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# Methane flux and oxidation at two types of intermediate landfill covers

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**Abstract**

Methane emissions were measured on two areas at a Florida (USA) landfill using the static chamber technique. Because existing literature contains few measurements of methane emissions and oxidation in intermediate cover areas, this study focused on field measurement of emissions at 15-cm-thick non-vegetated intermediate cover overlying 1-year-old waste and a 45-cm-thick vegetated intermediate cover overlying 7-year-old waste. The 45 cm thick cover can also simulate non-engineered covers associated with older closed landfills. Oxidation of the emitted methane was evaluated using stable isotope techniques. The arithmetic means of the measured fluxes were 54–2 g $CH_4$ $m^{-2}$ $d^{-1}$ from the thin cover and the thick cover, respectively. The peak flux was 596 g $m^{-2}$ $d^{-1}$ for the thin cover and 330 g $m^{-2}$ $d^{-1}$ for the thick cover. The mean percent oxidation was significantly greater (25%) at the thick cover relative to the thin cover (14%). This difference only partly accounted for the difference in emissions from the two sites.

Inverse distance weighing was used to describe the spatial variation of flux emissions from each cover type. The geospatial mean flux was 21.6 g $m^{-2}$ $d^{-1}$ for the thick intermediate cover and 50.0 for the thin intermediate cover. High emission zones in the thick cover were fewer and more isolated, while high emission zones in the thin cover were continuous and covered a larger area. These differences in the emission patterns suggest that different $CH_4$ mitigation techniques should be applied to the two areas. For the thick intermediate cover, we suggest that effective mitigation of methane emissions could be achieved by placement of individualized compost cells over high emission zones. Emissions from the thin intermediate cover, on the other hand, can be mitigated by placing a compost layer over the entire area.


## 1. Introduction and background

In the USA, landfill emissions are 30% of the anthropogenic input to atmospheric methane (Hogan, 1993). The imbalance between sources and sinks of $CH_4$ in the global budget is less than 6% of the total of global sources (Dlugokencky et al., 1994) or perhaps even approaching balance (Dlugokencky et al., 1998; Etheridge et al., 1998). Therefore, a small decrease in $CH_4$ source strength could result in stabilization of atmospheric $CH_4$, or, even better, in a reduction in the atmospheric concentration (Lelieveld et al., 1998; Thompson et al., 1992). As $CH_4$ is a more potent greenhouse agent than is $CO_2$, lowering the atmospheric $CH_4$ concentration is a very realistic and worthwhile goal. The relatively short residence time of $CH_4$ in the atmosphere (7–10 yr) relative to $CO_2$ (100 yr) means that the effects of mitigation efforts would be rapidly observed.

Landfills can emit methane at rates varying from 0.0004 to 4000 g $m^{-2}$ $d^{-1}$ (Bogner and Spokas, 1993; Bogner et al., 1997; Czepiel et al., 1996; Borjesson and Svensson, 1997; Chanton and Liptay, 2000). Bogner and Matthews (2003) used a model that linked per capita waste generation with per capita energy consumption and estimated global

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emissions of methane to be 16.4–18.1 Tg/y. This flux represents a conglomeration of point sources and as such could be readily mitigated. The global landfill emission estimated by Bogner and Matthews is about 3.5% of the total global methane emission of 500 Tg/y (Fung et al., 1997). Previous estimates of global landfill emissions were 40 Tg/y, 8% of the total (Fung et al., 1997). The IPCC IPCC, 2001 estimates that landfill emissions are 7% of global methane emissions.

Active landfills generally include areas with final cover, areas with intermediate cover, and areas with daily cover. Emissions of methane to the atmosphere can occur from all of these areas and at different rates. Towards this goal, the object of the study was to evaluate methane emissions and oxidation at two different types of landfill covers, a 45 cm thick intermediate cover consisting of a soil layer (sandy clay) overlain with well-vegetated topsoil, and a 15 cm thick non-vegetated intermediate soil cover. The 15 cm thickness is also a typical thickness for daily cover for state-approved programs under RCRA subtitle D provisions. Previous literature indicates that thicker soil covers reduce methane emissions, at least partly due to increased methane oxidation. We hypothesized that the flux from the thicker cover would be more patchy and dominated by hotspots, while the flux from the thinner cover would be higher but more uniform.

