The History and Future of Methyl Bromide Alternatives in the Southern United States

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Abstract: This article gives a brief history of the efforts of the Southern Forest Nursery Management Cooperative (SFNMC) in testing methyl bromide (MBr) alternatives for soil fumigation. In the southeastern United States, fumigation with MBr has been the most commonly used method for producing high quality, pest-free forest seedlings in an environment that is conducive for soil-borne pathogens, nematodes, and weeds. As a result of the Montreal Protocol, the production and use of MBr was to be incrementally phased out beginning in 2005. Included in this process are exemptions allowing for continued use and testing of fumigants with the goal of finding an alternative that is economically feasible and efficacious. Testing by the SFNMC has shown that, although there are alternatives to MBr, they are not as efficacious. Any choice of currently available alternatives will most likely require an increase in pesticide use to compensate for alternative short-falls. The effects of all alternatives following 4 to 5 crop rotations without MBr are unknown. Currently, recommended alternatives vary in their effectiveness from one nursery to another. The most significant development in soil fumigant research in the last 5 years has been the availability of high barrier plastics that will allow lower fumigant rates to be used. The most efficacious alternative for forest seedling nurseries in the southern United States is one that contains a significant percentage of chloropicrin as its active ingredient.

Keywords: soil fumigation, chloropicrin, loblolly pine, high barrier plastics, broadcast fumigation

Introduction

Soil fumigation with methyl bromide (MBr) has been the standard method for producing high quality, pest-free forest seedlings in the southeastern United States. Methyl bromide has shown broad efficacy in the control of soil insects, nematodes, soil-borne pathogenic fungi, and problematic weeds such as nutsedge (*Cyperus* spp.). In the southern United States, *Fusarium, Pythium*, and *Rhizoctonia* are 3 fungal genera that are of primary concern in the production of pine seedlings, as they are associated with seedling root and foliage diseases. Over the years, MBr has been effective in controlling all 3 of these soil-borne pathogens in a wide variety of soil types.

Since soil fumigant alternatives vary in efficacy between nurseries, a description of forest seedling bareroot culture in the southern United States may be beneficial. Loblolly pine (*Pinus taeda* L.) is the primary tree species produced in southern forest seedling nurseries. Seeds are sown in mid-April and lifting begins in December of that same year. Soil pH ranges from 5.0 to 6.0, and soil organic matter from 0.8% to 1.9%. Most nursery soils are in the sandy-loam or loamy-sand classification. Generally, forest seedling nurseries operate on a 3-year cropping system with 2 seedling production years per soil fumigation. Fumigation can occur in either October or March. October fumigation provides a greater biological and operational window to obtain proper soil moisture and temperatures. The average nursery fumigates about 8 ha (20 ac) per year using a certified fumigation contractor. All fumigations are broadcast/flat fume using 4 m (13 ft) rolls of plastic glued together.

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 1991. The Southern Forest Nursery Management Cooperative (SFNMC) began looking for alternative to MBr before the official phase-out program began, and this paper will outline the sequence of products tested and their results. While finding an alternative for MBr has been a priority within the forest seedling nursery industry, it has been difficult to find a soil fumigant that is as broad-spectrum as MBr.

Alternatives for MBr can be classified into 2 groups, that is, non-conventional and conventional. Non-conventional alternatives include: 1) solarization, that is, the use of solar energy to control soil pathogens; 2) biofumigation that uses gases from the biodegradation of organic matter; 3) hot water to heat the soil to temperatures that kill weeds, nematodes, and other organisms; and 4) other miscellaneous alternatives such as chicken litter, yard waste, crab processing residues, cricket litter, and the management of soil microorganisms. These non-conventional alternatives can be effective under limited conditions, such as small plots, but not for large acreage. SFNMC has not encouraged their widespread use. The second group would be considered conventional alternatives that include chemicals, both individual compounds and combinations. This latter group of alternatives has been the focus of the SFNMC research program because they are more easily adapted to large acreages.

The nursery industry realizes the importance of testing new fumigants, rates, and application techniques and, since 1972, the SFNMC and its cooperators have invested over US$ 2.8 million in alternative research in 57 research studies in cooperation with many member nurseries. The largest number of studies has been undertaken in Georgia nurseries.

