An assessment of odour emissions from land applied swine manure

E. Smith[1, 3]*, R. Gordon[1], A. Campbell[2] and C.P.A Bourque[3]

*[1]Engineering Department, Nova Scotia Agricultural College, P.O. Box 550, Truro, Nova Scotia B2N 5E3, Canada; [2]Crop and Livestock Research Center, Agriculture and Agri-Food Canada, 440 University Avenue, Charlottetown, Prince Edward Island C1A 4N6, Canada; and [3]Faculty of Forestry and Environmental Management, The University of New Brunswick, P.O. Box 4400, Fredericton, New Brunswick E3B 5A3, Canada. *Email: elsmith@nsac.ca*

Smith, E., Gordon, R., Campbell, A. and Bourque, C.P.A. 2007. **An assessment of odour emissions from land applied swine manure**. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **49**: 6.33 - 6.40. Land application of manure generates more odour complaints than any other stage in livestock production. Livestock odours have been found to be complex and challenging to accurately measure in field environments. For land applied manure management strategies to be implemented, odours generated in the field must be accurately quantified. The objective of this research was therefore to quantify odour emissions from surface applied swine manure using olfactometry and assess and evaluate a theoretical profile shape (TPS) micrometeorological approach in combination with olfactometry for odour flux field assessments. Liquid and solid manure application rates of 100, 200, and 500 kg of NH_4-N/ha, as well as the effect of rainfall before and after manure application, were evaluated. Liquid manure initially generated higher odour emissions; however, odour emissions from solid manure persisted for longer. Increased application rates and applying manure after a heavy rainfall generally produced higher emissions; applying manure before a rainfall event, however, reduced emissions. The TPS micrometeorological approach for measuring emissions in the field is a valid flux measurement approach, which is well suited to olfactometry due to the limited fast response systems available. Olfactometry, however, continues to be the challenge and is not a highly sensitive method of measurement in field conditions. There is a need for improvements in fast response odour assessments. Future investigations with these methodologies, such as the electronic nose, may provide a good comparative method for olfactometry studies and continuous flux measurement. **Keywords:** hog manure, micrometeorology, odour concentration, odour flux, olfactometry.

L'épandage au sol des fumiers et lisiers est à l'origine d'un plus grand nombre de plaintes liées aux odeurs que toutes les autres étapes de production des élevages. Les odeurs provenant des élevages sont complexes et il est difficile de les mesurer de façon précise au champ. Pour que des stratégies de gestion d'épandage des fumiers et lisiers soient mises en place, les odeurs dégagées lors de ces opérations doivent être quantifiées de manière précise. Par conséquent, l'objectif de ce projet était de quantifier les émissions d'odeur résultant de l'épandage au sol de lisier de porcs en utilisant l'olfactométrie et d'étudier et d'évaluer une approche météorologique de profil de contour théorique (TPS) en combinaison avec les estimations par olfactométrie des flux d'odeur aux champs. Des épandages de lisier et de fumier à des taux de 100, 200 et 500 kg de NH_4-N/ha ainsi que l'effet d'une pluie avant et après l'épandage ont été évalués. Des émissions d'odeur supérieures ont été générées initialement par le lisier ; toutefois, les émissions d'odeur provenant du fumier persistaient plus longtemps. Des taux d'épandage plus élevés et un épandage suivant une forte pluie produisaient des émissions plus élevées ; cependant un épandage avant une pluie réduisait les émissions. L'approche météorologique TPS pour mesurer les émissions aux champs constitue une approche valide pour la mesure de flux, et celle-ci convient bien à l'olfactométrie à cause de la disponibilité des systèmes dont rapidité de réponse est limitée. Cependant, l'olfactométrie continue d'être l'élément limitant et n'est pas une méthode très précise de mesure en conditions de champ. Des améliorations dans les mesures d'odeur à réponse rapide sont nécessaires. Des recherches futures utilisant ces technologies, tel le nez électronique par exemple, pourraient fournir une bonne méthode comparative pour les études d'olfactométrie et les mesures de flux continu. **Mots clés**: lisier/fumier de porcs, micrométéorologie, concentration d'odeur, flux odorant, olfactométrie

