SOIL FUMIGATION IN SOUTHERN UNITED STATES FOREST TREE NURSERIES

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Abstract.--Methyl bromide soil fumigation can be effectively, efficiently, and safely applied in bareroot forest tree nurseries. The primary target organisms are the soilborne, pathogenic fungi that cause recurrent damaging root rot and damping-off on both conifer and hardwood seedlings. A formulation of 67 percent methyl bromide and 33 percent chloropicrin has consistently provided the most effective control of these disease problems. Methyl bromide soil fumigation is presently used in over 90 percent of the nurseries in the Southern United States. This paper provides information on fumigant types, application methods, fumigation guidelines, benefits and costs, registration and safety, and advantages and disadvantages of soil fumigation. Guidelines and precautions are presented concerning the biological (target organisms), chemical (soil fumigant), and environmental (soil) factors affecting soil fumigation results.

Additional keywords: Methyl bromide, chloropicrin, nursery application techniques, fumigation guidelines and precautions, benefits, costs, registration and safety.

Chemical fumigants have been used extensively during the past four decades to control pests in nursery soil. A variety of chemical formulations have been marketed as soil fumigants, and many of these have been tested in forest tree nurseries. Success in controlling different types of pests has resulted in the use of soil fumigation in over 90 percent of our nurseries in the Southern United States (Boyer and South, 1984).

This paper summarizes current information on effective soil fumigation. It provides information on fumigant types; application methods; use guidelines; benefits and costs; registration and safety; and advantages and disadvantages of soil fumigation. For more detailed information, the appropriate references can be consulted.

FUMIGANT TYPES

Several types of soil fumigants have been utilized with variable success in forest tree nurseries (Vaartaja, 1964). These include methyl bromide, chloropicrin, ethylene dibromide, vapam, vorlex, and mylone. However, the methyl bromide-chloropicrin (MBC) fumigant formulations have consistently provided the most effective and efficient soil treatment results (Cordell, 1983; Seymour and Cordell, 1979). The MBC formulations are liquid mixtures containing various ratios of methyl bromide and chloropicrin. The ones most commonly used in forest tree nurseries are MBC-33 (67 percent methyl bromide, 33 percent

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chloropicrin) and MBC-2 (98 percent methyl bromide, 2 percent chloropicrin). MBC-33 is most effective and widely used in controlling certain nursery soilborne fungi that cause severe seedling root disease problems. MBC-2 is a broad spectrum treatment that controls some soil fungi, weed seeds, nematodes, and soil insects. MBC-2, however, has been less effective than MBC-33 in controlling damaging soilborne fungi that are pathogenic on seedling roots and have highly durable and resistant spore stages, such as the charcoal and cylindrocladium root rot fungi. The vast majority (90+ percent) of our southern nurseries presently use either MBC-33 or MBC-2 for soil fumigation (Boyer and South, 1984). MBC-33 is used where resistant root disease organisms are known to occur and where highly susceptible seedling hosts are to be grown. Consequently, the remainder of this paper will focus primarily on soil fumigation with MBC-33 and MBC-2.

APPLICATION METHODS

MBC fumigants are most commonly applied with a chisel injector that applies the chemical beneath the soil (Cordell and Wortendyke, 1972). This tractor-drawn machine is equipped with chisels not over 30 cm apart and adjusted to inject the fumigant at the optimum depth of 20 to 25 cm (Great Lakes Chemical Corporation, 1976). More recently, machines have been developed that permit fumigant injections at soil depths of 30 cm or more where particularly damaging disease organisms threaten the production of deep-rooted seedling species, such as yellow-poplar (*Liriodendron tulipifera* L.), black walnut (*Juglans nigra* L.), and sweetgum (*Liquidambar styraciflua* L.), and where fine-textured soils reduce fumigant penetration.

MBC mixtures can also be applied to the soil surface (Cordell and Wortendyke, 1972). In this treatment, the mixture is released from pressurized containers into evaporation pans located under polyethylene covers. The polyethylene covers are raised above the soil surface to permit horizontal gas movement across the treated area. This method is most suitable for fumigating small seedbeds, transplant beds, and other localized areas. Advantages of this method include the relative low cost of the equipment and simplicity of application. A primary disadvantage is the time required to treat large areas. Several times more nursery acreage can be fumigated per day with the mechanized soil-injection machines than with the labor-intensive surface applications.

