Comments on Alternatives to Methyl Bromide for Quarantine Purposes in Forest Nurseries

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South DB. 2008. Comments on alternatives to methyl bromide for quarantine purposes in forest nurseries. In: Dumroese RK, Riley LE, technical coordinators. National Proceedings: Forest and Conser-vation Nursery Associations—2007. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-57:18-26. Available at: http://www.fs.fed.us/rm/pubs/rmrs_p057.html

ABSTRACT
Viewpoints will vary in regards to the best alternative to methyl bromide (CH_3Br) fumigation. In some cases, crop value will determine the best alternative. As the value of the crop increases, the rate (and cost) of the best treatment might increase as well. In addition, the recommendation will depend on if the individual has a vested interest in the production of high quality seedlings. An individual with no economic incentive might recommend an uneconomical, impractical, or unreliable alternative. In contrast, an individual who intends to make a profit might recommend an alternative that would cause minimal impact on costs and revenue. According to tests in both the southern and western US, chloropicrin applied under a tarp at 336 kg/ha (300 lb/ac) will cause a minimal disruption to a well-managed forest nursery. If nematodes are present, a fumigant like 1,3-D may be applied at time of treatment. Although chloropicrin is not as effective as CH_3Br on certain perennial weeds, sanitation and the effective use of herbicides can minimize the population of troublesome weeds.

KEYWORDS
fumigation, chloropicrin, herbicides, nematodes, disease, weed control

Introduction

Methyl bromide (CH_3Br) is a natural compound that is produced by phytoplankton in oceans, by forest fires, by certain plants, and by ectomycorrhiza. The amount produced by natural events in the southern hemisphere troposphere might amount to 6 ppt of CH_3Br (which is enough to affect the stratospheric ozone layer) (Montzka and others 2003). Of the total amount of CH_3Br in the stratosphere (about 8.2 ppt), natural sources amount to 81%, while manufactured sources account for 19% (Fahey 2006). However, attempts to separate natural and anthropogenic components has generated considerable scientific and regulatory controversy. In the 1990s, oceans were thought to be a net source of CH_3Br. In 2007, oceans are viewed as a net sink (Yvon-Lewis and Butler 1997). Some assume that all "unknown" sources of methyl bromide are the result of human activity (Saltzman and others 2004), while others assume some of the "unknown" sources could be from natural sources. Some believe the 8.2 ppt level detected in 1997 (in the southern hemisphere) is about 1.6 ppt higher than it should be (Figure 1). As a result, an international agreement (the Montreal Protocol) put limits on the manufacture of CH_3Br and other ozone depleting substances (Parker and others 2005). Due to countries adhering to the Montreal Protocol, production of ozone depleting substances was reduced from 1.8 million weighted tonnes/year (2.0 million tons/year) in 1987 to about 83,000 tonnes/year (91,500 tons/year) in 2005 (EPA 2007). Therefore, annual production (by humans) of ozone depleting substances has been reduced by more than 95%. The global consumption of CH_3Br was about 71,764 tonnes/year (79,100 tons/year) in 1991. By 2005, it was reduced to about 20,752 tonnes/year (22,875 tons/year) (MEBTOC 2006).

From 1998 to 2003, the bromide levels in the troposphere decreased by about 0.8 ppt (Montzka and others 2003). Dr Ian Porter of Australia (a co-chair of the United Nations MB Technical Options Committee) purportedly said that, due partly to the reduction in use of manufactured methyl bromide, "the hole in the ozone layer (Figure 2) should begin to decrease in size over Australia within the next few years" (Dowler 2007). Due to the phase-out, the price of CH_3Br has increased, and some managers are now seeking alternative treatments.

Quarantine and Pre-shipment

Paragraph 6 of Article 2H of the Montreal Protocol exempts the use of CH_3Br used for quarantine and pre-shipment (QPS). The Montreal Protocol provided no limitation to the production and consumption of CH_3Br when used for QPS purposes. When CH_3Br is used for this purpose, it is referred to as "QPS gas." Some nursery managers fumigate with QPS gas to help ensure that seedlings shipped are "free of injurious pests." A phytosanitary certificate is typically required before seedlings can be shipped over state or international borders. For example, in 2004, nursery stock and Christmas trees were shipped from Oregon to over 70 foreign countries. Soil fumigation (for example, QPS gas) is a tool used