INTRODUCTION

In Canada, growth of the swine sector has been substantial with a 400% increase in production since 1982 (Statistics Canada 2001). It is also estimated that 24.4 million tonnes of swine manure are produced annually in Canada (Statistics Canada 2001). The increasing size of swine production facilities, coupled with human encroachment into rural areas, has resulted in increased odour complaints (Hanna et al. 2000; Zhou and Zhang 2003; Guo et al. 2005; Trabue et al. 2006). Odours generated from manure tend to be the primary air quality challenge in rural communities (Hanna et al. 2000; Zhou and Zhang 2003).

Land application of manure has been found to generate more odour complaints than any other component of livestock production (Williams 1984; Pain et al. 1991; Misselbrook et al. 1997; Guo et al. 2005). In some areas of Canada, manure related odour has been the primary catalyst to restrict the growth of the swine industry.

Innovative methods of manure odour management must therefore be implemented to ensure the future viability of the industry. Odours generated from manure consist of complex mixtures of several compounds. It has been suggested that at least 168 different compounds exist in swine manure odour (O'Neill and Phillips 1992). Most of these compounds can be grouped as either volatile fatty acids, phenols, nitrogen derivatives, or reduced sulphur compounds (Misselbrook et al. 1997). While odour reduction strategies such as earthen manure storage and lagoon covers, diet manipulation, nitrification

Table 1. Selected characteristics for both liquid and solid swine manure obtained from the swine facility at the Agriculture and Agri-Food Canada (AAFC) Harrington (PE) Research Farm in 2003 - 2005.

Manure characteritics	2003 liquid	2003 solid	2004 liquid	2005 liquid
pH	7.0	6.4	7.2	6.3
Dry matter (%)	5.0	35.8	2.6	5.5
N (%)	0.68	0.95	0.70	0.70
NH_4-N (%)	0.36	0.33	0.33	0.28
Carbon (%)	0.57	12.5	0.53	1.9
Phosphorus (%)	0.17	0.78	0.12	0.09
Calcium (%)	0.22	0.97	0.04	0.09
Magnesium (%)	0.07	0.24	0.01	0.04
Copper (ppm)	14.4	37.7	7.4	5.0
Zinc (ppm)	96.0	224.5	23.5	37.8

inhibitors, and manure injection have been utilized, many options have yet to be fully assessed (Pahl et al. 2001). The challenge is that odour is a subjective problem. Both the ability to smell and the level of offensiveness of a given odour can vary widely from person to person. Also, the complex volatile compounds present in swine manure make it difficult to identify specific compounds which correlate with people's perception of odour (Pain et al. 1991; Misselbrook et al. 1997). Before technologies to reduce manure odours can be tested, it is necessary to establish an objective means of measuring odour dispersion. To date limited methodologies have been established to measure odour fluxes, especially in the field.

Olfactometry is frequently used to measure odour intensity (AC'SENT 1999) and is widely recognized as a standard method (Hobbs et al. 1999). An olfactometer is a dilution instrument, which mixes odorous air in specific ratios with odour free air for presentation to trained panelists (AC'SENT 1999). The olfactometer produces a measure of an odour concentration (OC), which is defined as the number of dilutions at which 50% of the panelists detect an odour. It is often expressed as odour units per cubic meter (OU/m^3) of air (Hobbs et al. 1999). Dynamic forced-choice olfactometry is widely used for evaluating livestock odours (Watts et al. 1994; Ogink et al. 1997; Hobbs et al. 1999). This is a system where human panelists, upon assessing a particular sample dilution, are forced to make one of three choices: (i) guess, (ii) detect (the selection is different from the other two) or (iii) recognize (the selection smells like something).

