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Preliminary and Regional Reports

Soil Fumigants to Replace Methyl Bromide for Weed Control in Ornamentals

Robert E. Uhlig^{1,4}, George Bird², Robert J. Richardson³, and
Bernard H. Zandstra¹

ADDITIONAL INDEX WORDS. 1,3-dichloropropene, dazomet, iodomethane, metham sodium, chloropicrin

SUMMARY. A field study was conducted to evaluate fumigant alternatives for methyl bromide (MB). Iodomethane (IM), chloropicrin (CP), 1,3-dichloropropene (1,3-D), metham sodium (MS), and MB in various combinations were applied to a sandy soil field site in Sept. 2002. Some treatments were tarped. Plant injury, plant growth, fresh weight, and dry weight were evaluated for seven ornamental species: cushion spurge (*Euphorbia polychroma*), globe thistle (*Echinops bannaticus* 'Blue Globe'), common lavender (*Lavandula angustifolia* 'Hidcote Blue'), hosta (*Hosta* 'Twilight PP14040'), silvermound artemisia (*Artemisia schmidtiana* 'Silver Mound'), shasta daisy (*Leucanthemum ×superbum* 'Snow Lady'), and thread leaf coreopsis (*Coreopsis verticillata* 'Moonbeam'). Weed control was evaluated in Apr. 2003, July 2003, and May 2004. All treatments gave almost complete control of all annual weeds, except for IM 50% + CP 50% (200 lb/acre, tarped) and MS (75 gal/acre, 1:4 water, not tarped), which did not give adequate control of common chickweed (*Stellaria media*), mouseear cress (*Arabidopsis thaliana*), common lambsquarters (*Chenopodium album*), or common purslane (*Portulaca oleracea*). None of the treatments caused visual injury to any crop species. Treatments did not affect plant size in Nov. 2003. However, some treatments resulted in larger thread leaf coreopsis and silvermound artemisia plants in May 2004. There was no difference in dry weight at harvest between treatments for all species.

Fumigants are used to control soil-borne pests to obtain larger yields of high-quality horticultural products (Messenger and Braun, 2000). Methyl bromide has been the most widely used fumigant, with 68,424 t used worldwide in 1996.

The United States uses almost half of world consumption of methyl bromide (MB), and 70% of that is used for soil fumigation (Ware and Whitacre, 2004). Atmospheric MB originates from oceanic emissions and anthro-

pogenic sources, such as biomass burning, agricultural applications, leaded gasoline combustion, and structural fumigation. The relative contributions of anthropogenic and natural emissions to total atmospheric MB are not well known (Butler and Rodriguez, 1996). However, it was estimated that anthropogenic sources account for 20% to 50% (Singh and Kanakidou, 1993).

Methyl bromide research has been conducted extensively in high-value crops such as tobacco (*Nicotiana tabacum*), tomato (*Lycopersicon esculentum*), pepper (*Capsicum annuum*), cucumber (*Cucumis sativus*), and strawberry (*Fragaria ×ananassa*) (Csinos et al., 2000; Fennimore et al., 2003; Gilreath et al., 2004). However, there has been limited research reported for MB alternatives in ornamentals (Carpenter et al., 2000; Schneider et al., 2003).

The manufacture and importation of MB was essentially phased out in developed countries for general agricultural uses in 2005, and developing countries have agreed to eliminate most chlorofluorocarbons (CFC) by Jan. 2010 (United Nations Development Programme, 2006). The MB phaseout will affect agricultural production adversely, especially where alternative fumigants are not available. For example, the ornamental and nursery industries may lose \$129 million in California and \$14 million in North Carolina, due to differences in yield and control costs between the alternatives and MB (Carpenter et al., 2000). Loss of MB will affect cut-flower and ornamental crop production adversely more than other industries because breeding programs focus primarily on plant aesthetic qualities and not on disease tolerance, often leaving crops susceptible to diseases (Sances, 2005).

Metham sodium, chloropicrin, 1,3-dichloropropene, and iodomethane are potential substitutes for

¹Department of Horticulture, Michigan State University, Plant and Soil Sciences Building, East Lansing, Michigan 48824-1325.

²Department of Entomology, Michigan State University, Natural Science Building, East Lansing, Michigan 48824-1115.

³Crop Science Department, North Carolina State University, Williams Hall, Box 7620, Raleigh, North Carolina 27695.

