Volatilization and Distribution of Methyl Iodide and Methyl Bromide after Subsoil Application

J. Gan,* S. R. Yates, H. D. Ohr, and J. J. Sims

ABSTRACT

Methyl iodide (MeI) was recently proposed as a potential replacement for methyl bromide (MeBr) as a soil fumigant, but little is known about its fate in the environment. Volatilization of MeI was measured and compared with that of MeBr in packed soil columns with different soils and under various soil surface conditions. Under the same conditions, MeI volatilization loss was greater than that of MeBr, and the enhanced volatilization was attributed to its slower degradation in soil. In a Greenfield sandy loam (coarse-loamy, mixed, thermic Typic Haploxeralfs), the greatest loss occurred in a non-tarped application (78% for MeI and 62% for MeBr), with the smallest loss in a high-barrier plastic-tarped treatment (28% for MeI and 24% for MeBr). Covering the soil surface with polyethylene film was ineffective in preventing MeI or MeBr volatilization. Volatilization losses of MeI and MeBr were also influenced by soil type, and were significantly less from soils that were high in organic matter content and capable of rapidly degrading the fumigants. Ten days after a point application (30 cm) in field plots covered with polyethylene film, higher MeI concentrations were detected at most depths. Because of its longer persistence in soil, MeI may have a greater tendency to reach groundwater than MeBr.

Because of its ozone-depleting nature, MeBr (bromomethane, MeBr), the currently most widely used soil fumigant, will be banned by the year 2001 in the USA, and at a later time in the rest of the world (USEPA, 1993; The United Nations Environment Programme, 1995). Alternative fumigants or fumigation techniques are urgently needed to substitute for MeBr to control soilborne pests (The National Agricultural Pesticide Impact Assessment Program, 1993; Ferguson and Padula, 1994). Methyl iodide (iodomethane, MeI) was recently proposed as a direct replacement for MeBr (Ohr et al., 1996). One distinguishing advantage that MeI possesses over MeBr is that MeI has a very short atmospheric life time (4–8 d, compared with 1.5–2.0 yr for MeBr), and therefore is unlikely to reach the stratosphere to contribute to ozone depletion (Solomon et al., 1994; Ohr et al., 1996). In several greenhouse and field-efficacy tests, MeI was consistently found to be more or at least equally active as MeBr in controlling selected parasitic nematodes, weeds, insects, bacteria, and fungi (Sims et al., 1995; Ohr et al., 1996; Becker et al., 1997; Zhang et al., 1997). However, since MeI is not a registered pesticide, many aspects of its behavior in the soil-water-air environment are unknown. Before much more effort is invested to develop this chemical into a commercial fumigant, information is needed on a few fundamental processes, for example, transport and transformation, and the potential for causing air or groundwater contamination.

MeI has a time-weighted threshold concentration for human exposure in air of 2 ppm (ACGIH, 1994). Excessive discharge of MeI into the air during fumigation may therefore be hazardous to field workers or nearby residents. MeI has a moderate toxicity (subcutaneous LD\(_0\) in mice = 110 mg kg\(^{-1}\), Kutob and Plaa, 1962), and was once a suspected carcinogen (International Agency for Research of Cancer, 1986). Contamination of groundwater with MeI, particularly at sites where the groundwater table is high, may be another concern. Knowledge of MeI transport and distribution in the soil profile is also necessary for the design of optimal application methods that will allow the use of a minimum amount of chemical while achieving sufficient control. As the efficacy of a fumigant generally correlates well with its distribution patterns in soil (Kolbezen et al., 1974; McKenry and Thomason, 1974), measures that maximize concentrations in the pest-infested zones will likely lead to better control. As found for MeBr and a few other fumigants, several application and soil-related variables, for example, use of surface cover, change of injection depth and water management, may be modified to maximize a fumigant’s effectiveness while reducing its environmental risk (Reible, 1994; Jin and Jury, 1995; Gan et al., 1996, 1997).