The development of land applied manure management strategies and the establishment of minimum separation distance guidelines are dependent on first being able to quantify odour emissions. It should be noted that limited odour studies exist that include concentration and flux estimates, especially in relation to manure spreading. Past studies (Misselbrook et al. 1993; Smith and Watts 1994; Zhou and Zhang 2003) have primarily focused on point source odour emissions from barns and manure storage facilities.

A number of challenges exist with the use of current odour flux measurement techniques. Olfactometry measures an OC; however, its use is limited by sampling challenges, background odour concentration in sampling bags (Parker et al. 2003; Trabue et al. 2006), high cost of analysis, and labour, as well as the fact that it is a slow response system. Most standard micrometeorological techniques require fast response systems, which are presently not available for OC measurements. One option however, is to estimate odour flux through the use of the theoretical profile shape (TPS) method. The TPS method is a simple mass balance micrometeorological technique developed by Beauchamp et al. (1978). This non-interfering diffusion model can be used to estimate fluxes based on an integrated product of the wind speed and gas concentration. Wilson et al. (1982) found that horizontal flux profiles over the center of a circular source for various cases of atmospheric stability intersect at a single height, known as ZINST. Therefore flux estimates can be performed for various circular sources independent of atmospheric stability by only understanding wind speed, concentration, and roughness length. Gordon et al. (1988) utilized this approach for small (7 m diameter) circular plots, describing the benefits of small plots for replicated field studies.

The objective of this study was therefore to quantify odour emissions from surface applied swine manure, using olfactometry in conjunction with the TPS method (Gordon et al. 1988) to assess emissions over a range of spreading and atmospheric conditions.

METHODOLOGY

Site description and experimental setup

Several field trials were established on a stubble grain field at the Agriculture and Agri-Food Canada (AAFC) Harrington Research Center in Harrington, Prince Edward Island (PE) (46° 20'N, 63° 10'W) during the 2003-2005 growing seasons. Trials evaluated odour emissions following the surface application of 100-500 kg of NH_4-N/ha (30,000-180,000 L NH_4-N/ha) of liquid swine manure. Trials were performed on a Charlottetown fine sandy loam soil classified as an Orthic Humo-Ferric Podzol Charlottetown soil (MacDougall et al. 1988) as defined by the Canadian System of Soil Classification (Canada Soil Survey Committee 1978). The soil had a pH of 5.6-5.9. Soil and manure samples were obtained prior to starting each trial (Tables 1 and 2).

Flux measurement approach

The TPS method was employed to measure odour emissions. This approach requires simultaneous measurements of both wind speed and OC at a specific sampling height (ZINST) (Pain et al. 1991). Although this method has been extensively used to quantify ammonia (NH_3) emissions (Gordon et al. 1988, 2001; Huijsmans et al. 2003), its use for estimating odour emissions has been limited (Pain et al. 1991).

Odour samples were obtained at a ZINST height of 125 mm (Gordon et al. 1988, 2001) in the center of each 7 m diameter circular plot, with plots separated by 5 m. At this height, ZINST, the atmospheric stability is assumed to have a minimal effect on the ratio of the horizontal flux to the vertical flux from the ground (Gordon et al. 1988). The ZINST is dependent on the surface roughness length (~10 mm for stubble) and is assumed to be homogenous over the source area.

Circular plots were established perpendicular to the direction of the prevailing wind to prevent cross contamination of

Table 2. Selected characteristics for the Ortho Humo-Ferric Charlottetown soil used in 2003-2005 odour trials at the Agriculture and Agri-Food Canada (AAFC) Harrington (PE) Research Farm.

