Impact of Straw Cover on Greenhouse Gas and Odor Emissions from Manure Storage Lagoons Using a Flux Hood

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Abstract. This article presents the use of a flux hood (wind tunnel) and sampling procedure to evaluate greenhouse gases and odour emissions from earthen manure storage. Two similar intensive livestock production facilities that only differed in manure storage practices were used. One facility used straw cover on the primary cell to reduce odour complaints, whereas the other left the manure storage uncovered. It was shown that the straw cover provided relief in odour emission by an average of 37.8%, but magnified CH4 emissions by an average of 247.2%. Although a slight increase in N2O levels were observed, the straw cover did not have a statistically significant impact on overall CO2 and N2O emissions. Since CH4 is 21 times more potent than CO2 as a greenhouse gas, a net negative effect of straw cover in terms of global warming capacity was observed. This reinforces the necessity for alternative approaches to control emissions from manure storages, despite the fact that straw covers might be a convenient and cost-effective practice to reduce odour complaints from communities neighboring livestock facilities. Further testing is being performed to confirm preliminary results presented in this article as well as determination of net annual greenhouse gas flux from similar systems.

Keywords. Greenhouse gas emissions, odour emissions, lagoons, straw cover, intensive livestock production facilities, flux hood, hog production

Introduction

One of the most intriguing and controversial topics of our time is the adoption of the Kyoto Protocol to the United Nations Framework Convention on Climate Change in 1997. The Kyoto Protocol agreement sets ambitious limits to the emissions of greenhouse gases, with most of the attention being focused on CH4, CO2, and N2O. The goal is to reduce greenhouse gas emissions to 94% of 1990 levels by 2012 (AAFC, 2000). Although Canada has yet to establish the precise contribution of all sources and sinks of greenhouse gases within its borders, the federal government has moved forward with ratification of the agreement.

Analyses of best available data conducted by Agriculture and Agri-Food Canada (AAFC, 2000) estimated agriculture accounts for approximately 10% of the total anthropogenic greenhouse gas emissions in Canada, with 40% of that originating from livestock production. It was also estimated that one-third of the livestock production contribution was attributed to manure management (Lague, 2002). The reliability of these estimates is low and require a concerted effort in data collection. AAFC also emphasized the need for establishing accurate assessment techniques and for collecting on-site data and reliably quantifying the emissions of CH4, CO2, and N2O form manure storage systems.

There have been a number of studies in recent years which investigated greenhouse gas emissions from manure storage facilities. Husted (1994) reported methane emissions in the range of 0.4 to 28.3 g/m³-day depending on the source and type of manure. On the other hand, Phillips et al. (1997) reported methane emission ranging from 0.014 to 0.039 g/m³-day for various types of manure facilities. This large discrepancy is just on example of the highly variable results reported on this issue. Additionally, Phillips et al. concluded that N2O emissions form manure storage facilities was negligible, whereas Brown et al. (2000) and Tenuta et al. (2001) reported large N2O emissions where sufficient aeration allowed for NO3- accumulation during storage of solid manures. Peu et.al (1999) developed an open chamber system which was floated on the surface of an aerated manure storage facility for the sampling of N2O. This study concluded that less than 1% of the total nitrogen input was...
converted to N₂O. Large variations in livestock practices, geographical location, solid loading, reservoir depth, and ambient wind and temperature, result in these differing experimental observations.

Covering outdoor manure storage units with biological materials such as straw, sawdust, and wood shavings, can provide an effective way of reducing odour emission, and has thus gained increased popularity in the last ten years (Clanton et al., 2001). Straw is blown onto the surface of the storage to a total of 250mm thickness to retain odorous gases in solution (Bicudo, 1999). Sinking of the straw and the need for additional agitation of the manure prior to pumping are the main operational drawbacks of this process (Zhang et al., 2002). Greenhouse gas emissions from straw covered manure storage units have been studied on a limited basis. Huther et al. (1997) reported that straw covers can increase both N₂O and CH₄ emissions. This was confirmed by laboratory scale investigations conducted on pig and dairy manure (Jungbluth et al., 2001). Results on practical scale systems in the same study, however, exhibited the opposite trend with lower N₂O and CH₄ emissions under straw covered conditions. In another study conducted with cattle slurry in pilot scale storage containers the impact of various type covers were studied (Sommer et al., 2000). It was concluded that straw covers significantly lowered CH₄ emissions, presumably due to enhanced CH₄ oxidation in the interface between the cover and the stored liquid (Sommer et al., 2000). These contradictory results in literature can be attributed to the differences in data collection and experimental set-ups. There are no studies reported on actual facilities which operate side by side and vary only in storage cover practices. Additionally no dynamic emission measurement tools were employed in the above stated research efforts.

