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Evaluation of methyl bromide alternatives on loblolly pine production and seedling quality over three growing seasons at the Pine Hill Nursery in Camden, Alabama

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Forest-tree nurseries in the United States have relied on methyl bromide (MBr) soil fumigation to control weeds, fungi, and nematodes. Due to the world-wide phase-out of MBr use, finding a soil fumigant alternative for MBr has been a priority for the forest nursery industry. A large-scale study comparing seven fumigants using operational application techniques and normal nursery management practices over three growing seasons was installed to determine the effects of MBr alternatives on seedling quality and quantity. Seedling densities at the end of the first growing season were similar across all soil fumigants tested. The newer chemistries, Pic+ and dimethyl-disulfide (DMDS), had seedlings with similar root collar diameters (RCDs) as MBr during the first and second growing seasons. Seedling RCDs declined for all treatments over the 3-year rotation due to the buildup of soilborne pests and weeds. Seedling root architecture and root morphology were similar for all soil fumigants. At the end of each growing season, nursery soils had similar levels of *Trichoderma* and nematode populations across all soil fumigants tested. These trials indicate that, while not the perfect replacement in all nursery soils, seedling production is still possible without MBr if compounds such as chloropicrin are used and managers pay close attention to weed and nematode pests that are less susceptible to chloropicrin than MBr.

Key words: Soil fumigation, chloropicrin, soilborne fungi, nematodes, *Pinus taeda*.

INTRODUCTION

Fumigation with methyl bromide (MBr) mixtures has been the most commonly used method for producing high quality, pest-free forest-tree seedlings in the southeastern United States (Jang et al., 1993). Forest nurseries in the United States have relied for many years on MBr soil fumigation to control yellow (*Cypress esculentus*) and purple (*Cypress rotundus*) nutsedge, soil insects, nematodes and soilborne pathogenic fungi (Cordell et al.,

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1989). Forest-seedling nursery managers have long recognized the importance of MBr to control these soilborne pathogens in the production of forest-tree seedlings (South et al., 1997). Due to the concern over ozone depletion in the stratosphere, the Montreal Protocol under the Clean Air Act began a phase-out program for MBr use in 2005 (Jang et al., 1993). Since 1991, finding alternatives for MBr has been a priority for the forest nursery industry. Other materials tested by the Southern Forest Nursery Management Cooperative, without much success, include basamid, hot pepper sauce, steam, hot water, and biologicals that included bacteria and fungi (Mousseaux et al., 1988; Enebak et al., 1999). Although it may be difficult to find a soil fumigant alternative that is as broad-spectrum as MBr, the nursery industry realizes the importance of testing new compounds, rates and application techniques.

The southeastern region represents the main softwood producing area of the United States and accounts for approximately 64% of the total timber harvested in the nation (Smith et al., 2001). Timberland and land ownership patterns have shifted to non-industrial private land, while forest industry timberland holdings have fallen in correspondence with the increase in non-industrial private land gains. Despite the recent trend, approximately 55% of the total forest industry timberlands are in the southeastern region (Smith et al., 2001). Loblolly (*Pinus taeda* L.) and slash (*Pinus elliottii* Engelm.) pine are the primary timber species grown in the southeastern United States, representing the second largest softwood group by volume (Smith et al., 2001). Loblolly pine has a number of favorable characteristics that have attributed to its widespread planting in the southeast. The species is ideal for site restoration as it easily regenerates and is the hardiest of the southern pines in terms of its reproductive ability and rapid growth rate on diverse sites. This adaptability has led to it being planted extensively across the southeast, both on and off sites preferred by the species. These characteristics made loblolly pine ideal for the heavily eroded soils of the early 20th century, and the diverse sites that the forest industry manages today. With genetically improved loblolly pine available, the opportunity for expansive plantings on a full range of site conditions, with genetically similar trees has become the new norm in the southern United States (Byram et al., 2005).