We have conducted a series of studies to compare MeI and MeBr transformations and transport after soil application. Methyl bromide was used as a reference chemical in these studies because it is structurally analogous to MeI, and in addition, many aspects of its behavior are already well understood. In a previous study, MeI was shown to degrade significantly more slowly than MeBr in soil, and under the same conditions, the partition of MeI from air into water or from water into soil was slightly greater than that of MeBr (Gan and Yates, 1996). From these differences, and the difference in their vapor pressures and boiling points, atmospheric volatilization losses and soil distribution patterns of MeI can be expected to be different from those of MeBr following similar applications.

In this study, we used packed soil columns and field plots to determine the difference between MeI and MeBr in atmospheric volatilization and soil distribution. In the column experiments, effect of surface cover was studied by using three surface conditions, non-tarped, polyethylene film-tarped, and high-barrier film-tarped. To assess the effect of soil type, volatilization and distribution of MeI and MeBr were also determined in four different soils, ranging from an organic matter-rich potting mix to an organic matter-poor sandy loam. In the

Abbreviations: MeI, methyl iodide; MeBr, methyl bromide; PE, polyethylene film; HDPE, high-density polyethylene film; HB, high-barrier film; SL, sandy loam; CL, clay loam; LS, loamy sand.
### Table 1. Characterization of soil columns used for methyl iodide (Mel) and methyl bromide (MeBr) transport and volatilization studies

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Water Content</th>
<th>Air Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greenfield SL</td>
<td>0.92%</td>
<td>2.28 g mL⁻¹</td>
</tr>
<tr>
<td>Carsitas LS</td>
<td>2.51%</td>
<td>2.28 g mL⁻¹</td>
</tr>
<tr>
<td>Linne CL</td>
<td>2.99%</td>
<td>2.28 g mL⁻¹</td>
</tr>
<tr>
<td>Nursery Potting Mix</td>
<td>2.99%</td>
<td>2.28 g mL⁻¹</td>
</tr>
</tbody>
</table>

The density of liquid MeBr was 1.73 g mL⁻¹, and that of MeI was 1.66 g mL⁻¹. Both had a purity of 99.5%. Before use, gaseous MeBr was chilled to liquid MeBr with dry ice and then kept at -15°C. MeBr (Matheson Gas Products Inc., East Rutherford, NJ) and MeI (Alfa Aesar, Ward Hill, MA) were used in determining the effect of surface cover.

**Volatilization and Vapor Transport**

In packed soil columns, the loss of applied fumigant occurs only via volatilization from the surface or degradation in the soil column. Carefully sealed. In this system, the loss of applied fumigant was measured as milligrams per hour per column, and the cumulative volatilization rates were equivalent to ~110 kg ha⁻¹ (100 lb acre⁻¹) for both chemicals, with values ranging from 0.17 to 0.29 mg (mean 0.21 mg) for MeBr and 0.29 to 0.32 mg (mean 0.30 mg) for MeI in the same column. Conditions of the packed columns used in this study are given in Table 1.

**Soil Properties**

- **Treatment Soil Type:** Greenfield SL, Carsitas LS, Linne CL, Nursery Potting Mix
- **Properties:** Bulk density, water content, air content, clay content
- **Source:** A closed, packed soil column system was used to measure the properties of these soils were given elsewhere (Gan and Yates, 1996). The soil in the field plots was an Arlington SL, that contained 1.3% organic matter in the top 30 cm, but decreased to <0.5% below 60 cm. For laboratory studies, moist soils were passed through a 2-mm sieve without air drying, and the final water content was adjusted to 12% for Greenfield SL or Covered with the high-barrier film (HB-tarped). To study the effect of surface cover, Greenfield SL Nontarped, Linne CL PE-tarped, Carsitas LS PE-tarped, Greenfield SL HB-tarped, and Greenfield SL PE-tarped were used in the column experiments.