1970 to 1979—Decade of Methyl Bromide Acceptance

In 1975, a survey of 55 southern nurseries determined that 39 nurseries were using MBr, and 28 of those nurseries were fumigating on a yearly basis. During this decade, 10 studies were conducted in cooperation with the Weed Control Cooperative at Auburn University comparing herbicides with MBr.

MBr (98:2) (98% MBr plus 2% chloropicrin) was being used up to 504 kg/ha (450 lbs/ac) by most nurseries. At one nursery in Georgia, 1,3-dichloropropene (1,3 D) was tested. Research studies compared the economics of fumigation versus hand-weeding or herbicides for controlling weeds. Several interesting conclusions came from these studies:

1) Due to the low hourly labor cost, fumigation was not justified for weed control, unless nutsedge was a problem.
2) Control of nutsedge with MBr 98:2 at 497 kg/ha (444 lbs/ac) in the fall was recommended.
1) Supplementing soils with endomycorrhizae was justified if using MBr.
4) 1,3-D did not significantly reduce endomycorrhizae levels.
5) Alternatives were needed that would not reduce endomycorrhizae levels.

1980 to 1989—Decade of Herbicides

During the 1970s, the use of MBr became widespread and its broad efficacy was recognized and accepted in the production of forest seedlings. During the decade following 1980, the Nursery Cooperative did not conduct a single soil fumigation study. Research efforts instead focused on obtaining new herbicide registrations for use in nurseries over conifer seedlings. These herbicides included, Goal® (Dow AgroSciences LLC, Indianapolis, IN), Modown® (Makhteshim Agan Industries, Airport City, Israel), Poast® (BASF Corporation, Triangle Park, NC), Fusilade® (Syngenta Crop Protection Incorporated, Greensboro, NC), Roundup® (Monsanto Company, St Louis, MO), and Cobra® (Valent USA Corporation, Walnut Creek, CA), most of which are still being used in 2011. Nursery research also focused on increasing seed efficiency and seedling quality.

1990 to 1999—Decade of Losers and Winners

In the Spring 1992 issue of the SFNMC Newsletter, nurseries were notified for the first time that there was a chance of losing MBr due to Environmental Protection Agency (EPA) regulations mandating a MBr phase-out under the Clean Air Act. At that time, it was estimated that MBr would be phased out by the year 2000.

Chloropicrin was recognized as a possible MBr alternative, but required additional research. While the compound had been shown to be efficacious on soil-borne fungi, insects, and nematodes, the compound was not as effective on weeds, especially nutsedge.

In 1993 and 1994, small plot alternative research trials were established to compare dazomet, chloropicrin, metham sodium with and without chloropicrin, and 1,3-D in addition to soil bio-amendments. In some studies, high density plastic tarps (HDPE) were used, and in other cases no tarp was used. As a result of these studies, applications of less than 280 kg/ha (250 lbs/ac) chloropicrin or less than 314 kg/ha (280 lbs/ac) dazomet were not recommended. Metham sodium produced seedlings similar in quality to those grown in MBr-treated soil. There was no significant difference in the results whether HDPE tarps were used or not. Dazomet reduced the beneficial soil fungus *Trichoderma* in one trial by 91%; chloropicrin more than doubled *Trichoderma* in other trials. These studies were the first to indicate that dazomet resulted in variable seedling quality and fungal control and was therefore not a strong alternative. Nurseries were strongly encouraged to plan alternative soil fumigant trials and evaluations in their own nurseries before the final phase-out of MBr.

In 1994, a fumigation trial using hot water was established in Camden, AL. Hot water at 43 °C (110 °F) was shank-injected and mechanically mixed in the soil up to 15 cm (6 in). This process used the equivalent of 345,830 l/ha (37,000 gal/ac) of water traveling at 0.8 km/hr (0.5 mi/hr) and produced inconsistent soil temperatures. The amount of diesel fuel required to heat this water was not reported. As a result, the Nursery Cooperative recognized that this was not a viable large-scale alternative to MBr.

By spring 1996, only 30% of nurseries in the southern US fumigated their soils following every crop, and 66% fumigated every 2 or more seedling crops. Alternatives that appeared to be effective were: chloropicrin; chloropicrin plus 1,3-D; and metham sodium plus chloropicrin both tarped and untarped. There was still concern about weed control using these alternatives. The SFNMC therefore began evaluating EPTC (Eptam®; Gowan Company, Yuma, AZ) for nutsedge control at 6.72 kg ai/ha (6 lbs ai/ac) rotovated through 15 cm (6 in) of soil. Initial results showed good weed activity. By the end of the decade, however, the use of EPTC diminished due to the stunting of seedlings (carry-over) and the necessity to rotovate this product into the soil. Soil fumigation applicators did not have the equipment to both rotovate EPTC and simultaneously inject soil fumigants using 4-m (13-ft) broadcast tarp applications.

