Auburn University Southern Forest Nursery Management Cooperative

TECHNICAL NOTE 96-2

THE LOSS OF METHYL BROMIDE AS A FUMIGANT IN FOREST TREE NURSERIES AND THE IMPACT ON REFORESTATION PROGRAMS

by
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INTRODUCTION

Methyl bromide (MBr) is currently used as a soil fumigant in most southern forest tree nurseries. Over the past 40 years MBr has proven to be a consistantly reliable pesticide that enhances seedling production and suppresses soil-borne pests. It has become the industry standard and is an essential component of virtually every pest management program in southern forest tree nurseries. By reducing populations of many pests, the use of MBr can reduce the demand for more specific pesticides such as herbicides, fungicides, and insecticides. Moreover, MBr typically results in superior seedling growth. There is little doubt that MBr is one of the most important pesticides used in the production of forest tree seedlings in the southern U.S.

The U.S. Environmental Protection Agency has ordered a complete ban on the production of MBr after January 1, 2001 and production is currently frozen at 1991 levels. Legal jurisdiction for this ban falls under the Clean Air Act which the EPA administers. This act addresses chemicals suspected of depleting stratospheric ozone. A consensus has emerged in the scientific literature during the last 20 years that the concentration of stratospheric ozone was declining and that chlorinated fluorocarbons (CFC's) were the cause. To address this, the Montreal Protocol on substances that deplete the ozone layer was signed by several nations in 1987 to bring about the eventual phase-out of CFC's. Little attention was given to bromine until 1991 when its class of chemicals was added to a growing list of potential ozone depleters. MBr is 84% bromine by weight and is considered by the EPA to be a significant contributor to ozone depletion. Even though Montreal Protocol signees decided in 1992 that the MBr issue should be reconsidered in

1995 after a technical options assessment, MBr was already (in 1992) scheduled for termination in the U. S. Lawsuits brought by several environmental groups had triggered an automatic phaseout of MBr under the Clean Air Act. The Montreal Protocol, but not the Clean Air Act has allowances for economic and scientific uncertainty.

Nursery managers and pest specialists are very concerned about the probable loss of this important pesticide. This Technical Note reviews the current status of MBr use in forest tree nurseries, its effects on seedling production, and the most probable alternative fumigants. We hope to provide a basis for further rational discussion regarding the potential loss of MBr and subsequent effects on forest tree seedling production in the South.

MBR USE IN SOUTHERN NURSERIES

Application Frequency and Rates

Approximately 96% of southern nurseries use soil fumigation and 90% of the fumigant used is MBr (Jang et al. 1993). MBr is most commonly applied in southern nurseries once every four years prior to two years of pine seedling production followed by two years of cover crop. Fumigation is usually applied in the fall or spring preceeding the first pine crop in the rotation. The gas is injected into the soil and immediately covered with a continuously overlapping plastic tarp.

The total amount of MBr used in southern forest nurseries is estimated at 161,000 pounds. This is about 0.33% of the estimated 49 million pounds used for soil fumigation in the U.S. in 1990 (U.S.D.A. 1994). Amounts of MBr used to produce seedlings vary between individual nurseries based on rotation schemes, seedbed densities, and formulation (Table 1). The standard application rates are either 350 lbs/ac of 98% MBr (MC2) or 400 lbs/ac of 66% MBr (MC33) (South and Zwolinski 1996). Using these rates, the bromine applied would be 330 lbs/ac for MC2 formulations and 194 lbs/ac for MC33 formulations. There is, therefore, the potential for

TABLE 1. Bromine requirements for the annual production of 20 million seedlings using MC2 or MC33 for two fumigation schedules and at two seed bed densities.

Crops/Treatment	Seedlings/ft^2	Acres Treated	Bromine in Tons MC2[b]	Bromine in Tons MC33
1	15	46	6.60	5.04
1	25	27.5	3.96	3.01
2[a]	15	23	3.31	2.52
2	25	13.75	1.98	1.51

(a) two years of pine production followed by two years of cover crop
(b) MC2 is 350 lb/ac 98% MBr and 2% chloropicrin, MC33 is 400 lb/ac 66% MBr, and 33% chloropicrin

considerable variability in the amount of bromine used per unit of production between nurseries. Just over the range of schedules considered in Table 1, bromine requirements varied from 1.5 to 6.6 tons per year for the production of 20 million seedlings.