**Chemicals and Soils**

- **Chemicals:** MeBr, MeI, Pe = polyethylene film; HB = High-barrier film.
- **Soils:** Sandy loam (SL, OM = 0.92%), a Carsitas clay loam (fine-loamy, mixed, hyperthermic Typic Torripsamments), and a nursery potting mix (1:1 mix of topsoil and fir sawdust, OM = 9.60%).

**Injection**

A Gas Chromatograph (GC) equipped with an ECD (electron capture detector) was used. A 12-m, high-resolution capillary column (30 m by 0.25 mm by 1.4 µm, Restek Corp., Bellefonte, PA); (30 m by 0.25 mm by 1.4 µm, Restek Corp., Bellefonte, PA); 3% of the sample was injected. The injection port and detector temperatures were 240°C and 280°C, respectively, and the column and detector were operated isothermally at 90°C; equilibration time, 10 min; and sample loop, 100 µL.

**Analysis**

- **Detection:** Both chemicals were measured using a reported method (Gan et al., 1995). The conditions for analysis were given elsewhere (Gan et al., 1996, 1997). In brief, the sieved moist soil was packed into a closed-bottom, 62-cm high by 12.5-cm (i.d.) glass column to a predetermined bulk density and volumetric water content. A piece of the selected plastic film was placed between the column and the sampling chamber, and the connection was sealed onto the soil column, allowing incremental distances along the soil column to allow soil gas to be sampled at different depths. With the tarped treatments, gas sampling port 30 cm below the soil surface was placed, and an airflow of 150 mL rain⁻¹ above the soil surface was used to sweep the volatilized fumigant into a charcoal sampling tube (ORBO-32, Supelco, Bellefonte, PA). This flow rate did not induce convective movement in the column. The flow of air was provided by a 12.5-cm (i.d.) tube (ORBO-32, Supelco, Bellefonte, PA) placed in the bottom of the glass column.
Volatilization from a Sandy Loam under Various Conditions

At different time intervals, 0.5 mL of soil air was withdrawn through the Teflon tubing into the soil. Three plots were then used in the same model to estimate volatilization from diffusing below 60 cm in the soil columns, such laboratory column measurements overestimate fumigant volatilization losses compared with the field situation. An extrapolation method based on a transport model was used to correct the lower boundary effect and extrapolate the measured volatilization rates to an analogous field situation; that is, with an infinite lower boundary condition (Gan et al., 1996). In brief, the design of the sampling probe was described in detail by Kolbezen et al. (1974). The plots were 90, 180, and 270 cm. The design of the sampling probe was still existed), Ficks law is believed to be adequate for describing transport (Leffelaar, 1987; Amali and Rolston, 1993). Similar experimental setup and model extrapolation procedures might be used in previous studies to estimate values close to field observations (Gan et al., 1996, 1997).

Distribution of MeI and MeBr in the soil profile following 30-cm deep applications were calculated as mg L⁻¹ of soil air. Soil air in the syringe was quickly transferred into the column. Soil air (20 or 40 mL) were withdrawn from the sampling probes using a 60-mL syringe. The sample was passed through a charcoal sampling tube (ORBO-32, Supelco), and MeBr was quickly forced into the soil under pressure. To apply MeI, 100 g MeI was directly injected with a syringe septum on the serum bottle. When the bottle was inverted, the open end of Teflon tubing and then pierced through the ice, and a double-ended hollowed needle was first forced into the center of the plot, with one end buried 30 cm below the surface and the other end aboveground. To apply MeBr, 100 g MeBr in a crimp-sealed serum bottle was chilled overnight on dry ice, and a double-ended hollowed needle was first forced into the center point, and a soil gas sampling probe was carefully installed in the hole. The sampling probe allowed soil air to be sampled from the following depths: 0, 15, 25, 60, 120, and 270 cm from the center point, with the average air temperature during the experiment was 21.7°C, with the average daily high at 30.2°C, and the average daily low at 15.6°C.

