Alternatives to Chemical Fumigation Technology Development Project: Preliminary Results

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Abstract- Preliminary results indicate that each nursery requires different soil management regimes to help reduce the need for chemical fumigation. Several treatments contributed to production of seedlings with densities and morphology similar to or better than with chemical fumigation. Beneficial cultural practices included 1) Incorporation of slowly decomposing organic soil amendments, for example, aged sawdust with additional nitrogen provided to seedlings; 2) Bare fallowing, with and without periodic tilling, and with weed control; 3) Sowing of conifer seed early and shallow, and covering seed with a non-soil mulch such as aged sawdust or hydromulch.

The project, "Alternatives to Chemical Fumigation", was funded by the USDA Forest Service, Forest Pest Management, Technology Development Program, beginning in spring 1993. The overall objective is to enhance the implementation of integrated pest management at forest tree nurseries, especially by developing cropping and soil treatment regimes for production of high quality seedlings without chemical fumigation. Thirteen Federal, State, and industrial nurseries from across the United States are cooperating in the project.

CHEMICAL FUMIGATION

Many forest tree nurseries use chemical biocides for soil fumigation treatment prior to sowing. Methyl bromide (67 percent) with chloropicrin (33 percent) is one of the most commonly used fumigants, and generally considered the best for achieving a uniform, vigorous crop of quality seedlings and controlling soil-borne diseases and insects, weeds, and nematodes. Dazomet (Basamid Granular) is also used, and its granular form is considered more safe to handle than gaseous methyl bromide mixtures.

Because methyl bromide has a high potential to deplete stratospheric ozone, production and importation in the United States will be prohibited after January 1, 2001 (World Meteorological Organization 1995; EPA 1995). Since 1994, methyl bromide production in the United States has been restricted to 1991 levels. Reliance on any chemical biocide to maintain production is inherently risky over the long term. Such chemicals are likely to become restricted in use, due to human or environmental health hazards.

In addition to the health hazards of chemical biocides, fumigation drastically disrupts the biology of the soil system, destroying beneficial and detrimental organisms alike. The first microorganisms to recolonize the soil, through blowing dust or on equipment, may be pathogenic ones. Populations of beneficial microorganisms, especially those that limit the growth of pathogens, develop slowly while the pathogen populations are allowed freedom to increase rapidly. Fumigation tends to result in the need for continued fumigation.

PROJECT OBJECTIVES

The overall objective of the project is to enhance implementation of integrated pest management (IPM) of soil-borne diseases at forest tree nurseries. The three facets of the project include:

1. Develop and evaluate cropping and soil treatment regimes for production of high quality seedlings without chemical fumigation;

2. Develop and evaluate combinations of biocontrol agents and application methods for suppression of soil-borne diseases of seedlings;

3. Develop accurate sampling and disease-forecasting techniques for soil-borne Fusarium.

COOPERATING NURSERIES

This paper presents some of the preliminary results from the first facet of the project-the seedbed treatments at cooperating nurseries. Cooperators include thirteen Federal, State, and Industrial nurseries as follows:

In the Northeast Area, USDA Forest Service (USFS) J. W. **Toumey** Nursery in Watersmeet, Michigan; and Wisconsin State **Griffith** Nursery in Wisconsin Rapids.

In the Southern Region, Florida State **Andrews** Nursery in Chiefland; International Paper Company **Supertree** Nursery in Blenheim, South Carolina; and USFS W. W. **Ashe** Nursery in Brooklyn, Mississippi.

In the Northern Region, USFS **Coeur d'Alene** Nursery in Coeur d'Alene, Idaho.

In the Intermountain Region, USFS **Lucky Peak** Nursery near Boise, Idaho.

In the Pacific Southwest Region, California State **Magalia** Nursery in Magalia; USFS **Humboldt** Nursery near Eureka, California; and USFS **Placerville** Nursery near Placerville, California.

In the Pacific Northwest Region, USFS **Bend Pine** Nursery in Bend, Oregon; USFS **J. Herbert Stone** Nursery in Central Point, Oregon; and USFS **Wind River** Nursery near Carson, Washington.

SOIL-BORNE DISEASE

The disease cycle revolves around interactions between the host, pathogen, and environmental conditions. Host susceptibility can depend on host physiology, anatomy, and the growing environment. Infection depends on the susceptibility of the host, the population level of pathogen (inoculum) present, and the vigor and virulence of the pathogen. Even after the pathogen infects host tissue, the expression of disease may be delayed if environmental conditions favor the host over the pathogen. Environmental conditions affect susceptibility of the host to infection, disease expression, and vigor of the pathogen.