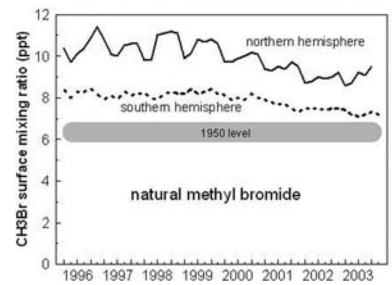

Figure 1. The amount of methyl bromide (CH_3Br) has declined in the stratosphere above the northern and southern hemispheres (Butler and others 2004; Fahey 2006). Higher levels of CH_3Br in the northern stratosphere are due, in part, to a greater amount of vegetation combined with more biomass burning (CH_3Br sources) in the northern hemisphere, and more oceans (CH_3Br sink) in the southern hemisphere. In 1950, the amount of CH_3Br in the stratosphere may have averaged 7 ppt (Fahey 2006).

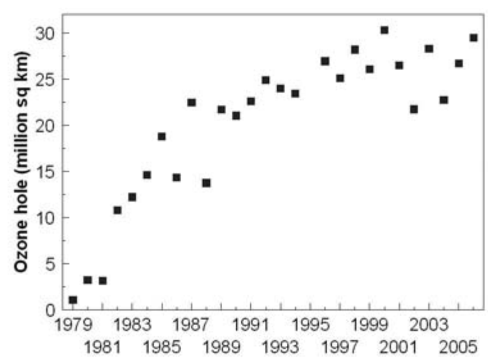

Figure 2. The ozone hole above Antarctica has increased from less than 5 million km^2 (1.9 million mi^2) in 1980 to more than 25 million km^2 (9.6 million mi^2) in 2006. On September 25, 2006, the size was 29.5 million km^2 (11.4 million mi^2). If computer models prove to be accurate, the recovery of the ozone hole should take place around 2060.

The following is from the 2006 Report of the Methyl Bromide Technical Options Committee (MEBTOC 2006).

The Seventh Meeting of the Parties decided in Dec. VII/5 that:

(a) Quarantine applications, with respect to methyl bromide, are treatments to prevent the introduction, establishment and/or spread of quarantine pests (including diseases), or to ensure their official control, where:
(i) Official control is that performed by, or authorized by, a national plant, animal, or environmental protection or health authority;
(ii) Quarantine pests are pests of potential importance to the areas endangered thereby and not yet present there, or present but not widely distributed and being officially controlled;

(b) Pre-shipment applications are those treatments applied directly preceding and in relation to export, to meet the phytosanitary or sanitary requirements of the importing country or existing phytosanitary or sanitary requirements of the exporting country;

(c) In applying these definitions, all countries are urged to refrain from use of methyl bromide and to use non-ozone-depleting technologies wherever possible. Where methyl bromide is used, Parties are urged to minimize emissions and use of methyl bromide through containment and recovery and recycling methodologies to the extent possible.

to reduce the risk of spreading invasive diseases and pests on nursery stock.

The use of QPS gas is increasing in response to the International Standard for Phytosanitary Measures (ISPM 15), which is encouraging CH_3Br use on wooden packaging materials (FAO 2002). Ajavon and others (2007) believe, however, this increased use of QPS gas is offsetting the reductions which have occurred in soil fumigation and other non-QPS uses. They say that that "technical alternatives" exist for almost all controlled uses of CH_3Br. However, "technical alternatives" such as methyl iodide (a soil fumigant) and halosulfuron-methyl (an herbicide with activity on nutsedge), may not be used legally unless registered by the US Environmental Protection Agency (EPA). Thus far, we know of no herbicide or fumigant that EPA has approved as an alternative to CH_3Br fumigation in forest tree nurseries. Because EPA has not approved use of halosulfuron-methyl, MSMA, methyl iodide, or sodium azide, nursery managers will continue to use chemicals that have been approved by EPA.

Silvicultural Alternatives to QPS Gas

Landowners who wish to regenerate a stand after harvest have several options. Some landowners may choose to conduct a prescribed burn and then allow natural regeneration to occur. This option will result in some CH_3Br being released into the atmosphere during the burn. Global emissions of methyl bromide from biomass burning are estimated to be in the range of 10,000 to 50,000 tonnes/year (11,000 to 55,000 tons/year), which is comparable to the amount produced by ocean emission and pesticide use, and represents a major contribution (an estimated 30%) to the stratospheric bromine budget.