Because of the species' wide-spread use and value to landowners, loblolly pine is the primary species produced in southern forest nurseries (McNabb and VanderSchaaf, 2003) and many soilborne pests can negatively affect their production (Cordell et al., 1989). Despite the phase-out of MBr, forest nursery managers still need soil treatments that are comparable to MBr for control of soilborne pests. As part of the USDA-ARS Areawide Pest Management Project for MBr Alternatives, these studies are part of a long-term continuing effort to identify and evaluate soil fumigants against common nursery pests. Information from these studies should be used by nursery managers in the southern United States to select an MBr alternative that assists with the production of forest-tree seedlings in their particular nursery. The identification of a soil fumigant using operational application techniques under normal nursery management practices will allow continued reforestation programs important to the economy of the southern United States.

MATERIALS AND METHODS

Soil fumigants

Included in this trial at the Pine Hill Nursery, Wilcox County, Alabama, (32° 03' 53" N; 87° 20'57" W) were eight soil fumigants: six were selected from previous Southern Forest Nursery Management Cooperative fumigation studies (Enebak et al., 2012) and two were rates of iodomethane, which had never been tested in the production of forest-tree seedlings (Table 1). The fumigants were shank-injected on 23 March, 2009. Iodomethane treatments were covered with virtually impermeable film (VIF), while all other treatments were covered with a 1 mm high density polyethylene (HDPE) Tarp (AEP Industries Inc.) as a broadcast/flat tarp (Table 2). The experimental area occupied approximately 2.5 ha and the trial was laid out in six nursery sections that consisted of nine seedling beds between the irrigation pipelines with each bed being approximately 170 × 1.2 m. The experiment was a randomized complete block design with each treatment being 85 m long and replicated four times. Each 9-bed nursery section included 3 soil fumigation treatments (3 nursery beds per treatment). Because of the different plastic requirements, the iodomethane treatments could not be placed with the other soil fumigants and thus, were analyzed as a separate experiment. After fumigation and in each of the three growing seasons (2009 - 2011), a single family of loblolly pine seed was sown to the area at 236 seed/m^2. Seedlings in the trial area were maintained using standard nursery cultural practices (fertilization, irrigation, pest management, etc.) until lifting took place each winter (November to December). After lifting the seedlings at the end of each 9-mo growing season (November to December), the treatment area was left fallow and prepared for sowing the following spring (April).

Seedling quality and quantity

The effect of the soil fumigant treatments on seedling densities and growth characteristics were assessed in four subplots (1.2 × 0.3 m) per treatment plot at 7 weeks post-sowing, mid-summer (15 weeks post-sowing) and just prior to lifting in the fall (26 weeks post-sowing) in 2009, 2010 and 2011, respectively. Twenty-five loblolly pine seedlings per subplot were collected in the fall of each cropping season and returned to the laboratory at Auburn University for analysis. Seedling root collar diameter (RCD), shoot height and seedling dry weight (biomass) and root weight ratio (RWR) were measured for each seedling as well as overall root morphology. For root morphology, 10 seedlings per subplot were examined for total root length, total root surface area, average root diameter and the number of root tips using a flat-bed scanner and analysis of the root image using WinRhizo® software developed by Regents Instruments Inc., Quebec, Canada.

Soilborne *Trichoderma* and nematodes

Throughout the three cropping seasons, 20 soil samples (15 cm soil probe) were systematically collected from the center seedling bed of each 3-bed plot: at pre-sowing, post-sowing, mid-summer and

Table 1. MBr alternative soil fumigants and rates used in the 2009 - 2011 demonstration trial at the Pine Hill forest-tree nursery in Camden, AL.