⁴Corresponding author. E-mail: uhlig@msu.edu

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
9.3540	gal/acre	L·ha ⁻¹	0.1069
2.54	inch(es)	cm	0.3937
0.4536	lb	kg	2.2046
1.1209	lb/acre	kg·ha ⁻¹	0.8922
6.8948	psi	kPa	0.1450
(°F - 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

Table 1. Weed control ratings 7 and 10 months after fumigation on 12 Sept. 2002, on a loamy sand soil, Hudsonville, Mich.; fumigants were injected 6–8 inches (15.2–20.3 cm) below the surface at a pressure of 80–120 psi (551.6–827.4 kPa).

Treatment ^y	Tarp	Rate ^x	Control rating ^z							
			24 Apr. 2003			9 July 2003				
			MECR ^w	COGR	COCW	RRPW	COLQ	COPU	COGR	YEFT
Non-treated	No	—	1.0 c ^v	1.0 b	1.0 e	1.0 c	1.0 d	1.0 c	1.0 b	1.0 c
Non-treated (tarped)	Yes	—	7.0 b	8.1 a	6.3 b	1.0 c	1.0 d	1.0 c	1.0 b	1.0 c
IM (50%) + 50% CP	Yes	300 lb/acre	9.8 a	10 a	9.8 a	10 a	10 a	9.2 a	9.8 a	10 a
IM (50%) + 50% CP	Yes	200 lb/acre	1.8 c	6.0 b	2.1 d	8.8 a	8.3 bc	5.7 b	8.3 a	9.5 a
1,3-D (64%) + 35% CP ^u	Yes	35 gal/acre	9.3 a	10 a	9.8 a	9.8 a	9.7 ab	8.7 a	10 a	10 a
MB (98%) + 2% CP	Yes	350 lb/acre	10 a	10 a	9.8 a	10 a	10 a	9.2 a	9.7 a	10 a
IM (98%) + 2% CP	Yes	150 lb/acre	9.5 a	10 a	9.8 a	10 a	10 a	9.3 a	9.8 a	10 a
MS	No	75 gal/acre (1:4 water)	3.0 c	9.7 a	5.0 c	9.5 a	7.5 c	5.0 b	9.5 a	8.5 a
MS	Yes	75 gal/acre (1:2 water)	9.0 a	10 a	9.3 a	9.7 a	10 a	9.0 a	9.7 a	10 a
MS	Yes	75 gal/acre (1:4 water)	9.5 a	10 a	9.7 a	10 a	10 a	9.2 a	10 a	10 a
1,3-D (97.5%) ^t	Yes	35 gal/acre	10 a	10 a	10 a	10 a	10 a	9.3 a	9.7 a	10 a
1,3-D (97.5%) ^t + MS	Yes	35 gal/acre + 75 gal/acre (1:4 water)	10 a	10 a	10 a	10 a	10 a	9.5 a	9.8 a	10 a
MB (67%) + 33% CP	Yes	350 lb/acre	10 a	10 a	10 a	10 a	10 a	9.7 a	9.8 a	10 a
1,3-D (64%) + 35% CP ^u and MS	Yes	35 gal/acre + 75 gal/acre (1:4 water)	9.8 a	10 a	9.7 a	10 a	10 a	9.5 a	10 a	10 a

^zControl was evaluated on a scale from 1 to 10, where 1 = no weed control and 10 = total weed control.

^yIM = iodomethane; CP = chloropicrin; 1,3-D = 1,3-dichloropropene; MB = methyl bromide; MS = metham sodium.

^x1 lb/acre = 1.1209 kg ha⁻¹, 1 gal/acre = 9.3540 L ha⁻¹.

^wMECR = mouseear cress (*A. thaliana*), COGR = common groundsel (*Senecio vulgaris*), COCW = common chickweed (*S. media*), RRPW = redroot pigweed (*Amarantus retroflexus*), COLQ = common lambsquarters (*Chenopodium album*), COPU = common purslane (*Portulaca oleracea*), YEFT = yellow foxtail (*Setaria glauca*).

^vWithin columns, means followed by same letter are not different at $P \leq 0.05$.

^tTelone C-35 (Dow Agrosciences LLC).

^uTelone II (Dow Agrosciences LLC).