Direct seeding does not rely on the use of QPS gas and is another silvicultural option that some landowners have employed. The cost of site preparation, seeds, labor, and herbicides may range from US$ 615 to 1230/ha (US$ 250 to 500/ac) and the risk of failure can be high.

Some landowners may decide to purchase and plant container stock. In some locations, the price of container stock is similar to that of bareroot stock. For example, in the Pacific Northwest, container stock may cost US$ 0.34 per seedling, while bareroot stock (produced after fumigating soil with QPS gas) might cost US$ 0.30 per seedling. When container seedlings cost more than bareroot stock, one option is to plant fewer container seedlings to offset the higher cost. When container stock is 33% more expensive than bareroot stock, the cost to the landowner could be offset by reducing stocking by 25%. For example, if bareroot seedlings are sold for US$ 0.30 each, 1,000 trees would cost US$ 300. In comparison, if container seedlings are sold for US$ 0.40 each, 750 trees would cost US$ 300. Typically, hand-planting costs will also be reduced when stocking is reduced by 25%.

Bareroot nurseries in the Netherlands once relied on methyl bromide, but they increased the use of metham sodium and increased the use of container plants (MBTOC 2006). In British Columbia, the use of container stock gradually increased (van Eerden 1996). Recently, the International Forest Company (based in Georgia) decided to close 4 bareroot nurseries and to expand the production of container stock. The capital required, however, to convert from a bareroot nursery to a container nursery can be a limiting factor. Many state-owned nurseries operate under funding constraints and many privately-owned bareroot nurseries have no incentive to convert to container production. Applying alternative chemical fumigants is cheaper than investing in container equipment and facilities.

Chemical Alternatives to QPS Gas

A number of chemical fumigants have been tested in forest nurseries. Some are not registered and some have not proved to be effective. The following comments pertain to the practical alternatives to QPS gas.

Chloropicrin Under a Tarp

Chloropicrin has been tested in forest nurseries for more than 60 years. For example, chloropicrin was applied to conifer seedbeds in Nisqually, Washington (Breakey and others 1945). This treatment has shown promise in the Lake States, Pacific Northwest, and in the South (Enebak and others 1990a; Rose and Haase 1999; South 2007). New formulations that include "solvents" have also proven effective. Rates of 336 to 400 kg/ha (300 to 360 lb/ac) have been effective in forest nurseries.

Chloropicrin Plus 1,3-D Under a Tarp

At some nurseries, nematodes can be a problem and can reduce both yield and seedling quality. Therefore, monitoring of soil for nematodes will likely increase as the use of methyl bromide decreases. In cases where injurious populations are confirmed, nursery managers may decide to include 1,3-D when fumigating with chloropicrin. The rate may vary with nursery, but some managers have applied a rate of 269 kg/ha (240 lb/ac) chloropicrin plus 180 kg/ha (160 lb/ac) 1,3-D.

1,3-D without a Tarp

The rotation commonly used at a nursery may affect the timing of application. In some regions, there is one seedling crop per fumigation. Soil may be fumigated with QPS gas in the autumn; the following spring, seeds are sown to produce a 2+0 or 3+0 crop. This is often followed by a cover crop, and then the sequence is repeated. In the southern US, 2 or sometimes 3 seedling crops may follow the initial QPS fumigation. If the nematode population reaches a high level during the first rotation, an untarped treatment of 1,3-D may be applied in the spring (prior to sowing the second crop). In this case, a rate of 127 kg/ha (113 lb/ac) may be applied followed by pressing the soil with a roller (sealing) and then applying 1 to 2 cm (0.4 to 0.8 in) irrigation. When 1,3-D is applied more than once in 3 years, a buffer zone of 31 m (102 ft) may be required.

MITC Compounds

Methyl-isothiocyanate (MITC) is an active compound that is produced by several fumigants (dazomet, potassium methyldithiocarbamate, sodium methyldithiocarbamate). The MITC compound is produced when these compounds react with water. Most labels indicated sealing the soil by either a "water seal" or plastic tarp will increase efficacy. In addition, a water seal may reduce the amount of MITC that is released into the atmosphere (Wang and others 2006). In some cases, however, the soil has been sealed by a roller to compress the soil surface. Labels typically indicate that activity will be increased when the soil is covered with a plastic tarp.