Efficacy for Soil-Borne Pest Control

MBr is used to control weed seed, soil-born fungi, nematodes, and insects. Formulations with 2% chloropicrin are suggested when perennial weeds and nematodes are the primary pest problem, and those with 33% chloropicrin are indicated when more difficult-to-kill fungi are the pest target (South and Zwolinski 1996, May 1985). MBr fumigants were instrumental in greatly reducing the impact of difficult-to-control soil fungi such as the charcoal root rot pathogen *(Macrophomina phaseolina)* at some nurseries (Seymour and Cordell 1979). MBr fumigation has been superior to soil drenches containing fungicides for the control of *Fusarium* spp. in nurseries (Rowan 1981).

MBr containing fumigants help control perennial weeds, such as nutsedge *(Cyperus* spp.), which currently registered preemergent herbicides seldom adequately control. Postemergent nutsedge control is limited because of the lack of herbicide selectivity. The use of MBr for weed control in hardwood seedbeds may even be more critical because of the lack of suitable pre- or post-emergent herbicides (South 1994). Nursery managers will therefore often fumigate immediately prior to every hardwood seedling crop to reduce the amount of hand weeding that otherwise would be required.

THE EFFECTS OF MBR ON SEEDLING PRODUCTION AND QUALITY

The extensive use of MBr in forest tree nurseries across the South (Jang *et al.* 1993) is our best indication of its consistent effectiveness across a wide range of conditions. Moreover, increases in both size and numbers of seedlings after fumigation are abundantly documented in studies carried out in forest tree nurseries over the last 40 years. Table 2 summarizes the results of 40 years of research regarding the effect of MBr on seedling numbers and size. Most of the currently available fumigants were tested between the late 1940's and 60's. After the superiority of MBr was established, little additional research occurred until the loss of MBr's registration became likely. Only 6 of the 33 reports included in Table 2 are less than 20 years old. Most data applies to pines or spruces. For these comparisons, not fumigated beds produced 33% fewer seedlings than those fumigated with MBr or MC33. Not fumigated beds contained 27% fewer seedlings than Metham-sodium (SMDC) treatments which were the second best in average performance of the widely tested fumigants. Based on average performances, where MBr fumigated beds produced 100 seedlings, controls would be expected to produce 67 seedlings (that is 100 - 33%). Using a South-wide production figure of 904 million seedlings (Moulton *et al.* 1995), Methyl bromide could theoretically be responsible for 33% of this production, or 298 million seedlings. Calculating at $30/1000 seedlings, the value of this production increase is 8.9 million dollars annually,

TABLE 2. Effects of fumigation on numbers and sizes of plantable forest tree seedlings as the average percent reduction in not treated compared to treated nursery beds. (From Carey, 1994a)

Chemical	% Reduction from the Controls (# comparisons) Seedling Numbers	Seedling Size	N*W[a]
Mbr	33 (99)	14 (36)	41
MC33	33 (58)	1 (20)	28
Metham Sodium	27 (58)	5 (26)	5
Ethylene Dibromide	22 (17)	-2 (12)	27
Dazomet	15 (48)	2 (28)	17
Formaldehyde	14 (5)	14 (4)	27
Chloropicrin	14 (13)	22 (12)	36
DD	6 (27)	6 (4)	3
Mean (sum)	25 (345)	25 (142)	2

[a]Difference in products of seedling weight and number for treatment minus that for control as a percent of treatment.