Another type of MBC fumigation applied in southern nurseries is treatment of bulk soil mixes and mulch materials such as grain straw, pine needles, pine bark, sawdust, or compost. The soil mixes are used for container-grown seedlings, while the various types of mulches are used on bareroot nursery seedbeds.

MBC dosage rates are usually based on the amount of methyl bromide active ingredient needed per hectare; rates vary between 280 to 672 kilograms per hectare (Miller and Norris, 1970). A dosage rate of 392 kilograms per hectare is a standard "broad spectrum" treatment (Cordell, 1983). This is the <u>maximum registered dosage rate</u> for the <u>MBC-33 formulation</u> by the United States Environmental Protection Agency (EPA). For bulk soil and mulch materials, fumigant dosage rates are 0.59 kg/M^3 of material for either MBC-33 or MBC-2.

Soil can be fumigated in the spring or the fall. In the fall, soil temperature and moisture conditions in the Southern United States are near optimum for fumigation, and treatment then fits nicely into nursery work schedules. Spring fumigation has the major advantage of being soon before spring sowing and thereby reducing the probability of treated seedbed recontamination. Spring soil fumigation is also highly recommended in conjunction with artificial nursery seedbed inoculations with ectomycorrhizal fungi (Marx and others, 1985).

The fumigated soil or mulch material must be adequately covered or sealed to promote maximum fumigation effectiveness. The most effective cover is polyethylene thick and strong enough to resist punctures from sharp objects such as stones and soil clods. The fumigation and tarping can be done on entire fields or on single strips (Fig. 1). Fumigation of entire areas minimizes the opportunity for contamination from adjacent nonfumigated strips. In addition, the fumigation time requirement for continuous tarping is considerably shorter than for strips. Thus, an earlier planting date following spring fumigation is possible and the probability of unfavorable weather interference is reduced. A major disadvantage of the continuous tarping is that the large covers that are required are much more subject to damage from winds than the smaller covers used in strip fumigation.

A soil pasteurization technique has been tested in nurseries in the United States, including a southern nursery (English, Mitchell, and Barnard, 1982). With this technique, clear polyethylene tarping is placed on freshly prepared soil. The soil is partially sterilized by the high temperatures produced by solar energy. A major advantage of this technique is exclusion of the potentially hazardous and relatively expensive chemical fumigant. A major limiting factor, however, is that soil temperatures of 50+C must be present for at least 48 hours at soil depths of 15+ cm to obtain effective sterilization. Also, soil pathogenic fungi such as the charcoal or black root rot fungi are favored by high soil temperatures (35C) (Rowan, 1971). In tests in a Florida nursery, soil pasteurization was ineffective in reducing populations of *Macrophomina phaseolina*, while MBC-2 fumigation was highly effective (English, Mitchell, and Barnard, 1982).

FUMIGATION GUIDELINES

Soil fumigants are broad spectrum biocides that are relatively expensive to purchase and apply. Consequently, it is highly desirable to apply a soil fumigant under conditions that maximize its effectiveness (Table 1). Safety, as well as effectiveness and efficiency, have been considered in formulating guidelines for soil fumigation in the Southern United States (Cordell, 1983; Seymour and Cordell, 1979).

REGISTRATION AND SAFETY

Methyl bromide and methyl bromide-chloropicrin formulations are specifically registered by the U.S. Environmental Protection Agency (EPA) as preplanting soil fumigants for the control of a variety of soil fungi, nematodes, insects, broadleaf weeds, and grasses in forest tree nurseries. Although these fumigants are highly toxic to humans, animals, and plants, they can be as safely employed as any other chemical pesticide by considering their potential toxicity and taking appropriate precautions.

The label for the specific fumigant formulation to be used should be read and understood prior to use. All handling and application directions and safety precautions should be closely followed. The fumigant should be applied

Figure 1.--Two methyl bromide soil fumigation techniques routinely used in southern forest tree nurseries are solid tarping (above) and strip tarping (below).