## 2. Methods

### 2.1. Site description

Measurements were performed at an MSW landfill which had no gas extraction system, located in Leon County, FL, USA (Chanton and Liptay, 2000). Two different locations for detailed sampling were selected for measurements associated with this paper. The first location, designated S1-Grid, had 7-year-old waste covered with about 45 cm of sandy clay and sandy loam. The area was thickly vegetated and entirely covered with a mixture of local grasses and occasional shrubs. A second location, designated S4-Grid, had 1-year-old waste covered with about 15 cm of sandy clay and is representative of a daily cover.

The S1-Grid was 60.8 m (200 ft) on a side and was divided into 64 squares, 7.6 by 7.6 m (25 by 25 ft). The S4-Grid was 64 m (210 ft) on a side and was also divided into 64 squares, 8 by 8 m (26 by 26 ft). Methane emissions were measured in the middle of each grid square. Additional locations (inside selected squares) were sampled at shorter distances to better define the flux spatial variability at small distances. The average flux was used for locations where the flux was repeatedly measured. For the S1-Grid, six squares had additional sampling locations in each quadrant, as well as one in the middle. In these squares, the minimum separation distance between sampling locations was 2.69 m (8.84 ft). For the S4-Grid, two squares had 12 additional sampling locations with a 1–8 m separation. Flux measurements and stable isotope testing to determine methane oxidation at the S1-Grid were conducted from September 2003 to February 2004. Measurements at the S4-Grid were conducted from February 2004 to May 2004.

### 2.2. Methane emission rates and gas analysis

Methane emission rates from the landfill surface were determined using a static chamber technique. Static chambers are the most frequently used technique for the measurement of gas fluxes from soils. The chamber technique is low in cost, simple to operate and especially useful for addressing research objectives needing spatial and temporal variability of fluxes at a small scale. Chambers are particularly well suited to in situ studies addressing physical, chemical and biological controls on surface-atmosphere trace gas exchange (Livingston and Hutchinson, 1995). The principle of static chambers is to seal a volume above a gas-emitting or consuming surface such that the emitted (or consumed) gas cannot escape and its accumulation in the volume can be monitored. The chambers used in this study were constructed with polished aluminum sheeting and have dimensions of $0.63 \times 0.63 \times 0.2$ m (covering an area of 0.4 $m^2$). They contained a small fan to circulate air inside the chamber. Chambers were sealed to the ground by firming soil around the outside or by clamping them to pre-installed collars. Methane samples were collected from a chamber immediately after sealing (time 0) and after 2, 5, 10, and 15 min using 60-mL plastic syringes fitted with plastic valves. Chamber air was sampled via a 1 m long 1/8 in. plastic tube sealed at the outward end with a valve. Samples were analyzed on a gas chromatograph equipped with a flame ionization detector within 4 h of collection. Methane flux was determined from concentration data ($C$ in ppmv) plotted versus elapsed time ($t$ in minutes). The data generally fit a linear relationship, in which case $dC/dt$ is the slope of the fitted line. The methane flux, $F$ ($g/m^2/d$), was then calculated as follows:

$$F = PVMU(dC/dt)/(ATR), \quad (1)$$

where $P$ is pressure (atm), $V$ is chamber volume (80 L, plus collar volume), $M$ is the molar mass of methane (16 g/mol), $U$ is the units conversion factor (0.00144 L min/(μL d)), $A$ is the area covered by the chamber (0.4 $m^2$), $T$ is chamber temperature (K), and $R$ is the gas constant (0.08205 L atm/(Kmol)). The slope of the line, $dC/dt$, was determined by linear regression between $CH_4$ concentration and elapsed time. Following the approach of Barlaz et al. (2004), a non-zero flux was reported only if the there was 90% confidence ($p < 0.1$) in the correlation between $CH_4$ concentration and time, otherwise a zero-flux is reported.

