Methyl Bromide Emissions from a Covered Field: II. Volatilization

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ABSTRACT

An experiment to investigate the environmental fate and transport of methyl bromide in agricultural fields is described. The methyl bromide volatilization rate was determined as a function of time for conditions where methyl bromide was applied at a rate of 843 kg in a 3.5-ha (i.e., 240 kg/ha) field covered with plastic at a depth of 25 cm. Three methods were used to estimate the methyl bromide volatilization rate, including: the aerodynamic, theoretical profile shape and integrated horizontal flux methods. The highest methyl bromide volatilization rates were at the beginning of the experiment. Within the first 24 h, approximately 36% of the applied methyl bromide mass was lost. Diurnally, the largest volatilization rates occurred during the day when temperatures were high and the atmosphere was unstable. Cooler temperatures, light winds, and neutral to stable atmospheric conditions were present at night, reducing the flux. The total emission calculated using these methods was found to be approximately 64% (±10%) of the applied mass. A mass balance was calculated using each flux estimation technique and several methods for analyzing the data. The average mass recovery using all the flux methods was 867 kg (±83 kg), which was 102.8% (±9.8%) of the applied mass (i.e., 843 kg). The range in the mass balance percent (i.e., percent of applied mass that is measured) is from 88 to 112%. The averaged mass balance percent for the aerodynamic method, which involved using the measured data directly, was approximately 100.8%. The total emission calculated using the aerodynamic method was found to be approximately 62% (±11%) of the applied mass.

Methyl bromide has been used for decades as a soil fumigant for the control of nematodes, weeds, and fungi and has recently come under scrutiny as a chemical that depletes stratospheric ozone. As a result of the Clean Air Act, methyl bromide is scheduled for phase-out by the year 2001. The USDA National Agricultural Pesticide Impact Assessment Program has completed an assessment of methyl bromide and determined that there will be substantial adverse economic impacts on the agricultural community if the use of methyl bromide is restricted.

Much of the concern for using methyl bromide for agricultural fumigation results from its high vapor pressure (1420 mm Hg at 20°C). Vapor diffusion plays a predominant role in the spreading of methyl bromide throughout the soil profile and in controlling pests (Goring, 1962; Kolbezen et al., 1974). When injected into the soil, compounds with a high vapor pressure can diffuse to the soil surface and escape into the atmosphere. It has been long established that volatilization is an important pathway for loss of organic chemicals with moderately high vapor pressures from land surfaces (Taylor, 1978; Cliath et al., 1980), and is a major mechanism affecting transport to the atmosphere for highly volatile pesticides such as methyl bromide (Reible, 1994; Yagi et al., 1993). Volatilization of organic chemicals during their use, or following the disposal of waste or consumable goods containing the chemical, is an important source of organic pollutants to the atmosphere.

Volatilization of chemicals from soils can be estimated from a consideration of the physical and chemical factors controlling their concentration at the soil surface (Spencer et al., 1982). When an organic chemical is mixed into the soil, the volatilization rate depends on complex interactions between the sorbed, liquid and vapor phases, movement of the liquid, interactions between the liquid and soil–gas phases, movement from vapor diffusion, and advection as well as other external processes such as energy-induced movement (i.e., induced from heating, barometric pressure, or surface wind), diffusion through a surface boundary layer, turbulent transfer in the atmosphere, etc.

Volatilization of soil-incorporated chemicals volatilize at a rate dependent on three major factors: (i) their effective vapor