Disease can be avoided in two ways: by preventing infection, or by preventing disease expression, that is, by manipulating the seedling environment to favor the host and suppress the pathogen. Delay in the expression of disease symptoms occurs, for example, with Fusarium root rot. Infection takes place quite early, soon after seed germination. For seedlings that do not succumb early to damping-off, the root rot disease is expressed later, usually by mid summer, when temperatures and moisture stress begin to favor the pathogen over the host.

The best control for disease is to prevent infection; this can be done by reducing pathogen populations, or by providing physical or temporal barriers to infection. Chemical fumigation reduces pathogen populations by killing the organisms. Without a chemical biocide, pathogen populations can be reduced by removing the available food base and encouraging competitive saprophytes. "Green manures" from cover crops incorporated into soil tend to stimulate increases in populations of pathogenic soil fungi (Stone and Hansen, 1994). Many pathogenic fungi can function as saprophytes, and their populations increase due to the greatly increased food base.

TREATMENTS FOR PREVENTING INFECTION

Strategy 1: Reduce Patbogen Populations

Treatments that reduce pathogen populations include bare fallowing, with or without tilling, and incorporation of slowly decomposing organic soil amendments. A season of bare fallow depletes the food base for pathogens, and periodic tilling continually brings pathogen propagules to the soil surface where they are exposed to desiccation and lethal temperatures. Weeds provide a food base for pathogens and shade the soil surface, and thus diminish the beneficial effects of bare fallowing.

Slowly decomposing organic soil amendments, such as aged sawdust or compost, favor the growth of competitive soil saprophytes to the detriment of soil pathogens. Amendments with high carbon to nitrogen ratios are difficult for pathogens to utilize as a food base. Other soil saprophytes are able to thrive and can out-compete pathogens. The low nitrogen levels will eventually stunt tree seedlings, and they require additional nitrogen. Delay in nitrogen application until well after seedling germination may further limit the growth of soil pathogens.

Strategy 2: Barriers to Infection

Treatments that provide barriers to infection include early sowing, and shallow sowing with mulching. The barriers act to separate the germinating seedling-the most susceptible host condition-from the pathogens in the soil. Early sowing provides a temporal barrier by allowing conifer seed to germinate, and the radicle to become suberized, before the time when soil temperatures reach optimum for pathogens.

Covering the seed with mulch, rather than soil, provides a spacial barrier that partially separates the germinating seedling from the pathogen in the soil. A slowly decomposing mulch, like sawdust, may also provide a biological barrier, where competitive saprophytes displace pathogens.

PRELIMINARY RESULTS

Western Nurseries

Summary tables for western nurseries provide Bend Pine Nursery Figure data from the first growing season for conifer bare root stock grown under various treatments. Pre sow soil treatments included cover cropping, fallowing, fumigation, and incorporation of soil amendments. Mulch treatments covered seed after sowing. Seedling density and morphology data are means of measurements, taken in October 1994, from five replicates per treatment. Significant differences (P>0.05) between treatments were determined by analysis of variance; and are indicated by different letters following data. Where significant differences occur in seedling density, seedling morphology data may not be useful, because low densities often result in large seed lings. Seedling height was measured in the beds, while root volume and shoot length were measured in the laboratory. The Key provides explanations and definitions for recurring abbreviations used in the summary tables.

Key to Terms Used in Summary Tables

Treatment	Explanation
MBC	Fumigation with 67 percent methyl bromide and 33
Dazomet	Fumigation with Basamid Granular at 350 lb/ac.
BFT	Bare fallowing with periodic tilling.
BF	Bare fallowing without tilling.
S+N	Soil amended by incorporation of aged sawdust and some

Data	Explanation
Density	Seedlings per square foot.
Mortality	Percent of seedlings with diseased-caused mortality.
Fusarium	Propagules of Fusarium spp. per gram of soil, assayed at
Weeds	Weed plants per square foot, counted within a few weeks

Bend Pine Nursery, 1-0 Ponderosa Pine

Treatment	Density	Mortality	Fusarium
Pea cover crop, MBC	21.4 a	0.06 a	170 a
BFT, S+N	22.3 a	0.11 a	618 a
BF, S+N	22.4 a	0.09 a	948 a
Peas, no fumigation	7.3 b	0.39 b	3711 b

At Bend Pine Nursery, the conventional pea cover crop without fumigation resulted in significantly greater disease-caused mortality, and lower seedling density. The bare fallowing treatments included sawdust plus nitrogen incorporated at the beginning of the bare fallowing. Bare fallowing treatments, with or without periodic tilling, were comparable to methyl bromide fumigation, resulting in similar seedling densities and low mortality.