Treatment	Application rate (kg/ha)	Plastic type[y]	Fumigant components
Pic+	336	HDPE	85% chloropicrin and 15% solvent
Chlor 100	336	HDPE	100% chloropicrin
MBr	392	HDPE	67% MBr and 33% chloropicrin
MBC 70/30	448	HDPE	70% MBr (98/2) and 30% solvent
Chlor 60	448	HDPE	60% chloropicrin and 40% 1,3-dichloropropene (Telone)
DMDS + Chlor	113 (l/ha)	HDPE	79% dimethyl disulfide and 21% chloropicrin
[z]Midas 98/2	112	VIF	98% iodomethane and 2% chloropicrin
Midas 50/50	180	VIF	50% iodomethane and 50% chloropicrin

[y]HDPE, High density polyethylene; VIF, virtually impermeable film. [z]The Midas treatments were considered a separate trial from the other soil treatments due to the plastic requirement.

Table 2. Site information for the 2009 - 2011 demonstration trial at the Pine Hill forest-tree nursery in Camden, AL.

Trial parameter	Camden, AL
Fumigation date	23 March, 2009
Fumigation type	Shank injected; broadcast/flat tarp
Experimental area	2.5 ha
Air temperature	16 - 25°C
Wind speed	5 - 10 km/h
Soil moisture	7.6%
Soil series	Lenoir silt loam
Plastic in place	14 days

Table 3. Loblolly pine seedling density at lifting over three growing seasons (2009 - 2011) for the demonstration trial at the Pine Hill forest-tree nursery in Camden, AL.

Fumigant	Seedling density (m^2)		
	2009	2010	2011
MBr	224[ax]	269[a]	226[a]
Chlor 100	226[a]	253[a]	222[a]
MBC 70/30	227[a]	277[a]	280[a]
Chlor 60	221[a]	234[a]	252[a]
Pic+	228[a]	250[a]	236[a]
DMDS + Chlor	210[a]	252[a]	237[a]
[y]$LSD_{(0.05)}$	(31)	(78)	(65)
[z]Midas 50/50	203[a]	253[a]	209[a]
Midas 98/2	196[b]	253[a]	200[a]
$LSD_{(0.05)}$	(5)	(75)	(33)

[x]Means (within a column) followed by the same letter are not significantly different based on Duncan's multiple range test ($p \leq 0.05$). [y]Least significant differences are in parenthesis. [z]The Midas treatments were considered a separate trial from the other soil treatments due to the plastic requirement.

just prior to seedling lifting at the end of each growing season. Half of each soil sample was plated onto Trichoderma-selective media (Elad et al., 1981) to determine soilborne fungi levels and the remaining half was sent to the Soils Laboratory at Auburn University for a quantitative assessment of nematode populations using a rapid centrifugal flotation technique (Jenkins, 1964).

RESULTS

Seedling quality and quantity

At the Pine Hill Nursery in Alabama, seedling densities at the end of the first growing season in 2009 were similar across all soil fumigants tested, ranging from 210 to 228 seedling/m^2 (Table 3). Similar results were observed for the 2010 and 2011 growing seasons for the soil fumigants used under the HDPE plastics. In contrast, soils treated with Midas had significantly fewer seedlings than the MBr treatments in 2009 (Table 3). However, by the end of the second and third growing seasons in 2010 and 2011, there were no significant differences in seedling densities for any of the soil fumigants tested, as all treatments gave similar seedling densities as the standard MBr soil fumigation treatment.

Differences in seedling RCDs among the soil fumigants tested at the Pine Hill Nursery were observed during the final growing season with MBr-treated soils producing significantly larger seedling diameters over all other soil fumigants tested (Table 4). Some of the newer chemistries, Pic+ and dimethyl-disulfide (DMDS), had seedlings with similar RCDs as MBr during the three growing seasons. Seedling RCDs declined for all treatments over the 3-year rotation (Table 4).

Seedling root architecture and root morphology as measured by root length, surface area, root diameter and root tips were similar for all soil fumigants over the three cropping seasons (Table 5). Generally, first year soil fumigation results in larger seedlings. However, as far as an MBr alternative, all soil fumigant alternatives performed as well as MBr across all the root morphology measurements. Like that of RCD, and time since soil fumigation, root characteristics tended to decrease over the three growing seasons (Table 5).