Abbreviations: TPS, theoretical profile shape.
Vapor density of a chemical in soil is a reflection of its inherent vapor pressure, its water solubility, and its properties in the subsurface. The relationship between vapor pressure within the soil, (ii) their rate of movement away from the surface through the air boundary layer, and (iii) their rate of movement and pressure that occur in the field, methyl bromide is effectively increasing the treated region from the surface to as much as several meters deep. At normal temperatures and pressure in the soil, mainly adsorption. Temperature effects are also from the soil to the atmosphere. This may be particularly for a plastic is present. For a similar conditions compared with Majewski et al. (1995). Yagi et al. (1993, 1995) found that 34 to 87% of the applied treatments obtained from an estimate of methyl bromide degradation and mass remaining in the atmosphere. The objective of this article is to describe the extent of methyl bromide volatilization into the atmosphere and to describe the results when methyl bromide is applied at a shallow depth under the dynamics of the methyl bromide volatilization rate and restricting methyl bromide use will have severe consequences on agriculture in the USA (USDA-NAPIAP, 1993), a research project was initiated to determine the extent of methyl bromide volatilization into the atmosphere and to describe the results when methyl bromide is applied at a shallow depth under the dynamics of the methyl bromide volatilization rate and its mass balance.
The TPS method, described by Wilson et al. (1982), can be used to determine the gaseous pesticide flux from field experiments. The pesticide flux is estimated by observing the concentration of pesticide and ammonia volatilization from treated fields, Wilson et al. (1983). This method is based on the trajectory simulation model described by Wilson et al. (1981a,b,c) and does not depend on the wind speed. Although the method was originally developed for circular plots, it can be easily modified for square or rectangular plots, with a concomitant increase in computer calculations. Since, to our knowledge, this method does not depend on the wind speed, it is suitable for general atmospheric stability conditions, is relatively insensitive to the atmospheric stability, and the source area, which extends from 0 ≤ x ≤ Xmmax, is discretized into M sections of equal length. A large number of particles are emitted from each section and tracked until the particles reach the collector located at Xmmax, which coincides with the position of the sampling mast in the field. From repeated applications of Eq. [6] through [8], the instantaneous number of particles is emitted from each section and tracked until the particles reach the collector, the count of particles is incremented by one. As the simulation progresses using a transformed coordinate system, the turbulence is assumed to be homogeneous (i.e., spatially uniform in the treated region; there is no temperature and wind gradients and stability corrections needed at only one height, and the sensor is placed at a particular time interval, t, are (Rosenberg et al., 1983) needed. This ratio depends on the surface roughness and the ratio of the horizontal to vertical flux, \( \frac{\mathbf{f}}{\mathbf{z}} \), using the trajectory simulation model. This ratio is related to the Eulerian velocity, \( \mathbf{u} \), time, \( t \), and air density, \( \rho \), coordinates. The actual vertical height is related to the transformed coordinate system, the turbulence is assumed to be homogeneous (i.e., constant length, velocity, and time scales). In this coordinate system, the turbulence is assumed to be homogeneous (i.e., constant length, velocity, and time scales).
the results against height produces a curve similar to that of the surface flux. One difficulty using the TPS approach is the value of $\omega$ is then used in Eq. [4] to provide an estimate of the location where the effects of atmospheric stability are minimized. The theoretical location of this minimum is shown in Fig. 1. The height where the three curves converge is the same for both strongly unstable and neutral atmospheric conditions. Plotting the curves shown in Fig. 1 depends on the distance between fetch and either $Z_\text{s}$, or $f_2$. The procedure used here is to develop a relationship between the fetch distance and wind direction, which is accomplished using simple trigonometry. Next, a relationship between wind direction and the instrument height is determined, and the distance of the source area upwind from the sampling mast must be known. An advantage of this method over the aerodynamic method is that corrections for vertical diffusion are not required. Also, information regarding the source area and the wind direction is sufficient to determine the distance of the source area upwind from the sampling point. To use this method, the concentration profile at several heights must be determined, and the distance of the source area upwind from the sampling point is equal to the mass that passes through the upwind fetch distance is the independent variable. Applying regression, using the information shown in Fig. 1, where the ratio of horizontal to vertical flux as a function of height is obtained through simulation be conducted for several upwind source distances (operationally this is the intersection of the stable and unstable thermal gradients in the atmosphere, which occurs at the time of application).
Coupled to cool temperatures, which decreases diffusion through the plastic, this causes reduced night time flux values. During the day, mechanical mixing is high along with buoyancy forces; producing moderately negative $R_i$. This indicates unstable conditions but the magnitude is much less compared with the 0800- to 1000-h interval.

Shown in Fig. 2B is the estimated mass (kg) lost from the field during the experiment as a function of time. This was obtained by multiplying the flux measurement by the duration of the specific time interval and integrating over the area of the field (i.e., $34,892 \text{ m}^2$) and provides an estimate of the mass emitted from the soil surface for the experiment. The total methyl bromide loss is approximately 547 kg or approximately 65% of the applied mass (i.e., 843 kg). From the aerodynamic method data, it is clear that most of the methyl bromide mass that leaves the treated soil does so during the first 24 hours.