### 2.3. Geospatial analysis

Two commonly used interpolation methods are kriging and inverse distance weighing (IDW). In kriging, a model of the overall spatial measured variance structure is used

to generate the interpolated contours. The measured variance structure is shown as a variogram with half the variance on the *y*-axis and sample separation distance on the *x*-axis. Key variables for a variogram are the nugget (unexplained or error variance), sill (total model variance, equal to nugget plus "scale"), and range (distance where the variance reaches the sill) (Yates and Warrick, 2002). In IDW, the interpolation contours are calculated by weighing neighbouring data using the inverse of the separation distance to a power. IDW uses weighted averaging techniques to fill the elevation matrix. The interpolated value of a cell is determined from values of nearby data points taking into account the distance of the cell from those input points. Weights are inversely proportional to the power ($p$) of the distance. A power value of "2" is commonly used for mapping mountainous terrains with sharp peaks (Surfer, 2002) and was selected for our analysis. IDW is considered an exact interpolator because the model value equals the measured value at a measurement point. Spokas et al. (2003) compared IDW with kriging in interpolating methane flux data and reported that IDW is an acceptable method to map methane flux emissions from landfill surfaces. Abichou et al. (2005) reported that IDW resulted in similar geospatial emissions to those obtained using kriging.

A three-dimensional surface was created using the flux contour map obtained with IDW over the sampled area. Fig. 1 shows a typical surface created using IDW. The total volume of positive emissions from the entire area was then obtained by calculating the volume of the positive side of flux contour map (Fig. 1). The total volume of negative emissions or (uptake by the cover) was obtained by calculating the volume of the negative portion of the same contour map (Fig. 1). The net volume of emissions from the entire area is then calculated by subtracting the volume of the negative portion of the flux contour from the positive portion of the same map. The geospatial mean was calculated by dividing the net emissions by the area. The flux contours were also divided into emission zones (high, medium, and low emission zones). All modeling and quantity calculations were performed using Surfer (2002), developed by Golden Software, Inc., Golden, CO.

### 2.4. Stable isotopes: methane oxidation

Recently, stable carbon isotopic analysis of methane has been employed to quantify the oxidation of methane in landfill cover soils (Bergamaschi et al., 1998; Liptay et al., 1998; Chanton and Liptay, 2000; Borjesson et al., 2001; and Christophersen et al., 2001.) There are two stable isotopes of carbon, $^{12}C$, which comprises 99% of carbon atoms and $^{13}C$, which is about 1% abundant. Carbon isotopic composition is expressed in the $\delta$ notation ($\delta^{13}C$), which is defined as follows:

$$\delta‰ = ((R_{sample}/R_{standard}) - 1) \times 1000, \quad (2)$$

where $R_{sample}$ is the $^{13}C/^{12}C$ ratio of the sample and $R_{standard}$ is the $^{13}C/^{12}C$ ratio of the marine carbonate standard (Pee Dee Belemnite (PDB), $R_{standard} = 0.01124$). Typical landfill microbial $CH_4$ is produced at values below $-55‰$ (Chanton et al., 1999). Following partial oxidation, residual $CH_4$ may exhibit $^{13}C$ enriched values of $-30$ to $-50‰$. Typical organic matter is $^{13}C$ enriched relative to $CH_4$ with a $\delta^{13}C$ value of $-25‰$. The negative $\delta$ value indicates that the sample is $^{13}C$ depleted relative to the carbonate standard. The more negative the value, the more $^{13}C$ depletion is indicated.

