EFFECTIVE SOIL FUMIGATION

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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 losses on both conifer and hardwood seedlings. The MC-33 fumigant formulation has consistently and repeatedly provided the most effective control of these disease problems. Precautions are needed concerning the non-target, beneficial, soil organisms, particularly the endomycorrhizae on hardwood seedlings and when artificial ectomycorrhizal inoculations are utilized on conifer and some hardwood seedlings. Guidelines and precautions are presented concerning the biological (target organisms), chemical (soil fumigant), and environmental (soil) factors affecting consistent, effective, soil fumigation results.

Additional key words: Methyl bromide, methyl bromide-chloropicrin, MC-33, MC-2, target organisms, non-target, beneficial organisms, biological characteristics, chemical activity, environmental factors.

Pest control by fumigation is not a new practice. Attempts to control soil nematodes chemically date back to 1881. Carbon disulphide was extensively used for control of phylloxera of grape in Europe during the close of the last century. The practice of soil fumigation, however, has become widespread only since World War II. Since then, a number of fumigants, such as methyl bromide, chloropicrin, dichloropropenes, and ethylene dibromide, have been widely developed; and today, fumigation with these materials is an accepted practice in many agricultural areas. In fact, methyl bromide is the most widely used, general-purpose fumigant in the world (Cordell and Wortendyke, 1972).

Soil fumigation has been routinely practiced in southern forest tree nurseries during the past two decades. During more recent years, this chemical soil treatment practice has also been expanded to nurseries in the northeastern, central, north-central, and western United States. Several types of soil fumigants, such as methyl bromide, chloropicrin, vapam, vorlex, and mylone, have been tested and utilized, with varying degrees of success. However, the methyl bromide-chloropicrin fumigant formulations have consistently provided the most effective and efficient soil treatment results (Cordell and Wortendyke, 1972; Seymour and Cordell, 1979).

METHODS

A variety of methyl bromide-chloropicrin formulations are available and registered by the United States Environmental Protection Agency for specific forest tree nursery pest problems. These formulations range from the "broad

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spectrum" fumigants, such as methyl bromide - 98 percent; chloropicrin - 2 percent (MC-2), to stronger formulations, such as methyl bromide - 67 percent; chloropicrin - 33 percent (MC-33). The MC-2 formulation is effective against most weed seeds, nematodes, soil insects, and some soil fungus pathogens. The MC-33 formulation is particularly effective against difficult-to-control fungus pathogens on both conifer and hardwood seedling host species (Cordell and Wortendyke, 1972). The primary target pest organisms in nursery soil fumigation practices are soilborne, pathogenic fungi responsible for the recurrent damaging root rots and damping-off in southern nurseries. In the past, annual weeds were the primary target pests. However, the recent development of equally effective and less expensive herbicides has resulted in major modifications in nursery pest control objectives (South and Gjerstad, 1980).

The methyl bromide fumigant is most commonly applied by a chisel injection method beneath the soil. This method involves a tractor-drawn, soil injection rig equipped with chisels not over 12 inches apart and set to inject the fumigant at an optimum 8-10 inch depth (Great Lakes Chemical Corporation, 1976). More recently, soil injection rigs have been developed that permit fumigant injections at soil depths of 12 inches or more where particularly damaging disease problems threaten the production of deeper-rooted hardwood seedlings, such as black walnut and yellow poplar. Fumigant dosage rates vary between 250-600 pounds methyl bromide active ingredient per acre (Miller and Norris, 1970). A dosage rate of 350 pounds per acre is standard as a "broad spectrum" treatment and is the maximum registered dosage rate for the MC-33 formulation. The fumigant dosage rate is equal to the concentration times the exposure time (Table 1; Dow Chemical Company, 1967). Therefore, both the fumigant concentration and the exposure time must be adequate to obtain effective control results. The fumigated soil is covered immediately with a clear polyethylene plastic covering, preferably a minimum 2 ml thickness. The fumigation and tarping can be effectively applied in either alternate strips or as continuous fumigated and tarped fields using custom application equipment. The major advantages of the continuous fumigation and tarp method are outlined in table 1. A major disadvantage in some localities is the wind factor, which makes the continuous, large-area tarping much more difficult.