Between 1997 and 1999, the Nursery Cooperative was optimistic with research using chloropicrin in combination with metham sodium and believed that this combination could be used without a tarp. By not using a plastic tarp, the additional problem of disposing of the tarp following fumigation was avoided.

The optimism was short-lived. In the fall of 1999, a nursery in Texas fumigated more than 4 ha (10 ac) with metham sodium plus chloropicrin without a tarp. Following a temperature inversion that night, the fumigant did not dissipate in the atmosphere but rather settled onto areas of adjacent seedlings ready to be lifted. More than 20 million seedlings were killed that evening. As a result, all non-tarped soil fumigation applications were halted.

2000 to 2010 — The Decade of Chloropicrin

During the early years of this decade, the dazomet manufactures changed their protocol in an attempt to identify a treatment that would provide consistent results in southern US nurseries. Further tests continued with metham sodium plus chloropicrin and metham potassium plus chloropicrin. Studies also examined shank injected and tarped applications of methyl iodide plus chloropicrin, methyl iodide, and Telone C-35® (65% 1,3-D plus 35% chloropicrin).

The results of these studies showed metham sodium, 1,3-D, and dazomet were marginally better than methyl iodide and metham potassium. The high cost of methyl iodide (nearly five times that of MBr and chloropicrin mixtures) was a concern to nursery managers. Telone C-35® provided good nematode control and enhanced weed control. Although metham sodium plus chloropicrin showed promising results, both metham sodium and metham potassium were dropped from further testing due to application difficulties. Broadcast/flat tarp fumigation equipment technology would not allow a one-pass rotovation plus shank injected fumigant followed by the standard 4-m (13-ft) tarp application. Until market forces bring about new application technologies, all broadcast alternatives that require some sort of rotovation will not be part of the MBr alternatives used in forest seedling nurseries in the southern US.

In 2003, the first small test plots using high barrier plastic tarp (virtually impermeable film [VIF]) were established. Due to the inability to glue consecutive strips of VIF using conventional HDPE plastic glue, both ends of the tarp were buried in the ground. A new chloropicrin formulation, PIC+®, that was 85% chloropicrin plus 15% solvent was also evaluated. This formulation of chloropicrin with a solvent performed similarly to a slow-release fertilizer, keeping the chloropicrin in the soil for a longer period of time. The presence of a tarp improved the efficacy of nutsedge control using PIC+®. There was no difference in weed control between PIC+® and chloropicrin. Chloropicrin and PIC+® also enhanced *Trichoderma* in the soil. These studies suggested that application rates of MBr and chloropicrin could be reduced by as much 50% when using high barrier plastics.

In 2004, dimethyl disulfide (DMDS) was first tested. Seedling quality and the amount of Trichoderma in soils treated with this new compound were equal to MBr. DMDS, however, had an unpleasant smell, described as similar to propane, which remained in the soil for most of the growing season.

In 2005, 2 fumigation studies were established that would evaluate fumigant efficacy over 2 growing seasons. The first trial in Georgia compared both methyl iodide and MBr under both VIF and HDPE plastic with dazomet using another new protocol and a water seal. The results of the 2-year study showed methyl iodide had more weeds than other fumigants tested. The seedling quality with methyl iodide was similar to MBr. Seedling quality using VIF was similar to that using HDPE at twice the fumigant rate. At the end of the first growing season, seedlings that received dazomet never grew tall enough to be top clipped. At the end of the second growing season, only seedlings in the edge drills of the beds were top clipped. In addition, *Trichoderma* counts for the dazomet plots were the lowest compared to other treatments. During the third year, a cover crop of corn was sown in the test area, and corn sown in the dazomet plots had extremely low germination.

A second 2-year fumigation study was established in Texas testing Chlor 60® (60% chloropicrin plus 40% 1,3-D), PIC +®, 100% chloropicrin, and dazomet. At the end of both the first and second growing seasons, the PIC+® plots were visibly taller than any other soil fumigation treatment. Other seedling quality data confirmed that PIC+® was the best alternative in this study. Dazomet again produced the lowest quality seedlings in both growing seasons. Following the results of these two studies, the decision was made to stop further testing of dazomet as an alternative to MBr.

