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Full Length Research Paper

Effect of methyl bromide alternatives on seedling quality, nematodes and soilborne fungi at the Blenheim and Trenton nurseries in South Carolina: 2008 to 2009

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Fumigation with methyl bromide (MBr) has been the most commonly used method for producing high quality, pest-free forest tree seedlings in the southeastern United States. Of the 1 billion seedlings produced annually, approximately 95% of seedlings grown for reforestation purposes are loblolly pine. Growth and survival of seedlings after outplanting is strongly linked to high quality, pest-free forest-tree seedlings produced in the nursery. This large scale study compares seven soil fumigants and a non-fumigated treatment using operational fumigation methods and standard operating nursery management practices over two growing seasons at two nurseries in South Carolina. Soilborne fungi, nematode and weed control was dependent upon nursery and soil fumigant tested. When examining overall seedling characteristics, the best MBr alternatives tested were chloropicrin, Pic+ and Chlor 60, all of which resulted in similar seedling densities to that of MBr. Information gathered from this study should be used by nursery managers in the southern U.S. to choose an MBr alternative that would be useful in the production of forest-tree seedlings in their nurseries based on their individual nursery soil conditions and pest pressures.

Keywords: Soil fumigation, chloropicrin, soilborne fungi, nematodes, loblolly pine.

INTRODUCTION

While fumigation with methyl bromide (MBr) has been the most commonly used method for producing high quality, pest-free forest-tree seedlings in the southeastern United States, concerns on the continued reliance of MBr in these production systems has resulted in new soil fumigant chemistries. As part of a long-term, continuing effort to identify and evaluate soil fumigants as an alternative to methyl bromide (MBr), a program funded by the USDA – ARS Area-wide Pest Management Project for Methyl Bromide Alternatives – South Atlantic Region, was undertaken in 2006. This 5-year program was to look at the efficacy of a number of soil fumigants against common nursery pests and their effect on seedling quality of forest-tree seedlings in the southern United States under normal nursery management practices over a two year cropping cycle in forest-tree nurseries that varied by ownership, production methods and soil types. While studies were previously conducted in Georgia, these studies compare seven soil fumigants at the ArborGen Super Tree Nursery in Blenheim, SC and the South Carolina Forestry Commission's Nursery in Trenton, SC, for the production of loblolly pine. Information from these studies should be used by nursery managers in the southern U.S. to choose an MBr alternative that would be useful in the production of forest-tree seedlings in their nurseries.

MATERIALS AND METHODS

Soil fumigation treatments at these two nurseries included two MBr rates and five currently available alternatives selected based on results of small plot studies previously conducted by the Southern Forest Nursery Management Cooperative (Table 1). The

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Table 1. Soil fumigants and rates used in the 2008 to 2009 USDA Areawide demonstration plots at the ArborGen Super Tree Nursery in Blenheim, SC and the South Carolina Forestry Commission's Taylor Tree Nursery in Trenton, SC.

Soil fumigant treatment	Rate used	Chemical components
methyl bromide + chloropicrin #1	392 kg/ha (400 lb/a)	98% MBr and 2% chloropicrin
methyl bromide + chloropicrin #2	265 kg/ha (235 lb/a)	98% MBr and 2% chloropicrin
dimethyl disulfide + chloropicrin	107 l/ha (70 gal/a)*	79% DMDS and 21% chloropicrin
MBrC 70/30	448 kg/ha (400 lb/a)	70% MBr (98/2) and 30% Solvent A
Pic+	336 kg/ha (300 lb/a)	85% chloropicrin + 15% Solvent A
chloropicrin	336 kg/ha (300 lb/a)	100% chloropicrin
Chlor 60	448 kg/ha (400 lb/a)	60% chloropicrin and 40% 1,3-dichloropropene (Telone®)

* Compound is now labeled under the name Paladin®. Solvent A is a proprietary compound of Hendrix and Dail approved by EPA for use in forest-tree nurseries and under full label considerations.