Volatilization fluxes of methyl iodide and methyl bromide from Greenfield sandy loam in 30-cm packed soil columns under various field conditions are shown in Fig. 1 and 2. The same column system and sampling procedures were used in previous studies to determine MeBr emissions under various application surface conditions. Inserts show fluxes for the infinite lower boundary condition (Gan et al., 1996). Since the closed column bottom prevented MeI or MeBr from escaping, the Ficks permeation coefficient (k_p) was at the ~9-em depth. Inserts show fluxes for the infinite lower boundary condition (Gan et al., 1996). In brief, the design of the sampling probe was described in detail by Kolbezen et al. (1974). The plots were 90, 180, and 270 cm. The design of the sampling probe was still existed), Ficks law is believed to be adequate for describing transport (Leffelaar, 1987; Amali and Rolston, 1993). Similar experimental setup and model extrapolation procedures might be used in previous studies to estimate values close to field observations (Gan et al., 1996, 1997).
The overall volatilization loss was 75% for MeBr, and volatilization fluxes of both chemicals decreased rapidly. After extrapolation to infinite time, the cumulative loss of MeBr was 75% for MeBr, and 52% for MeI. The Hyti-bar film apparently served as a better barrier than polyethylene in keeping MeI or MeBr in the soil, and less volatilization of MeI occurred as a result of more extensive degradation compared to MeBr.

The maximum flux of MeBr (4.3 mg m⁻²) occurred immediately after application, at 6 to 10 h, at a level similar to that of MeBr (Fig. 2a). After the peak was reached, volatilization was detected at 1.5 h, and its maximum was reached at 4.5 to 5 h (see insert in Fig. 2a). MeI volatilization fluxes were attained at 0.7 to 13.76 mg m⁻², half of those from the nontarped column (Fig. 2b). MeBr volatilization was first detected at 1 h, while MeI volatilization was detected at 2.5 h (Fig. 2b insert). The maximum fluxes (1.9 to 2.1 mg m⁻²) of MeI from the PE-tarped treatment (Fig. 1a and 1b) were only about a third of the fluxes from the nontarped column, and 72% of the applied MeI, would be emitted for the polyethylene film-tarped treatment.

When the soil surface was covered with the polyethylene film, the maximum fluxes (1.9 to 2.1 mg m⁻²) of MeI in the air may be hazardous to workers or nearby residents due to its acute toxicity. Nontarped applications will still likely result in significant MeI emissions, and the volatilization flux of MeI from a Greenfield sandy loam in 60-cm packed soil columns when soil surface was (a) nontarped; (b) tarped with 0.13-mm polyethylene film; and (c) tarped with Hyti-bar film. Application of MeBr and MeI was first detected at 1 h, while MeI volatilization was first detected at 2.5 h (Fig. 2b insert). The cumulative volatilization loss was 90% within the first 5 d of applications of MeBr and MeI occurring at 10 to 12 h were only about a third of the fluxes from the nontarped column (Fig. 2b).

Though polyethylene tarping did not significantly reduce the overall volatilization loss of MeI, maximum volatilization fluxes were reduced, especially for shallow applications (The United Nations Environment Programme, 1995). A few studies indicate that polyethylene plastics are relatively permeable to MeBr, resulting in insufficient containment or loss, and open openings caused by injection chisels in the field (De Heer et al., 1983; Rolph et al., 1989; Bureau of Mines, 1994). Effective in stopping MeI volatilization loss, this inefficiency was partly due to the slower degradation of polyethylene resin and a lower vapor pressure than MeBr, nontarped applications will still likely result in significant MeI emissions. This study indicates that polyethylene was even less effective in stopping MeI volatilization loss than MeBr, which left more MeI for volatilization and downwards transport through the soil.