In order to calculate the isotope ratio of the methane emitted ($\delta_E$) from the soil during flux sampling, it was necessary to account for the local atmospheric methane present in the air within the chamber at the initiation of the emission measurement:

$$\delta_E = \frac{(\delta_F c_F) - (\delta_I c_I)}{c_F - c_I}, \quad (3)$$

where $\delta_I$ and $c_I$ are the methane $\delta$ and concentration for the initial gas sample taken from the chamber, and $\delta_F$ and $c_F$ refer to the final sample.

Significant isotopic fractionation occurs when methane is oxidized. Microbial culture studies have shown that

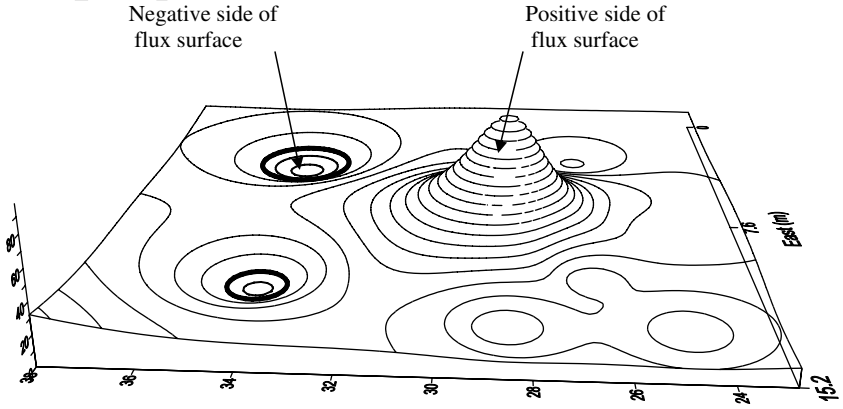


Fig. 1. Typical contour surface map obtained by Surfer. *Note*: Net emissions from the shown surface is volume of positive emissions minus the volume of negative emissions.

methanotrophic organisms preferentially consume $CH_4$ containing the lighter isotope $^{12}C$, leaving residual $CH_4$ enriched in $^{13}C$ (Coleman et al., 1981; Barker and Fritz, 1981). With an estimate of the preference of the bacteria for the lighter isotope, $\alpha_{ox}$, one may calculate the extent of oxidation from the isotopic difference between the unaffected (anoxic zone methane) and the residual (or left over) methane which has been exposed to oxidation but not itself oxidized. The percentage of $CH_4$ oxidized in transit through the cover soil ($f_o$%) is determined by the following equation which describes isotopic fractionation in an open system:

$$f_o\% = 0.1(\delta_E - \delta_A)/(\alpha_{ox} - \alpha_{trans}), \quad (4)$$

where $\delta_A$ is the $\delta^{13}C$ value of anoxic zone $CH_4$ (−55.4‰ determined from soil probe data), $\alpha_{ox}$ is the isotopic fractionation factor for bacterial oxidation and $\alpha_{trans}$ is the isotopic fractionation associated with gas transport. To the extent that gas transport is dominated by advection of gases across the landfill cap, $\alpha_{trans}$ will approach 1. However, if diffusion plays a significant role in gas transport, $\alpha_{trans}$ will be greater than 1 causing this approach to yield conservative values of methane oxidation (De Visscher et al., 2004). We assumed that gas transport across the landfill surface was dominated by advection so that $\alpha_{trans}$ approached 1. This is a reasonable assumption because there was no gas collection system at this landfill so gas pressure should be greater within the landfill due to $CH_4$ and $CO_2$ production. Consistent with this assumption, Czepiel et al. (2003) reported a strong negative relationship between landfill methane emission and atmospheric pressure. Bergamaschi et al. (1998) also observed that landfill gas transport is dominated by advection.