Flux hoods (or wind tunnels) are suitable choices for emission sampling in these environments, as dynamic measurements on both odour and greenhouse gases can be performed and a direct comparison can be conducted. Various types and configurations of flux hoods have been used for sampling odor emission from manure surfaces (Gostelow et al., 2003). Smith and Watts (1994) evaluated the performance of two wind tunnels of different sizes in measuring odor emission from feedlots and reported that there was strong dependence of the measured emission rate on the air velocity inside the tunnel. They recommended that the air velocity should be specified whenever emission rates measured by wind tunnels are reported. This means that odor emission rates from manure storage reported in the literature are obtained at certain wind speeds used in wind tunnels but may not reflect the rates in the field where the wind speed changes instantaneously. Researchers have attempted to correlate the odor emission rate to the wind speed and found that measured emission rate increased exponentially with the bulk tunnel wind speed (Heber, 1999, Schmidt et al., 1999). Despite several studies on odour emissions form agricultural lagoons using flux hoods, no such studies have been reported on greenhouse gas emissions from similar sources.

This paper presents the development of a sampling device and procedure to evaluate simultaneously greenhouse gases and odour emissions from manure storage lagoons using a flux hood. Emissions were determined in two very similar intensive livestock production facilities which only differed in their manure storage practices. One facility used straw cover on the primary cell to reduce odour complaints, whereas the other left the storage uncovered. The impact of the straw cover on greenhouse gas and odour emissions was determined.

**Methods and Materials**

**Site selection**

In order to compare odour and greenhouse gas emissions from open manure storage and straw covered storage, two farms located south of the city of Winnipeg, Manitoba (Farms A and B) were...
selected for this research. These two farms are identical in design, size, and operation. They both were 3000-sow farrowing operations, with two-cell manure storage facilities located behind the building. The only difference was that farm A had straw cover on its primary storage cell and farm B has open surfaces for both storage cells.

**Apparatus**

A portable flux hood was constructed and utilized to take emission samples. This hood was developed by adopting a design from the University of New South Wales, Australia (Gostelow et al., 2003). A schematic representation and a picture of the hood are shown in Figure 1. The fan connects to a 12-volt battery, and pulls air through an activated carbon filter which is mounted at the inlet of the apparatus. The fan then pushes the air through 100mm-diameter PVC tubing to the main chamber, constructed of stainless steel. The bottom of the chamber is open to the emission surface and covers an area of 0.3 m² (0.75 m x 0.4 m). As the air passes through the hood at a fixed speed of 0.3 m/s, it mixes with the gases from the emission surface and then passes through the outlet. There is a sampling port above the outlet. One end of Teflon tubing is connected to the sampling port, and the other end to a vacuum chamber (AC’SSENT Vacuum chamber, St. Croix Sensory, Inc., Stillwater, Minnesota) which was used to collect gas samples in 10 L Tedlar bags. When sampling, a bag was placed in the chamber and the inlet of the bag was connected to a teflon probe which was connected to the sampling port on the flux hood. A hand-held vacuum pump was used to create a vacuum inside the chamber and air from the emission source was drawn into the bag through the teflon probe by vacuum suction.

A floatation device attached to the hood was previously used in some field experiments for uncovered liquid lagoons. However, in the case of covered liquid surfaces, any possibility of surface disturbance had to be eliminated. Therefore, a new design involving the use of two thirty-foot aluminum poles attached to the sides of the hood, was developed. The setup was supported at each end by car jacks on stands, which allowed for height control. A picture of the apparatus at the site with the straw-covered lagoon is shown in Figure 2.
Sampling Procedure

Samples were collected on three different days and at the same time of the day (10:30 a.m. to 12:30 p.m.) from each farm. Samples from farm A (straw covered primary cell) were collected from each corner of the primary cell of the manure storage. Samples from Farm B were collected only from two corners of the primary cell of the storage because steep ramps on the other two corners of the storage caused difficulty in placing the wind tunnel.