### Table 1. Mass balance.

<table>
<thead>
<tr>
<th>Method used to generate data in Fig. 2.</th>
<th>Mass lost after soil was covered</th>
<th>Mass lost after cover was removed</th>
<th>Percent lost while soil was covered</th>
<th>Percent lost while cover was removed</th>
<th>Estimated and difference (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerodynamic method (discrete) (62 + 111% volatilized)</td>
<td>532</td>
<td>63.2</td>
<td>14</td>
<td>1.7</td>
<td>29 103.4</td>
</tr>
<tr>
<td>C:0.2 &amp; 0.8 m</td>
<td>605</td>
<td>71.7</td>
<td>12</td>
<td>1.4</td>
<td>99 111.7</td>
</tr>
<tr>
<td>C:0.5 &amp; 0.8 m</td>
<td>392</td>
<td>46.5</td>
<td>19</td>
<td>2.3</td>
<td>- 107 87.3</td>
</tr>
<tr>
<td>Average (SD)</td>
<td>510 (88)</td>
<td>60.5</td>
<td>15 (3)</td>
<td>1.8</td>
<td>7 100.8</td>
</tr>
<tr>
<td>Aerodynamic method (profile) (67 + 6% volatilized)</td>
<td>513</td>
<td>60.8</td>
<td>10</td>
<td>1.2</td>
<td>5 100.6</td>
</tr>
<tr>
<td>C:2-6; U:1-3</td>
<td>604</td>
<td>71.6</td>
<td>8</td>
<td>1.0</td>
<td>94 111.2</td>
</tr>
<tr>
<td>Average (SD)</td>
<td>558 (46)</td>
<td>66.2</td>
<td>9 (1)</td>
<td>1.1</td>
<td>50 105.9</td>
</tr>
<tr>
<td>Theoretical profile shape (60 + 3% volatilized)</td>
<td>349</td>
<td>41.7</td>
<td>3</td>
<td>0.4</td>
<td>- 166 80.3</td>
</tr>
<tr>
<td>C:2-6; U:1-6</td>
<td>569</td>
<td>67.8</td>
<td>3</td>
<td>0.3</td>
<td>54 106.3</td>
</tr>
<tr>
<td>C:3-6; U:1-6</td>
<td>557</td>
<td>67.2</td>
<td>9</td>
<td>1.1</td>
<td>48 105.7</td>
</tr>
<tr>
<td>SELective: C:2-6, C:3-6, C:4-6</td>
<td>528</td>
<td>63.6</td>
<td>8</td>
<td>0.9</td>
<td>18 102.1</td>
</tr>
<tr>
<td>Average (SD)</td>
<td>501 (26)</td>
<td>60.1</td>
<td>6 (2)</td>
<td>0.7</td>
<td>12 98.6</td>
</tr>
<tr>
<td>Integrated horizontal flux (70 + 3% volatilized)</td>
<td>549</td>
<td>65.1</td>
<td>9</td>
<td>1.1</td>
<td>40 104.8</td>
</tr>
<tr>
<td>Discrete C:1-6; U:1-6</td>
<td>596</td>
<td>70.8</td>
<td>9</td>
<td>1.1</td>
<td>88 110.4</td>
</tr>
<tr>
<td>Profile C:2-6; U:1-6</td>
<td>591</td>
<td>70.1</td>
<td>9</td>
<td>1.1</td>
<td>82 109.8</td>
</tr>
<tr>
<td>Average (SD)</td>
<td>579 (21)</td>
<td>68.7</td>
<td>9 (0)</td>
<td>1.1</td>
<td>70 108.3</td>
</tr>
</tbody>
</table>

Mass applied: 843.1 kg; mass remaining: 0.261 kg; mass degraded: 324.9 kg.
In this case, about 30 kg (- 36.5 %) of the total applied methyl bromide is lost during the first 24 h and an additional 15 kg (- 18.4 %) was lost between 24 and 48 h. Of the 65% lost over the entire experiment, <0.1% is due to volatilization occurring after Day 6. This temporal behavior agrees with the work of other researchers studying methyl bromide emissions from fields (Yagi et al., 1993; Majewski et al., 1995) and due primarily to the shallow injection depth and high air temperatures that occurred during this experiment.

Table 1 contains a mass balance summary for each of the flux estimation methods and data combinations that were used to determine the flux. Shown in the footnote to Table 1 are estimates of the mass applied, (843.1 kg), degraded (325 kg), and mass remaining in the soil (0.26 kg) from (Yates et al. 1996). A balance can be calculated by subtracting the mass lost from the field (i.e., volatilization and degradation) and the mass remaining from the amount applied. Negative mass differences, shown in Column 6, indicate less than complete mass recovery. The information in Table 1 was obtained using several data combinations for the methyl bromide concentration and several procedures for estimating the flux. Integrating over space and time yields a value for the mass lost. Several data combinations and analyses were used to provide supplementary information on the average behavior of the volatilization rate, to reduce the effect of errors or deviations in the data, and to identify aberrant behavior from any particular flux-estimation method.