When the surface cover was the less permeable Hyti-bar film in keeping MeI or MeBr in the soil, and less volatilization of MeI occurred as a result of more extensive degradation compared to MeBr. The consistency of column performance, and the lower boundary conditions, the total volatilization loss of methyl iodide and methyl bromide from a Greenfield sandy loam in 60-cm packed soil columns when soil surface was (a) nontarped; (b) tarped with 0.13-mm polyethylene film; and (c) tarped with Hyti-bar film. Application of MeBr and MeI was first detected at 1 h, while MeI volatilization was first detected at 2.5 h (Fig. 2b insert). The cumulative volatilization loss was 90% within the first 5 d of applications of MeBr and MeI occurring at 10 to 12 h were only about a third of the fluxes from the nontarped column (Fig. 2b). MeBr volatilization was first detected at 1 h, while MeI volatilization was detected at 2.5 h (Fig. 2b insert). The maximum fluxes (1.9 to 2.1 mg m⁻²) of MeI from the PE-tarped treatment (Fig. 1a and 1b) were only about a third of the fluxes from the nontarped column, and 72% of the applied MeI, would be emitted for the polyethylene film-tarped treatment.

When the surface cover was the less permeable Hyti-bar film, MeI or MeBr volatilization further decreased, and the volatilization was more gradual, and detectable volatilization continued for 940 h, or 39 d. The total cumulative volatilization loss was 45% for MeBr and 90% for MeI (Fig. 2c). After correction for lower boundary effect, it was estimated that 48% of the applied MeBr, and 72% of the applied MeI, would be emitted for the polyethylene film-tarped treatment.
The use of a less permeable plastic Saranex in the Netherlands resulted in drastic reduction in MeBr emissions, and significant increase in soil Br- (Hamaker et al., 1983; Wegman et al., 1983).

In all the treatments, the time that volatilization flux of MeI became measurable was 1.5 h later than for MeBr. The delay in MeI volatilization during the initial hours may be beneficial in providing a time window for better worker protection. It may also allow additional procedures, such as packing the surface to close chisel openings, or surface irrigation (Jin and Jury, 1995), be incorporated into the fumigation process to further reduce volatilization. The delay in MeI volatilization may be attributed to its higher boiling point (42°C vs. 4°C for MeBr) and lower vapor pressure (400 vs. 1600 mm Hg for MeBr). The time needed for liquid fumigant to vaporize can be estimated from the equation derived by Bird et al. (1960):

\[ V = S \cdot F_s \cdot \frac{4 \cdot D \cdot t}{\pi} \]

where \( V \) is volume of vapor a fumigant forms (m³ (gas)); \( S \) is surface area of vaporization (m²); \( F_s \) is the saturated vapor pressure of a fumigant divided by the total pressure; and \( t \) is time (s). Assuming applied MeI and MeBr are exposed to the same conditions, the time for the same molar amount of MeI to completely vaporize is roughly 20 times that for MeBr.

Volatilization from Different Soils

When the soil surface was covered with polyethylene film, volatilization of MeBr and MeI varied greatly depending on the type of soil in the columns (Fig. 3, 4, 1b, and 2b). While the maximum fluxes were similar in columns packed with Greenfield SL (Fig. 1b), Carsitas LS (Fig. 3a) and Linne CL (Fig. 3b), volatilization both MeI and MeBr in the later two soils decreased more rapidly after maximum fluxes were reached; and detectable volatilization stopped much sooner than in the Greenfield soil. The maximum volatilization fluxes from the potting mix column (Fig. 3c) were smaller than that from the other soil columns, but the total volatilization loss was similar to that from the Carsitas LS. The measured or extrapolated cumulative volatilization losses for both chemicals follow the order: Greenfield SL > Linne CL > Carsitas SL = potting mix (Table 2).

The diffusion of a volatile compound such as a fumigant in fairly dry soil that is typical of fumigation is predominantly through the vapor phase (Jury et al., 1983; Jin and Jury, 1995). Therefore diffusion in the water phase and advection may be ignored and fumigant transport may be simplified as below for the experimental conditions:

\[ \frac{\partial Ce(z,t)}{\partial t} = D_s \cdot \frac{\partial^2 Ce(z,t)}{\partial z^2} - \mu \cdot \frac{Ce(z,t)}{h} \]

