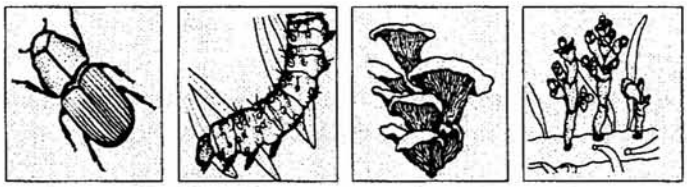
Forest Health Protection



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AN EVALUATION OF THE EFFECTS OF DAZOMET ON SOIL-BORNE DISEASES AND CONIFER SEEDLING PRODUCTION - USDA FOREST SERVICE LUCKY PEAK NURSERY BOISE, IDAHO

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ABSTRACT

An evaluation was conducted at the USDA Forest Service Lucky Peak Nursery to investigate efficacy of dazomet (Basamid® granular) soil fumigant to reduce soil populations of *Fusarium* and *Pythium* spp. and subsequent post-emergence damping-off and root diseases. Effects on ponderosa and lodgepole pine seedling establishment, density, growth, and biomass production were also evaluated. Results were compared with soil fumigation with methyl bromide/chloropicrin (MBC) and fallow (non-fumigation) which had been done previously in nearby fields. Dazomet greatly reduced soil populations of potentially pathogenic *Fusarium* and *Pythium* spp. as well as populations of potentially antagonistic *Trichoderma* spp. Populations of *Fusarium* spp. gradually increased in fields growing pine seedlings to levels higher than were present prior to fumigation. Ponderosa and lodgepole pine seedling mortality was generally lower in areas fumigated with MBC than in areas either fumigated with dazomet of left fallow. Seedlings were also consistently taller in MBC-treated areas. Root volume was consistently less in seedlings grown in dazomet-treated fields. Dazomet soil fumigation was not nearly as effective as MBC fumigation in controlling soilborne diseases at the nursery. Fallowing fields for at least one year prior to sowing was at least as effective as dazomet fumigation. In this evaluation, dazomet was not an effective alternative to MBC as a soil fumigant at the Lucky Peak Nursery.

INTRODUCTION

Soil at many United States bareroot forest nurseries is fumigated before sowing to reduce impact of soil-borne fungal and nematode pathogens, kill weed seeds, and reduce populations of potential insect pests (Cordell 1982; Hill 1959). Methyl bromide/chloropicrin (MBC) mixtures are the most effective fumigant at most nurseries (James 1989; Miller and Norris 1970). Since about 1978, the USDA Forest Service Lucky Peak Nursery near Boise, Idaho has fumigated nursery beds with MBC (Dowfume MC-33: 67 percent methyl bromide, 33 percent chloropicrin)(Hoffman and Williams 1988). MBC use at many nurseries often results in production of superior-quality seedlings that are larger and healthier than those produced in non-fumigated soil (Boyd 1971; James and others 1990, 1996; Smith and Bega 1966). As a result of its extreme effectiveness, growers at many nurseries have

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come to rely on MBC as an important pre-plant treatment in production fields despite its high cost.

However, methyl bromide has recently been selected for phase-out and eventual elimination in the United States by the Environmental Protection Agency as part of compliance with the Clean Air Act (Shaheen 1996) because it is an important depleter of stratospheric ozone (Evans and Greczy 1995; Sims and others 1997). Initially, elmininationof methyl bromide use and manufacture was to occur on January 1, 2001 (Environmental Protection Agency 1993; Shaheen 1996). However, elimination has recently been extended to comply with phaseouts proposed for other countries (Shaheen 1996). In any event, methyl bromide will be eventually eliminated from use as a soil fumigant in the United States (James and others 1993, 1994; Linderman and others 1994) and nurseries that relied on the chemical will have to develop alternative ways of controlling soil pests.

An alternative soil fumigant extensively scrutinized and tested is dazomet (Basamid® granular). Dazomet is applied over the soil surface and has the consistency of powdered sugar (Boone 1988). After application, beds are often compacted with a heavy roller (Chapman 1992) and the material is then disked into the soil and either covered with plastic tarp or left uncovered (Boone 1988; Hildebrand and Dinkel 1988). If uncovered, treated fields are sealed with overhead irrigation, which also activates the fumigant. The major active ingredient in dazomet is methylisothiocyanate, a general biocide (Boone 1988; Kelpsas and Campbell 1994). Dazomet has effectively controlled soil-borne pathogens in some cases (Barnard and others 1994; Campbell and Kelpsas 1988; Chapman 1992; James and others 1990), but yielded less than desirable results in others (Carey 1995; Evans and Greczy 1995; Hildebrand and Dinkel 1988).