Table 1.--Recommended guidelines and precautions for effective soil fumigation with methyl bromide.[1]

Soil fumigation factors	Guidelines and precautions
Soil preparation	Work into fine, loose, friable condition to minimum depth of 20 to 25 centimeters. Soil should be as free of clods as possible.
Organic matter	Do not use nondecayed organic matter. Organic matter can render fumigant ineffective and harbor fungi and nematodes. Cut or chop green organic matter into the soil a minimum of 3 to 4 weeks prior to fumigation.
Soil moisture	Soil moisture neither too high nor too low. Coarse-textured sandy soils - 75 percent field capacity[2] Fine-textured clay soils - 25 to 50 percent field capacity
Soil temperature	Soil temperature above 10C at 15-centimeter depth. Air and soil temperatures not usually correlated.
Soil fumigants and target pests	Mixtures of 98% methyl bromide/2% chloropicrin fumigant; broad spectrum for nematodes, weeds, insects, and most soilborne fungi. Mixtures of 67% methyl bromide/33% chloropicrin fumigant; particularly effective against soilborne fungi with tough resistant stages.
Calibrating and monitoring soil fumigation equipment.	Fumigant dosage = concentration X time. Dosage determined by injector nozzle size, fumigant pressure, and tractor speed. Fumigant injected at minimum 20-centimeter soil depth. Deeper soil injections for deeper-rooted species. Maintain constant pressure, tractor speed, and fumigant flow through all nozzles for uniform, effective coverage.
Soil tarping	Apply clear polyethylene tarp with adequate strength and thickness immediately after fumigation for maximum effectiveness. Alternate strips require longer fumigation and time intervals and afford opportunity for contamination from adjacent nonfumigated soil strips. Solid tarping requires shorter fumigation time interval and minimizes opportunity for soil contamination. Repair and seal any holes and open glue joints immediately.
Fumigation exposure period	Consult fumigant label for recommendations. Minimum of 48 hours at soil temperature above 15C at 15-centimeter depth. At lower temperatures and during wet weather (following fumigation) double the exposure period.
Fumigation aeration period	Consult fumigant label for recommendations Minimum of 48-72 hours; varies with fumigant, soil, temperature, moisture, and crop to be planted. Double aeration period in wet weather or at temperatures below 15C.
Extended aeration for seedbeds receiving artificial inoculations of ectomycorrhizal fungi	Aerate soil at least 3 weeks following mixture of 67% methyl bromide/33% chloropicrin fumigation. This strong fumigant has extended residual toxicity to all soil fungi, including those which form mycorrhizae.
Contamination of fumigated soils	Avoid possible contamination by movement of soil, plants, mulches, etc., into fumigated areas. Clean, by steam or equivalent, all equipment: plows, bed shapers, tractor tires, etc. Avoid transplanting from nonfumigated soils.
Fumigation of mulch materials	Prefumigate mulch materials such as pine needles, straw, and bark with mixture of 67% methyl bromide/33% chloropicrin or mixture of 98% methyl bromide/33% chloropicrin formulations at a dosage rate of 0.59 kg/m^3. Tightly compacted or baled materials should be a maximum of 45 centimeters deep. Loose pine needles, straw, etc., may be 0.8 to 1.2 meters deep. Fumigation procedures and precautions (tarping, temperature, moisture, exposure, aeration periods, etc.) are same as for soil fumigation.
Soil nutrient alterations	Level of soluble salts and ammonia nitrogen may be increased due to decreased populations of nitrifying bacteria. Do not use ammonia fertilizers on plants requiring nitrates or those sensitive to ammonia. Apply only nitrate fertilizers until seedlings are established and soil temperature is above 20C. Base your fertilizer applications on soil tests made after fumigation.
Water requirements	Water requirements per unit of plant production are generally less. Water requirements per acre are increased due to generally larger plants and increased production.
Cover crops	Green manure cover crop plants such as corn, peas, sorghum, and soybeans are highly susceptible hosts for the charcoal and black root rot fungi. Grain crops such as millet, sudan, and rye are considered nonhosts.
Safety	The methyl bromide/chloropicrin formulations are highly toxic to animals (including humans) and plants. Handle fumigants with care and only by certified competent personnel.
	ALWAYS READ FUMIGANT LABEL PRIOR TO USE AND FOLLOW ALL DIRECTIONS AND PRECAUTIONS CLOSELY.

1/ Seymour, C. P. and Cordell, C. E. 1979. Control of charcoal root rot with methyl bromide in forest nurseries. Southern Journal of Applied Forestry. Vol. 3:3. p. 104-108.

2/ Water-holding capacity of the soil against the force of gravity.

only by nursery personnel who are certified by the respective state pesticide regulatory agency. Recommended protective equipment should always be utilized as directed.

Remember, methyl bromide and methyl bromide-chloropicrin formulations are listed as restricted use pesticides by EPA.

