigated plots were often within the range found among fumigated plots with cover crops. There is very little experimental basis for the practice of cover cropping in the Northwest (McGuire and Hannaway 1984). Benefits cited include disease control from crop rotation, soil stabilization, and increased levels of soil organic matter with supposed improvements in soil structure. Actual species used for cover cropping vary from nursery to nursery, depending on the experience of local managers.

The potential use of mustard to lower soil population levels of *Fusarium* and *Pythium* needs further investigation. While *Fusarium* numbers decreased substantially in mustard plots

Table 2. *Pythium* populations (colony-forming units per grain dry weight of soil at various times during the two-year crop cycle in soils of two Douglas-fir seedling nurseries subjected to various combinations of cover crops and fumigation[1]

Nursery and Treatment	Sampling Time: Pre-Fumigation Sept. 1985	Post-Fumigation Nov. 1985	Presowing June 1986	Aug. 1986	Aug. 1987
Nursery A					
Fumigated	280a[1]	4a	4a	2a	10a
Fallow	640a	0a	4a	6a	20a
Oats	680a	0a	30a	10a	10a
Peas & Oats	940b	1a	2a	20a	30a
Peas					
Unfumigated	160A	260A	150A	130A	100A
Fallow	780B	790B	200A	150AB	230A
Oats	630B	580B	400A	170AB	250A
Peas & Oats	1060B	1100B	240A	530B	380A
Peas					
Nursery B					
Fumigated					
Fallow	2a	0a	0a	0a	0a
Sudan	20b	1a	0a	0a	0a
Beans	80b	0a	0a	0a	0a
Unfumigated					
Fallow	0A	100A	10A	0A	4A
Sudan	30B	60A	10A	20B	20A
Beans	80B	110A	30A	20B	20B

[1]Within a column segment for a single nursery and fumigation treatment, populations followed by the same letter (lower case letter = fumigated areas, uppercase letter = unfumigated areas) are not significantly different by Fischer’s protected LSD (P = 0.05).

following incorporation compared to grass, these levels were still much higher than the standard grass and fumigation treatment and generally higher than the fallow areas. This may be partially due to the higher levels of Fusarium found in the mustard treatments prior to incorporation and/or fumigation (Table 4). Data are not yet available on whether these higher Fusarium levels affect seedling survival or quality in Douglas-fir grown from seed sown into these areas.

The addition of sawdust reduced levels of these pathogens in the soil. Apparently the benefits of adding organic matter are greater than those limited to improving the physical properties of the soil. Whether this benefit of lowering propagule levels transfers to higher seedling survival and quality is unknown. Previous reports dealing with pine in the northwest would indicate this is likely to happen (Wright *et al*. 1963, Lu 1968, Johnston and Zak 1977). Additional field plots have been established during the spring of 1990 to further investigate the use of cover crops and soil amendments to lessen soil borne propagule counts and future disease losses.

These studies confirm the value of fumigating forest tree nursery beds before sowing. As long as fumigation is the standard practice, there is little practical significance to the results about cover cropping or soil amendments without fumigation. Fumigation is a costly procedure, however, and the chemicals used are extremely toxic. Both economic and environmental pressures are stimulating interest in alternative strategies for disease control. The influence of cover crops and soil amendment on pathogen populations will be an important factor in proposed programs of integrated biological and cultural control.

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Table 3. Number and quality of Douglas-fir seedlings grown in two nurseries with and without cover cropping and fumigation[1]

Nursery and Treatment	Packable Seedlings[2]	Shoot/Root Ratio	Fusarium Isolation[3]	Seedling Count[4] June 1986	Seedling Count[4] Aug. 1986
Nursery A					
Fumigated					
Fallow	195a	2.7a	3a	28.3a	27.1a
Oats	200a	--	--	28.7a	26.3a
Peas & Oats	193a	2.7a	3a	29.7a	26.9a
Peas	204a	--	--	28.8a	27.5a
Unfumigated					
Fallow	186A	2.2A	11A	28.3A	26.9A
Oats	180A	--	--	28.1A	25.3A
Peas & Oats	205A	2.5A	27B	28.5A	26.3A
Peas	197A	--	--	26.4A	24.9A
Nursery B					
Fumigated					
Fallow	313a	1.5a	7a	38.0a	32.0a
Sudan	283b	1.8a	17a	32.8a	26.3ab
Beans	223b	1.9a	48b	34.8a	23.3b
Unfumigated					
Fallow	197A	1.6A	44A	29.5A	18.1A
Sudan	161B	1.6A	73B	28.8A	15.4AB
Beans	143B	1.4A	73B	30.5A	14.6B

[1]Within a column segment for a single nursery and fumigation treatment, populations followed by the same letter (lower case letter = fumigated areas, uppercase letter = unfumigated areas) are not significantly different by Fischer's protected LSD (P = 0.05).