When sampling was initiated, the flux hood was carefully lowered to the liquid surface. The fan was turned on to run for 2 minutes. Then, vacuum was turned on to collect the sample into Tedlar bags. Each sample was taken in two steps: (i) the bag was filled with 2 L of sample air and then evacuated to "coat" the bag, and (ii) emission air was collected into the bag until the bag was 3/4 full. Ambient temperature and wind velocity were also recorded for each sampling day.

Analytical Methods

Odour Analysis

A dynamic-dilution olfactometer (AC'SCENT International Olfactometer, St. Croix Sensory, Inc., Stillwater, MN) and six screened assessors were used to determine the odour concentration (level) of each sample (fig. 4). The olfactometer was capable of providing 14 dilution levels, with dilution ratios between 8 and 66667. The odour concentration measured by the olfactometer was expressed as odour unit per m$^3$ of air (OU/m$^3$), which represented the number of dilutions needed to bring the odour down to the level that could be detected by 50% of a population.

The testing was done at the Sensory Laboratory of the Canadian Food Inspection Agency. The room that housed the olfactometer had a positive ventilation system with carbon-filtered air to eliminate background odours. For each sensory session, flow rates of the olfactometer were calibrated before and after testing and the average of the two calibrations were used in calculating dilution ratios. The triangular forced-choice method was used to present samples to the assessors, with a 3-s sniff time. Panel data were retrospectively screened to remove outliers by comparing assessors’ individual threshold estimates with the panel average.

GHG Analysis

Analysis of the gas samples for greenhouse gases was done by the department of Soil Science, by gas chromatography. 20 mL of gas from the Tedlar sampling bags were transferred into evacuated glass vials of a physical inner volume of 12 mL and analyzed for carbon dioxide (CO$_2$), methane (CH$_4$), and nitrous oxide (N$_2$O) using a Varian 3800 Gas Chromatograph equipped with a CombiPal auto-sampler.
Results and Discussion

Odour

Results on the odour analysis are summarized in Table 1 for Farm A and Farm B. The impact of the straw cover on odour emission is evident. On average, a 37.8% lower odour emissions were observed with the implementation of the straw cover. If maximum odour emissions are compared between sampling days, 53.1% lower odour (from 3,089 to 1,448 OU/m$^3$) is observed. These results are in agreement with previous research on odour emission reduction in straw covered manure storages. Possible sources for standard deviations in the straw covered environment include the uneven distribution of straw and the partial soaking of the straw in some locations. Other factors effecting reproducibility for both the covered and open systems are sampling location as it relates to the manure pumping inlet and liquid depth, and liquid temperature. Ambient wind effects are eliminated with the use of the constant air-flow flux hood which was placed adjacent to the emitting surface. Any ambient odour influence is also avoided with the use of activated carbon for inlet air filtration.

Table 1. Comparison of odour concentrations obtained from straw covered versus open manure storage units for two identical size livestock production facilities

<table>
<thead>
<tr>
<th>Farm A (Straw Covered Primary Manure Storage Cell)</th>
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<tbody>
<tr>
<td>Sampling day</td>
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<tr>
<td>--------------</td>
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<tr>
<td>Aug 13, 2003</td>
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<td>Aug 18, 2003</td>
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<td>Aug 23, 2003</td>
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<table>
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<tr>
<th>Farm B (Open Primary Manure Storage Cell)</th>
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</thead>
<tbody>
<tr>
<td>Sampling day</td>
</tr>
<tr>
<td>--------------</td>
</tr>
<tr>
<td>Aug 14, 2003</td>
</tr>
<tr>
<td>Aug 19, 2003</td>
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<tr>
<td>Aug 20, 2003</td>
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</tbody>
</table>

Greenhouse Gases

Results on the greenhouse gases, CO$_2$, N$_2$O, and CH$_4$ are summarized in Table 2. No impact of the straw cover on CO$_2$ emissions is evident, as concentrations in both locations were within the commonly accepted ambient levels (350-450 ppmv). Although not statistically significant, a slightly increasing trend in average N$_2$O concentrations in the straw covered storage (+7.61%) was observed. This marginal increase could be attributed to possible improved nitrogen oxidation in the
straw-water matrix at the surface of the lagoon. Once again, concentrations were within the commonly accepted range of atmospheric N₂O.