Not only has MBr increased the average number of seedlings produced per unit area of nursery bed, it has also increased the average size of those seedlings. A review of 36 published comparisons conducted over the past 40 years in which some aspect of seedling size was compared between seedlings from not fumigated and MBr treated beds (Table 2), found that seedlings from the MBr treated beds averaged 14% larger (Carey 1994a). The effect of bed density on seedling size was not addressed in the original reports but logical inferences can be made. If fumigation effected the number of seedlings without enhancing the growth of individual seedlings, then as bed density increased mean seedling size would decrease. Among the studies averaged in Table 2, this occurred only for ethylene dibromide (EDB) treatment and seedlings were both larger and more numerous for other fumigation treatments and this growth enhancement was greatest for MBr treatments. In Table 2, the variable N*W is a dimensionless number. Within each study, N*W is the product of seedbed density and either average biomass (if reported) or diameter for not treated beds compared to that for fumigated beds. In Table 2, the number presented for N*W is the average for the number of comparisons for seedling size.

NON-TARGET EFFECTS OF MBR USE

Effect on Non-Target Soil Microorganisms

There is a general conception that MBr is universally toxic to all organisms and that fumigated soils are left essentially sterile. This is not true and populations of soil fungi after fumigation are well documented (Munnecke *et al.* 1978. Wensley 1953). For example, *Trichoderma* has been shown to be resistant to MBr. This highly competitive soil fungus suppresses several pathogenic fungi (Strashnow *et al.* 1985, Danielson and Davey 1969, Wensley 1953). In AUSFNMC trials through the South (Carey 1996, 1995b) *Trichoderma* has consistently increased after treatments with MBr or chloropicrin but decreased after some other treatments. A. L. Foster (1961) concluded 35 years ago that "MBr may well be as important for what it leaves in the soil as for what it removes." It is unfortunate, and surprising, that differences in the "selectivity" of MBr among microbes is known with little more precision today than in 1961.

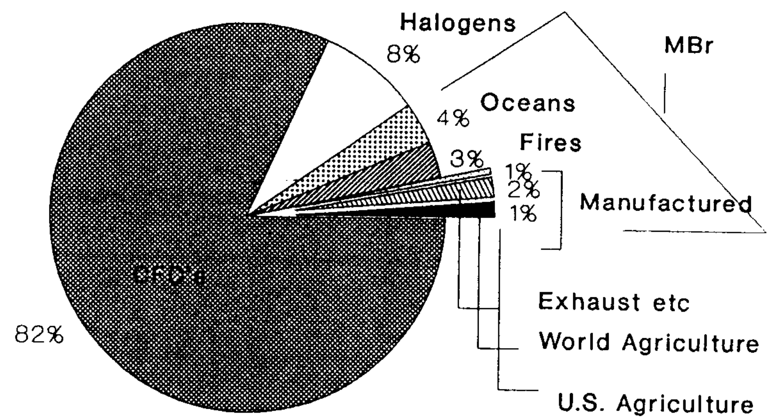
Human Health

MBr is a toxic substance that when used on the scale required to fumigate a forest tree nursery is probably best left to professionals. Although exposure is most likely to come thorough inhalation, dermal contact can also cause serious, systemic symptoms. Although not as acutely toxic as some other currently used fumigants MBr would be more hazardous were it used in pure form (as in some structural fumigation) due to its lack of color and odor. The MBr formulations used in nursery soil fumigations are mixed with chloropicrin, a potent lacrimator and the active ingredient in tear gas, which provides an effective early warning signal of exposure. *Toxicity* refers to the inherent poisonous potency of a compound, and *Hazard* refers to the risk or danger of poisoning when a compound is used or applied (Ware 1978). A one-hour exposure to MBr at 2,000 ppm can be lethal (Thompson 1992). That is the equivalent of a one-pound can of MBr dispersed in 2,000 ft^3 of air or roughly a large bedroom (15 ft by 15 ft). Carbon tetrachloride, once common in chemistry labs and dry-cleaning shops, could be lethal at 300 ppm, and EDB at 200 ppm (Thompson 1992). Chloropicrin is about 1,000 times more toxic than MBr, yet Army personnel are regularly exposed to it during training. Chloropicrin can be lethal to mammals at an exposure of 8 ppm for only 10 minutes. This is one pound dispersed in a 290,000 ft^3 or a 6.5 ft high room the size of a football field. Nevertheless, because nobody voluntarily breaths even very dilute concentrations of tear gas (as little as 1 ppm is intolerable), the more *toxic* chloropicrin added to the odorless MBr reduces the *hazard.*