[2]Average number of seedlings (per 1- x 1.2 m plot) meeting nursery standards at final harvest.

[3]Average frequency (%) of isolations of Fusarium from 10, 1 cm sections of tap root on Komada's medium.

[4]Number of healthy seedlings in 0.93 m^2 of bed at the indicated dates.

Table 4. Numbers of *Fusarium* and *Pythium* propagules before fumigation and/or incorporating cover crops into soil[1]

	Sawdust			
	Nursery D		Nursery E	
	Fusarium	Pythium	Fusarium	Pythium
Fallow	8297a[2]	98a	2133a	36a
Fallow & Tarp	1708a	112a	6290b	22a
Mustard	11201bc	153a	11333b	398b
Mustard & Tarp	30341c	136a	5733ab	253b
Grass & Fumigation	19885c	117a	5947ab	15a
Grass	7834ab	108a	4858ab	55b
Overall	13044	120	6089	5[3]
	No Sawdust Added			
Fallow	6184a	140a	16161b	35a
Fallow & Tarp	17017a	305a	13501b	102a
Mustard	48417bc	127a	7274ab	503b
Mustard & Tarp	30989c	96a	7678ab	313b
Grass & Fumigation	42500c	141a	3122a	121a
Grass	14067ab	103a	7823ab	677b
Overall	26529	152	9260	292[3]

[1]Propagules per gram of dry soil
[2]Numbers in a single column followed by the same letter not significantly different at P = 0.05
[3]Significantly different at p = 0.05

Table 5. Numbers of Fusarium and Pythium propagules 12 weeks following fumigation and/or cover crops incorporation[1]

	Sawdust			
	Nursery D		Nursery E	
	Fusarium	Pythium	Fusarium	Pythium
Fallow	19426a2	687c	6636b	28b
Fallow & Tarp	7639b	127b	10746bc	12b
Mustard	24946b	705cd	23056c	247c
Mustard & Tarp	41138b	257b	18357c	274c
Grass & Fumigation	1232a	0a	0a	0a
Grass	54561b	843d	76240d	265c
Overall	24824	437	22506	154[3]
	No Sawdust Added			
Fallow	38650b	455c	10606b	84b
Fallow & Tarp	59019b	229b	27230bc	236bc
Mustard	111750b	561cd	42610c	816d
Mustard & Tarp	138305b	301b	44434c	444cd
Grass & Fumigation	337a	0a	0a	0a
Grass	168823b	1129d	63328d	192bc
Overall	56147	446	31368	295[3]

[1]Propagules per gram of dry soil
[2]Numbers in a single column followed by the same letter not significantly different at P = 0.05
[3]Significantly different at p = 0.05

Table 6. Numbers of Fusarium and Pythium propagules eight months following Fumigation and/or cover crop incorporation (prior to sowing)[1]

	Sawdust			
	Nursery D		Nursery E	
	Fusarium	Pythium	Fusarium	Pythium
Fallow	4935bc[2]	203b	1616ab	52b
Fallow & Tarp	324a	103b	1768ab	18b
Mustard	5676bc	334b	5225b	163c
Mustard & Tarp	8390c	424bc	4606b	176c
Grass & Fumigation	4529b	19a	3518a	8a
Grass	9421c	1060c	13196c	81c
Overall	5546	357	4988	83
	No Sawdust Added			
Fallow	7320b	305b	4920ab	41b
Fallow & Tarp	6702ab	542b	5765ab	103b
Mustard	24660c	404b	4361b	554c
Mustard & Tarp	12280bc	604bc	5503b	342c
Grass & Fumigation	2990a	76a	1927a	2a
Grass	11715c	791c	15933c	228c
Overall	10994[3]	454	6402	212

[1]Propagules per gram of dry soil

[2]Numbers in a single column followed by the same letter not significantly different at P = 0.05

[3]Significantly different at p = 0.05

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