J. Herbert Stone Nursery, 1-0 Douglas-fir

Treatment	Density	Mortality	Fusarium	Weeds
BFT, S+N, dazomet	19.5 ab	0.099 ns	135 a	3.3 a
BFT, S+N	16.9 ab	0.131 ns	2194 a	10.9 a
BF, S+N	14.9 a	0.157 ns	3469 b	89.5 b
BFT, No S	19.1 ab	0.117 ns	1106 a	4.9 a
BFT, S, delayed N	23.8 b	0.098 ns	808 a	1.3 a

At J. Herbert Stone Nursery, all treatments included bare fallow with tilling at three week intervals, except one without tilling. Sawdust plus nitrogen was incorporated as a soil amendment at the beginning of the bare fallow. In the "S delayed N" treatment, extra nitrogen was provided only after seedling germination.

Douglas-fir density after dazomet fumigation was not different from that after the bare fallow with tilling treatments. Weed density was high in the plots without tilling, with effects similar to a cover crop Fusarium populations increased and seedling density decreased. Sawdust soil amendment with delayed application of N may tend to suppress both weed and pathogen development.

J. Herbert Stone Nursery, 1-0 Ponderosa Pine

Treatment	Density	Caliper, mm	Shoot length, cm
BFT, S+N, dazomet	19.9 a	4.8 b	12.0 b
BFT, S+N	21.4 a	4.6 a	11.8 a
BF, S+N	16.7 a	3.7 a	8.4 a
BFT, No S	20.9 a	4.7 b	12.0 b
BFT, S, delayed N	23.2 a	4.3 a	10.1 a

For ponderosa pine, all treatments resulted in similar densities. Seedling morphology was similar between the no sawdust amendment treatment and the dazomet treatment.

Coeur d'Alene Nursery, 1-0 Douglas-fir

Treatment	Density	Root volume, cc	Shoot length, cm
BFT, Dazomet	30.0 a	0.6 b	4.5 b
BFT, Bark	27.3 a	0.3 a	3.5 a
BFT	27.0 a	0.3 a	4.5 b
BFT, Pine Mulch	30.9 a	0.6 b	5.6 c
BFT, Sludge	26.4 a	0.5 b	5.8 c

At Coeur d'Alene Nursery, all treatments included bare fallow with tilling. Soil amendments incorporated before bare fallowing included composted bark chips (Bark) and sewage sludge (Sludge). The "Pine Mulch" treatment was a layer of old pine needles covering the seed. Douglas-fir density was similar after all treatments. As measured by root volume and shoot length, seedlings were smallest after the composted bark chips amendment and the bare fallow with tilling alone. Shoot length was greatest after the pine mulch and sludge amendment treatments.

Lucky Peak Nursery, 1-0 Ponderosa Pine			
Treatment	Density	Root Volume, cc	Shoot Length, cm
BFT	23.3 a	3.1 b	11.0 b
BF	15.3 a	3.0 b	10.7 b
BF, Compost	15.7 a	2.0 a	8.1 a
BF, S+N	20.1 a	2.03 a	11.1 b
BF, MBC	19.3 a	2.2 a	8.1 a

At Lucky Peak Nursery, all treatments included bare fallowing without tilling except for one with tilling. Soil amendments included composted mushroom medium (Compost) and commercial sawdust with nitrogen. No significant differences in ponderosa pine seedling density were found after the first growing season.

Ponderosa pine seedling shoot length was significantly greater in the bare fallow with and without tilling, and with sawdust amendment, than in the compost and fumigation treatments. Root volume was significantly greater in the bare fallow with and without tilling, than in the soil amendments and fumigation treatments.

Lucky Peak Nursery, 1-0 Lodgepole Pine				
Treatment	Density	Mortality	Root Volume, cc	Shoot Length, cm
BFT	17.0 a	0.18 ab	2.1 a	6.8 b
BF	20.4 b	0.16 ab	2.0 ab	6.7 b
BF, Compost	13.9 a	0.30 b	1.3 b	4.6 a
BF, S+N	16.5 a	0.21 ab	1.5 b	6.4 b
BF, MBC	20.1 b	0.11 a	2.2 a	8.1 c

For lodgepole pine at Lucky Peak Nursery, bare fallow alone resulted in similar seedling density to bare fallow followed by MBC. Root volume was greater without soil amendments, while shoot length was greater with MBC.

Placerville Nursery, 1-0 Shasta Red Fir

Treatment	Density	Mortality
BFT, ST, Soil, Late	18.5 a	0.41 a
BFT, ST, Hydro, Early	29.9 b	0.07 b
BFT, S, Hydro, Early	26.7 b	0.13 b
BFT, S, S, Early	27.8 b	0.16 b
BFT, Pine, Hydro, Early	25.9 b	0.11 b
BFT, Bare, Hydro, Early	24.1 b	0.12b

At Placerville Nursery, all treatments began with bare fallow with tilling, then an overwinter soil covering of rice straw (ST), sawdust (S), pine needles (Pine), hydromulch (Hydro), or nothing (Bare). Shasta red fir seed was sown in March (Early) or mid April (Late), and covered with soil, hydromulch, or sawdust. The conventional late sowing with soil covering the seed resulted in significantly lower seedling density, and greater mortality caused by disease. Seedling root volume, caliper, and height were not significantly different.