Dazomet has been used in forest nurseries for more than 60 years. In 1956, Wilson and Bailey (1958) applied 156 kg/ha (139 lb/ac) at a nursery in Ohio; the following year, trial samples were sent to 70 forest nurseries. In 1963, a rate of 325 kg/ha (290 lb/ac) was tested (Iyer 1964). Three decades later, a rate of 140 kg/ha (125 lb/ac) was applied (Enebak and others 1990b). Recently, researchers applied 448 kg/ha (400 lb/ac) dazomet in Wisconsin (Wang and others 2006) and up to 560 kg/ha (500 lb/ac) have been applied in Georgia (Fraedrich and Dwinell 2003). The "recommended" application rate has increased by about 60 kg/decade (132 lb/decade). One possible explanation of the increase in rates is due to inconsistent results from lower rates (Enebak and others 1990b).

Several problems have been reported when using MITC fumigants. Most problems occurred when not using a tarp and when an inversion layer occurred soon after treatment. In some cases, the evolution of MITC has damaged pines (that is, bleached out needles) that were growing 120 m (400 ft) from the treated area (Buzzo 2003). Injury of this type has occurred at nurseries in Arkansas, Texas, Oregon, and Washington. At some nurseries, a negative effect of fumigation on soil fertility has persisted for years. In a Georgia nursery, corn (*Zea mays*) was stunted 2 years after treatment with dazomet and, at another nursery, *Trichoderma* levels remained depressed for more than a year.

Herbicides

QPS gas can be used to reduce the risk of spreading noxious weeds such as cogongrass (*Imperata cylindrica*), because methyl bromide will likely kill the seeds. Many nurseries rely on fumigation with QPS gas to control perennial weeds such as nutsedge (*Cyperus* spp.). At some nurseries, herbicides can be an economical alternative to controlling annual weeds (South and Gjerstad 1980).

Many predict herbicide use will increase as use of methyl bromide declines. This is based on reports where weed populations were higher when certain alternative fumigants were tested (but where herbicide treatments were absent). Several researchers believe that most weed populations can be kept low by applying sanitation in combination with judicial use of herbicides. The ability to maintain low weed populations, however, depends on both a sound knowledge of herbicide efficacy and an adequate number of legal herbicides. There can be several reasons why the number of herbicides available to nursery managers is small and may decrease in the future.

NOT A MAJOR FOOD CROP

A number of effective herbicides might be used in forest nurseries. However, the list of herbicides that are legal for use in conifer seedbeds is shorter than the list that the Environmental Protection Agency (EPA) has approved for use on major food crops. Prior to 1972, a nursery manager could legally apply any herbicide to control weeds, but managers can now only use an herbicide that is "registered for the site." For example, if a nursery manager wishes to control nutsedge with halosulfuron-methyl, *Zea mays* (a food crop) could be treated with an aerial application of 70 g/ha (1 oz/ac), but EPA would not permit hardwood seedlings (a non-food crop) to be treated with a ground application of 7 g/ha (0.1 oz/ac) of halosulfuron-methyl. To be legal, research would be required, and then a chemical company would need to file a special local need (24-C) label. In some states, the 24-C label might be approved while rejected in other states. Therefore, it is easy to understand why many farmers (who do not fumigate soil with methyl bromide) have relatively weed-free corn fields, while nursery managers (who fumigate soil prior to sowing hardwoods) may require 500 hours of weeding/ha (200 hours/ac). If managers could legally apply any food-crop herbicide to suppress weeds in hardwood seedbeds, hand weeding times might be less than 50 hours/ha (20 hours/ac) and the need for fumigation to suppress troublesome weeds would be minimized.

LAWSUITS

Pesticide use in forest nurseries has evolved from relying on just 1 or 2 pesticides before 1940, to relying on a number of pest control products (some even with activity only on certain genera). This evolution was accomplished through cooperation and trust among nursery managers and researchers. This cooperation is essential if knowledge is to be increased in this important management area. It is important that knowledge obtained by nursery managers be shared with researchers, and that researchers share results from their trials with nursery managers. However, this cooperation was weakened by several lawsuits during the 1990s. For example, the EI Dupont Company withdrew the fungicide benomyl after numerous lawsuits and claims originated from horticultural nurseries. In one case, a forest nursery in North Carolina claimed that poor germination resulted after pine seeds were treated with benomyl. In New York, a manager applied oryzalin to young tree seedlings and then filed suit against the chemical company. As a result, nursery managers throughout the US may now no longer apply this herbicide to either seedbeds or seedling transplant beds. In addition, all the researchers' time and effort testing oryzalin in forest nurseries were wasted by one lawsuit. One should therefore not be surprised when some researchers are reluctant to share information with managers who might later sue a chemical company for monetary gains. "The actions of one individual can erase the potential benefit of many research years" (South 2002).