where \( Ce \) is fumigant concentration in soil vapor phase (mg cm⁻³); \( t \) is time (d); \( D_s \) is effective diffusion coefficient of fumigant in soil gas phase (cm² d⁻¹); \( z \) is distance (m); \( \mu \) is degradation rate constant of fumigant in soil (d⁻¹); \( f(z) \) is fumigant concentration in the atmosphere (mg cm⁻³); and \( h \) is the mass transfer coefficient (cm d⁻¹). From the model, it is apparent that soil diffusion and volatilization of a fumigant are affected by its diffusion coefficient, degradation or persistence in soil, and the resistance (i.e., \( 1/h \)) to vapor transport between the soil and atmosphere. In extrapolating measured column volatilization fluxes, \( D_s \) for different soil columns was calculated (Table 1). Different packing conditions (i.e., water content and bulk density) and adsorption coefficients (Gan and Yates, 1996) resulted in large \( D_s \) for the Linne CL column. The higher emission loss of MeBr and MeI from the Linne CL compared with the Carsitas LS and potting mix could be partially attributed to the difference in their \( D_s \) values. However, the substantial difference in volatilization losses between these three columns and the Greenfield SL column was clearly due to a different term—degradation. The half-degradation

![Fig. 3. Volatilization fluxes of methyl iodide and methyl bromide from 60-cm columns packed with different soils under 0.03-mm polyethylene film-tarped conditions.](image-url)
Fig. 4. Cumulative volatilization loss of methyl iodide and methyl bromide from 60-cm columns packed with different soils under 0.03-mm polyethylene film-tarped conditions. (a) Carsitas loamy sand; (b) Linne clay loam; and (c) nursery potting mix. Application of both chemicals was at the 30-cm depth.

The estimated half-lives (h/2) for MeI degradation was estimated to be 17 h for the Greenfield SL, but only 4, 5, and 5 d for the Carsitas LS, Linne CL and the potting mix, respectively; while the h/2 for MeBr was 9 d for the Greenfield SL, but only 2 d for the other three matrices (Gan and Yates, 1996). According to Eq. [2], degradation depletes the fraction of fumigant that is available for volatilization in the soil, thus decreasing volatilization losses.

Distribution in Soil Column Experiments

Measured (in symbols) and model fitted (in lines) fumigant concentrations in soil air are given in Fig. 5 for the Greenfield SL under various surface conditions and in Fig. 6 for different soils under polyethylene tarped conditions. Fitted data generally agreed well with the measured points. In the packed soil columns, due to the closed column bottom, fumigant distribution was distorted a few hours after the application due to the build up of concentrations at 60 cm. Under the same conditions, MeI behaved to a great extent like MeBr (Fig. 5 and 6). However, in the same soil column, especially during the initial hours, MeBr consistently spread out more rapidly than MeI. This difference was likely due to their different boiling points and diffusion rates. The estimated Ds for MeBr was consistently greater than that for MeI under the same conditions (Table 1).

In the nontarped column, MeI or MeBr concentrations at the soil surface (at 0-10 cm depth in Fig. 5a) were very low, indicating that in the field, nontarped fumigation will unlikely provide adequate control of the pests dwelling near soil surface (e.g., weeds). Covering the soil surface with plastic films clearly increased fumigant concentrations near the soil surface (Fig. 5b and 5c), and the overall fumigant concentrations were higher than in the nontarped column throughout the experiment. In polyethylene film-tarped field plots, MeBr concentrations at various depths were greater than in nontarped ones (Abdalla et al., 1974). Even though polyethylene film was relatively ineffective in reducing MeI volatilization, it nevertheless acted as a short-term barrier. Increased MeI concentrations in tarped soil indicate that tarped MeI fumigation should be more effective than nontarped fumigation.

The vertical distribution of MeI and MeBr was also determined in columns packed with different soils (Fig. 6; data for Greenfield SL are in Fig. 5b). Soil type clearly had an effect on MeI or MeBr distribution in the soil. This soil dependence is probably caused by the different soil water contents and bulk densities of the columns, and different degradation rate constants and adsorption coefficients in these soils. In the Carsitas LS, Linne CL and the potting mix (Fig. 6), MeI and MeBr concentrations in the soil became substantially smaller with time than that in the Greenfield SL (Fig. 5b). Degradation might have partly contributed to the observed rapid fumigant depletion from these soils. From the perspective of efficacy, the same dosage of MeI or MeBr in an organic matter-rich soil might not produce the same control as in an organic matter-poor soil.