Characteristics*	2003	2004	2005
Texture	sandy loam	sandy loam	sandy loam
pH	5.6	5.9	5.9
Bulk density (Mg/m^3)	1.1	1.2	1.5
Porosity (%)	50	51	50
Organic matter (%)	2.1	2.5	2.6
NO_3-N (ppm)	4.1	4.3	5.8
CEC (Meq/100 g)	12	11	12
Potash (ppm)	111	118	114
Phosphate (ppm)	191	197	196
Calcium (ppm)	728	739	784
Magnesium (ppm)	109	110	117
Copper (ppm)	0.7	0.7	0.7
Zinc (ppm)	1.3	1.5	0.8

*Analysis performed on a dry matter basis

samples. Odour samples were obtained using a specifically designed AC'SCENT vacuum pump (St. Croix Sensory, Inc., Stillwater, MN) at the ZINST sampling height. Air samples were pumped into 10-L Tedlar^{TM} bags (St. Croix Sensory, Inc., Stillwater, MN) using a vacuum pump. Before sampling occurred, bags were purged to ensure that no air was present before sampling. The vacuum pump was then allowed to run for approximately 8 min to collect the sample; bags at this time were approximately 75% full.

Background odour samples were obtained before spreading occurred and additional odour samples were obtained directly after spreading, then periodically up to 42-96 h afterwards. Standard errors could not be obtained due to limited replication, because of high cost of sampling and analysis. All samples were analyzed within 24 h to determine a mean odour detection threshold concentration (OC). Odour fluxes (OU m^{-2} s^{-1}) were calculated using OC, and wind speed collected at ZINST, using an inverted cup anemometer (Met One 014A, Grants Pass, OR) with a stall speed of 0.447 m/s. Odour flux was calculated from Eq. 1.

$$flux = \frac{OC \times u}{c} \qquad (1)$$

where:

OC = odour concentration (OU/m^3 of air),
u = wind speed (m/s), and
c = a constant.

The constant (c) has a value of 12, as defined by Gordon et al. (1988) for 7-m circular source plots.

Olfactometry measurements

Several OC measurements were obtained and analyzed over the experimental period with a dynamic flow olfactometer (AC'SCENT, St. Croix Sensory, Inc., Stillwater, MN), at the AAFC Olfactometry Laboratory in Harrington, PE. All samples were analyzed following the general guidelines of ASTM (1991) and recommendations provided by AC'SCENT (1999). Six trained panelists were selected to analyze a maximum of 10 samples during a given session. Sensitivity measurements of all the panelists were performed using 50 ppb of n-butanol.

The olfactometer presented each panelist with three samples, where the panelists then had to choose the odorous sample, commonly referred to as the triangular forced-choice method. Each sample was presented to the panelists in ascending order of sample concentration, with a range of six dilution levels, increasing two-fold, as suggested by ASTM (1991) and AC'SCENT (1999). The overall group detection threshold was then determined as the point at which 50% of the panelists could detect an odour.

Field trials conducted

Three sets of field trials were conducted to examine odour emissions and included: (i) liquid and solid swine manure at similar application rates, (ii) different application rates of liquid swine manure, and (iii) the result of applying manure before and after a rainfall event (Table 3). Liquid and solid manure trials 1-3 required manually spreading 100 kg NH_4-N/ha of manure onto the 7-m diameter plots. Trials 4-6 investigated the effect manure application rate had on odour emissions from three rates of liquid swine manure: 1x (100 kg NH_4-N /ha), 2x (200 kg NH_4-N/ha) and 5x (500 kg NH_4-N/ha). Trials 7-9 examined odour emissions from manure applied before and after simulated rainfall events (50, 100, and 150 mm). Rainfall was simulated using rain-tape (Irri-Plus, Natfim, CA) that was evenly placed in a spiral pattern within the circular plots. The rain-tape was connected to a tank where water was gravity fed to each plot.

RESULTS and DISCUSSION

Liquid and solid manure trials

Mean OC obtained after application, as well as minimum and maximum OCs for all trials are summarized in Table 3. The application rate for all liquid and solid trial comparisons was 100 kg NH_4-N/ha (30,000 L/ha). Background OC ranged from 13-19 OU/m^3 (Table 3). Odour concentrations at various times after application for all three trials ranged from 19-70 and 26-65 OU/m^3, for the liquid and solid manure, respectively (Fig. 1a and 1b, trials 2-3 data not shown). Results were comparable and within the lower range of 50-250 OU/m^3 reported by Moseley et al. (1998), who evaluated OC for 24 h after surface spreading liquid swine manure. Misselbrook et al. (1993) reported OC of 0-150 OU/m^3 using wind tunnels after a surface application of swine slurry. Overall, OC generally decreased over time, similar to that reported by Pain et al. (1991), Smith and Watts (1994), Zhou and Zhang (2003), and Oh et al. (2004) for land applied swine and dairy manure.

