Soil Fumigation in Southern United States Forest Tree Nurseries[1]

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Abstract.--Soils in bareroot forest tree nurseries in the Southern United States have been safely and efficiently fumigated for three decades. The primary target organisms are the soilborne pathogenic fungi that cause 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 diseases. Methyl bromide is presently used in over 90 percent of the southern nurseries. Alternative soil treatments are urgently needed. Guidelines and precautions on fumigants, application methods, benefits and costs, and registration and safety are presented. Factors affecting soil fumigation results are emphasized.

Additional keywords: Soil fumigants, nursery treatments, guidelines, precautions, benefits, costs, registration, and safety.

Soils in southern forest tree nurseries have been routinely fumigated for the past three decades. In more recent years, these chemical soil treatments have been utilized in nurseries in the Northeastern, Central, North-Central and Western United States. Mixtures of methyl bromide and chloropicrin, dicloropropenes, ethylene bromide, vapam, vorlex, and dazomet have been utilized with varying degrees of success. However, the methyl bromide-chloropicrin formulations have consistently provided the most effective and efficient results (Cordell, 1983; Seymour and Cordell, 19'79; Cordell and Kelley, 1985). The vast majority (90+ percent) of southern nurseries presently utilize methyl bromide (Boyer and South, 1984). Approximately 2,400 acres are treated annually at an estimated cost of $1.9 million. The methyl bromidechloropicrin - 33% (MC-33) formulation is routinely utilized where difficult-to-control root disease organisms are known to occur and highly susceptible seedling hosts will be grown. Alternative soil treatments are urgently needed and several chemical and nonchemical treatments are being tested as suitable alternatives to methyl bromide.

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APPLICATION METHODS

The methyl bromide-chloropicrin (MBC) soil fumigants are most commonly applied beneath the soil with a chisel injector (Cordell and Kelley, 1985). This tractor-drawn machine is equipped with chisels not over 30 cm. (12 inches) apart and adjusted to inject the fumigant at the optimum depth of 20-25 cm. (8 to 10 inches). More recently, machines have been developed that permit fumigant injections at soil depths of 30 cm. (12 inches) or more where particularly damaging disease organisms threaten the production of deep-rooted hardwood 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 (Cordell, 1983).

MBC fumigants can be applied to the soil surface (Cordell, 1983). For soil surface applications, the fumigant 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.

MBC mixtures also are used to fumigate bulk soil mixes and mulch materials such as grain straw, pine needles, and bark chips (Cordell, 1983). The soil mixes are used for container-grown seedlings, while the various types of mulches are used on bareroot nursery seedbeds.

Fumigant dosage rates are based on the amount of active chemical ingredient needed per hectare or acre. Rates vary by chemical, target organism, application method, soil type and environmental conditions. To be effective, a fumigant must remain in contact with the target organism for sufficient time and in sufficient concentration to kill. Therefore, the fumigant dosage must take into account the chemical concentration needed per unit of soil volume and the exposure period. For bulk soil and mulch materials, MBC (MC-33 or MC-2) fumigant application rates are 0.56 kg/m^3 (1.0 lb./yd^3)(Cordell, 1983).

The fumigated soil or mulch material must be adequately covered or sealed to promote maximum fumigation effectiveness. The most effective cover is polyethylene with sufficient strength and thickness to minimize fumigant escape. The fumigation and tarping can be done on entire fields or on alternate strips (Fig. 1). Fumigation of entire fields 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 continuous tarping is that the large covers that are required are much more subject to wind damage than the smaller covers used in strip fumigation (Cordell and Kelley, 1985).

Soil can be fumigated either 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 better into nursery work schedules. Spring fumigation has the major advantage of being closer to seed sowing time. As a result, the probability of recontamination of treated seedbeds is reduced. Spring soil fumigation is also highly recommended when the seedbeds will be artificially inoculated with ectomycorrhizal fungi (Marx and others, 1984).

Figure 1.--Solid tarping (above) and strip tarping (below) are two alternatives when fumigating with methyl bromide.

FUMIGATION GUIDELINES

Soil fumigants are broad spectrum biocides they can kill most living things - and they are relatively expensive to purchase and apply. Consequently, it is highly desirable to apply a soil fumigant under conditions and using equipment and procedures that maximize safety and effectiveness (Table 1). Safety and effectiveness have been considered in formulating guidelines for soil fumigation in the Southern United States (Seymour and Cordell, 1979; Cordell, 1983; Cordell and Kelley, 1985).