Table 2. Weed control ratings on 7 May 2004, 20 months after fumigation on 12 Sept. 2002, on a loamy sand soil, Hudsonville, Mich.; fumigants were injected 6–8 inches (15.2–20.3 cm) below the surface at a pressure of 80–120 psi (551.6–827.4 kPa).

Treatment ^y	Tarp	Rate ^x	Control rating ^z				
			MECR ^w	PRLE	COMA	COCW	RECL
Non-treated	No	—	1.0 e ^v	1.0 c	1.0 c	1.0 c	1.0 c
Non-treated (tarped)	Yes	—	1.0 e	1.0 c	1.0 c	1.0 c	1.0 c
IM (50%) + 50% CP	Yes	300 lb/acre	7.5 ab	6.8 abc	10 a	8.5 a	9.5 ab
IM (50%) + 50% CP	Yes	200 lb/acre	4.0 cd	8.3 ab	9.0 a	2.6 c	10 a
1,3-D (64%) + 35% CP	Yes	35 gal/acre	8.7 a	6.7 abc	9.2 a	8.5 a	8.3 ab
MB (98%) + 2% CP	Yes	350 lb/acre	8.3 a	6.0 bc	9.5 a	8.2 a	7.0 b
IM (98%) + 2% CP	Yes	150 lb/acre	8.0 a	6.7 abc	10 a	8.5 a	8.7 ab
MS	No	75 gal/acre (1:4 water)	5.8 bc	7.0 ab	9.8 a	4.5 b	9.7 a
MS	Yes	75 gal/acre (1:2 water)	8.3 a	7.3 ab	9.2 a	8.3 a	9.5 ab
MS	Yes	75 gal/acre (1:4 water)	8.8 a	7.3 ab	10 a	8.5 a	9.0 ab
1,3-D (97.5%)	Yes	35 gal/acre	7.6 ab	9.0 a	8.6 a	7.8 a	9.8 a
1,3-D (97.5%) + MS	Yes	35 gal/acre + 75 gal/acre (1:4 water)	8.7 a	5.8 bc	8.0 a	9.0 a	8.7 ab
MB (67%) + 33% CP	Yes	350 lb/acre	7.2 ab	7.2 ab	9.2 a	7.8 a	8.8 ab
1,3-D (64%) + 35% CP and MS	Yes	35 gal/acre + 75 gal/acre (1:4 water)	7.8 a	6.2 abc	8.4 a	8.0 a	8.2 ab

^zControl was evaluated on a scale 1 to 10, where 1 = no weed control and 10 = total weed control.

^yIM = iodomethane; CP = chloropicrin; 1,3-D = 1,3-dichloropropene; MB = methyl bromide; MS = metham sodium.

^x1 lb/acre = 1.1209 kg ha⁻¹, 1 gal/acre = 9.3540 L ha⁻¹.

^wMECR = mouseear cress (*A. thaliana*), PRLE = prickly lettuce (*L. serriola*), COMA = common mallow (*Malva neglecta*), COCW = common chickweed (*S. media*), RECL = red clover (*Trifolium pratense*).

^vWithin columns, means followed by same letter are not different at $P \leq 0.05$.

MB in ornamental production. The objective of this study was to evaluate crop safety and weed control with pre-transplant applications of these fumigants on seven ornamental species.

Materials and methods

The experiment was conducted at a commercial nursery in Hudsonville, Mich., on a Granby loamy sand (sandy, mixed, noncalcareous, mesic, typic Haplaquolls) with

81% sand, 8% silt, 11% clay, 2.5% organic matter, pH of 6.2, and cation exchange capacity of 9.3 meq/100 g.

The treatments were applied by a commercial applicator on 12 Sept. 2002. The fumigants were injected

Table 3. Effect of dazomet applied on 12 Sept. 2002 before transplanting on seven ornamental plant species; ornamentals were evaluated for crop injury (20 Aug. 2003), size (19 May 2004), and dry weight (Sept.–Oct. 2004).