Fluxes were high immediately after application, as expected, and decreased for the most part over time (Fig. 1a, trials 2-3 data not shown). Overall, mean odour fluxes for liquid manure in trials 1-3 were 4.2, 8.1, and 4.9 OU m^{-2} s^{-1}, respectively (Table 3). These fluxes were comparable to those reported by Pain et al. (1991), who measured odour emissions from surface applied liquid swine manure using the same approach. Mean fluxes for the solid manure were higher in all trials at 5.0, 8.2, and 5.0 OU m^{-2} s^{-1} for trials 1-3, respectively (Fig. 1, trials 2-3 data not shown). Solid manure generated more emissions over the entire monitoring periods for all trials (Table 3).

Table 3. Summarized application rates, background odour concentrations, mean and range of odour concentrations, odour fluxes, total odour emissions for 42 h, and total emissions for all trials conducted in 2003-3005.

Trial	Treatment	Rate (L/ha)	Date and duration of sampling (h)	Sample size	Back-ground OC (OU/m^3)	OC and range (OU/m^3)	Odour flux (OU m^{-2} s^{-1})	Total odour emissions (42 h) (10^6 OU/m^2)	Total odour emissions (10^6 OU/m^2)
1	Solid	30,000¶	June 18-20	55	13	54 (44-65)	5.0	0.69	0.71
	Liquid	30,000	2003 (46)			44 (19-70)	4.2	0.49	0.55
2	Solid	30,000¶	July 14-16	55	16	44 (31-64)	8.2	1.3	1.3
	Liquid	30,000	2003 (42)			44 (25-64)	8.1	1.2	1.2
3	Solid	30,000¶	Aug 5-8	77	19	36 (26-51)	5.0	0.83	1.1
	Liquid	30,000	2003 (70)			34 (27-42)	4.9	0.82	1.0
4	1x	30,000	Sept 3-7	66	10	71 (58-88)	2.7	0.43	0.99
	2x	60,000	2004 (96)			73 (66-87)	2.9	0.44	1.02
5	1x	36,000	June 17-20	666	13	60 (44-78)	2.4	0.34	0.71
	2x	72,000	2005 (72)			83 (62-99)	3.1	0.51	0.98
	5x	180,000				77 (44-88)	3.0	0.54	1.15
6	1x	36,000	Sept 8-11	555	19	25 (13-35)	2.4	0.49	0.61
	2x	72,000	2005 (72)			36 (31-40)	3.6	0.69	0.91
	5x	180,000				41 (35-50)	4.1	0.81	0.87
7	No rainfall	30,000	June 14-17	66	21	108 (55-152)	11.0	0.52	1.06
	50 mm*	30,000	2004 (72)			94 (55-151)	13.8	0.38	0.79
8	No rainfall	30,000	July 12-16	66	19	78 (61-93)	2.2	0.35	0.76
	100 mm**	30,000	2004 (96)			82 (56-106)	2.4	0.39	0.79
9	No rainfall	30,000	July 26-30	66	25	81 (50-155)	2.3	0.50	1.06
	150 mm*	30,000	2004 (96)			77 (66-88)	2.4	0.49	1.04

¶ Solid manure measured in kg/ha
* Rainfall after manure application
** Rainfall before application

The slightly lower mean odour emissions from the liquid manure, in the present study, may have been due to the infiltration capacity of the liquid manure into the sandy loam soil (Table 2). Mean concentrations of both liquid and solid manure were 44, 44, 34 and 54, 44, 36 OU/m^3 for trials 1-3 (Table 3), respectively. Odour concentrations obtained by olfactometry did not appear to show distinct differences between liquid and solid manure. Difficulty in determining OC treatment differences most likely can be attributed to high variability in the odour samples and possibly low sensitivity of the olfactometer. Many times an odour sample needs to be more than double the previous sample in order to detect differences in concentration with the olfactometer (Personal communication: M. McGinley, P.E. and Laboratory Director of St. Croix Sensory Inc., Lake Elmo, MN).