Even though MBC soil fumigation has been very effective at the Lucky Peak Nursery (Marshall 1983, 1985), previous experience with dazomet fumigation has been disappointing (Hoffman and Williams 1988). However, because of the urgency of locating effective alternatives to MBC fumigation, a more comprehensive dazomet evaluation encompassing several different fields was conducted. Efficacy was evaluated by determining treatment effects on soil populations of potentially pathogenic fungi and on seedling mortality and growth during a typical 2-year production cycle.

MATERIALS AND METHODS

Three fields at the Lucky Peak Nursery (1, 8, and 14) were selected for dazomet fumigation. All three fields had been used to produce conifer seedlings the year before fumigation. Fields were cultivated to reduce weeds and aerate soil. Dazomet was applied topically at 392kg/ha (350 lbs./acre) in early September; the fumigant was then incorporated into soil by discing and activated by overhead irrigation. Fumigated fields were not entered and kept fallow until sowing the following spring. In late April of the year following fumigation, fields were sown with ponderosa (*Pinus ponderosa* Laws.)(fields 1 & 14) or lodgepole pine (*Pinus contorta* Dougl.)(field 8) seeds using standard sowing practices. Several different seedlots were used in each field. Non-treated fields were not included for comparison at the time of dazomet fumigation because of expected production problems in non-fumigated soil (James 1996a). Therefore, data obtained from dazomet-treated fields were compared with data obtained previously in an evaluation of MBC fumigation and fallowing conducted in different fields at the nursery. In this previous test (Stone and others 1997), lodgepole and ponderosa pine production was evaluated in fields 4 and 13, respectively.

To test efficacy of dazomet soil fumigation on populations of potentially pathogenic fungi, several soil samples were collected and analyzed at different times during the production cycle. Samples were taken in September, just prior to fumigation and in October shortly after fumigation. Additional samples were taken at the time of sowing (the following April), at the end of the first growing season (October), and at the beginning (May) and end (November) of the second growing season (table 1). Twenty-five samples were collected near seedling monitoring plots (one per plot) which were systematically located throughout each fumigated field. Each soil sample consisted

of a core taken to a depth of about 15 cm. Soil was placed in labeled plastic bags, kept refrigerated, and transported to the laboratory for analysis.

Standard soil dilution techniques (Hoffman and Williams 1988; James and Gilligan 1985, 1986, 1990; Marshall 1983, 1985, 1986) were used to determine populations of two groups of potentially pathogenic fungi: *Fusarium* and *Pythium* spp. On plates used to assay *Fusarium* spp., populations of *Trichoderma* spp. were also determined. These latter fungi are common soil inhabitants and some species are potentially antagonistic toward pathogens including *Fusarium* (Papavizas 1985; Papavizas and Lumsden 1980). Soil was initially sieved (2 mm sieve) to remove rocks, pieces of undecomposed 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 or until sample weight had stabilized and all excess moisture was removed. Oven-dry weight was then calculated to provide a standard for comparison. For assay of *Fusarium* and *Trichoderma* populations, 0.05 g of field-moist soil was combined with 10 ml of 0.3 percent water agar (WA) and thoroughly mixed. One ml of solution was placed on each of 3 plates of selective agar medium (Komada 1975) and spread uniformly. Plates were incubated 5 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 calculated. Selected *Fusarium* isolates were transferred to carnation leaf agar (Fisher and others 1982) and potato dextrose agar for identification using the taxonomy of Nelson and others (1983). For assay of *Pythium* populations, 0.5 g of soil was combined with 10 ml of 0.3 percent WA. 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 Gilligan 1985, 1985, 1990; James and others 1990, 1996). 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. It was assumed that each colony originated from an individual propagule; populations were expressed as colony-forming units (cfu) per g of oven-dried soil.