Treatment ^z	Silvermound artemisia	Thread leaf coreopsis	Globe thistle	Cushion spurge	Hosta	Common lavender	Shasta daisy
	Injury rating ^y						
Untreated	1.0 a ^x	1.0 a	1.0 a	1.0 b	1.0 a	1.0 a	1.0 a
Dazomet	1.0 a	1.3 a	1.6 a	2.6 a	1.0 a	1.6 a	1.0 a
	Size index [(height + width)/2] (cm) ^w						
Untreated	21.0 a	37.9 a	43.4 a	46.1 a	14.6 a	32.9 a	25.0 a
Dazomet	21.4 a	35.8 a	38.8 a	23.5 b	14.6 a	26.7 a	24.4 a
	Dry weight ^v (kg/plot) ^w						
Untreated	2.27 a	2.56 a	1.19 a	1.29 a	0.11 a	2.25 a	1.02 a
Dazomet	2.30 a	2.03 a	0.73 a	0.53 a	0.14 a	1.28 b	0.91 a

^zDazomet 99% granular was applied at 350 lb/acre evenly over the plot surface and incorporated immediately after application with a rototiller. The plots were not tarped.

^yInjury was rated visually on a 1 to 10 scale, where 1 = no injury and 10 = dead plant.

^xWithin columns, means followed by same letter are not different at $P \leq 0.05$.

^w1 cm = 0.3937 inch, 1 kg = 2.2046 lb.

^vDry weight means are total of five plants for each plot.

6–8 inches below the surface with a nitrogen-pressurized fumigation machine at a pressure of 80–120 psi, mounted on a tractor with 11 chisels per bed spaced 12.5 inches apart. Treatments were IM 50% + CP 50% (tarped, 300 lb/acre); IM 50% + CP 50% (tarped, 200 lb/acre); 1,3-D 64% + CP 35% [Telone C-35 (Dow Agrosciences LLC, Indianapolis), tarped, 35 gal/acre]; MB 98% + CP 2% (tarped, 350 lb/acre); IM 98% + CP 2% (tarped, 150 lb/acre); MS (not tarped, 75 gal/acre, 1:4 water); MS (tarped, 75 gal/acre, 1:2 water); MS (tarped, 75 gal/acre, 1:4 water); 1,3-D 97.5% [Telone II (Dow Agrosciences LLC), tarped, 35 gal/acre]; 1,3-D 97.5% + MS (tarped, 35 gal/acre + 75 gal/acre, 1:4 water); MB 67% + CP 33% (tarped, 350 lb/acre); and 1,3-D 64% + CP 35% and MS (tarped, 35 gal/acre + 75 gal/acre, 1:4 water). Plot size was 13 × 100 ft. Plots were tarped with clear plastic mulch immediately after application, except the untreated control and MS (75 gal/acre, 1:4 water), which remained uncovered. Soil temperature at application was 72 °F at 5 inches.

Seven ornamental species (cushion spurge, globe thistle, common lavender, hosta, silvermound artemisia, Shasta daisy, and thread leaf coreopsis) were transplanted in June 2003 (9 months after treatment). Plants were planted in 4 rows 2 ft apart at the center of the fumigated area. The number of plants planted in each plot varied among species: 15–20 common lavender plants, six to eight plants of cushion spurge, globe thistle, and hosta, and a complete row (25–30 plants) of Shasta daisy and thread leaf coreopsis.

Plant injury was rated for each species on 23 July and 20 Aug. 2003 using a scale of 1 to 10, with 1 = no injury and 10 = dead plant. Weed control was rated for the whole plot on 24 Apr. and 9 July 2003 and 7 May 2004. Plant size was measured on 14 Nov. 2003 and 19 May 2004. Measurements were taken in 10 plants for all species except for cushion spurge and globe thistle, for which six to eight plants were measured, because of the smaller number of total plants in the plots. Plant size index was used to evaluate plant growth and was determined by adding the highest point and the widest point of the plant and dividing by 2 (Briggs and Whitwell, 2002).

Five plants of each species were randomly selected, dug, and placed in plastic bags in Sept.–Oct. 2004. All plants of a species were harvested the same day. The plants were kept in a cold room at 41 °F until they were weighed. Plants were separated into foliage and roots, and each plant part was weighed separately. The plants were then dried at 105 °F for 10 d and weighed again.

A randomized complete-block design was used for data analysis. Each species was analyzed separately. The experiment had six replications in the field. All data were subjected to analysis of variance and Fisher's protected least significant difference ($P = 0.05$) was used for mean separation. Data were analyzed using the general linear model procedure (SAS Institute, Cary, N.C.).

Dazomet was included in three of the six replications and data were

analyzed separately in a single degree contrast with the untarped control. Dazomet 99% granular was applied at 350 lb/acre evenly over the plot surface and incorporated immediately after application with a rototiller. The plots were not tarped.