The effectiveness and efficiency of methyl bromide soil fumigation can be increased and extended by following the guidelines and precautions outlined in table 1 (Seymour and Cordell, 1979).

RESULTS

Target Organisms

Difficult to control soil fungus diseases, such as cylindrocladium root rot, charcoal or black root rot, and phytophthora root rot, have caused severe, widespread damage to both conifer and hardwood nurseries throughout the United States during recent years. Soilborne, pathogenic fungi, such as Macrophomina phaseolina (charcoal root rot) and Cylindrocladium spp. (cylindrocladium root rot), with their tough, resistant, sclerotial fungus stages, are two of the most difficult soil fungi to control in nursery seedbeds. The MC-33 type formulations have repeatedly and consistently provided the most effective control of these disease problems. The soil pathogenic fungi have been either eliminated or reduced to tolerable levels, along with the consistent production of

Table 1. Suggested 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 8 to 10 inches. 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. Light sandy soils—slightly below field capacity.[2] Heavy clay soils—50-75 percent field capacity.
Soil temperature	Soil temperature above 50°F at 6-inch 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, and most soilborne fungi. Mixtures of 67% methyl bromide/33% chloropicrin fumigant: particularly effective against soilborne fungi with tough resistant stages. Mixtures of 98% methyl bromide/2% chloropicrin diluted with 30% solvent inert ingredients least effective against soilborne fungi.
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 8-inch soil depth. Maintain constant pressure, tractor speed, and fumigant flow through all nozzles for uniform, effective coverage.
Soil tarping	Apply minimum 2-mil-thickness clear polyethylene tarp 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	See fumigant label for recommendations. Minimum of 48 hours at soil temperature above 60°F at 6-inch depth. At lower temperatures and during wet weather (following fumigation) double the exposure period.
Fumigation aeration period	See 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 60°F.
Extended aeration for seedbeds receiving artificial inoculations of mycorrhizal 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 soil	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 sawdust with mixture of 67% methyl bromide/33% chloropicrin or mixture of 98% methyl bromide/2% chloropicrin formulations at dosage rate of one lb/yd^3. Tightly compacted or baled materials should be a maximum of 18 inches deep. Loose pine needles, straw, etc., may be 3-4 feet 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 65°F. 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, and soybeans are highly susceptible hosts for *M. phaseolina*. Grain crops such as millet or 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]*Cordell and Wortendyke 1972.*

[2]*Water-holding capacity of the soil against the force of gravity.*

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

higher quality tree seedlings with significantly increased field survival and growth capabilities (Affeltranger and Cordell, 1970; Seymour, 1969; Smith and Bega, 1964; Hodges, 1962; Foster, 1961; Peterson and Smith, 1975; Seymour and Cordell, 1979).

Non-target Organisms

Methyl bromide soil fumigation either eliminates or significantly reduces all living organisms within treated soils. The beneficial ectomycorrhizal and saprophytic soil fungi, however, usually re-invade fumigated soils first and build up to higher populations than in unfumigated soils. A distinction must be made between the ecto- or primarily "conifer-type" mycorrhizae and the endo- or primarily "hardwood-type" mycorrhizae. The conifer- or pine-type ectomycorrhizae produce an abundance of airborne spores that readily infest fumigated soils, while the hardwood-type endomycorrhizae are exclusively soilborne and, thereby, are very limited in fumigated soil reinfestation capabilities. Research and field evaluations are currently in progress concerning the practical application of specific ecto- and endo- mycorrhizal fungi in both conifer and hardwood nurseries (Marx, 1977). Special precautions are needed when soil fumigation is followed by artificial ectomycorrhizal inoculations in nursery seedbeds. When the stronger MC-33 formulation is used, a minimum two-week soil aeration period is required prior to the ectomycorrhizal inoculations. Also, methyl bromide soil fumigation, preferably spring fumigation, is considered mandatory for effective, artificial ectomycorrhizal inoculations in bareroot nursery seedbeds.