For monitoring effects of dazomet on seedling establishment, disease, and growth, 25 monitoring plots were systematically located throughout each of the three treated fields. Plots measured 0.46 m^2 (1.5 ft^2) and were delimited with wood stakes at each of their corners. These plots were located in the center portion of each bed and did not include seedlings in the outer two rows. Seedling establishment was evaluated within each monitoring plot about 30 days after sowing. Post-emergence damping-off was also determined by locating and removing diseased seedlings within each plot. Since precision sowing was not done, it was impossible to determine relative treatment effects on seed germination and pre-emergence damping-off. Seedling disease was monitored three more times (at about 1½ month intervals) during the first growing season. Diseased seedlings within monitoring plots were collected for laboratory analysis of associated pathogens. Seedling roots and stems were washed thoroughly under running water, surfaced sterilized in 10% aqueous sodium hypochlorite, rinsed in sterile water, and placed on the selective *Fusarium* medium (Komada 1975). Plates were incubated as described above and selected isolates were identified. At the end of the first growing season (October), seedling density (number per m^2) and height of 15 randomly selected seedlings were measured within each monitoring plot. First-year seedling disease was calculated as an accumulation of diseased seedlings located during the previous sampling periods.

At the end of the second growing season (November), seedlings were lifted using standard nursery procedures. Ten seedlings were randomly collected near each monitoring plot (250 seedlings per field). Sampled seedlings were measured for height and diameter (caliper). Root volume was estimated as oven-dry weights of roots following extensive washing to remove soil.

RESULTS AND DISCUSSION

Effects of soil fumigation with dazomet and methyl bromide/chloropicrin and fallowing on soil populations of *Fusarium*,*Trichoderma* and *Pythium* spp. are summarized for ponderosa and lodgepole pine production fields in tables 1 and 2, respectively. Dazomet consistently reduced, but did not eliminate, *Fusarium* populations, which increased throughout the 2-year crop cycle to levels that were higher than those found before treatment. Similar results were found with dazomet fumigation previously at the Lucky Peak Nursery (Hoffman and Williams 1988) and other forest nurseries (Hildebrand and Dinkel 1988). Under most nursery conditions, *Fusarium* populations in excess of 1000 cfu/g are of concern from the standpoint of potential disease (Hildebrand and Dinkel 1988; James and others 1990, 1996; Robbins and LaMadeleine 1979). However, it has been difficult to accurately predict level of disease based on soil *Fusarium* populations (Stone 1991; Stone and others 1997). One major reason is that the proportion of the *Fusarium* population made up of pathogenic isolates is unknown (James and others 1991). Pathogenic and non-pathogenic isolates appear morphologically similar (Bloomberg 1976; Gordon and Martyn 1997; Nelson and others 1983). They often can only be differentiated with extensive pathogenicity testing (James 1996b; James and others 1991), although recent molecular biology techniques have shown some promise in more easily identifying pathogenic isolates (Appel and Gordon 1996; Gordon and Martyn 1997; Gordon and Okamoto 1992).

In a previous test in different fields, MBC fumigation also reduced, but did not eliminate soil *Fusarium* populations (tables 1 and 2). Experience at some other nurseries (Fuller and others 1980; James and others 1990; Norris 1985; Stone and others 1997) indicated that MBC fumigation may completely eliminate soil populations of most microorganisms, including *Fusarium* spp. Levels of these potential pathogens often stay low or nondetectable throughout a 2-year crop cycle in MBC-fumigated fields (James and others 1990). Marshall (1985) previously found that MBC at the Lucky Peak Nursery effectively eliminates *Fusarium* spp. from the upper soil to a depth of 15 cm but may not penetrate sufficiently below 15 cm in dense soils to kill all pathogen propagules.

Soil fallowed for one year prior to sowing supported nearly the same *Fusarium* populations throughout the sampling periods (tables 1 and 2). Populations were usually well below disease threshold levels (Hildebrand and Dinkel 1988; Robbins and LaMadeleine 1979), and in some cases approximated those found in fumigated soil.