For the aerodynamic method, five values of the mass volatilized were obtained. Three were estimated using the field-measured data in Eq. [1] and are denoted as the aerodynamic method (discrete) in Table 1. Two estimates were obtained by fitting log-normal (with height) profiles to the measured concentration and wind speed data and are denoted as the aerodynamic method (profile) in Table 1.

For the aerodynamic discrete case, the time series of the measured concentration at 0.2 and 0.8 m (marked as C:0.2 and 0.8 m in Table 1), 0.2 and 0.5 m, and 0.5 and 0.8 m were used along with measurements of the air temperature at heights 0.2 and 0.8 m and the wind speed at 0.3 and 0.7 m above the soil surface. Incorporating these data in Eq. [1] produces a flux value for each sampling period. The most accurate value for the flux should be the one that uses the concentration data collected at 0.2 and 0.8 m above the soil surface, since the gradients for concentration, wind speed, and air temperature are all centered at 50 cm. The other flux values for the discrete case should be similar, however, since using the aerodynamic method requires a large fetch distance so that the gradients are fully developed. Under these conditions, nearly constant wind, temperature, and concentration gradients should exist near the surface in the fully developed layer. It is estimated from the aerodynamic discrete method that 525 kg (+91 kg) or 62% (+ 11%) of the applied mass volatilized from the field. The mass balance ranged from 87 to 112% with an average mass balance of approximately 100.8%.

For the aerodynamic profile case, least squares regression equations were fitted to the concentration data collected at heights: 0.1, 0.2, 0.5, 0.8, 1.2, and 1.6 m above the soil surface as a function of log-height and the slope of the profile equation was used for the concentration gradient in Eq. [1] (i.e., \( \frac{dC}{d\ln(z)} \)).
ent methods for describing the concentration profile are shown in Fig. 3 for the first six sampling intervals. The measured concentrations are shown as solid dots. The solid and dotted lines, respectively, indicate the use of linear regression with all six measured concentrations (denoted as $C_{1-6}$ in Table 1) or the five concentrations (denoted as $C_{2-6}$ in Table 1), which exclude the value at 10 cm. Generally, the measured concentration at 10 cm does not follow the logarithmic profile with height. This may be due to its closeness to the soil surface. According to Brutsaert (1982), log profiles generally occur in the dynamic sublayer, which begins at a height above approximately 1.5 to 3.5 $h_0$ from the soil surface and extends some tens of meters, where $h_0$ is a typical height of the roughness obstacles. Although the plastic material is relatively smooth, the surface of the field is not perfectly flat since soil is mounded at the point where two pieces of plastic are joined and surface irregularities can show through the plastic. No attempt was made to measure the obstacle heights, but a height of only $h_0 = 4$ to 5 cm would be sufficient to place the concentration measurement at 10 cm slightly below the dynamic sublayer and therefore, may provide an explanation for why this value does not follow a logarithmic profile.

Shown in Fig. 4 are the wind speed profiles for the first six sampling intervals. Two logarithmic profiles have been fitted to the measured wind speed using linear regression. The solid line, denoted as $U_{1-6}$ in Table 1, uses all six measured wind speeds. The dotted line uses the three wind speeds at 0.1, 0.3, and 0.7 m and is denoted as $U_{1-3}$ in Table 1. Since the wind speed as a function of height is logarithmic only under neutral conditions (Rosenberg et al., 1983, p. 143), the regression relationship using the three lowest heights was used to more accurately fit the profile, and thus the wind speed gradient, in this region. These cases should produce identical values if the wind profile data were exactly logarithmic. The percent mass lost estimated from the aerodynamic profile case, using both the concentration and wind speed profiles, is approximately 62 to 73 % of the applied methyl bromide. The mass balance for this approach ranges from 100.6 to 111.2%. The $C_{2-6}$, $U_{1-3}$ case is probably more representative of the actual mass lost since excluding the measured concentration at 0.1 m in the regression equation reduces the large deviations between the fitted and the measured concentration profiles.