The fractionation factor ($\alpha_{ox}$) was determined from soil temperature ($T$, °C) using the regression equation for $\alpha_{ox}$ with temperature for clay soil at this same landfill, reported in Chanton and Liptay (2000):

$$\alpha_{ox} = -0.000433T + 1.0421. \quad (5)$$

Stable isotopic ratios were determined using a Hewlett Packard Gas Chromatograph coupled via a combustion interface to a Finnegan Mat Delta S Isotope Ratio Mass Spectrometer (GCC–IRMS) following methods adapted from Merritt et al. (1995). For low-concentration samples (less than 1000 ppmv), a cryogenic focusing device was used on the front end of the gas chromatograph. The standard deviation for replicate analyses of standards and samples is generally 0.15‰ (Chanton et al., 1999). Stable isotopic ratios for the anoxic gases were determined using direct injection on the GCC–IRMS.

## 3. Results and discussion

### 3.1. Measured methane flux emissions

Eighty-eight flux measurements were performed in the S1-Grid and 76 flux measurements were performed in the S4-Grid (Table 1). The minimum measured methane flux was −6.07 g m$^{-2}$ d$^{-1}$ for the S1-Grid and −4.22 g m$^{-2}$ d$^{-1}$ in the S4-Grid. Negative values indicate areas where methane in the atmosphere was taken up by the soil and vegetation. The peak measured flux was 330 g m$^{-2}$ d$^{-1}$ in the S1-Grid area and 596 g m$^{-2}$ d$^{-1}$ in the S4-Grid area. The mean flux was 21.6 g m$^{-2}$ d$^{-1}$ and 53.6 g m$^{-2}$ d$^{-1}$ for the S1-Grid and S4-Grid, respectively. The median flux was 1.6 g m$^{-2}$ d$^{-1}$ for the S1-Grid and 3.3 g m$^{-2}$ d$^{-1}$ for the S4-Grid. A small number of high flux values resulted in skewed flux distributions.

Measured fluxes were grouped into three categories (low, medium, and high). The S1-Grid had 67 (76%) measured low fluxes, below 10 g m$^{-2}$ d$^{-1}$ (including negative fluxes), while the S4-Grid area had only 43 (51%). The number of measured medium methane fluxes (falling between 10 and 25 g m$^{-2}$ d$^{-1}$) was 6 (7%) for the S1-Grid and 13 (17%) for the S4-Grid. The S1-Grid area had 15 (17%) fluxes higher than 25 g m$^{-2}$ d$^{-1}$ and the S4-Grid area had 21 (26%) fluxes higher than 25 g m$^{-2}$ d$^{-1}$. Table 1 shows that 76% of the fluxes measured from the area representative of thick intermediate cover can be classified as low fluxes. On the other hand, only 57% of the fluxes measured on the thin intermediate cover area can be classified as low fluxes.

### 3.2. Methane oxidation at landfill surface

Anoxic zone methane $\delta^{13}C$ varied from −55.0 to −55.7‰ across the landfill (Table 2) and was similar to values reported by Chanton and Liptay (2000). Chanton and Liptay (2000) reported no seasonal variation in anoxic gas methane $\delta^{13}C$ as it is produced within the landfill where seasonal temperature variation is muted by the heat generated by the decay of organic matter. There was no difference in anoxic zone methane at the two sites. The $\delta^{13}C$ of the emitted methane, calculated from chamber initial and final isotope values using Eq. (3), varied from −34.5 to −54.8‰. The fraction of methane oxidized during transit across the soil was calculated using Eq. (4). The mean fraction of oxidation was 25.2%

Table 1
Summary of descriptive statistics of flux data

| | S1-Grid | | S4-Grid | |
|---|---|---|---|---|
| Number of tests | 88 | | 76 | |
| *Methane flux (g m$^{-2}$ d$^{-1}$)* | | | | |
| Minimum | −6.07 | | −4.22 | |
| Median | 1.63 | | 3.33 | |
| Maximum | 329.98 | | 595.86 | |
| Mean | 21.64 | | 53.60 | |
| Standard error | 5.91 | | 12.91 | |
| Flux range | Number | % | Number | % |
| Low[a] (<10 g m$^{-2}$ d$^{-1}$) | 67 | 76 | 43 | 57 |
| Medium (10–25 g m$^{-2}$ d$^{-1}$) | 6 | 7 | 12 | 16 |
| High (>25 g m$^{-2}$ d$^{-1}$) | 15 | 17 | 21 | 27 |

[a] Low fluxes include negative fluxes.