The RWR is defined as the weight of the roots divided

Table 4. Loblolly pine seedling RCD at lifting over three growing seasons (2009 - 2011) for the trial at the Pine Hill forest-tree nursery in Camden, AL.

Fumigant	Root collar diameter (mm)		
	2009	**2010**	**2011**
MBr	4.21^{ax}	4.01^{a}	3.89^{a}
Chlor 100	4.33^{a}	4.12^{a}	3.46^{b}
MBC 70/30	3.97^{a}	3.73^{a}	3.14^{b}
Chlor 60	4.46^{a}	4.13^{a}	3.34^{b}
Pic+	4.04^{a}	4.02^{a}	3.43^{b}
DMDS + Chlor	4.26^{a}	4.18^{a}	3.45^{b}
[y]LSD$_{(0.05)}$	(0.60)	(0.54)	(0.42)
[z]Midas 50/50	4.83^{a}	3.92^{a}	3.83^{a}
Midas 98/2	4.37^{a}	3.60^{a}	3.77^{a}
LSD$_{(0.05)}$	(1.87)	(1.92)	(0.93)

[x]Means (within a column) followed by the same letter are not significantly different based on Duncan's multiple range test ($p \leq 0.05$). [y]Least significant differences are in parenthesis. [Z]The Midas treatments were considered a separate trial from the other soil treatments due to the plastic requirement.

Table 5. Loblolly pine seedling root morphology at lifting over three growing seasons (2009 - 2011) for the demonstration trial at the Pine Hill forest-tree nursery in Camden, AL.

Fumigant	Root morphology											
	Root length (cm)			Root surface area (cm^2)			Root diameter (mm)			Root tips (#)		
	2009	**2010**	**2011**	**2009**	**2010**	**2011**	**2009**	**2010**	**2011**	**2009**	**2010**	**2011**
MBr	183^{ax}	167^{a}	138^{a}	51^{a}	53^{a}	44^{a}	0.89^{a}	1.02^{a}	1.02^{a}	398^{a}	457^{a}	299^{a}
Chlor 100	168^{a}	164^{a}	133^{a}	49^{a}	55^{a}	43^{a}	0.95^{a}	1.09^{a}	1.05^{a}	350^{a}	377^{a}	274^{a}
MBC 70/30	158^{a}	156^{a}	112^{a}	45^{a}	47^{a}	36^{a}	0.93^{a}	0.97^{a}	1.03^{a}	374^{a}	405^{a}	242^{a}
Chlor 60	169^{a}	163^{a}	116^{a}	49^{a}	52^{a}	37^{a}	0.93^{a}	1.03^{a}	1.04^{a}	328^{a}	381^{a}	244^{a}
Pic+	154^{a}	161^{a}	126^{a}	44^{a}	49^{a}	39^{a}	0.95^{a}	0.99^{a}	1.01^{a}	319^{a}	398^{a}	262^{a}
DMDS + Chlor	162^{a}	185^{a}	112^{a}	47^{a}	57^{a}	36^{a}	0.94^{a}	1.00^{a}	1.03^{a}	328^{a}	440^{a}	235^{a}
[y]LSD$_{(0.05)}$	(27)	(38)	(32)	(9)	(16)	(9)	(0.09)	(0.11)	(0.08)	(74)	(123)	(69)
[z]Midas 50/50	217^{a}	181^{a}	149^{a}	62^{a}	57^{a}	47^{a}	0.94^{a}	1.00^{a}	1.02^{a}	463^{a}	354^{a}	298^{a}
Midas 98/2	202^{a}	159^{a}	145^{a}	57^{a}	52^{a}	46^{a}	0.92^{a}	1.04^{a}	1.04^{a}	435^{a}	300^{a}	313^{a}
LSD$_{(0.05)}$	(359)	(127)	(142)	(54)	(10)	(30)	(0.78)	(0.67)	(0.52)	(531)	(440)	(278)