Ragsdale and Wheeler (1995) provide a good summary of the long term effects of exposure to Mbr. They found little evidence for chronic (or cumulative) effects in laboratory animals. In long term studies, no cancers were detected in rats exposed by inhalation to various concentrations for 5 days/week for 6 hr/day for 29 months. Neither did rats fed food treated with MBr (up to 500 ppm Br) develop cancers or have reduced reproductive performance or increased birth defects. These are very reassuring statistics and even more remarkable when compared to some of the other more commonly used agricultural pesticides. In the final analysis the authors concluded that MBr can be safely used when label precautions are followed.

Ozone Depletion

Measurable and historic reductions in stratospheric ozone (O_3) are believed to have occurred and to be occurring due to human-made chemicals. Stratospheric ozone absorbs ultraviolet (UV) light especially wavelengths around 280 nm (UVB). UVB is biologically active, it can kill microorganism, causes skin to sunburn and tan, and exposure correlates with increases in skin cancer. Therefore, reduced ozone could increase UVB and cause reductions in global biological productivity and increases in human skin cancer. Current science supports the idea that certain chemicals deplete stratospheric O_3. The bromine from MBr is one of the chemicals that is believed to contribute to this change. Much of the inorganic Br in the stratosphere (about 46%) is from halons (Br containing CFC's) and since some halons persist for 40 years the annual flux to



Estimated from abundance X activity.

Figure 1. Stratospheric Ozone Depletors (chloronated and brominated only)

Figure 1 summarizes some general estimates (abundance x activity) for the contributions of the major components to ozone depletion. Most of these are from a 1994 article by R. J. Cicerone. About half the organic Br in the stratosphere is probably from halon and most of the rest is from MBr of which about 20% is thought to be manufactured. Although Br is less than 1% as abundant as Cl in the stratosphere it is thought to be 40 times (+ or - 50%) more destructive per atom. Therefore, about 18% of O_3 destruction (assuming incorrectly that all is from either Br or Cl) would be by Br with the 20% of Br from manufactured MBr causing about 5.6% of O_3 destruction. About one third of manufactured MBr is from soil fumigation. The Figure 1 projection of 4% for anthropogenic MBr is less, but not much less than the estimate from UNEP, 1992 of from 5 to 10%.

the stratosphere is roughly the same as production, which in 1990 was about 7.2 million Kg (Cicerone 1994). Estimates for the actual percentage of ozone decline are controversial. In fact, a minority of scientists, including S. Singer developer of the ozone-sensing instrument flown on satellites, believe there is insufficient evidence to indicate any decrease (Monastersky 1995).

The contributions of what are currently thought to be the significant ozone depletors are represented in Figure 1. These estimates were generated by trying to reach a balance between estimates from the papers cited throughout this paragraph. However, estimates in atmospheric chemistry frequently include large margins for error and different pictures can be generated. Nevertheless, the contribution of MBr used in agriculture can be seen to be a small part of the picture. Unlike the CFC's, which are all human-made, there are significant natural sources and sinks of MBr (Butler 1994). It is estimated that the atmospheric concentration of MBr is between 9-13 pptv (parts per trillion volume) which indicates a total quantity of 1.5 to 2.1 x 10^8 kg. Approximations based on what are thought to be major sources are (in millions of kg) oceans 35, fires 30, motor vehicles 15, and MBr manufactured for pesticides etc 30. There are significant problems with calculating these numbers. These and most other estimates include a margin of error of about 50%. Secondly, the estimated magnitudes of MBr sources have changed considerably during the last two years. For example, the magnitude of fire (used largely to clear land for agriculture) as a source was only recently discovered (Mano and Andreae, 1994) as was the potential for the oceans to function potentially as both a source and a sink for MBr possibly compensating for changes in other sources (Butler 1994). Also, it has only recently been determined that under many soil conditions, 50% or less of MBr applied during fumigation "escapes" to the atmosphere (Gan *et al.* 1995, Yates *et al.* 1995). The atmospheric residence time of MBr was estimated to be close to two years in 1993 (Mano and Andreae, 1994) but recently has been estimated to be as short as nine months (Adler 1995). Obviously, our understanding of ozone depletion and the relative contributions of human and natural influences on ozone flux is far from satisfactory.