Table 2. Site information for Trenton, SC and Blenheim, SC fumigation.

Application parameter	Trenton, SC	Blenheim, SC
Fumigation date	October 2, 2007	April 3, 2008
Fumigation type	Broadcast/Shank Injected	Broadcast/Shank Injected
Area in trial	2 ha	2 ha
Air temperature range	16 - 28°C	6 to 9°C
Wind speed	5 – 17 km/h	8 – 18 km/h
Soil moisture	5%	7%
Soil series	Wagram sand – (sandy loam)	Autryville sand – (loamy sand)
Plastic in place	10 days	7 days
Soil particle size	75:15:10 (sand: silt: clay)	87:6:7 (sand: silt: clay)

experiment occupied approximately 2 ha out of a total 35 production ha within each nursery and for each, the soil fumigants were shank-injected to a depth of 20 to 25 cm using a Raven Flow Meter Control System® (Sioux Falls, SD) and immediately covered with 1 mm High Density Polyethylene Tarp (Cadillac Plastics Inc.) under the weather and soil conditions listed in Table 2. At the Trenton Nursery, the nursery manager allowed a non-fumigated control treatment (no soil fumigation) to be installed. Soil fumigants were applied in October 2007 (Blenheim) and April 2008 (Trenton) and were laid out in nursery sections that contained nine seedling beds between irrigation pipelines (20 m), with each treatment plot approximately 100 m long × 4 m wide. The experimental design was a randomized complete block replicated four times over the five nursery sections. Each 9-bed nursery section contained three soil treatments. Both the Blenheim and Trenton nurseries sowed a single family of loblolly pine (*Pinus taeda* L.) seed in late April 2008 with the first seedling crop lifted in early December 2008. The area was fallow during the winter of 2008 and in March 2009 the beds were prepared for sowing. The second seedling crop was sown in April 2009 with seedlings lifted in December 2009. With respect to seedling production over the two growing seasons, standard nursery production systems used at each nursery (e.g. irrigation, fertilization, weed control, insect control, etc.) were allowed to continue within the experimental area.

Seedling quality

To determine the effects of the various fumigants on seedling quality, seedling and soil samples were collected from the middle seedling bed of each 3-bed treatment plot within each section.

Seedling densities were assessed in four subplots 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 both production years. To determine the effect of each soil fumigant on seedling quality, at the end of each growing season in 2008 and 2009 at both nurseries, 25 seedlings per subplot and returned to the laboratory for measurements. Each seedling was measured for root collar diameter (RCD), shoot height and seedling dry weight (biomass). In addition, root morphology which included total root length, root surface area, average root diameter and the number of root tips was measured on ten seedlings per subplot using WinRhizo® software by Regents Instruments Inc. Quebec, Canada.

Soil Trichoderma and nematodes

Throughout the two cropping seasons, soil samples were collected from the center seedling bed of each 3-bed plot: at pre-sowing, post-sowing, mid-summer and just prior to seedling lifting in November of each season. Soils were returned to Auburn University where half of each soil sample was plated onto *Trichoderma*-selective media (Elad et al., 1981) and the remaining half was sent to the Soils Laboratory at Auburn University for a quantitative assessment of nematode populations.

RESULTS

Seedling quality

At the end of the first growing season, there were no

Table 3. Loblolly pine seedling density (No./m^2) at the end of each cropping season at Blenheim, SC and Trenton, SC.