The olfactometer operates on a dilution scale that doubles at each dilution level; because of this the scale becomes non-linear with an unequal spread between values. To enable the scale to have equal differences between the dilution levels (0.3 difference in log) a log scale is introduced (logarithm base 10 transformations). The perception of odours is a logarithmic phenomenon (Stevens 1960). The purpose of the log scale is to make the differences between the dilution levels closer to equal differences in human perception and also to stabilize the variance. Therefore, it often requires large differences in concentrations for panelists to identify differences between two dilution levels of odour. The problem is that panelists, in the method of olfactometry, perceive odours by a geometric progression (i.e., each dilution level is twice the concentration) and findings by AC'SCENT show that humans may only detect differences in odour levels when concentrations are 1.5-3 times the previous concentration (Personal communication: M. McGinley, P.E. and Laboratory Director of St. Croix Sensory Inc., Lake Elmo, MN). This is a challenge when trying to identify differences between treatments, suggesting that this method may not be sufficiently sensitive to detect small changes in concentrations. Samples with low OC (<100 OU/m^3) make it difficult to differentiate between samples. Sommer and Hutchings (2001) found that treatment effects could not be recognized; they attributed this to high variability between samples. Parker et al. (2003) and Trabue et al. (2006) have identified background contaminants from commonly used Tedlar bags, suggesting this maybe also be a reason for lack of treatment effects. Although OCs do not appear to show

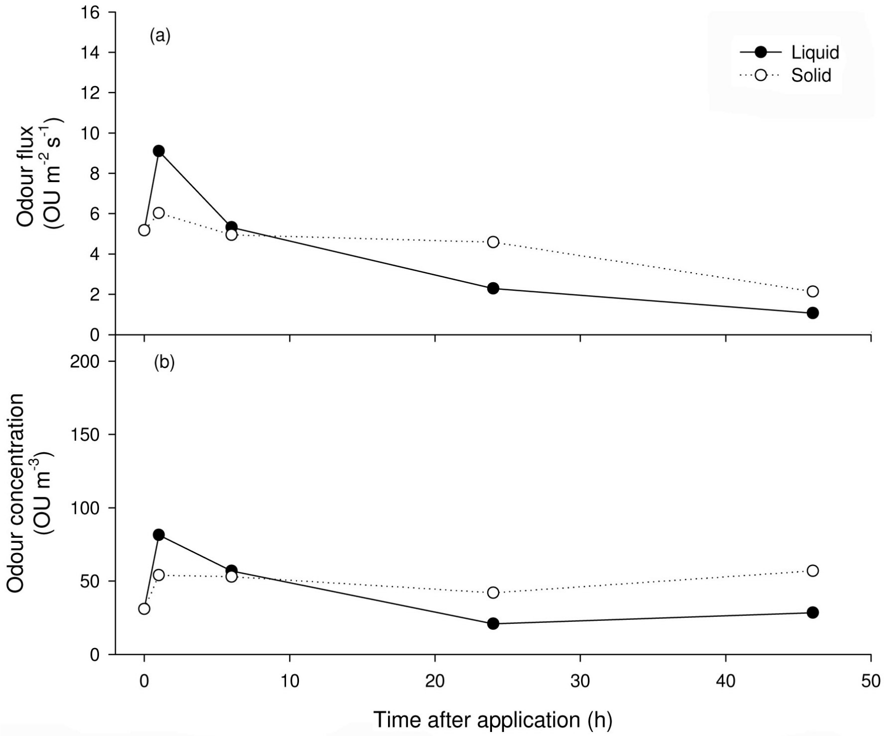

Fig. 1. Trial 1: (a) odour fluxes and (b) odour concentrations from both liquid (○) and solid (●) swine manure applied at 100 kg NH_4-N/ha in June 18-20, 2003.

treatment differences, Fig. 1 does show an interesting trend in the initial measurement period for both liquid and solid manure.