AN EVALUATION OF MBR SUBSTITUTES

Four of the currently available soil fumigants that we listed in Table 3 (MBr, chloropicrin, 1,3-dichloropene, and dazomet) these, plus metham sodium and the several combinations of these five chemicals are our most probable choices for replacements that will be available by the year 2001. Although methyl iodide seems potentially to be an effective replacement and has worked well in trials (Ohr *et al.* 1996, Sims *et al.* 1995) it still needs a sponsor who will pay for the environmental and toxicological studies needed for registration. Each of the four currently available MBr substitutes has its own physical characteristics, application methodologies, and effect on seedling culture.

Fumigant efficacy depends on uniform distribution through the soil and toxicity to soil organisms, both pathogenic and beneficial organisms. Soil characteristics at fumigation such as moisture and organic matter content, can alter the distribution of fumigants through the profile (Munnecke and Van Gundy 1979) as well as the sensitivity of soil microorganisms to exposure

TABLE 3. Properties of Fumigants (from Munnecke and Van Gundy 1979)

	Fumigant			
	MB	Chloropicrin	1,3 dicloro-propene	Dazomet
Molecular Weight	95.0	154.0	112.0	--
Vapor Pressure (mm Hg @ 20°C)	1,380.0	20.0	21.0	21
Boiling point (C°)	4.6	112.0	104.0	--
Solubility in H_2O (% @20°C)	1.6	0.2	0.3	0.76

(Danielson and Davey 1969, Wensley 1953). The better the diffusion of a fumigant through both the air and the water fractions of a soil the more homogenous will be concentrations through the profile. The superior physical characteristics of MBr, especially with respect to vapor pressure (the gas pressure when at equilibrium with the liquid phase) and solubility in water as compared to some alternative fumigants for its distribution throughout a soil profile, should be apparent from Table 3.

Data from more recent studies are summarized in Table 4 which is limited to 1993 and 1994 trials carried out by the AUSFNMC. Together, the data in Tables 2 and 4 provide our best estimates for the efficacy of different fumigation treatments within forest tree nurseries. Changes in cultural practices have undoubtedly modified the impacts of fumigation since most of the data in Table 2 were collected. Considering recent trials only (Table 4), seedling numbers have differed negligibly between treatments and controls. However, these trials did not occur in nurseries with the severe soil-borne disease problems that were common during early fumigation studies and since MBr has done much to reduce the population of soil-borne pests at most nurseries its effects cannot be entirely removed from these trials. Differences may be smaller than they would have been in nurseries not previously treated with MBr. The effects of fumigation on seedling size have been similar among the older studies presented in Table 2 and among the more recent studies in Table 4. Significant increases in seedlings size have occurred in this instance without a change in bed density.

Solarization

Solarization is a treatment often mentioned as a possible substitute for MBr. By covering the ground with plastic tarps, soil temperatures can sometimes be raised high enough to kill some species of pathogenic fungi, nematodes and insects. This technique has been used for soil treatment in vegetable production. In forest tree nurseries, however, its potential utility is limited. To reach temperatures lethal to target pests, the plastic must be placed over clean soil, preferably well tilled, and not too dry, during several weeks in the summer. Since our nurseries are sown in the early to mid spring to avoid the negative effects of high soil temperatures on germination and seedling establishment this would require solarization to be done the previous summer. Either the

TABLE 4. Average percent reduction in numbers and weights of conifer seedlings among control beds by fumigation treatment for trials in 1993 and 1994. (From Carey 1995a)