Treatment	Blenheim, SC		Trenton, SC	
	Dec 2008	**Dec 2009**	**Oct 2008**	**Oct 2009**
MBr #1	236^{a}	247^{a}	182^{a}	118^{a}
MBr #2	226^{a}	247^{a}	169^{a}	115^{a}
Chloropicrin	247^{a}	247^{a}	170^{a}	115^{a}
Chlor 60	247^{a}	247^{a}	161^{a}	114^{a}
MBrC 70/30	236^{a}	236^{a}	175^{a}	117^{a}
DMDS+Chloropicrin	247^{a}	258^{a}	173^{a}	114^{a}
Pic+	236^{a}	247^{a}	174^{a}	121^{a}
Control	-	-	175^{a}	116^{a}
$lsd_{(0.05)}$	22	22	24	21

Within column means followed by the same letter do not differ at P = 0.05 level using Duncan's Multiple Range Test. Target seedling density is 236 seedlings/m² at Blenheim, SC and 247 seedlings/m^2 at Trenton, SC.

Table 4. Loblolly pine seedling root collar diameter (mm) at the end of each growing season at Blenheim, SC and Trenton, SC.

Treatment	Blenheim, SC		Trenton, SC	
	Dec 2008	**Dec 2009**	**Oct 2008**	**Oct 2009**
MBr #1	4.37^{ab}	4.38^{cd}	4.02^{b}	4.51^{abc}
MBr #2	3.93^{c}	4.21^{d}	3.97^{b}	4.52^{abc}
Chloropicrin	4.46^{a}	4.43^{bcd}	4.08^{ab}	4.61^{ab}
Chlor 60	4.22^{ab}	4.52^{bc}	4.00^{b}	4.65^{ab}
MBrC 70/30	4.18^{b}	4.32^{cd}	4.10^{ab}	4.79^{a}
DMDS + Chloropicrin	4.43^{a}	4.81^{a}	3.89^{b}	4.61^{ab}
Pic+	4.32^{ab}	4.65^{ab}	4.34^{a}	4.48^{bc}
Control	-	-	3.08^{c}	4.33^{c}
$lsd_{(0.05)}$	0.25	0.28	0.32	0.29

Within column means followed by the same letter do not differ at P = 0.05 level using Duncan's multiple range test.

significant differences for seedling densities among the soil fumigants tested at either the Blenheim or Trenton nurseries (Table 3). With respect to meeting seedling production targets, Blenheim was at or above their production target while Trenton was far below the target of 247 seedlings per m^2 for both growing seasons at an average of 172 and 116 seedlings per m^2 for 2008 and 2009, respectively (Table 3).

At Blenheim in 2008, seedlings growing in soils treated with either Chloropicrin or DMDS + Chlor had significantly larger RCD than seedlings from soils treated with a lower rate of MBr (265 kg/ha) and the MBrC 70/30 (Table 4). In 2009, seedlings grown in soils fumigated with DMDS+Chlor and Pic+ had larger RCDs than either of the MBr treatments. In the 2008 growing season at Trenton, the root collar diameter (RCD) of loblolly pine seedlings growing in the non-fumigated treatment was significantly smaller than all other soil fumigants. Of the soil fumigants tested at this nursery, seedlings growing in Pic+ were significantly larger than seedlings growing in MBr, DMDS + Chlor and Chlor 60 treated soils (Table 4). Not unexpected, the effect of soil fumigants producing larger seedlings was lessened and, in 2009, there was no significant difference in seedling RCD between MBr, Pic+ and the non-fumigated treatments.

The proportion of seedlings for each grade in 2008 was variable across all soil treatments examined with none of the soil fumigants standing out at Blenheim (Table 5). In contrast, Chlor 60 had the highest proportion of seedling culls when compared to the other soil fumigants tested in Blenheim soils. In 2009, the proportion of Grade 1 seedlings increased for all soil treatments except 100% chloropicrin. Despite the low seedling densities at the Trenton nursery, the proportion of seedlings produced in 2008 for each grade was similar for all soil fumigants tested: 22% Grade 1, 60% Grade 2 and 20% Cull, except the non-fumigated soil which had the greatest percent of culls with 68% (Table 6). In 2008, soils treated with Pic+

Table 5. Loblolly pine seedling grade by soil fumigation in 2008 and 2009 at Blenheim, SC.