In Fig. 1, OCs and odour fluxes appear to be the highest approximately 1-2 h after application. Emissions tended to spike shortly after application and are initially higher for liquid manure. Beyond the 1-2 h period after application however, OC and emissions from liquid manure declined (Fig. 1), most likely as a result of rapid infiltration into the soil and drying. Solid manure, in contrast, had a higher dry matter content (35.8%) than the liquid manure (5.0%) and as a result, more odorous material remained on the soil surface potentially generating higher emissions for an extended period of time (Table 1).

Limited research has been conducted in measuring odour emissions from manure spreading and currently there is no standardized methodology. Due to this, the best job in terms of quantifying odour fluxes may be to calculate an integrated flux over a standard period (i.e. 42 h) of time. This study attempts to standardize the data over a 42-h measurement period (Table 3). Results again demonstrate that solid manure generated, on average, 12% more emissions than liquid manure, over the same measurement period for all trials (Table 3).

Application rate trials

Trials 4-6 were conducted using liquid manure application rates of 1x (100 kg NH_4-N /ha), 2x (200 kg NH_4-N/ha) and 5x (500 kg NH_4-N/ha). Background OCs ranged from 10-19 OU/m^3 (Table 3). Odour concentrations and fluxes were generally higher for the higher application rates of 2x and 5x concentrations however tended to be variable throughout the trials. This variability was most likely due to differences in vertical mixing of the air above the soil surface, associated with variable windspeed, air temperature, and relative humidity.

In trial 4 (Table 3) no strong differences in OC or fluxes were discernible between the 2x and 1x application rates. Initial OCs following manure spreading in trial 5 and 6 appeared to be highest for the higher application rates of 2x (31-99 OU/m^3) and 5x (35-88 OU/m^3), compared to a single application rate (13-78 OU/m^3). Total emissions over 42 h ranged from 0.34-0.49, 0.44-0.69 and 0.54-0.81×10^6 OU/m^2 for 1, 2 and 5x, respectively (Table 3). Results indicate that a higher application rate will generate 22 and 38% more odour for double and 5x the rate, respectively (Table 3). Explaining that odour nuisance complaints may be reduced if over application is avoided. It should be noted however, that it does not take large amounts of manure to cause odour.

Rahman et al. (2001; 2005) found that when applying swine manure in Manitoba at three application rates of 280, 560, and 1120 kg/ha, no differences in emissions were found when using a wind tunnel. Rahman et al. (2005) found odour emissions that ranged from 94-105 OU m^{-2} s^{-1} and did not show treatment differences, which were attributed to high variability of the data (Rahman et al. 2005). Fluxes in the present study were lower and ranged from 2.4-4.1 OU $m^{-2}s^{-1}$, where similar application rates of 100, 200, and 500 kg NH_4-N/ha were utilized. Differences however, are most likely attributable to different methodologies used (i.e. where and how odour samples were obtained), soil, manure composition, and time of year.

Rainfall before vs after manure application trials

Farmers often tend to apply manure when it is convenient and when their manure storage capacity requires them to do so. At times, field conditions may not be best suited for spreading and minimizing odour emissions. Trials 7-9 were conducted to evaluate how odour was affected through applying manure before and after rainfall events. Background samples ranged for all trials from 19-25 OU/m^3 (Table 3). During the trials, 50, 100, and 150 mm of water (i.e. simulated rainfall) was randomly applied on the field plots (either immediately before or after manure application, Table 3), while the remaining plots did not receive any water. Odour concentrations and emissions from both treatments appear to be variable and similar in range (Table 3). The average OC where manure was applied after rainfall (Table 3) was similar (82 compared to 78 OU/m^{-3}, for the plot that did not receive any rainfall). Total emissions over a 42-h period were higher in the wet plot at 0.39 ×10^6 OU/m^2 compared to the dry plots, with emissions of 0.35 ×10^6 OU/m^2 over the same period. Indicating that applying manure after a rainfall increased odour emissions by 10% (Table 3).