The most common *Fusarium* species consistently isolated from soil was *F. oxysporum* Schlecht. (table 3). It comprised more than 93 percent of all *Fusarium* isolates obtained from five different fields at the Lucky Peak Nursery. *Fusarium oxysporum* has previously been described at the nursery as an important soil inhabitant (James 1996a; Marshall 1983, 1985) and most often associated with diseased seedlings (James 1996a). *Fusarium oxysporum* is by far the most important soil-borne pathogen in many bareroot conifer nurseries in western North America (Bloomberg 1971, 1976; Enebak and others 1989; Hansen and others 1990; James and others 1990, 1991, 1996). However, because pathogenic soil isolates of this species cannot easily be differentiated from saprophytic isolates (Gordon and Martyn 1997; Nelson and others 1983), an unknown proportion of the population is capable of eliciting disease. Factors in addition to population densities that probably contribute to disease severity caused by *F. oxysporum* include soil temperature and moisture content (Bloomberg 1979; Brownell and Schneider 1985) and levels of competing microorganisms (Baker and Cook 1974; Papavizas and Lumsden 1980). Other Fusarium species were found at much lower levels in soil (table 3). These included *F. solani* (Mart.) Appel & Wollenw., *F. acuminatum* (Ell. & Ev.), *F. avenaceum* (Fr.) Sacc., *F. sambucinum* Fuckel, *F. equiseti* (Corda) Sacc., and *F. sporotrichioides* Sherb. Although some of these species have been implicated as potential pathogens of conifer seedlings (James and others 1989, 1991), most are probably saprophytic on soil organic matter.

Table 1. Effects of dazomet and MBC fumigation and fallowing on soil populations of *Fusarium*, *Trichoderma* and *Pythium* spp. in ponderosa pine production fields at the USDA Forest Service Lucky Peak Nursery, Boise, Idaho.[1]

	Month - Year						
Treatment	May-1	Sep-1	Oct-1[2]	Apr-2[3]	Oct-2	May-3	Nov-3
Dazomet[4]							
Fusarium	--	433	206	74	199	249	834
Trichoderma	--	909	270	644	379	750	901
Pythium	--	3	1	1	1	1	3
T/F Ratio[5]	--	2.1	1.3	8.7	1.9	3.0	1.1
MBC[6]							
Fusarium	96	1283	--	80	--	--	--
Trichoderma	4889	6186	--	10030	--	--	--
Pythium	0	0	--	0	--	--	--
T/R Ratio[5]	50.9	4.8	--	125.4	--	--	--
Fallow[6]							
Fusarium	265	868	--	369	--	--	--
Trichoderma	5714	5722	--	7276	--	--	--
Pythium	1	2	--	0	--	--	--
T/R Ratio[5]	21.6	6.6	--	19.7	--	--	--

[1] Values expressed as cfu/g oven-dry soil. Horizontal lines indicate no sample taken.
[2] Post-fumigation sample.
[3] Sample at the time of sowing.
[4] Populations from fields 1 and 14.
[5] Ratio of *Trichoderma* to *Fusarium* populations.
[6] Populations from field 13.

Table 2. Effects of dazomet and MBC fumigation and fallowing on soil populations of *Fusarium*, *Trichoderma* and *Pythium* spp. in lodgepole pine production fields at the USDA Forest Service Lucky Peak Nursery, Boise, Idaho.[1]

	Month - Year						
Treatment	May-1	Sep-1	Oct-1[2]	Apr-2[3]	Oct-2	May-3	Nov-3
Dazomet[4]							
Fusarium	--	238	5	303	170	184	666
Trichoderma	--	5147	151	1502	1159	1242	2883
Pythium	--	53	1	4	1	3	10
T/R Ratio[5]	--	21.6	28.0	4.9	6.8	6.7	4.3
MBC[6]							
Fusarium	83	654	--	108	--	--	--
Trichoderma	1373	5419	--	9310	--	--	--
Pythium	182	153	--	8	--	--	--
T/R Ratio[5]	16.5	8.3	--	86.2	--	--	--
Fallow[6]							
Fusarium	329	475	--	483	--	--	--
Trichoderma	3905	2992	--	3432	--	--	--
Pythium	138	190	--	150	--	--	--
T/R Ratio[5]	11.9	6.3	--	7.1	--	--	--

1 Values expressed as cfu/g dry soil. Horizontal lines indicate no samples taken.
2 Post-fumigation sample.
3 Sample taken at time of sowing.
4 Populations from field 8.
5 Ratio of *Trichoderma* to *Fusarium* populations.
6 Populations from field 4.

Table 3. *Fusarium* species isolated from soil within selected fields at the USDA Forest Service Lucky Peak Nursery, Boise, Idaho.