Soil treatment	2008				2009			
	Total	Grade 1	Grade 2	Culls	Total	Grade 1	Grade 2	Culls
MBr #1	236^{a}	64^{ab}	161^{ab}	11^{a}	247^{a}	75^{b}	150^{a}	21^{a}
MBr #2	226^{a}	32^{b}	172^{ab}	21^{a}	247^{a}	63^{b}	139^{a}	22^{a}
Chloropicrin	247^{a}	96^{a}	139^{b}	11^{a}	247^{a}	86^{b}	150^{a}	11^{a}
Chlor 60	247^{a}	43^{b}	129^{b}	7^{a}	247^{a}	96^{ab}	139^{a}	11^{a}
MBrC 70/30	236^{a}	43^{b}	182^{a}	11^{a}	236^{a}	75^{b}	139^{a}	21^{a}
DMDS + Chlor	247^{a}	86^{a}	150^{b}	11^{a}	258^{a}	118^{a}	129^{a}	11^{a}
Pic+	236^{a}	75^{a}	150^{b}	11^{a}	247^{a}	107^{a}	129^{a}	11^{a}
lsd (0.05)	22	27	29	14	22	23	21	12

Within column means followed by the same letter do not differ at P = 0.05 level using Duncan's Multiple Range Test. Numbers are seedlings per square meter of nursery bed. Target seedling density was 236 seedlings/m².

Table 6. Loblolly pine seedling grade by soil fumigation in 2008 and 2009 at Trenton, SC.

Soil treatment	2008				2009			
	Total	Grade 1	Grade 2	Culls	Total	Grade 1	Grade 2	Culls
MBr #1	182^{a}	39^{b}	107^{a}	36^{b}	118^{a}	53^{a}	54^{a}	11^{ab}
MBr #2	169^{a}	34^{b}	101^{ab}	34^{b}	115^{a}	47^{a}	53^{a}	15^{a}
Chloropicrin	170^{a}	36^{b}	110^{a}	24^{bc}	115^{a}	48^{a}	51^{a}	16^{a}
Chlor 60	161^{a}	32^{b}	98^{ab}	28^{bc}	114^{a}	53^{a}	56^{a}	5^{b}
MBrC 70/30	175^{a}	45^{ab}	99^{ab}	31^{b}	117^{a}	59^{a}	49^{a}	9^{ab}
DMDS + Chlor	173^{a}	24^{bc}	109^{a}	40^{b}	114^{a}	54^{a}	49^{a}	11^{ab}
Pic+	174^{a}	62^{a}	92^{b}	17^{c}	121^{a}	49^{a}	62^{a}	10^{b}
Control	175^{a}	9^{c}	49^{c}	117^{a}	116^{a}	39^{a}	58^{a}	19^{a}
lsd (0.05)	24	25	12	12	21	17	18	9

Within column means followed by the same letter do not differ at P=0.05 level using Duncan's Multiple Range Test. Numbers are seedlings per square meter of nursery bed. Target seedling density was 247 seedlings/m²

had a greater proportion of Grade 1 seedlings than all the other soil fumigant treatments examined. In 2009, the proportion of Grade 1 seedlings increased for all soil treatments; with 44% Grade 1, 46% Grade 2 and 9% Cull. In 2009, the higher proportion Grade 1 and Grade 2 seedlings resulted in a lower proportion of cull seedlings compared to 2008. As expected, the non-fumigated soils produced the highest number of cull seedlings. Lower seedling densities typically results in a higher seedling RCD (less seedling to seedling competition), yielding more Grade 1 seedlings per square meter. Thus, the higher number of Grade 1 seedlings in the second season (2009) is due to the lower seedling densities in 2008 compared to 2009.