		Percent reduction among controls		
Chemical	No. Of Studies	Seedling Numbers	Seedling Weight	N*W[a]
MC33	5	0	17	17
Metham Sodium	2	4	6	10
Dazomet	6	-6	12	3
Chloropicrin	7	0	18	17
Triform	3	0	21	21
Mean		-2	16	13

[a]Difference in products of seedling weights and numbers for treatment minus that for control as a percent of treatment.

plastic would have to be maintained for several months or the ground would be exposed to the forces of erosion for a long period of time. Either way, the land would have to remain fallow. Large-scale field solarization will invariably have irregular effectiveness due to wet spots and soil texture influences. Although it may not be difficult to raise mean surface temperatures to near 50°C, at a depth of 6 to 10 inches temperatures will be 15-2° cooler.

Organic Amendments

The possibility of using organic amendments to manage populations of soil microorganisms so that pathogens are held in check by natural processes has long been a research ambition of plant pathologists. Interests in that area of research has increased and abated for several decades as positive laboratory results failed to be duplicated in the field and the mechanisms responsible for the behavior of soil microorganisms have not become much more apparent (Papavizas 1973). However, research has been reanimated by the potential loss of MBr and there is some hope that organic amendments will provide protection from disease and enhance seedling growth in forest tree nurseries (Kannwischer-Mitchell *et al* 1994). Although the actual effectiveness of this practice is not proven, the use of such amendments to improve overall soil health and tilth is a worthy goal. Even so, the cost of these amendments could easily make them impractical. Treatments being investigated range from 1 to 4 inches of compost materials (135 to 540 $yards^3$/ ac). Although the cost of compost materials vary widely between nurseries under current average demands, which are for maintaining soil organic mater, we suspect that efforts to obtain 8,100 yds^3 (or enough material to apply 2 inches to 30 acres) would do little to decrease costs. If the material cost $7.5 a yard, two inches could cost close to twice as much as fumigation even before the increased costs of fertilizer, insect and weed controls were calculated. Cost/benefit ratio for organic amendments are not available.

Regeneration Success

Based on the average outplanting performances among published studies, grade 1 seedlings can have a present net value (PNV) of $100 per thousand more than grade 2 seedlings (South and Mexal 1984). Using South and Mexal's estimate, the data presented in Table 5 indicate that fumigation with MBr increased the seedling value per nursery acre $13,380 without increasing the number of seedlings. However, since values should be based on outplanting performance, what would the impact on the rest of the forest industry be? More conservative projections based on increased growth of outplanted seedlings indicate that treating the entire Glennville nursery with MBr could have increased plantation productivity by 2.3% (Carey and South 1995). Such increases could effect the economy of the South more than the $35 million loss projected by the USDA for forest tree nurseries after the loss of MBr.

TABLE 5. Treatment comparisons for the 1994 Glennville, Ga. Fumigation trial[a]

Treatment	Seedling/ft^2	Diameter	#1's/ft^2
Dazomet	19.6a	5.2a	14.1a
MC2	22.2a	5.8 b	19.8 b
MC33	20.5a	5.9 b	18.1 b

[a]Means in the same column followed by the same letter do not differ at 0.05.

CONCLUSIONS

1. Methyl bromide has a proven tract record as a safe and effective pesticide in forest tree nurseries and in agriculture in general over the past 40 years. By controlling soil-borne pests, MBr has consistently enhanced the production of larger numbers of improved quality seedlings per unit of land. The reliability of this pest control program has allowed nursery managers to concentrate on improving seedling quality in such areas as size, morphology and nutrient balance, and in increasing seedling uniformity and customer satisfaction.

2. Although not a focus of this note, it seems apparent that MBr originating from agricultural activities has little impact on stratospheric ozone.

3. None of the chemical or cultural methods investigated as possible replacements for MBr fumigations have been as cost effective as MBr. None of the alternatives control the wide variety of soil-borne pests controlled by MBr.

4. The use of MBr has resulted in the production of larger, seedlings that have a positive effect on the economics of plantation forestry across the South.

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