FOREST STEWARDSHIP COUNSEL

The Forest Stewardship Council (FSC) is an international non-profit organization created to support environmentally appropriate, socially beneficial, and economically viable management of the world's forests and plantations. FSC has developed a list of herbicides that may not be used in forest nurseries (FSC 2005). Plantation owners seeking FSC certification might not be allowed to obtain seedlings from nurseries that use herbicides such as atrazine, fluazifop-butyl, metalochlor, oxyfluorfen, and pendimethalin. Therefore, nursery managers who sell seedlings to customers who desire FSC certification for their plantations may have a very short list of permitted herbicides. In addition, FSC does not permit FSC seedlings to be treated with metam sodium or QPS gas (without special permission from FSC).

LIMITED HERBICIDE RESEARCH

At one time, a number of researchers were conducting herbicide studies in forest nurseries. Trials were conducted in Alabama, Connecticut, Idaho, Indiana, New York, and Oregon. Trials were initially funded by the USDA Forest Service, and then several forest companies sponsored research at universities. The interest in funding herbicide research declined and some researchers moved to other, better funded areas of forestry. Herbicide screening is now limited mainly to nurseries who are members of nursery cooperatives in the South and Pacific Northwest. If research on nursery weed control continues to decline (due in part to company mergers, a decline in artificial regeneration research at universities, and forest industry owning less land), nursery managers may have fewer weed control tools in the future.

Table 1. Estimates of prices of various fumigation treatments and the increase in seedling production required to justify the cost of fumigation (at a price of US$ 0.10/seedling).

Fumigant	Active ingredient/ha[z]	Price/ha (US$)[y]	Yield increase required per ha[x]
Methyl bromide (98%)—QPS	448 kg	3953	39,530
Chloropicrin under a tarp	336 kg	4200	42,000
Chloropicrin plus 1, 3-D under a tarp	270 kg + 180 kg	4448	44,480
1,3-D with no tarp	127 kg	482	4,820

[z] Active ingredient/ac is 1 kg/ha = 0.9 lb/ac
[y] Price per ac is US$ 100/ha = US$ 40.50/ac
[x] Yield increase per ac is 1000/ha = 405/ac

Economics

Opinions on the best alternative to QPS gas will vary depending on both economics and the individual's job. In some cases, crop value will determine the best alternative (South and Enebak 2006). As the value of the crop (per ha) increases, the rate (and cost) of the "best" treatment will increase. Therefore, a manager who routinely makes a profit of US$ 8000/ha (US$ 3,240/ac) will likely use a more expensive fumigant than someone who makes a profit of only US$ 800/ha (US$ 324/ac). Likewise, a manager that is required by law to "break-even" (that is, no profit) will likely be told (by a financial officer or lawyer) to select a low-cost soil fumigation treatment. At some nurseries, the cost of soil fumigation may exceed US$ 4000/ha (US$ 1620/ac) (Table 1).

Some nurseries produce more than 20 million seedlings annually and can afford to have a contractor apply fumigants that are classified as "restricted use pesticides." Fumigants in this category include methyl bromide, chloropicrin, and 1,3-D. In contrast, when the annual production at some nurseries is less than 2 million seedlings, the managers might not be able to afford to have professional applicators treat only 1 or 2 ha (2.5 or 5 ac) of seedbeds. Therefore, some managers may decide to apply fumigants that are not classified as restricted (for example, dazomet, potassium-N-methydithiocarbamate, sodium methyl dithiocarbamate). These fumigants may be applied by personnel that do not have a restricted pesticide license.

Summary

Some managers will use QPS gas to reduce or prevent the shipment of noxious pests from bareroot nurseries. Others might reduce their use of CH_3Br by ceasing the production of bareroot stock and by producing only container stock. Some managers will continue to produce less expensive bareroot stock by switching to alternative fumigants and increasing the use of herbicides and nematicides. Some managers who want to make a profit may decide to fumigate with chloropicrin (336 kg/ha [300 lb/ac]) under a tarp. These managers will likely treat soil with 1,3-D if the population of pathogenic nematodes exceeds acceptable levels. Troublesome weeds (for example, *Cyperus* spp.) will be controlled using effective herbicides on fallow ground, in cover crops, and in seedbeds.

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