	Field Number						
Percent[1]	1	4	8	13	14	Average	Sample[2]
FOXY	82.4	97.3	96.5	95.2	95.2	93.3	2809
FSOL	15.9	1.5	1.7	0.2	0	3.9	130
FACU	1.7	0	0.3	2.9	3.3	1.6	48
FSAM	0	1.2	0.5	1.5	0.9	0.8	29
FAVE	0	0	0.3	0	0.6	0.2	7
FEQU	0	0	0.5	0	0	0.1	3
FSPO	0	0	0	0.2	0	0.1	1

[1] Percent of *Fusarium* isolates recovered from soil: FOXY= *F. oxysporum;* FSOL= *F. solani*; FACU=*F. acuminatum*; FSAM= *F. sambucinum*; FAVE= *F. avenaceum*; FEQU= *F. equiseti*; FSPO= *F. sporotrichioides.*

[2] Number of isolates sampled.

Trichoderma spp. are common soil-inhibiting fungi whose levels fluctuate in response to other soil fungi (Papavizas 1985). Some *Trichoderma* spp. are antagonistic toward pathogenic fungi, including *Fusarium* spp. (Papavizas 1985; Papavizas and Lumsden 1980). Experience has shown that the higher the *Trichoderma* level in soil, the lower the *Fusarium* level, unless soil is fumigated with general biocides (James and others 1990, 1996). *Trichoderma* spp. are very rapid recolonizers of fumigated soil (Banerjee and Anderson 1992; Carey 1995; Danielson and Davey 1969); shortly after fumigation they may be the major component of the soil mycoflora (Banerjee and Anderson 1992; Munnecke and Van Gundy 1979; Vaartaja 1967). The proportion of *Trichoderma* in soil often decreases with time. We found that *Trichoderma* spp. responded to soil fumigation like *Fusarium* (tables 1 and 2). Levels following fumigation were reduced, but populations often increased rapidly following fumigation, especially in MBC-treated soil. The ratio of *Trichoderma* to *Fusarium* (T/F) populations has been useful as an approximate estimate of potential disease suppressiveness in nursery soils (James 1996a; James and others 1996). Generally, the higher the ratio, the less potential for *Fusarium*-caused disease. Ratios were not as greatly affected by either dazomet or MBC fumigation (tables 1 and 2). Fallowing likewise had little impact on T/F ratios over time. Apparently, because of their extensive propensity to recolonize MBC-fumigated soil (Danielson and Davey 1969; Vaartaja 1967), *Trichoderma* spp. may limit *Fusarium*-caused disease in treated fields.

Pythium levels at the Lucky Peak Nursery are usually low, except in some fields where poor water drainage allows standing water for extended periods (Hoffman and Williams 1988; James 1996a; Marshall 1985). *Pythium* levels exceeding about 100 cfu/g may result in important disease losses (Hildebrand and Dinkel 1988). Populations in ponderosa pine production fields were very low or nondetectable (table 1). However, in some portions of lodgepole pine fields, levels were initially high but responded as expected to soil fumigation (table 2). *Pythium* populations did not greatly change in fallowed areas.

Soil populations of fungi such as *Fusarium, Trichoderma* and *Pythium* give only rough

estimates of potential disease. The most important measurements determining efficacy of any soil treatment are amount of seedling mortality, seedling density (which is directly related to disease levels), and effects on seedling growth (Boyd 1971; Campbell and Kelpsas 1988). Seedling growth is manifested by height, diameter, and, most importantly for root pathogen effects, by root volume. Both *Fusarium* and *Pythium* spp. may adversely affect seedlings without eliciting above-ground disease symptoms (James and Gilligan 1988a, 1988b; James and others 1991). Reductions of root production may be determined by comparing root volumes (Stone 1991; Stone and others 1997). Root volumes are most easily compared from oven-dry root weights (James and others 1996). Other ways to evaluate sub-lethal effects include determining root infection levels (James and Gilliagn 1988a, 1988b; James and others 1991) and monitoring outplanting performance of infected seedlings (Dumroese and others 1993).