[x]Means (within a column) followed by the same letter are not significantly different based on Duncan's Multiple Range Test ($p \leq 0.05$). [y]Least significant differences are in parenthesis. [Z]The Midas treatments were considered a separate trial from the other soil treatments due to the plastic requirement.

by the total seedling weight with an optimum seedling having a RWR of >27% with higher RWR having better survival after outplanting. The RWR of seedlings grown in the different soil treatments resulted in differences in seedling root ratios only during the first growing season (Table 6). Of all the soil fumigants tested, Chlor 60 had the lowest RWR of all the treatments in 2009. However, treatments had similar RWRs in 2010 and 2011 (Table 6). While none of the treatments resulted in the optimum RWR, a number of factors affect RWR, including the time of lifting, growing density, the time of root pruning, irrigation and fertilization. For these trials, none of the MBr alternatives were detrimental to root growth that could affect seedling survival after out planting.

Soilborne *Trichoderma* and nematodes

At the end of each growing season, nursery soils at the Pine Hill Nursery in Alabama had similar levels of *Trichoderma* across all soil fumigants tested (Table 7).

Nematode populations within the soil are rarely

Table 6. Loblolly pine seedling RWRs at lifting over three growing seasons (2009-2011) for the demonstration trial at the Pine Hill forest-tree nursery in Camden, AL.

Fumigant	Root weight ratio (%)		
	2009	2010	2011
MBr	12.6[abx]	15.7[a]	14.7[a]
Chlor 100	12.4[ab]	15.4[a]	15.9[a]
MBC 70/30	12.4[ab]	13.6[a]	14.7[a]
Chlor 60	11.2[b]	15.3[a]	14.5[a]
Pic+	12.0[ab]	14.9[a]	15.0[a]
DMDS + Chlor	14.0[a]	15.1[a]	15.1[a]
[y]$LSD_{(0.05)}$	(2.3)	(1.9)	(2.4)
[z]Midas 50/50	13.3[a]	16.3[a]	14.5[a]
Midas 98/2	17.1[a]	17.1[a]	16.3[a]
$LSD_{(0.05)}$	(41.3)	(1.6)	(13.0)

[x]Means (within a column) followed by the same letter are not significantly different based on Duncan's Multiple Range Test ($p \leq 0.05$). [y]Least significant differences are in parenthesis. [Z]The Midas treatments were considered a separate trial from the other soil treatments due to the plastic requirement.

Table 7. Number of *Trichoderma* colony forming units (CFUs) from soils collected over three growing seasons (2009-2011) for the demonstration trial at the Pine Hill forest-tree nursery in Camden, AL.

Fumigant	*Trichoderma* (CFUs/mg soil)					
	2009		2010		2011	
	June	December	June	November	June	November
MBr	82.5[ax]	101.0[ab]	99.0[a]	59.0[ab]	79.0[a]	76.0[a]
Chlor 100	59.8[a]	179.0[a]	111.0[a]	38.3[b]	95.2[a]	76.5[a]
MBC 70/30	36.3[a]	135.0[ab]	112.5[a]	82.0[a]	80.7[a]	76.2[a]
Chlor 60	26.3[a]	111.8[ab]	188.8[a]	46.5[b]	82.7[a]	69.0[a]
Pic+	22.5[a]	53.5[b]	124.3[a]	32.5[b]	55.0[b]	76.8[a]
DMDS + Chlor	35.5[a]	77.3[ab]	92.3[a]	32.5[b]	92.6[a]	97.2[a]
[y]$LSD_{(0.05)}$	(67.4)	(109.9)	(107.3)	(32.2)	(17.7)	(30.9)
[z]Midas 50/50	123.0[a]	56.3[a]	187.0[a]	74.7[a]	94.7[a]	85.4[a]
Midas 98/2	28.3[b]	34.8[a]	101.7[b]	116.7[a]	75.4[a]	94.0[a]
[y]$LSD_{(0.05)}$	(51.9)	(44.4)	(36.3)	(36.8)	(21.2)	(16.1)