Results and discussion

All the treatments controlled 80% to 100% of annual weeds, except IM 50% + CP 50% (200 lb/acre, tarped) and MS (1:4 water, 75 gal/acre, not tarped), which had poor control of common chickweed and mouseear cress in Apr. 2003 and May 2004 (Tables 1 and 2), and common lambsquarters and common purslane in July 2003 (Table 1). However, IM 50% + CP 50% (300 lb/acre, tarped) had almost 100% control of these weeds at 7 and 10 months after fumigation, suggesting that 200 lb/acre was too low a rate for total weed control and that the effective rate must be between 200 and 300 lb/acre. These results are similar to those of Shrestha et al. (2005), who observed similar weed control with MB + CP (400 lb/acre) and IM + CP (400 lb/acre). Schneider et al. (2005) also reported that IM 67% + CP 33% (300 lb/acre, shanked, tarped) gave weed control comparable to MB at 600 lb/acre.

MS (75 gal/acre, 1:4 water, not tarped) did not control weeds as well as in the same tarped treatment, indicating that tarping after fumigation was an important factor in controlling weeds. This result agrees with the findings of Csinos et al. (1997), who found that pest control in tobacco and pepper were better with MS

(51 gal/acre) plus 1,3-D 83% + CP 17% (13 gal/acre) covered immediately with polyethylene compared with a similar treatment sealed mechanically but not tarped, and of Unruh et al. (2002), who found poorer weed control with MS + CP (80 gal/acre + 15 gal/acre, not tarped) compared with MB at 5 weeks after fumigation.

There was no crop injury from any of the treatments in July and Aug. 2003. There were no differences in plant size between treatments in Nov. 2003. However, in May 2004, larger silvermound artemisia and thread leaf coreopsis plants were observed in plots treated with 1,3-D 64% + CP 35% (tarped, 35 gal/acre), IM 98% + CP 2% (tarped, 150 lb/acre), MS (tarped, 75 gal/acre, 1:4 water), 1,3-D 97.5% (tarped, 35 gal/acre), 1,3-D 97.5% + MS (tarped, 35 gal/acre, 75 gal/acre, 1:4 water), and MB 67% + CP 33% (tarped, 350 lb/acre). In addition, MB 98% + CP 2% (tarped, 350 lb/acre) and 1,3-D 64% + CP 35% and MS (tarped, 35 gal/acre + 75 gal/acre, 1:4 water) resulted in larger plants in silvermound artemisia, and MS (tarped, 75 gal/acre, 1:2 water) resulted in larger plants in thread leaf coreopsis. The increase in size may be caused by a reduction in weed competition with the crop. In a similar experiment, Gerik (2005) did not find differences in plant height of stock (*Matthiola* spp.), snapdragon (*Antirrhinum majus*), and dutch iris (*Iris xiphium*) grown in soil previously drip fumigated with MB 50% + CP 50% (400 lb/acre), IM 50% + CP 50% (400 lb/acre), and 1,3-D 61% + CP 33% (395 lb/acre).

No differences between treatments in total fresh weight, root fresh weight, total dry weight, root dry weight, and foliage dry weight were observed. The 1,3-D 64% + CP 35% (35 gal/acre, tarped) and IM 98% + CP 2% (150 lb/acre, tarped) treatments reduced foliage fresh weight of cushion spurge ($P = 0.045$), and IM 50% + CP 50% (300 lb/acre, tarped) and MS (75 gal/acre, 1:4 water, tarped) reduced foliage fresh weight of common lavender ($P = 0.048$).

Dazomet gave good control of all weeds except for prickly lettuce (*Lactuca serriola*) in May 2004. It caused injury (2.6 out of 10) and

reduced plant size in cushion spurge. Dazomet reduced total dry weight in common lavender (Table 3).

In conclusion, most fumigants tested provided good weed control up to 20 months after application. IM 50% + CP 50% (200 lb/acre, tarped) and MS (75 gal/acre, 1:4 water, not tarped) had the poorest control of most summer annual weeds. In the first case, lower rate, and in the second case, no tarp, could be the factors that contributed to the inadequate weed control. Fumigants did not injure the ornamental crops evaluated in this experiment, and some of the treatments increased plant size in two species.

All of the fumigants tested appear to have potential to replace MB in ornamental production. They were safe to the ornamental species studied, and they provided effective weed control.

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