Effects of soil fumigation and fallowing on seedling mortality, density, and growth are summarized for ponderosa and lodgepole pine in tables 4 and 5, respectively. Seedling mortality for both pine species was lower in areas fumigated with MBC than in areas either fumigated with dazomet or left fallow. The major *Fusarium* species consistently associated with dead and dying seedlings was *F. oxysporum*. This species, which was the most common *Fusarium* soil inhabitant (table 3), was usually isolated from roots, stems, and cotyledons of diseased seedlings.

Seedling density was generally less in dazomet-treated fields at the end of the first growing season (tables 4 and 5). Seedlings were consistently taller in MBC-treated fields. Seedlings produced in fallowed areas were about the same size as those grown in dazomet-treated soils. However, root volume was consistently less in seedlings grown in dazomet-treated fields.

We found that dazomet was not nearly as effective as MBC fumigation at the Lucky Peak Nursery when comparing seedling disease levels, density, and growth. One possible explanation for reduced efficacy of dazomet is that the active ingredient of the fumigant (methylisothiocyanate) is readily absorbed to clay in soil (Ben-Yephet and Frank 1985). As a result, dispersal and penetration of pathogen-toxic chemicals may be limited in the high clay soils of the Lucky Peak Nursery. For greatest efficacy, soil must be extensively worked prior to fumigation to provide as much aeration as possible (Barnard and others 1994). Also, dazomet should only be applied when soil moisture and temperatures are optimum for penetration of volatile chemicals (Hildebrand and Dinkel 1988; James and others 1990; Munnecke and Van Gundy 1979).

Although diseases at the Lucky Peak Nursery varies from year to year, at least some disease usually occurs in both fumigated and non-fumigated fields during the first growing season (Hoffman and Williams 1988; James 1996a). In extreme cases, extensive *Fusarium*-associated losses can occur if environmental conditions are conducive to disease and sufficient soil inoculum is present (James 1996a). One goal of disease control is to maintain soil pathogen populations at sufficiently low levels to ensure that diseases don't severely impact seedling crops. Soil at the Lucky Peak Nursery appears conducive to buildup of *Fusarium* populations (Marshall 1983, 1985, 1986) and is apparently not as amenable to dazomet fumigation as soil at some other nurseries (Barnard and others 1994; Campbell and Kelpsas 1988; Chapman 1992; James and others 1990). Therefore, it may be more difficult to consistently control *Fusarium*-associated diseases at the Lucky Peak Nursery, especially without use of MBC. Alternative soil fumigants other than dazomet may be more effective. Chloropicrin has shown some promise in conifer seedling nurseries where dazomet was not effective (Linderman and others 1994). Metam-sodium is another common fumigant that warrants evaluation (Barnard and others 1994; Linderman and others 1994; Sumner and others 1997). Methyl iodide is currently being developed as a potential alternative soil fumigant and has shown promise in some agricultural systems (Sims and others 1997).

Table 4. Effects of dazomet and MBC fumigation and fallowing on ponderosa pine seedling mortality and growth at the USDA Forest Service Lucky Peak Nursery, Boise, Idaho.

	Soil Treatment		
Parameter	Dazomet[1]	MBC[2]	Fallow[2]
Mortality[3]	23	4	16
Density[4]	151	204	204
First Height[5]	9	12	11
Second Height[6]	21	23	21
Diameter[7]	.4	5.5	5.4
Root Volume[8]	3.1	3.7	3.5

1 From seedlings grown in fields 1 and 14.
2 From seedlings grown in field 13.
3 Percent first season seedling mortality.
4 Average seedling density at the end of the first growing season (no. seedlings/m^2)
5 Average seedling height (cm) at the end of the first growing season.
6 Average seedling height (cm) at the end of the second growing season.
7 Average seedling above-ground diameter (caliper)(mm) at the end of the second growing season.
8 Average seedling root oven-dry weight (g) at the end of the second growing season.

Ideally, it would be best to avoid chemical soil fumigation altogether. This would not only significantly reduce seedling production costs, but would allow eventual stabilization of soil microorganism populations. Microorganism stabilization may mean lower future disease because many soil microorganisms effectively compete with or are antagonistic toward soil-borne pathogens (Baker and Cook 1974; Papavizas and Lumsden 1980). As a result, under stable conditions, pathogen levels probably would not fluctuate widely from year to year, resulting in predictable low disease levels.