BENEFITS AND COSTS

Specific fumigants vary in their effectiveness against specific soil organisms. MC-33 has repeatedly and consistently provided the most effective control of soilborne pathogenic fungi such as <u>Machrophomina phaseolina</u> and <u>Fusarium</u> spp., the causes of charcoal and black root rot; <u>Phytophthora</u> spp. <u>Phythium</u> spp., the causes of damping-off and root rot diseases; and <u>Cylindrocladium</u> spp., the causes of cylindrocladium root rot (Cordell, 1983; Cordell and Kelley, 1985; Seymour and Cordell, 1979; Smith and Bega, 1966; Johnson and Bigelow, 1975). These organisms are the primary targets of soil fumigation in southern nurseries. MBC formulations have also provided effective control of nematodes, soil insects, certain weed seeds, and other soilborne pathogenic fungi (Hansbrough

Table 1. Suggested guidelines and precautions for effective soil fumigation[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 reeks 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 I0C 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/m3
	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 ad 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 produce 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 MO FOLLOW ALL DIRECTIONS AID 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.

and Hollis, 1957; Hodges, 1960; Clifford, 1951; Hill, 1955; Foster, 1961; Thomason, 1959). In the past, annual weeds were the primary target pests in southern nurseries. 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). 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 resulted in 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, 1984).

The present cost of soil fumigation in southern nurseries ranges between $2,000 and $2,500 per hectare ($800 and $1,000 per acre). The cost varies with the fumigant type and formulation, dosage rate, soil cover type and thickness, acreage fumigated, and whether the fumigant is commercially or privately applied. Based on the present average southern pine seedling production of 1.85 million seedlings per hectare (750,000 seedlings per acre), this cost ranges between $1.07 and $1.33 per thousand seedlings. Assuming an average pine seedling value of $30.00 per thousand, the present cost of fumigation is less than 5 percent of the seedling value.

REGISTRATION AND SAFETY

The chemical fumigants mentioned previously 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 most of 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 pesticide label for the specific fumigant type and formulation to be used should be <u>read</u> and <u>understood prior to use</u>. All handling and application directions and safety precautions should be closely followed. The fumigant <u>must</u> be applied <u>only</u> by nursery personnel who are <u>certified</u> by the respective State pesticide regulatory agency. Recommended protective equipment should <u>always</u> be utilized as directed.

<u>Remember</u>, fumigants such as MBC formulations are listed as <u>restricted</u> use <u>pesticides</u> by EPA. That designation means that use of them is restricted to the conditions, concentrations, and applications specified by EPA and listed on the pesticide label.

DISCUSSION AND CONCLUSIONS

When the cost of soil fumigation is compared with the benefits from its use, it becomes apparent that this practice 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). Benefit/cost analyses in an Alabama State Nursery showed that soil fumigation with MBC 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).

Effective, efficient, and safe soil fumigation has been repeatedly obtained with the techniques and procedures previously described. MC-33 has been most effective for controlling soilborne, fungus-caused diseases such as root rots which are the most damaging pests in southern nurseries. However, alternative soil treatments are urgently needed for the intensively utilized MBC fumigants. Withdrawal of these formulations from the current EPA pesticide registration list for nursery fumigation would severely limit the quantity and quality of seedling production in southern nurseries.

An alternative chemical fumigant, metam sodium (vapam, 33% a.i.) has possible applications in U.S. nurseries. It has proven effective in Israel for control of soil pathogenic fungi (Ben-Yephet and others, 1988; Widin and Kennedy, 1983). Application methods include broadcasting vapam granules and mixing them into the soil, drenching the soil with a liquid formulation, and application through the nursery irrigation system.

Recently, a soil solarization technique has been developed and perfected in Israel to control soil pathogens (Katan and others 1976). This technique has been independently tested with variable success in several countries (Horiuchi, 1984; Katan and others, 1976; Stapleton and DeVay, 1986). Soil solarization is a rather simple technique that involves covering wet soil with clear plastic covers to create a greenhouse effect with the natural sunlight for a period of 4 to 6 weeks during the hottest months of the year. This procedure raises the soil temperature high enough (40 to 50 C) to significantly reduce the populations of undesirable soil organisms. Two primary factors affecting the success of the technique are high soil temperatures and adequate moisture (Horiuchi, 1984). Solarization has failed to control certain soil pathogenic fungi, such as the charcoal or black root rot fungi which have relatively high temperature tolerances (_> 50C) (Mihail and Alcorn, 1984; Stapleton and DeVay, 1986; English, Mitchell, and Barnard, 1982). Effective results have been obtained with a combination of solarization and chemicals where the efficacy of the chemical was increased at the higher soil temperatures (Ben-Yephet and others, 1988).

MC-33 soil fumigation or its equivalent is presently considered mandatory in southern nurseries where susceptible seedling hosts and root rot disease fungi occur in combination. The previously described 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 capabilites 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.

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