BENEFITS AND COSTS

MBC formulations are nonselective soil biocides; they kill a variety of soil organisms. MBC-33 has repeatedly and consistently provided the most effective control of soilborne pathogenic fungi such as *M. phaseolina* and *Fusarium* spp., the causes of charcoal and black root rot; *Phytophthora* spp. and *Pythium* spp., the causes of damping-off and root rot diseases; and *Cylindrocladium* spp., the causes of cylindrocladium root rot (Cordell, 1983; Seymour and Cordell, 1979; Smith and Bega, 1966; Johnson and Bigelow, 1985; Boyd, 1971). Such organisms are the primary targets of soil fumigation in tree nurseries. MBC formulations have also provided effective control of nematodes, soil insects, certain weed seeds, and other soilborne pathogenic fungi (Hansbrough and Hollis, 1957; Hodges, 1960; Clifford, 1951; Hill, 1955; Foster, 1961; Thomason, 1959). Soil fumigation with MBC formulations has also consistently improved seedling quality and reduced cull factors in nurseries (Clifford, 1963; Hodges, 1960; Rowan, 1971; Seymour and Cordell, 1979). Soil fumigation with MBC-2 in a Louisiana experimental nursery almost doubled the production of plantable seedlings and caused corresponding significant increases in seedling quality (Hansbrough and Hollis, 1957). Variable effects have been observed on nontarget organisms and other related soil factors (Foster, 1961; Hacskaylo and Palmer, 1957; Kelley and Rodriguez-Kabana, 1979). For example, the beneficial ectomycorrhizal fungi are usually only temporarily decreased, even after spring soil fumigation (Marx and others, 1985).

The present cost of methyl bromide soil fumigation ranges between $2,000 and $2,500 per hectare. The cost varies with the MBC formulation, dosage rate, tarp cover type and thickness, acreage fumigated, and whether the fumigant is commercially or privately applied. Based on the present average southern loblolly and slash pine seedling production of 1.85 million seedlings per hectare, this cost ranges between $1.08 and $1.35 per thousand seedlings. Assuming an average loblolly and slash pine seedling cost of $22.00 per thousand, the present cost of MBC fumigation is only 5 to 6 percent of the seedling value. This cost has been further reduced in several nurseries by growing two successive seedling crops in seedbeds and fumigating only prior to planting the first crop.

When the cost of MBC fumigation is compared with the benefits from its use, it becomes apparent that soil fumigation is economically justified in southern nurseries. This is particularly apparent where damaging soilborne root diseases and susceptible seedling host species occur. Charcoal root rot caused the loss of approximately 16.5 million saleable seedlings of five species of southern pines in a Florida nursery in 1976 (Seymour and Cordell, 1979). MBC soil fumigation benefit/cost analyses in an Alabama State Nursery showed that soil fumigation was economically justified when seedling root disease caused a loss of 1.8 percent or more of the saleable pine seedlings (Kucera, 1981). Also, these benefits have been extended to the outplanting site, where increased survival and more rapid early growth have been observed on seedlings from fumigated nursery beds (Foster, 1961).

ADVANTAGES AND DISADVANTAGES

Advantages

1. Effective control of a variety of soilborne pests, including pathogenic fungi with resistant spore stages, nematodes, insects, and some weed and grass species.

2. Improved quality of seedlings and reduced cull factors.

3. Increased survival and early growth in field plantations.

4. Insurance against unpredictable losses in nursery beds or in field plantings.

Disadvantages

1. Additional cost for producing seedlings.

2. Reduced populations of beneficial mycorrhizal fungi and competitive and saprophytic fungi and bacteria.

3. Delayed seed sowing after spring fumigation if soil moisture and temperature are unfavorable.

4. Potential pesticide hazard. The MBC formulations are highly toxic to all living organisms--including man.

CONCLUSIONS

Methyl bromide soil fumigation controls a variety of pests in southern forest tree nurseries, and nurserymen have different opinions about its use. These range from routine preventive applications to use only after pest problems have been identified and evaluated.

The root disease fungi are the most damaging pest problems in southern nurseries, and soil fumigation is the only practical way to control them. Consequently, methyl bromide soil fumigation is considered mandatory in nurseries where root disease hazards occur. The potential pest threats without fumigation, along with the consistent benefits derived from its use, clearly demonstrate the biological and economical advantages of this practice. It helps to ensure the sustained production of high-quality seedlings with improved survival and growth capabilities for field plantings. Consistently effective results can be obtained by considering the target organisms and the nursery environment when selecting and applying a soil fumigant.