[x]Means (within a column) followed by the same letter are not significantly different based on Duncan's multiple range test ($p \leq 0.05$). [y]Least significant differences are in parenthesis. [Z]The Midas treatments were considered a separate trial from the other soil treatments due to the plastic requirement.

distributed uniformly across the nursery beds and these studies had a wide range (0 to 67 nematodes /100 cc soil) in numbers and species for all soil fumigants used (Table 8). Because of the variability, there were no differences between treatments for any of the soil fumigants tested.

Overall, all soil fumigants were effective in eliminating nematode populations the first growing season, which were maintained during the 3-year rotation. There was an increase during the second growing season, but populations did not increase into the third season (Table 8). One of the more troublesome species on seedling production is the stunt nematode (*Tylenchorhynchus claytoni*) which appeared only during the second cropping season. Of the soil fumigants tested, Chlor 60 was the only soil fumigant not to have any nematodes recovered in soil samples over the course of the study at the Pine Hill Nursery.

DISCUSSION

The primary objective of the USDA Areawide MBr

Table 8. Average number of nematodes per 100 cubic centimeters (cc) of soil over three growing seasons (2009 - 2011) for the demonstration trial at the Pine Hill forest-tree nursery in Camden, AL.

Fumigant	Nematodes (# per 100 cc of soil)					
	2009		2010		2011	
	June	December[x]	June	November[y]	June[z]	Nov
MBr	0	29	0	0	0	0
Chlor 100	0	0	0	47	67	0
MBC 70/30	0	0	0	65	0	0
Chlor 60	0	0	0	0	0	0
Pic+	0	0	0	12	0	0
DMDS + Chlor	0	26	0	0	0	0
Midas 50/50	0	17	0	0	0	0
Midas 98/2	0	28	0	43	0	0

[x]Nematodes recovered in December, 2009 were stunt nematodes. [y]Nematodes recovered in November, 2010 were stubby root nematodes. [z]Nematodes recovered in June, 2011 were spiral nematodes.

alternative program is to identify possible alternatives to MBr using large-scale, multi-year trials in various soil types and environmental conditions throughout the southern United States. One of the unique aspects of MBr as a soil fumigant is its ability to consistently control weeds, insects, nematodes and fungi across many different growing conditions and nursery soil types. Studies conducted within the southern United States in forest-tree nurseries have yet to find an MBr alternative that fits all of these characteristics (Enebak et al., 2012). The true test of an MBr alternative is its performance during the second and third growing season where treatment differences usually begin to appear as disease, weed, and nematode pressures increase. Based on these trials, those soil fumigants with chloropicrin appear to be the most useful in controlling pests and producing quality seedlings as seedling densities and root characteristics were similar to MBr.

One of the primary reasons for determining the effects of these soil fumigants on root architecture is that a more fibrous root system increases the chance of seedling survival in the field (Hatchell and Muse 1990; Frampton et al., 2002; Davis and Jacobs, 2005). One soil fumigant, DMDS + chloropicrin was comparable to MBr in RCD, root morphology characteristics and soilborne *Trichoderma* levels, but had a significant odor problem (that is, garlic or strong propane) that lasted long into the growing season. The lingering odor with this particular soil fumigant may limit its acceptance by growers as an alternative to MBr. The best MBr alternatives tested were Pic+ and Chlor 60 with both soil fumigants controlling nematodes and producing quality seedlings similar to MBr (Tables 3, 4, 5 and 6).