Theoretical Profile Shape Method

A relationship that returns the upwind source distance given known values for the wind direction for this experiment is

$$
\text{Fetch, m} = \frac{69}{\cos(\theta)}; \quad 305.1 \leq \theta < 54.9^\circ \\
= \frac{98}{\sin(\theta)}; \quad 54.9 \leq \theta < 138^\circ \\
= -\frac{109}{\cos(\theta)}; \quad 138^\circ \leq \theta < 222^\circ \\
= -\frac{98}{\sin(\theta)}; \quad 222^\circ \leq \theta < 305.1^\circ
$$

[10]

Using Eq. [10], a regression relationship was obtained, which gives the ratio of the horizontal to vertical flux, $\alpha$, as a function of upwind fetch. Since the upwind distance also affects the instrument height, it was also necessary to obtain a regression relationship for $Z_{\text{inst}}$ and interpolate between the available data to obtain the concentration at this height. These relationships are
shown in Fig. 5, where the circles indicate the \( Z_{\text{inst}} \) (A) and \( f_2 \) (B) values for specified fetch distances and the lines were obtained using linear regression. With this information, the methyl bromide flux can be determined for any wind-direction averaging period. To obtain a flux value, first the measured wind direction and wind speed were averaged for the desired time interval. Using the averaged wind direction data and Eq. [10], the upwind fetch distance was determined. From fetch distance, Fig. 5A can be used to calculate the instrument height for the time interval. Since the sampling heights were fixed during the experiment but the instrument height varies with wind directions, the concentration and wind speed were estimated at the instrument height using regression relationships where a log-normal profile was fitted to the field-measured values. After estimating the wind speed and concentration, the ratio of the vertical to horizontal flux for a given fetch distance was obtained from Fig. 5B and the volatilization rate determined from Eq. [4].

Shown in Fig. 6A is a plot of methyl bromide volatilization (\( \mu \text{g/m}^2\text{s} \)) from the field during the experiment where each point represents either a 2- or 4-h averaging period. Like Fig. 2A, the insert in Fig. 6A is an enlargement of the flux values beginning at Day 3. The overall behavior is similar to the aerodynamic case, with the largest volatilization rates occurring during the first 24 h. The maximum flux value is off the scale used in Fig. 6 and is 786 \( \mu \text{g/m}^2\text{s} \). The zero-flux values are caused when the top (i.e., the height where the concentration is zero) of the log-profile for the concentration is below the estimated instrument height for the prevailing wind direction. This tends to occur during times when the flux would normally be low and probably indicates that the true concentration profile differs slightly from a log-normal assumption. For these conditions the flux estimate is zero. The behavior of the flux is somewhat different than the aerodynamic case where the peak flux was preceded by two periods with lower values. Also, during the first 24 h, 401 kg or 47.5% of the applied methyl bromide was lost; during the next 24 h, an additional 92 kg or 10.9% was lost.

Shown in Fig. 6B is a graph of the mass lost (kg) estimated from the theoretical profile shape method. The estimates of the total methyl bromide emission range from approximately 352 kg (or 42%) to 571 kg (or 68%) and are listed in Table 1. The lower value of this range is probably not correct since this estimate is based on using the C:2-6 concentration profiles. When this information is used, many of the time intervals produce a zero flux. When the C:3-6 and C:4-6 profiles are used, additional nonzero flux values can be included in determining the total mass lost. The additional periods with a measurable flux increase the total emissions to the 65% range. The case denoted as Selective uses all 28 flux values obtained from the C:2-6 profiles along with 19 additional C:3-6 values (when C:2-6 produces zero flux) and three additional C:4-6 flux values. This is probably the most representative value since the greatest quantity of data is used in determining the flux. The mass balances ranged from nearly 80 to 106%, with an average mass balance of 98.6% (+3.4%).

**Integrated Horizontal Flux Method**

Two approaches were used to estimate the methyl bromide flux using the integrated horizontal flux method. The first involves a discrete approximation to the integral in Eq. [9], that is,

\[
\int_{Z_o}^{Z_{\text{max}}} \frac{\rho(z)}{\lambda} dz = \sum_{i=1}^{n} \frac{\rho(Z_i)}{\lambda} AZ_i \tag{11}
\]

Alternatively, the flux was estimated by solving the integral directly. Given that the horizontal wind speed and methyl bromide concentration can be adequately characterized using linear equations with respect to the logarithm of height, that is

\[
u(z) = A + B \ln(z) \tag{12}
\]

and

\[
u(z) = F + G \ln(z) \tag{13}
\]

then substituting Eq. [12] and [13] into Eq. [9] and solving gives

\[
\int_{Z_o}^{Z_{\text{max}}} \frac{\rho(z)}{\lambda} dz = \int_{Z_o}^{Z_{\text{max}}} e(z) \lambda dz = Z_o \left[ (A - B) F + (2B - A) G + (BE - Z_{\text{max}}(A - 2B) G) \right] \ln(z) + BG \ln(z)^2 \tag{14}
\]

where \( Z_{\text{max}} \) is the estimated height where the concentration profile reaches zero and \( Z_o \) is the height, below which the wind speed is zero.
Fig. 6. (A) Methyl bromide flux (lag/m²s) and (B) mass lost from volatilization as a function of time using the theoretical profile shape method.