LITERATURE CITED

Boyd, R. J. 1971. Effects of soil fumigation on production of conifer nursery stock at two Rocky Mountain nurseries. USDA For. Serv. Res. Pap. INT-91. 19 p.

Cordell, Charles E. 1983. Effective soil fumigation. In Proceedings: 1982 Southern Nursery Conferences. USDA For. Serv., State and Private Forestry, Region 8, Atlanta, Ga. Technical Pub. R8-TP4. p. 196-201.

Cordell, C. E. and Wortendyke, J. T. 1972. Background document for methyl bromide. USDA For. Serv. Tech. Rep. 70 p.

Clifford, E. D. 1963. The effects of soil sterilant chemicals on the germination and development of conifer seedlings and weed control. USDA For. Serv. Tree Planters' Notes 58:5-11.

Clifford, E. D. 1951. Methyl bromide to control weeds in conifer seedbeds. USDA For. Serv. Tree Planters' Notes 7:17-18.

English, J. T., Mitchell, D. J., and Barnard, E. L. 1982. Influence of soil solarization on populations of Macrophomina phaseolina and saprophytic microorganisms. In Florida Scientist. Vol. 45 (suppl.). p. 7.

Foster, A. A. 1961. Control of black root rot of pine seedlings by soil fumigation in the nursery. Ga. For. Res. Council. Rep. 8. 5 p.

Great Lakes Chemical Corporation. 1976. The handbook of agricultural fumigation. Great Lakes Chem. Corp. Tech. Bull. 19 p.

Hacskaylo, E. and Palmer, John G. 1967. Effects of several biocides on growth of seedling pines and incidence of mycorrhizae in field plots. Plant Dis. Rptr. 41:354-358.

Hansbrough, Thomas and Hollis, John P. 1957. The effect of soil fumigation for the control of parasitic nematodes on the growth and yield of loblolly pine seedlings. Plant Dis. Rptr. 41:1021-1025.

Hill, J. A. 1955. Methyl bromide gas controls weeds, nematodes, and root rots in seedbeds. USDA For. Serv. Tree Planters' Notes 21:11-12.

Hodges, Charles S. 1960. Effect of soil fumigation in the nursery on growth of loblolly pine seedlings and control of weeds. USDA For. Serv. Tree Planters' Notes 42:23-27.

Johnson, D. W. and Bigelow, C. A. 1975. Effects of soil treatments on fungal populations and ponderosa pine seedling survival at the Bend Nursery. USDA For. Serv., PNW, Region 6 Office Rep., Portland, Oregon. 20 p.

Kelley, Walter D. and Rodriguez-Kabana, Rodriguez. 1979. Effects of sodium azide and methyl bromide on soil bacterial populations, enzymic activities, and other biological variables. Pesticide Sci. 10:207-215.

Kucera, Bob. 1981. Black root rot of pine. In Proceedings: 1980 Southern Nursery Conference. USDA For. Serv., State and Private Forestry, Region 8, Atlanta, Ga. Tech. Pub. SA-TP17. p. 109-111.

Marx, D. H.; Cordell, C. E.; Kenney, D. S.; Mexal, J. G.; Artman, J. D.; Riffle, J. W.; and Molina, R. J. 1984. Commercial vegetative inoculum of Pisolithus tinctorius and inoculation techniques for development of ectomycorrhizae on bare-root tree seedlings. For. Sci. Monogr. No. 25. 101 p.

Miller, W. O. and Norris, M. G. 1970. A new review of soil fumigation practices for use in forest nurseries. Down to Earth 26:9-12.

Rowan, S. J. 1971. Soil fertilization, fumigation, and temperature affect severity of black root rot of slash pine. Phytopathology 61:184-187.

Seymour, C. P. and Cordell, C. E. 1979. Control of charcoal root rot with methyl bromide in forest nurseries. South. Jo. Appl. For. 3:3. p. 104-108.

Smith, R. S., Jr. and Bega, R. V. 1966. Root disease control by fumigation in forest nurseries. Plant Dis. Rptr. 50:245-248.

Thomason, I. J. 1959. Chisel application of methyl bromide for control of root-knot nematode and Fusarium wilt. Plant Dis. Rptr. 43:580-583.

Vaartaja, O. 1964. Chemical treatment of seedbeds to control nursery diseases. The Botanical Review 30(1):1-91.