The application of Midas® (iodomethane and chloropicrin) in these trials was the first large-scale use of this compound on the production of forest-tree seedlings in the United States. Considered a drop-in replacement by the US Environmental Protection Agency, the US Department of Agriculture and the European Union, the compound was applied under VIF at less than half the rates of the other soil fumigants. The reduced active ingredient was done for two reasons: 1) the iodomethane was expensive (twice the cost of chloropicrin per ha) and 2) the VIF film increased the effectiveness of the compound by limiting the off-gassing. While the compound showed promise as an MBr alternative with respect to seedling quality and soilborne pest control, Arysta Life Science removed Midas® from the North American market in 2012 due to increasing costs and environmental pressures to re-examine the compound's registration in the US.

In addition to the weed pressures, some nursery soils have a history of nematodes reaching levels that affect seedling production (Cram and Fraedrich, 2005). For these reasons, 1, 3-dichloropropene (Telone®) may need to be used in nurseries with reoccurring nematode pressure. The soil type at the Pine Hill Nursery (Lenoir silt loam) has a higher soil density than that of most forest-tree nurseries and generally has not resulted in production issues due to nematode populations. Chlor 60 (containing 40% Telone®) had the lowest nematode levels and may be an option for nurseries that have nematode issues in the second growing season. While the seedling densities and root characteristics with chloropicrin were encouraging, one of the potential pitfalls with using 100% chloropicrin at 336 kg/ha is the buffer zone restrictions under current soil fumigation practices in the US. If these restrictions limit the use of 100% chloropicrin, then Pic+ with 85% chloropicrin would be the best alternative to MBr. The final decision when selecting an MBr alternative at individual nurseries should take into consideration the soil fumigant's ability to work under individual nursery soil conditions and the impact from new soil fumigation rules that came into place in 2012.

Soil fumigation is effective for reducing pathogenic soilborne fungi in the nursery that can positively affect seedling production and survival after outplanting. In other trials, the soil fumigants tested were found to be effective in controlling Pythium, Rhizoctonia, and Fusarium when inoculated onto oatmeal (Enebak et al., 2012).The wide-spread use of MBr has minimized extensive seedling losses due to soilborne pathogenic fungi. Pythium still can cause damping-off problems in the early spring and is often limited to areas of poor drainage and standing water. The soil-type at the Pine Hill Nursery is conducive to damping-off caused by Pythium early in the growing season. Rhizoctonia can appear in nurseries both as root decay and as a foliar blight, especially in second-year crops post-fumigation as the fungus increases over the first growing season (Carey and McQuage, 2004). Soilborne pathogens did not appear to affect seedling production in this 3-year trial, however, nursery managers remain uncertain for what the future holds once MBr is unavailable.

One of the unique aspects of soil fumigants is that they do not completely eliminate the beneficial soilborne fungi which are needed for seedling growth, especially *Trichoderma* which is necessary for pine seedling growth (Bailey and Lumsden, 1998; Mousseaux et al., 1998). In these trials, the population levels of non-target soilborne fungi rebounded quickly. Likewise, all soil fumigants used in previous Nursery Cooperative research has shown that *Trichoderma* is not as sensitive to MBr as other soil fumigants (Carey et al., 2005). In contrast, dazomet, a soil fumigant tested by the Nursery Cooperative for several years,significantly reduced the levels of beneficial fungi which remained after two growing seasons (Starkey et al., 2006).

While many nursery managers would prefer to use MBr in perpetuity to grow forest-tree seedlings, MBr will eventually be unavailable and each nursery manager will need to identify the best alternative for their nursery conditions. These trials at the Pine Hill Nursery indicate that seedling production is still possible if compounds such as chloropicrin are used and managers pay close attention to weed and nematode pests that are less susceptible to chloropicrin than MBr.

REFERENCES

Bailey BA, Lumsden RD (1998). Direct effects of *Trichoderma* and *Gliocladium* on plant growth and resistance to pathogens. In *Trichoderma* and *Gliocladium*, vol. 2.Edited by G.E. Harman and C.P. Kubicek.Taylor and Francis, Inc., Bristol, Pa. pp.185–204.