The most significant observations were found for CH₄ emissions. Despite high standard deviations in the data, a clear increase in CH₄ concentrations from the surface of the straw-covered storage is observed. For the average of all data, 247.2 % higher CH₄ emissions was observed with straw cover. If maximum CH₄ emissions are compared between sampling days, a 136.5 % difference (from 5.17 to 12.23 ppmv) is observed, with concentrations at specific locations in the straw covered storage reaching levels as high as 27.38 ppmv (ambient is 1.7 ppmv!). The strong relationship between straw cover and CH₄ emissions can be attributed to two possible factors. Firstly, reduced surface mixing and aeration in a covered environment increases the depth of the anaerobic zone within the storage and creates lower average oxidation reduction potential (ORP) conditions favorable to methanogenic microorganisms. Secondly, straw material sinking to the bottom of the reservoir, over time, provides an additional carbon source for anaerobic bacteria, stimulating CH₄ emission.

As CH₄ is 21 times more potent than CO₂ as a greenhouse gas, the practice of covering manure storage units with straw may have a significant overall impact on greenhouse gas emissions, which may ultimately outweigh its benefits in odour management. Recent developments in the area of negative-pressure synthetic storage covers, where emissions of any kind are captured and concentrated in an effluent stream, may resolve the predicament faced with natural covers.

The uneven distribution and partial soaking of the straw in some locations of the storage are strong possible reasons for high standard deviations in the CH₄ emissions results. Since the activated carbon filters will not remove the target greenhouse gases, ambient wind conditions during sampling will also be a factor effecting reproducibility for both the covered and open systems. Proximity to manure pumping inlet and relative water depth of the sampling location will also influence deviations in experimental data. The results presented here are still preliminary and will be further verified by additional testing. Ambient CO₂, N₂O, and CH₄ concentrations at the hood inlet will be measured to provide total emissions and refine estimates of agriculture’s share of anthropogenically derived greenhouse gas emissions.

Table 2. Comparison of greenhouse gas emissions from straw covered versus open manure storage units for two identical size livestock production facilities

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<thead>
<tr>
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<tbody>
<tr>
<td>Aug 13, 2003</td>
<td>417.79</td>
<td>2.52</td>
<td>0.33</td>
<td>0.01</td>
<td>7.71</td>
<td>3.82</td>
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<tr>
<td>Aug 18, 2003</td>
<td>420.73</td>
<td>20.76</td>
<td>0.33</td>
<td>0.03</td>
<td>11.13</td>
<td>11.31</td>
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<tr>
<td>Aug 23, 2003</td>
<td>419.10</td>
<td>55.05</td>
<td>0.33</td>
<td>0.01</td>
<td>12.23</td>
<td>10.87</td>
</tr>
</tbody>
</table>

Farm B (Open Primary Manure Storage Cell)

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<td>Aug 14, 2003</td>
<td>387.15</td>
<td>22.25</td>
<td>0.30</td>
<td>0.01</td>
<td>2.48</td>
<td>0.57</td>
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<tr>
<td>Aug 19, 2003</td>
<td>397.74</td>
<td>1.92</td>
<td>0.31</td>
<td>0.00</td>
<td>1.30</td>
<td>0.26</td>
</tr>
<tr>
<td>Aug 20, 2003</td>
<td>440.83</td>
<td>42.87</td>
<td>0.31</td>
<td>0.00</td>
<td>5.17</td>
<td>3.60</td>
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Conclusion

Both odour and greenhouse gas management require simultaneous attention to limit the overall environmental footprint of intensive livestock operations. It has been shown that natural straw covers for manure storage facilities provide relief in odour emission by an average of 37.8 %, but exacerbate CH$_4$ emissions by an average of 247.2 %. Although a slight increase in N$_2$O levels were observed, straw covers did not have a statistically significant impact on overall CO$_2$ and N$_2$O emissions. Since CH$_4$ is 21 times more potent than CO$_2$ as a climate change agent, a net negative effect of straw covers in terms of greenhouse gas emissions was observed. This reinforces the necessity for alternative approaches to control emissions from manure storage reservoirs, despite the fact that straw covers might be a convenient and cost-effective practice to reduce odour complaints from communities neighboring livestock facilities. Further testing will be conducted to confirm preliminary results presented in this article.

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