Beginning in 2007, the MBr alternative research program of the SFNMC began focusing on replicated large plot studies (greater than 1.6 ha [4 ac]), testing of similar alternatives (when possible) in different nurseries (Table 1), and the collecting of similar data (Table 2) over 2- to 3-year growing cycles.

This new research approach was taken with the assistance of a 5-year grant from a USDA Agricultural Research Service South Atlantic Area-wide Pest Management Program for Methyl Bromide Alternatives. This grant allowed the SFNMC to have yearly replicated studies across nurseries in the southern US. The data collected through this project has been used by EPA in their evaluation of the criteria needed for the soil fumigant Re-registration Eligibility Decisions (REDs).

Table 2. Seedling quality parameters measured and frequency.

Seedling Parameter	Frequency
Root collar diameter	at lifting
Height	at lifting
Seedling density	2 times/season
Soil assay for Nematodes	2 times/season
Soil assay for *Trichoderma*	2 times/season
Seedling biomass	at lifting
Root architecture:	
Root length	at lifting
Root diameter	at lifting
Root volume	at lifting
Root tips	at lifting

During the first year of this project, a new soil fumigant was tested. New PIC+® was a re-formulation of Pic +® but containing a different solvent. This fumigant produced similar seedling characteristics, control of nematodes and soil-borne pathogens, and *Trichoderma* levels to that of Pic+®, but resulted in a significant annual sedge (*Cyperus compressus*) problem. Because of the weed pressure when this compound was used, it was subsequently dropped from the program after 1 year.

One of the limiting factors in broadcast soil fumigations has been the inability to glue 2 pieces of impermeable film together along the seams to form an air-tight barrier. Since the beginning of the USDA ARS Areawide project in 2007, the largest private fumigation contractor in the southern US developed new technologies for gluing the high barrier plastic films used in broadcast fumigation. This glue tech-

Table 1. Fumigant tested, rates, plastic tarps, and number of research studies.

Fumigant	Rate (metric)	Rate (Imperial)	Components	Plastic[1]	#of studies
Chloropicrin	336, 280, 168, 112 kg/ha	300, 250, 200, 150, 100 lbs/ac	100% chloropicrin	HDPE, LDPE, VIF, TIF	7
Pic+®	336 kg/ha	300 lbs/ac	85% chloropicrin plus 15% Solvent A	HDPE, LDPE, VIF, TIF	7
New Pic+®	336 kg/ha	300 lbs/ac	85% chloropicrin plus 15% Solvent B	HDPE	2
DMDS + Chlor	690, 653 l/ha	74, 70 gal/ac	79% DMDS plus 21% chloropicrin	HDPE	5
Chlor 60®	336, 280, 168, 112 kg/ha	300, 250, 200, 150, 100 lbs/ac	60% chloropicrin plus 40% 1,3-D	HDPE, LDPE, VIF, TIF	7
Midas® 50/50	179 kg/ha	160 lbs/ac	50% methyl iodide plus 50% chloropicrin	VIF	1
Midas® 98/2	112 kg/ha	100 lbs/ac	98% methyl iodide plus 2% chloropicrin	VIF	1

[1]LDPE = low density polyethylene; HDPE = high density polyethylene; VIF = virtually impermeable film; TIF = totally impermeable film.

nology will allow forest seedling nurseries to use high barrier plastics and thus significantly reduce the amount of soil fumigants used. The use of the high barrier plastics will also increase soil fumigation efficacy by allowing the soil fumigant to remain in the soil at a higher concentration and possibly over a longer period of time. By reducing application rates, the buffer zones associated with the new EPA soil fumigant labels will also be reduced, allowing greater access to nursery operations.

Research by the SFNMC to date has shown that there are 3 competitive alternatives available for nursery use: Pic+®, 100% chloropicrin, and DMDS plus chloropicrin. These choices were made based upon overall seed efficiency, seedling quality at the end of the growing season, root biomass and morphology, *Trichoderma* levels after fumigation, with no excessive nematode or weed problems.