Byram TD, Mullin TJ, White TL, van Buijtenen JP (2005). The Future of Tree Improvement in the Southeastern United States: Alternative Visions for the Next Decade. Southern J. Appl. For. 29:88-95.

Carey WA, McCraw D, Enebak SA (2005).Seedling production by seed treatment and fumigation treatment at the Glennville Regeneration Center in 2004. Auburn University Southern Forest Nursery Management Cooperative Research Report 05-04.Auburn, AL. P. 5.

Carey WA McQuage K (2004). Control of Rhizoctonia foliage blight by fungicides and fumigation: Lower application rates and fumigation effects. Auburn University Southern Forest Nursery Management Cooperative, Research Report 04-03. Auburn, AL. P. 4.

Cordell CE, Anders R, Hoffard WH, Landis TD, Smith RS, Toko HV (1989). Forest nursery pests. Wash (DC): Agricultural Handbook. 680:184.

Cram M, Fraedrich SW (2005). Management options for control of a stunt and needle nematode in southern forest nurseries. In: Dumroese RK, Riley LE, Landis TD tech. coords. 2005. National proceedings: Forest and Conservation Nursery Associations; 2004 July 12–15; Charleston, NC; Proc. RMRS-P-35. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Davis AS, Jacobs DF (2005). Quantifying root system quality of nursery seedlings and relationship to out planting performance. New Forests. 30:295-311.

Elad Y, Chet I, Henis Y (1981). A selective medium for improving quantitative isolation of *Trichoderma* spp. from soil. Phytoparasitica 9:59-67.

Enebak SA, Wei G, Kloepper JW (1998). Effects of plant growth-promoting rhizobacteria on loblolly and slash pine seedlings. For. Sci. 44:139-144.

Enebak SA, Starkey TE, Quicke M (2012).Effect of methyl bromide alternatives on seedling quality, nematodes and pathogenic soil fungi at the Jesup and Glennville Nurseries in Georgia: 2007-2008. J.Hort.For. 4:1-7.

Frampton J, Isik F, Goldfarb B (2002). Effects of nursery characteristics on field survival and growth of loblolly pine rooted cuttings. South. J.Appl. For. 26:207-213.

Hatchell GE, Muse HD (1990). Nursery cultural practices and morphological attributes of longleaf pine bare-root stock as indicators of early field performance. USDA For. Serv. Res. Pap. SE. P. 277.

Jang E, Wood WS, Dorschner K, Schaub J, Smith D, Fraedrich S, Hsu H (1993). Methyl bromide phase out in the US: Impact and alternatives, In: USDA workshop on alternatives for methyl bromide. Crystal City, VA.

Jenkins H (1964). A rapid centrifugal flotation technique for separating nematodes from soil. Plant Disease Reporter 48:692.

McNabb K, VanderSchaaf C (2003). A survey of forest seedling production in the south for the 2002-2003 planting season. Technical Note 2003-01. Southern Forest Nursery Management Cooperative, Auburn University P. 16.

Mousseaux MR, Dumroese RK, James RL, Wenny DL, and Knudsen GR (1998). Efficacy of *Trichoderma harzianum* as a biological control of *Fusarium oxysporum* in container-grown Douglas-fir.New Forests. 15:11-21.

South DB, Carey WA, Enebak SA (1997). Chloropicrin as a soil fumigant in forest nurseries. For. Chron. 73:489-494.

Smith WB, Vissage JS, Darr DR, Sheffield RM (2001). Forest Resources of the United States, 1997. U.S. Dep. Agric., Forest Service, Gen. Tech. Rep. NC. P. 219.

Starkey TE, Enebak SA, McCraw D (2006). Seedling quality and weed control with methyl bromide and methyl iodide at the Glennville Regeneration Center 2005-2006. Auburn University Southern Forest Nursery Management Cooperative. Research Report 06-05. Auburn, AL. P. 5.