Disease-suppressive soils are not conducive to disease even though pathogens are present (Baker and Cook 1974; Schroth and Hancock 1989; Sneh and others 1987). Suppressive soils are often encountered in natural, undisturbed plant ecosystems (Schroth and Hancock 1982), but have also been developed under agricultural conditions (Schroth and Hancock 1982; Sneh and others 1987). Supplementing soil with beneficial microorganisms including bacteria (Baker and Cook 1974; Schroth and Hancock 1982), actinomycetes (Baker and Cook 1974), and fungi (Harman and others 1989; Papavizas 1985) may help establish suppressive soils. In some cases, adding mycorrhizal symbionts to soil has improved control of soil-borne pathogens including *Fusarium* spp. (Chakravary and others 1990; Duchesne and others 1989). Introducing biocontrol agents at relatively high levels may help develop disease-suppression in non-fumigated soils.

Table 5. Effects of dazomet and MBC fumigation and fallowing on lodgepole pine seedling mortality and growth characteristics at the USDA Forest Service Lucky Peak Nursery, Boise, Idaho.

	Soil Treatment		
Parmeter	Dazomet[1]	MBC[2]	Fallow[2]
Mortality[3]	20	11	17
Density[4]	183	215	204
First Height[5]	44.5 A	8	6
Second Height[6]	13	17	14
Diameter[7]	4.0	4.1	4.2
Root Volume [8]	2.2	3.0	2.6

1 From seedlings grown in field 8.
2 From seedlings grown in field 4.
3 Percent first season seedling mortality.
4 Average seedling density at the end of the first growing season (no. seedlings/m^2).
5 Average seedling height (cm) at the end of the first growing season.
6 Average seedling height (cm) at the time of lifting at the end of second growing season.
7 Average seedling above-ground diameter (caliper)(mm) at the end of the second growing season.
8 Average seedling root oven-dry weight (g) at the end of the second growing season.

Acceptable seedlings have been produced in fields fallowed for at least one year prior to sowing a conifer crop at the Lucky Peak Nursery. It is possible that fallowing for more than one year, with periodic cultivation to thoroughly mix soils, would even be better. Fallowing is a viable alternative to MBC fumigation at several bareroot nurseries in the western United States and Canada (Stone 1991; Stone and others 1997). It may become more important in the future, especially if pesticide use becomes more restricted. Fallowing is feasible if seedling production in forest nurseries remains below capacity.

Amending soil with organic matter, either by direct application of non-composted materials or incorporating a green manure crop, has often exacerbated seedling disease problems (Hansen and others 1990; James and others 1996). A major reason is that soil populations of potential pathogens, especially *Fusarium* spp., increase significantly when organic matter is added to soil (James and others 1996; Snyder and others 1959; Stone and others 1997). Most *Fusarium* spp., especially potential pathogens like *F. oxysporum* and *F. solani*, exist passively in soil as resting structures called chlamydospores or sclerotia (Bloomberg 1976; Nelson and others 1983). Resting structures germinate under the influence of available food sources, such as seedling roots or organic amendments, resulting in great population increases (Hansen and others 1990; James and others 1996). Organic matter may also stimulate competing soil microorganisms. However, most amendments stimulate *Fusarium* to such an extent that other microorganisms seem ineffective in keeping pathogen populations in

check (Hansen and others 1990; James and others 1996; Stone and others 1997).

One possible exception to this scenario is incorporation of *Brassica* green manure crops (Angus and others 1994; Clapp and others 1959). Several mustard, rape, and broccoli species have shown promise in suppressing soil-borne pathogens because they produce toxic metabolites upon decompostion. Some *Brassica* spp. produce methylisothiocyanate, the same active ingredient in dazomet, during decompostion following incorporation (Angus and others 1994; Clapp and others 1959; Gamliel and Stapelton 1993). Problems using *Brassica* species as green manure crops have occurred because pathogen levels sometimes respond more to the added organic matter than to toxic metabolites produced (Hansen and others 1990; James and others 1996). *Brassica* varieties with enhanced production of chemicals toxic to pathogens are currently under development. Developing proper growing regimes, e.g. enhancing root growth while discouraging top growth and flowering, are important in improving efficacy of these crops. Some sort of cover/green manure crop is often essential for control of soil erosion and/or maintaining soil organic matter. It would be beneficial if such crops were more suppressive than conducive to soil pathogens. Further testing of new *Brassica* varieties for control of soil-borne diseases is certainly warranted.

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