Except for average root diameter, the overall seedling root architecture and root morphology was less on seedlings during the 2009 growing season than on seedlings produced during the 2008 growing season at Blenheim (Table 7). Of the soil fumigants tested at this nursery, Pic+ and Chlor 60 consistently resulted in the best root morphology of the MBr alternatives. An interesting point in quantifying root systems is that total seedling root length in these trials ranged from 181 cm to 439 cm of total fine roots per seedling. Like that at Blenheim, the overall seedling root architecture and root morphology was less in 2008 than in 2009 at the Trenton nursery (Table 8). Of the soil fumigants tested, DMDS + Chlor and Chloropicrin consistently resulted in the best root morphology of the MBr alternatives to produce a fibrous root system which increases in seedling survival in the field after outplanting.

Soil Trichoderma and nematodes

At the end of the first growing season in 2008 at Blenheim, soils treated with Chlor 60 had significantly higher levels of the soil borne fungus *Trichoderma* than soil fumigation treatments that contained some amount of MBr (Table 9). By the end of the second growing season in 2009 the *Trichoderma* levels within the soil fumigants tested were similar to MBr. Within the two MBr rates, the higher rate of MBr (448 kg/ha) had higher *Trichoderma* levels than MBr at (265 kg/ha). At Trenton, soils treated with MBr had significantly lower levels of *Trichoderma* than treatments that contained Chloropicrin in 2008 (Table 9). By the end of the second growing season in 2009, *Trichoderma* levels within the soil fumigants

Table 7. Loblolly pine seedling root morphology at the end of each growing season, Blenheim, SC.

Treatment	Root length (cm)		Root surface area (cm²)		Avg root dia (mm)		No. root tips	
	2008	2009	2008	2009	2008	2009	2008	2009
MBr #1	420^{ab}	217^{ab}	79^{a}	74^{a}	1.09^{a}	0.59^{a}	826^{ab}	474^{abc}
MBr #2	346^{b}	209^{ab}	62^{a}	72^{a}	1.10^{a}	0.57^{a}	724^{b}	449^{abc}
Chloropicrin	419^{ab}	181^{b}	76^{a}	58^{a}	1.05^{a}	0.58^{a}	830^{ab}	400^{bc}
Chlor 60	416^{ab}	229^{a}	77^{a}	78^{a}	1.09^{a}	0.59^{a}	838^{ab}	502^{ab}
MBrC 70/30	408^{ab}	205^{ab}	75^{a}	69^{a}	1.09^{a}	0.59^{a}	832^{ab}	418^{bc}
DMDS+Chlor	439^{a}	198^{ab}	80^{a}	70^{a}	1.14^{a}	0.58^{a}	850^{a}	397^{c}
Pic+	411^{ab}	224^{ab}	75^{a}	76^{a}	1.12^{a}	0.58^{a}	801^{ab}	529^{a}
lsd (0.05)	86	45	19	21	0.11	0.56	122	105

Within column means followed by the same letter do not differ at P=0.05 level using Duncan's multiple range test.

Table 8. Loblolly pine seedling root morphology at the end of each growing season, Trenton, SC.

Treatment	Root length (cm)		Root surface area (cm²)		Avg root dia (mm)		No. root tips	
	2008	2009	2008	2009	2008	2009	2008	2009
MBr #1	239^{bc}	233^{a}	90^{ab}	48^{b}	1.25^{bc}	0.67^{ab}	547^{a}	518^{abc}
MBr #2	248^{ab}	262^{a}	98^{ab}	54^{ab}	1.22^{c}	0.69^{ab}	706^{a}	527^{abc}
Chloropicrin	234^{bc}	251^{a}	106^{ab}	54^{ab}	1.36^{a}	0.73^{a}	661^{a}	490^{bc}
Chlor 60	273^{ab}	255^{a}	100^{ab}	59^{ab}	1.26^{bc}	0.69^{ab}	652^{a}	567^{ab}
MBrC 70/30	272^{ab}	215^{a}	83^{b}	58^{ab}	1.25^{bc}	0.68^{ab}	553^{a}	599^{ab}
DMDS+ Chlor	258^{ab}	267^{a}	112^{a}	58^{ab}	1.34^{ab}	0.72^{a}	662^{a}	533^{abc}
Pic+	296^{a}	240^{a}	93^{ab}	64^{a}	1.24^{c}	0.70^{a}	629^{a}	616^{a}
Control	189^{c}	266^{a}	106^{ab}	36^{c}	1.27^{bc}	0.62^{b}	660^{a}	446^{c}
lsd (0.05)	58	56	26	14	0.09	0.07	211	121

Within column means followed by the same letter do not differ at P = 0.05 level using Duncan's multiple range test.