Table 2
Methane isotope ($\delta$) and oxidation results

| $n$ | Probes[a] | S1-Grid | | | | S4-Grid | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2 | 31 | | | | 15 | | | |
| | $\delta_A$ | $\delta_I$ | $\delta_F$ | $\delta_E$ | Oxidation (%) | $\delta_I$ | $\delta_F$ | $\delta_E$ | Oxidation (%) |
| Maximum | −55.02 | −46.02 | −42.02 | −34.53 | 63.9 | −47.59 | −43.78 | −42.21 | 43.2 |
| Median | −55.38 | −53.75 | −51.97 | −48.95 | 20.9 | −50.13 | −52.24 | −52.11 | 10.7 |
| Minimum | −55.73 | −67.18 | −59.41 | −54.81 | 2.0 | −71.00 | −57.43 | −57.91 | −8.3 |
| Mean | −55.38 | −55.51 | 51.87 | −47.64 | 25.2 | −53.26 | −51.40 | −50.98 | 14.4 |
| Standard deviation | 0.50 | 5.61 | 4.70 | 5.08 | 15.7 | 7.89 | 3.83 | 4.65 | 15.2 |

$\delta_I$ is the $CH_4$ $\delta^{13}C$ for the initial gas sample taken from the chamber, and $\delta_F$ refers to the final sample. $\delta_A$ is anoxic $CH_4$ $\delta^{13}C$ and $\delta_E$ is calculated with Eq. (3).
[a] Gas taken from 61 to 91 cm below surface.

for the S1-Grid and 14.4% for the S4-Grid (Table 2). The peak oxidation rate was 63.9% for the S1-Grid and 43.2% for the S4-Grid. Analyses of variance (ANOVAs) were performed to determine significant differences in oxidation among the two grid locations. Sample sizes were different; consequently unbalanced, one-way ANOVAs were performed. In this analysis, each sampling location was considered to be an independent sample. The $F$-value was 4.85 (df = 1.44, $p = 0.033$). A Duncan multiple range test ($p = 0.05$) showed that oxidation in the S1-Grid (mean = 25.2%) was significantly greater than in the S4-Grid (mean = 14.4%). It should be noted that although methane oxidation was significantly greater at the S1-Grid site, this difference is not sufficient to explain the greater $CH_4$ emission rates at the S4-Grid.

### 3.3. Geospatial methane flux emissions

The contours of $CH_4$ emissions from both areas show the existence of circular patterns associated with high fluxes using IDW (Figs. 2 and 3). A circular pattern demonstrates that extremely high peak values are obtained using IDW, whereas in kriging they tend to be smoothed downward. IDW contours also show that a single extreme point or clusters of dissimilar points have an effect on the contours. In spite of not being as smooth as contours obtained by kriging, Abichou et al. (2005) and Spokas et al. (2003) reported that IDW is an acceptable and significantly simpler method to map methane flux emissions from landfill surfaces. They also reported that IDW resulted in similar geospatial mean values when compared to kriging.