DISCUSSION

Effective, efficient soil fumigation has been repeatedly obtained with the methyl bromide-chloropicrin formulations previously described. As previously pointed out, the MC-33 formulation has been most effective for controlling soilborne, fungus-caused disease problems, such as the root rots, while the MC-2 formulation has been most effective as a broad spectrum fumigant for controlling nematodes, soil insects, weeds and grasses, and some soilborne fungi.

The present cost of methyl bromide fumigation ranges between $800 to $1,000 per acre ($1,975 to $2,475 per hectare). The cost varies with the methyl bromide-chloropicrin formulation, dosage rate, tarp cover thickness, acreage fumigated, and commercial or private application. Based on an average conifer seedling production in southern nurseries of 750,000 seedlings per acre, the cost ranges between $1.07 to $1.33 per thousand seedlings. The potential pest threats without fumigation, along with the benefits derived from fumigation, clearly demonstrates that this practice represents a profitable, economic investment to help ensure the sustained production of higher quality tree seedlings with improved survival capabilities for field plantings.

CONCLUSIONS

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 losses. The MC-33 fumigant formulation has consistently and repeatedly provided the most effective control of these disease problems. Due consideration and utilization of the basic biological (target organisms), chemical (soil fumigant), and environmental (soil) factors involved, however, are required to obtain consistent successful results.

REGISTRATION AND SAFETY

Registered Uses and Safety

Methyl bromide and methyl bromide-chloropicrin formulations are specifically registered through the U.S. Environmental Protection Agency as preplanting soil fumigants for the control of a variety of soil fungus organisms, nematodes, soil insects, 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 when maintaining due consideration and precaution for their potential toxicity and accompanying safety hazards.

The specific fumigant formulation label should be read and understood prior to use. All handling and application directions and safety precautions should be closely followed. The fumigant is applied only by nursery personnel that 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 the U.S. Environmental Protection Agency.

LITERATURE CITED

Affeltranger, C. E. and Cordell, C. E. A root rot plagues forest nurseries. Forest Farmer 29:12,16. 1970.

Cordell, Charles E. and Wortendyke, John T. Background document for methyl bromide. USDA Forest Service Technical Report. 1972. 70 p. (unpublished).

Dow Chemical Company. Calibration of soil fumigation equipment for gaseous fumigants. Midland, Mi. The Dow Chemical Company. Form No. 138-651-67R. 1967. 6 p. (unpublished).

Foster, Alfred A. Control of black root rot of pine seedlings by soil fumigation in the nursery. Georgia Forestry Research Council Report No. 8. Macon, Ga.: Georgia Forestry Research Council. 1961. 5 p.

Great Lakes Chemical Corporation. The handbook of agricultural fumigation. West Lafayette, In. Great Lakes Chemical Corporation. Technical Bulletin. 1976. 19 p.

Hodges, Charles S., Jr. Black root rot of pine seedlings. Phytopathology 52:210-219. 1962.

Marx, Donald H. The role of mycorrhizae in forest production. In Proceedings, TAPPI Annual Meeting, Feb. 14-16, 1977. Atlanta, Ga. Technical Association of the Pulp and Paper Industry. 1977. p. 151-161.

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

Peterson, Glenn W. and Smith, Richard S., Jr. (Technical Coordinators). Forest nursery diseases in the United States. USDA Agric. Handbook No. 470. Washington: U.S. Department of Agriculture; 1975. 125 p.

Seymour, C. P. Charcoal root rot of nursery-grown pines in Florida. Phytopathology 59:89-92. 1969.

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

Smith, Richard S., Jr. and Bega, Robert V. Macrophomina phaseolina in the forest tree nurseries of California. Plant Dis. Rptr. 48:206. 1964.

South, David B. and Gjerstad, Dean H. Nursery weed control with herbicides and fumigation - an economic evaluation. Southern Journal of Applied Forestry 4(1):40-45. 1980.