Humboldt Nursery, 1-0 Shasta Red Fir

Treatment	Density	Root Volume, cc	Shoot Length, cm
BF	19.3 a	0.47 ns	3.71 ns
BFT, Compost	19.6 a	0.58 ns	4.73 ns
BFT, Hydromulch	21.6 a	0.44 ns	4.25 ns
BFT, MBC	20.1 a	0.45 ns	3.87 ns
BFT, Dazomet	20.1 a	0.43 ns	4.20 ns

At Humboldt Nursery, all treatments began with bare fallow with tilling, except for one without tilling. Mulches after sowing include composted redwood chips (Compost) or hydromulch. Shasta red fir seedling density and morphology (root volume, shoot length) were not significantly different after all treatments.

Southern Nurseries

At Andrews Nursery, Chiefland, Florida, measurements were taken at the time of lifting 1 -0 slash pine from four replications per treatment in January 1994. This information was reported in more detail at the Southern/Northeastern Forest Nurserymen's Conference, Williamsburg, VA, July 1994, by M. E. Kannwischer-Mitchell, E. L. Barnard, D. J. Mitchell, and S. W. Fraedrich.

Soil amendments included pinebark or composted woody yard waste (Compost), applied as a layer, 2.5 cm (lx) or 5.0 cm (2x) thick, then incorporated into the soil. No treatments was applied in the check plots. Slash pine height and density were significantly different between the MBC and check, and intermediate in the soil amendment treatments. There were no differences in caliper.

Andrews Nursery, 1-0 Slash Pine

Treatment	Density	Caliper, mm	Height, cm
Check	16 a	4.6 a	19.5 a
Pinebark 1x	18 ab	4.5 a	21.8 ab
Pinebark 2x	18 ab	4.4 a	22.5 ab
Compost 1x	18 ab	4.7 a	23.6 ab
Compost 2x	18 ab	4.6 a	21.1 ab
MBC	20 b	4.9 a	25.2 b

At Toumey Nursery, Michigan, the standard practice for red pine is an oak seedling crop or winter rye cover crop, followed by an oat cover crop, then MBC fumigation and sowing. Treatments compared MBC with dazomet and no fumigation (Check).

Toumey Nursery, 1-0 and 2-0 Red Pine

Treatment	1-0 Density	2-0 Density	2-0 Caliper, mm
Check	26.9	26.5	2.7
Dazomet	25.5	24.6	2.5
MBC	26.9	25.5	3.2

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Between the 1 -0 and 2-0 years, there was little loss in seedling density. Seedling density was not significantly different between the unfumigated check, dazomet, and MBC. Height was more uniform in the MBC and check treatments than in the dazomet treatment.

After 2 growing seasons, seedling caliper was significantly greater in the MBC treatment, and met shipping specifications (3.0 mm). In the check and dazomet treatments caliper did not meet specifications. At the same time, none of the treatments resulted in sufficient height to meet specifications, and the seedlings were carried to 30. This is a fairly common occurrence in cold, upper Michigan soils. In some years red pine seedlings reach shipping specifications in the second year.

At Griffith State Nursery in Wisconsin, bare fallowing for four months resulted in lower seedling densities than fumigation with MBC or dazomet.

DISCUSSION AND SUMMARY

Preliminary results with the conifer species tested indicate that at many nurseries, modification of cultural practices can greatly reduce the need for chemical fumigation. At some nurseries current practices are sufficient and fumigation is not needed. Additional measurements-including numbers of shippable seedlings, results of repeated treatments, and testing of biocontrol agents- will be reported in future publications.

Cultural practices that can help reduce the need for chemical fumigation include:

***** Incorporation of slowly decomposing organic soil amendments, such as aged sawdust with additional nitrogen provided to seedlings.

***** Bare fallowing, with and without periodic tilling, maintained free of weeds.

***** Sowing conifer seed early and shallow, covered with a non-soil mulch such as aged sawdust or hydromulch.

Without chemical fumigation, practices that alleviate one problem may aggravate another, for example, bare fallowing may increase wind erosion. Other soil coverings that stabilize the soil surface and wind abatement strategies are available. The solutions to growing quality seedlings without chemical fumigation will be found in each situation as the resourceful culturist recognizes the benefits of freedom from reliance on broad spectrum biocides.

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