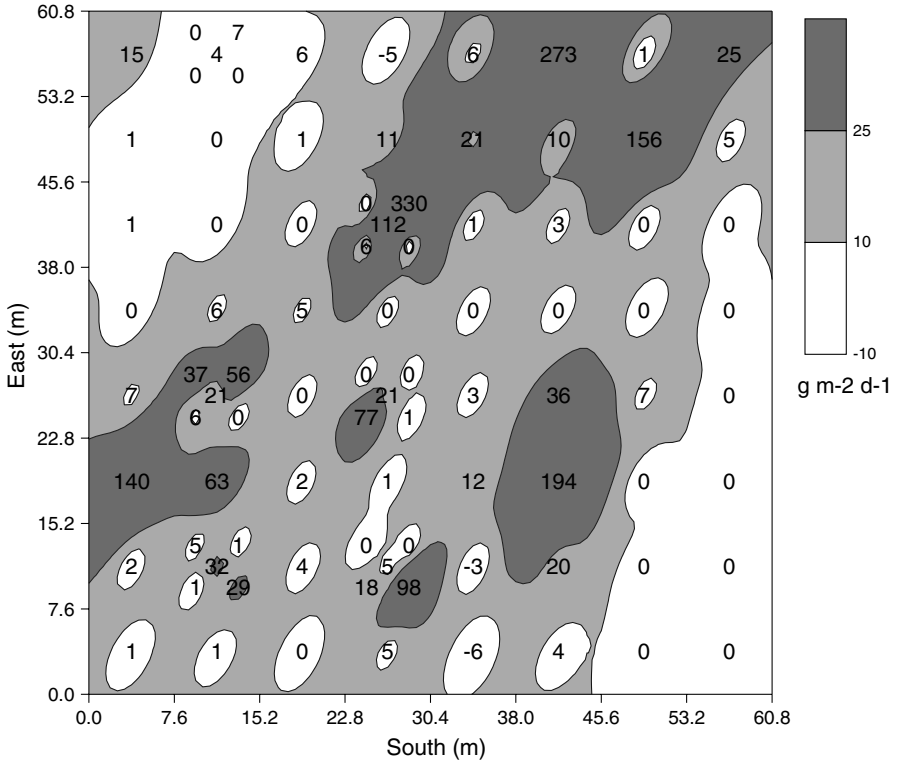


Fig. 2. S1-Grid Flux (g $m^{-2}$ $d^{-1}$) contours obtained using inverse distance weighing.

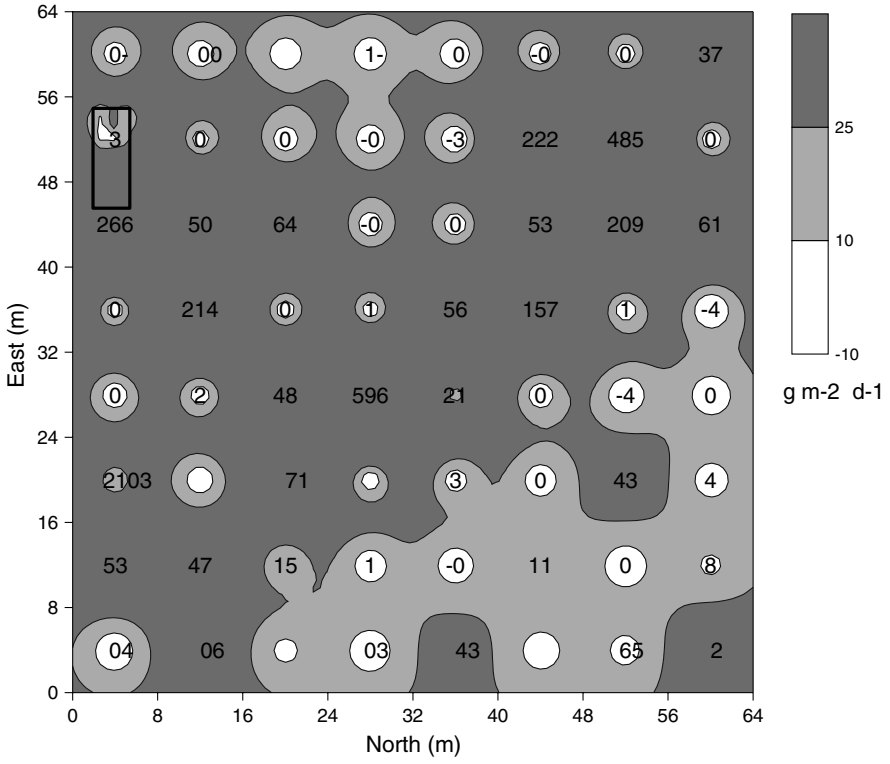


Fig. 3. S4-Grid Flux ($g\,m^{-2}\,d^{-1}$) contours obtained using inverse distance weighing. * The rectangle indicates the close-sampling area with 12 flux locations.