The dynamics of the methyl bromide emission rate at the start of the experiment are similar to the aerodynamic and theoretical profile shape methods with peak values early in the experiment and decreasing with time. During the first 3 d, the decreasing nature of the flux with respect to time appears to be somewhat smoother and has a more apparent exponentially decreasing shape. By 24 and 48 h after application, respectively, 402 kg (47.6%) and 103 kg (12.2%) of the applied methyl bromide was lost. The total fraction emitted into the atmosphere is estimated to be 66% with a 104.8% mass balance.

Fig. 7. (A) Methyl bromide flux (~tg/m²s) and (B) mass lost from volatilization as a function of time using the integrated horizontal flux method.

Insert is an expanded view of the flux.
concentration-height data resulted in values for the mass
lost ranging from 71 to 72%. The average mass lost
using the integrated horizontal flux method is 588 kg
(± 21 kg) or 69.8 % (+2.5 %). These values overestimate
the mass lost from the production of Br− method by
approximately 15%.

CONCLUSIONS
An experiment was conducted to investigate the dy-
amics of methyl bromide volatilization from agricultural
fields into the atmosphere. Methyl bromide was applied
at a rate of approximately 240 kg/ha at a depth of 25
cm. The soil was immediately covered with a 0.025-mm
(1-mil) polyethylene plastic, which was removed after
5 d. The atmospheric concentration and weather condi-
tions were continuously monitored (24 h/d) until the air
concentrations dropped below detectable values. Several
values for the averaged total methyl bromide emissions
from the field have been obtained and include an estimate
from the methyl bromide mass degraded (61 % of applied)
along with estimates from the aerodynamic 64 + 9%
(of applied), theoretical profile shape 60
±
3% (of ap-
plicated) and integrated horizontal flux methods 70 + 3%
(of applied). The average percent mass recovery using
all the flux methods listed in Table 1 is 867 kg, which
is 102.8%. The total mass lost from this experiment is
approximately 75% higher than the value reported by
Majewski et al. (1995), who estimated the total loss to
be approximately 36%. The diiferences in emission rate
are probably due to the climatic conditions in the Monte-
rey region compared with Moreno Valley. Decreased
temperatures would cause a reduction in the diifusion
through polyethylene plastic material (Kolbezen and
Abu-El-Haj, 1977) and increasing the residence time in
the soil causing a greater amount of methyl bromide to
be degraded in the soil. The range for total emissions
described herein also differs from the results of Yagi et
al. (1993) and Yagi et al. (1995), who report values of
approximately 87 and 34%, respectively, for experiments
with a similar methyl bromide application methodology,

[it is highly advisable that a mass balance be conducted
along with the use of several methods for estimating the
flux so that the accuracy of the total emissions rate from
agricultural fields can be determined. This will help to
dentify errors when determining the flux, the field-scale
legradation or the methyl bromide remaining in the field.

The large levels of emissions that result when methyl
>romide is applied at a shallow depth and the soil covered
vith a relatively permeable polyethylene tarp suggest
hat this application method is not efficient in terms of
nethyl bromide use for pest control nor in protecting
he atmosphere from anthropogenic sources of methyl
iromide. Research is urgently needed to develop suitable
nethods for containing methyl bromide in soils at lower
ates of usage and for longer periods of time so that soil
ergadation can occur. If improved application practices
an be found and not produce any economic impediments,
en a significant lowering of the anthropogenic methyl
iromide emissions would occur without any loss in pest-
ontrol efficiency.

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the field site and for many useful discussions concerning the
experiment. We also thank Tri-Cal Inc. for providing the
methyl bromide, plastic materials, application equipment, and
other assistance for this research.
ERRATUM

The Cadmium Content of British Wheat Grain

The German limit for Cd in wheat grain of 0.1 mg kg\(^{-1}\) fresh wt. (0.12 mg kg\(^{-1}\) dry wt.) (EGA, 1986) has been mistakenly labeled as the WHO limit in the above paper. There is as yet no FAO/WHO Cd in wheat grain limit.

Reference