Table 9. Post-fumigation recovery of *Trichoderma spp.* from nursery soils in Blenheim, SC and Trenton, SC nurseries in 2008.

Treatment	Blenheim, SC			Trenton, SC		
	7 weeks	15 weeks	26 weeks	7 weeks	15 weeks	26 weeks
MBr #1	47^{b}	28^{ab}	114^{a}	53^{a}	69^{a}	83^{ab}
MBr #2	20^{b}	15^{b}	40^{b}	54^{a}	74^{a}	101^{ab}
Chloropicrin	56^{ab}	33^{ab}	65^{ab}	69^{a}	76^{a}	61^{b}
Chlor 60	99^{a}	55^{a}	76^{ab}	57^{a}	57^{a}	67^{ab}
MBrC 70/30	24^{b}	18^{b}	79^{ab}	69^{a}	71^{a}	96^{ab}
DMDS+Chlor	31^{b}	17^{b}	62^{ab}	62^{a}	74^{a}	77^{ab}
Pic+	92^{a}	37^{ab}	68^{ab}	49^{a}	54^{a}	67^{ab}
Non-Control	-	-	-	69^{a}	69^{a}	124^{a}
lsd(0.05)	48	37	63	39	32	60

Within column means followed by the same letter do not differ at P=0.05 level using Duncan's multiple range test. There were no non-fumigated plots at Blenheim, SC. Numbers are in colony forming units (cfu's) per mg of soil.

examined were similar to those soils treated with MBr. The non-fumigated soils (6+ years) had the highest levels of *Trichoderma* out of all the soil fumigants at this nursery.

Over the course of the 2-year study, nematodes were assayed five times for both the number and species within the soil/seedling interface. Nematode populations within the soil are rarely uniformly distributed throughout the soil and these studies had relatively low numbers for all soil fumigants used at both nurseries (Table 10). Thus, there is no data to suggest that one soil fumigant is better than another in controlling nematodes as they were

Table 10. Soil nematode levels at the end of each growing season in Blenheim, SC and Trenton, SC.

Treatment	Nematode	Blenheim, SC		Trenton, SC	
		2008	2009	2008	2009
MBr #1	Stunt	0	0	2	24
	Root knot	0	0	0	1
	Ring	0	1	0	0
MBr #2	Stunt	1	0	1	8
	Root knot	0	0	1	0
	Ring	0	0	1	0
Chloropicrin	Stunt	0	0	27	69
	Root knot	0	0	0	1
	Ring	0	0	0	0
Chlor 60	Stunt	1	0	21	62
	Root knot	0	0	0	3
	Ring	0	2	0	0
MBrC 70/30	Stunt	0	0	2	9
	Root knot	0	0	0	1
	Ring	0	2	0	0
DMDS+Chlor	Stunt	2	0	8	96
	Root knot	0	0	0	0
	Ring	0	1	0	0
Pic+	Stunt	0	0	12	136
	Root knot	0	0	0	0
	Ring	0	1	1	2
Non-fumigated	Stunt	0	0	49	91
	Root knot	0	0	0	0
	Ring	0	0	11	0

Due to the non-uniform distribution of nematodes there were no differences observed for any treatment x nematode x year, P = 0.05. Numbers are the average of 5 replicates per treatment recovered in 100cc of soil.

equally as effective as MBr. However, at the Trenton nursery, the stunt nematode (*Tylenchorhynchus claytoni*), which can cause problems in seedling nurseries, appeared in all soil fumigant treatments during the second cropping season. It is interesting to note that Chlor 60, which contains Telone,® (a good soil nematicide), had more nematode species recovered from the soil samples than all other fumigants tested (Table 10).