The geospatial mean flux was 21.6 $g\,m^{-2}\,d^{-1}$ for the S1-Grid and 50.0 $g\,m^{-2}\,d^{-1}$ for the S4-Grid, similar to the means obtained (Table 1). Three relative zones were classified based upon methane emission contours at these sites, low (<10 $g\,m^{-2}\,d^{-1}$), medium (10–25 $g\,m^{-2}\,d^{-1}$), and high (>25 $g\,m^{-2}\,d^{-1}$). The S1-Grid had a larger zone with relatively low emissions (30.6%) as compared to the S4-Grid (4.8%). High emission zones represented 67.4% of the S4-Grid and 23.6% of the S1-Grid (Table 3). High emission zones in the S1-Grid were isolated spots (Fig. 2). In contrast, high emission zones in the S4-Grid were continuous and represented 67.4% of the total emissions area (Fig. 3). The contours also show that emissions from one-third of the thicker intermediate cover were classified as low emission zones as compared to only 4.8% of the daily cover area.

Table 3
Summary of geospatial results

| | S1-Grid | S4-Grid |
|---|---|---|
| Total area ($m^2$) | 3697 | 4096 |
| Geospatial mean ($g\,m^{-2}\,d^{-1}$)[a] | 21.61 | 50.0 |
| Total methane emissions (kg/day) | 80 | 205 |
| Low flux area (% area) | 30.6 | 4.8 |
| Medium flux area (% area) | 45.8 | 27.8 |
| High flux area (% area) | 23.6 | 67.4 |

[a] Volume under model surface divided by surface area obtained using IDW.

Contrasting the results shown in Tables 1 and 3, one can see that the differences in the numbers of high, medium, and low fluxes measured on the S1-Grid and the S4-Grid are not as significant as the differences in areas of high, medium, and low emissions shown in Table 3. This observation indicates that even though both sites have similar numbers of varying fluxes, the patterns of emissions from the S1-Grid and the S4-Grid are quite different. The pattern of emission is a function of how these emissions vary with space.

These differences in flux patterns suggest that different treatments should be used to mitigate methane emissions at different types of sites as represented by these two covers. Alternatively, differing treatments could be based on measured patterns of emissions. For example, landfill $CH_4$ emissions from covers similar to the S1-Grid (relatively thick and well-vegetated, and having isolated $CH_4$ hot spots) can most easily be reduced by placing individualized biocovers only on high emission areas typically referred to as "hot spots." Biocovers are layers of compost overlaying a porous dispersing layer (Huber-Humer, 2004). Such "hot spots" may be identified using a portable FID (Flame Ionization Detector). On the other hand, emissions from sites with thin intermediate covers are best mitigated by applying a layer of compost overlaying a porous dispersing layer (biocover) across the whole surface. A biocover applied over a thin intermediate cover can then be either stripped and then re-applied over the new active phase or left as part of the existing cover, as when there is an abundance of yard waste (Florida).

## 4. Summary and conclusions

Methane flux emissions were measured on two surfaces at a solid waste landfill. One surface was a thick intermediate well-vegetated soil cover and the other a thin intermediate non-vegetated soil cover. Both types of covers are significant sources of greenhouse emissions. Emissions from the thin cover were double the emissions from the thicker well-vegetated soil cover. Methane oxidation through the cover was only partly responsible for the lower emissions from the thicker cover. Mapping of the surface fluxes shows that the patterns of emission from each cover were different. Mitigation of emissions from the thin intermediate cover can best be achieved by placing a compost-amended biocover on the entire area. On the other hand, for a thicker well-vegetated intermediate cover, compost placement can be limited to high emission zones.

## 5. Uncited reference

Bogner et al. (1995).

## Acknowledgments

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