Field-Plot Experiments

The movement of MeI and MeBr was measured in the field, where a restrictive lower boundary as in the...
The distribution of MeI and MeBr in soil can be described in three phases. During the first phase that extended for the first few hours after application, MeBr diffused rapidly from the application point (30 cm below the surface) in all directions. In contrast, diffusion of MeI was more limited, and after 1 h, only a small portion had reached the sampling point (Fig. 7a). The slower diffusion of MeI was in agreement with the delay in detectable volatilization as well as the slower diffusion observed with packed columns. During the second phase lasting from a few hours to a few days, concentrations of both MeBr and MeI around the injection depth decreased very rapidly with time, and became very small 72 h after application (note the different x-axis scales in Fig. 7). Concentrations of MeI quickly approached and then surpassed those of MeBr around the depth of placement (Fig. 7b-7d). Methyl iodide was more confined to the layers adjacent to the depth of placement than MeBr. This was likely caused by its slower diffusion, which is in agreement with the difference in diffusion coefficients for MeBr and MeI, as reported by Gan and Yates (1996).

In the third phase (after 120 h), concentrations of MeI became higher than MeBr at most depths (Fig. 7e and 7f). For instance, 10 d (240 h) after application, concentration of MeI at 180 cm was more than three times that of MeBr (Fig. 7f). The fact that MeI remained in soil at higher levels at the later stage was likely because of its longer persistence than MeBr under the same conditions (Gan and Yates, 1996). The higher residual concentrations of MeI in soil imply that should MeI and MeBr have similar biological activities, the same dosage of MeI may provide better control than MeBr. On the other hand, the increased likelihood for MeI over MeBr to contaminate groundwater will depend on the soil and surface conditions. If the soil is slow in degrading MeI and its surface is covered, as in this field study, a small fraction of the applied chemical may reach groundwater if the water table is shallow. However, because of its high volatility, MeI in water dissipates rapidly through volatilization once the water is exposed to the air (Gan and Yates, 1996). Additional studies on the fate and toxicological effects of MeI in water should be conducted.
CONCLUSIONS

Mel behaved, to a great extent, like MeBr after subsurface application as would be expected from their similarities in structure and physical-chemical properties. This could be advantageous in that application techniques and management practices that are in use for MeBr may be directly adopted for Mel. A few differences, however, between Mel and MeBr were noticed in their volatilization into the air and distribution in soil. Loss of Mel through volatilization after subsurface application was found to be even greater than MeBr. The commonly used polyethylene film was ineffective in reducing the overall volatilization loss of Mel, but it reduced the maximum volatilization fluxes and increased Mel concentrations in surface soil layers. Greater Mel volatilization losses were likely caused by its slower degradation in soil than MeBr. Volatilization losses of both Mel and MeBr varied in different soils, and were significantly reduced in organic matter-rich soils which were capable of more rapidly degrading the chemicals. After subsurface application, Mel volatilization from the soil surface was temporarily delayed because of its lower vapor pressure, which may reduce worker exposure to Mel vapor during fumigation. Methyl iodide distribution in soil was more confined to the layers adjacent to the application point, and concentrations of Mel remained higher for a longer period of time. If the two chemicals have similar biological activity and the infested zones are close to the point of application, Mel will likely provide a better control than MeBr. In fields where water table is shallow, it is possible that Mel may reach the groundwater owing to its longer persistence. The potential for Mel to cause groundwater contamination needs further study under different application and soil regimes.

ACKNOWLEDGMENTS

We would like to thank P. Zhang and Steve Campbell for their technical assistance in obtaining some of the data reported herein. This work is partly funded by USDA Cooperative State Research Service Agreement 92-34050-8152.