DISCUSSION

The primary objective of the USDA Areawide MBr Alternative program is to identify possible alternatives to MBr using large-scale, multi-year trials in a number of different soils and growing conditions throughout the southern U.S. 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. Because of the cropping system unique to forest-tree nurseries, evaluations of MBr alternatives are conducted over two growing seasons because the true test of a soil fumigant is its performance during the second growing season where treatment differences usually begin to appear. These trials bear that out as the various MBr alternatives behaved differently at each of the nurseries tested.

When MBr is no longer available, those soil fumigants with chloropicrin appear to be most useful in controlling pests and producing high-quality seedlings at Blenheim, SC. MBr alternatives that could be considered for Blenheim are Pic+, DMDS+Chlor and Chlor 60. While there were good seedling characteristics with the soil fumigant DMDS+Chlor (Paladin®), this compound has a significant odor problem that persisted into the summer growing season which will limit its acceptance as an alternative. Of those treatments tested at Blenheim, Chlor 60 had more nematodes (numbers and species) despite having Telone®, and the largest percent of cull seedlings in the first growing season. The large percentage of culls with this soil fumigant during the first growing season is unexplainable but may be due to seedling sowing densities. Taken together, of the soil fumigants tested, Pic+ performed the best for seedling production at Blenheim, SC.

Similarly, at the Trenton nursery, those soil fumigants with chloropicrin appear to be the most useful in controlling pests and producing high-quality seedlings. DMDS + chloropicrin resulted in adequate RCD and root morphology characteristics and soil-borne *Trichoderma* levels. However, the strong odor of garlic to propane turned nursery personnel away from this treatment. By far the best MBr alternatives tested were Chloropicrin and Chlor 60, with both soil fumigants controlling nematodes and producing quality seedlings. If buffer zone restrictions that come into force in 2012 limit the use of 100% chloropicrin, then Chlor 60, with 60% chloropicrin would be the next best alternative at Trenton, SC.

One of the unique aspects of soil fumigants currently being tested in southern forest nurseries is that they do not completely eliminate beneficial fungi which are needed for seedling growth. Previous Nursery Cooperative research has shown that *Trichoderma* is not as sensitive to MBr as other soil fumigants (Carey et al., 2005; Starkey et al., 2006). In these two nurseries, the soil fumigants tested did not completely eliminate all soilborne fungi and the population levels of non-target soilborne fungi rebounded quickly with all soil fumigants. Not surprising, the highest levels of *Trichoderma* were in the non-fumigated plots at Trenton that had not been fumigated in over 6 years.

One of the aspects of determining the effects of MBr on root architecture is that a fibrous root system increases the chance of seedling survival in the field (Hatchell and Muse, 1990; Frampton et al., 2002; Davis and Jacobs, 2005). All of the soil fumigants tested were similar in their root morphology characteristics when compared to the standard MBr. Not surprisingly, the effects of soil fumigation on seedling quality can be observed in the second growing season. In all treatments, root morphology was less in the second season when compared to the first growing season. For this reason, most forest-tree nurseries limit their production to 2 seedling crops per soil fumigation as the soilborne pests become too severe to produce Grade 1 and 2 seedlings.

The final decision when selecting an MBr alternative needs to take into consideration the ability of the soil fumigant to work under individual nursery soil conditions and the impact of the new EPA reregistration eligibility decision (REDs) on each individual nursery. While it would be useful for nursery managers and researchers to continue to use MBr to grow forest-tree seedlings, MBr will eventually be unobtainable and each nursery manager will need to identify the best alternative for their nursery. For these trials, Pic+ was the better soil fumigant at Blenheim, while 100% chloropicrin would be the alternative of choice at Trenton.

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