Several other points should be considered when using these MBr alternatives. They all need to be used with high barrier plastics, either totally impermeable film (TIF) or VIF. Chloropicrin needs to be applied at minimum rate of 280 kg/ha (250 lbs/ac). Although DMDS is a decent alternative, the strong, lingering odor may limit its use and acceptance by nursery managers. Chlor 60® was an effective alternative in most nurseries with respect to seedling quality and would be recommended to nurseries with a nematode problem. Weeds may become an issue with Chlor 60® if managers do not aggressively control them. We have not had sufficient experience to adequately evaluate Midas® (methyl iodide). Arista Life Science, the manufacturer of Midas®, has not fully cooperated with our efforts to further evaluate methyl iodide in southern forest seedling nurseries. The manufacturer has not been willing to extend research studies much beyond Florida. The cost for a nursery to put in a study with methyl iodide is US$ 12,350/ha (US$ 5,000/ac), a minimum of 8 ha (20 ac), and the nursery is responsible to remove all tarps. In June 2011, EPA opened up a new comment period to examine some concerns of methyl iodide; it is therefore possible that this compound may have its label revoked.

Summary

After more than 35 years of MBr alternative research, we have reached the following conclusions:

1) Soil fumigant alternatives to MBr exist.
2) We have yet to find an alternative as efficacious as MBr.
3) Any choice of current alternatives will most likely require an increased use of pesticides (especially herbicides) to compensate for alternative short falls.
4) We do not know the long-term benefits of the alternatives. That is, what will happen in 4 or 5 fumigation cycles without MBr?
5) MBr is highly efficacious under many soil types and environmental conditions; however, alternatives do not have the same physical and chemical properties as MBr. Nurseries must pay close attention to factors such as soil moisture and temperature when using alternatives.
6) An effective alternative in one nursery may not be as effective in another nursery. All nurseries should be testing alternatives at varying rates whenever possible.
7) The most significant development in alternative research in the last 5 years has been the availability of high barrier plastics (TIF and VIF) and the technology to glue this plastic for broadcast fumigation applications.
8) When transitioning from low barrier plastic such as HDPE to high barrier plastics such as TIF and VIF, fumigation rates can be reduced by half. This recommendation should be used with caution because fumigant efficacy varies between nurseries.
9) An alternative becomes more efficacious when chloropicrin is part of the formulation at rates above 20%, for example: 1) DMDS versus DMDS plus chloropicrin (Paladin®); 2) methyl iodide versus methyl iodide plus chloropicrin (Midas®); or 3) Telone® versus Telone® plus chloropicrin (Chlor 60®).

Future Research with Alternatives

With EPA buffer zone restrictions coming into place in 2012, low barrier plastics (HDPE and LDPE) will become used less frequently. Since high barrier plastics (VIF and TIF) cost significantly more than low barrier plastics, fumigation costs can be reduced by decreasing the amount of soil fumigant used. In the future, we can expect new plastic technology for controlling emission rates. Although effective, high barrier plastics like TIF have been criticized for not allowing any gas to permeate through the barrier, thus potentially creating a problem when the tarps are cut for removal after 10 to 14 days. New, untested soil fumigants will be harder to register in the future than compounds already labeled and in the market. For example, SFNMC was evaluating sulfuryl fluoride as a soil fumigant until EPA expressed concern over the release of fluoride into the environment. Opportunities exist for new application technologies to be developed in broadcast fumigation that would allow a combination rotovator/injector/flat tarp applicator or a combination potassium thiosulfate applicator/injector/flat tarp applicator. There is also a need to explore changes in fumigant chemistry that will allow injections of several fumigants in a single pass, that is, using existing application techniques similar to tank mixing pesticides to make them more efficacious. Nurseries also need to look at current management practices that can be altered to reduce the impact of buffer zones (reduce emissions). For example, increasing soil organic matter will make seedling management easier and will provide additional buffer zone credits for fumigation.

During the last few years, the ability to use soil fumigation in forest seedling nurseries has dramatically changed. The future does not look optimistic for increasing the use of soil fumigants. The choices for viable alternatives will most likely be limited and decrease as each soil fumigant is reexamined again in 2013 for registration. The forest seedling nursery community must stay aware of regulatory changes that may impact future soil fumigation. For example, there was discussion concerning the possible elimination of chloropicrin as a soil fumigant. This idea was dropped for now. If it ever becomes an issue, there needs to be a unified response from the nursery community against any effort to eliminate chloropicrin. Chloropicrin is part of every efficacious fumigation alternative the forest nursery industry has.

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