When manure was applied before a rainfall, OC and odour fluxes were lower for the plots which received rainfall (Table 3). Total odour emissions from the dry and wet plots over 42 h resulted in 14% lower emissions for the wet plots when 50 and 150 mm of rainfall were applied after manure application, for trials 7 and 9, respectively (Table 3). It appeared that when manure was applied before a rainfall event, emissions were reduced. This was most likely due to the fact that the rainfall acted as a catalyst and enhanced the infiltration rate of the manure into the soil profile, resulting in reduced contact between the manure and the atmosphere. This suggests that applying manure before a rainfall event should reduce total overall odour emissions. Although not examined in this research investigation, it is recommended that this should only be practiced before a light rainfall (<10 mm) event to reduce possible runoff from the field.

Ammonia has been identified as a major component of odour from swine manure (O'Neill and Phillips 1992; Moseley et al. 1998) suggesting that when odour emissions are high from a field applied with manure, nutrients are also lost. Results from this study support that applying on a dry soil versus a wet soil is best when trying to reduce odour and nutrient losses. Smith and Watts (1994) however, reported that odour emissions from manure have the potential to immediately increase days after manure spreading following a rainfall event, as a result of evaporation of the water within the manure and soil.

As expected, odour emissions were generally found to decrease over time. Odour concentrations were in the lower range to those values previously reported (Pain et al. 1991; Misselbrook et al. 1993; Moseley et al. 1998). It is difficult to draw comparisons with these studies due to differences in methodology, animal diet and type, location, time of year, and lack of description of where and how OCs were obtained.

A simple micrometeorological method for measuring odour emissions provided a good, valid, flux measurement platform for measuring odour fluxes with olfactometry. Olfactometry did not however appear to be a highly sensitive method for measuring odour treatment differences in an open-field environment and the TPS method did not allow for odour flux measurement at the time of spreading and only after. It is therefore suggested that the use of a Nasal Ranger® (field olfactometer) may have the advantage for capturing instantaneous OC peaks at the time of spreading. This method may provide a good comparative method for olfactometry; however, flux measurements would be difficult. With this method it requires trained panelists to go directly to the field with an instrument known as a Nasal Ranger® (St. Croix Sensory, Inc., Stillwater, MN) to do their analysis. The method of olfactometry used in the present study differs from the Nasal Ranger® in that an odour sample is obtained over a period of time, approximately 8min. making it a composite sample of the ambient air. Zhang et al. (2002) found that when comparing odour intensity in the field, obtained by human odour assessors, to odour concentration measured using olfactometry, measurements high in odour intensity were detected by the human assessors in the field; however, OCs measured from the bagged samples were unchanged. The composite samples taken in the Tedlar bags could not capture instantaneous bursts of odour in the field (Zhang et al. 2002); the use of a Nasal Ranger® however, may allow us to do so.

A need continues to exist for a fast response system for assessing OC and fluxes in the field. Research has been conducted on the electronic nose (Hobbs et al. 1995; Misselbrook et al. 1997; Qu et al. 2001), which are instruments that can recognize particular patterns of simple or complex odours (Qu et al. 2001) using several electronic sensors. They can produce an almost instantaneous response and therefore may provide a suitable system for long-term, continuous flux measurements and have been used in several fields including, health and medical, as well as the food and perfume industry. In relation to manure odours, and their capacity, electronic noses have yet to provide a suitable option beyond olfactometry.

CONCLUSION

Generally, OC reached a maximum between 2-10 h after application and declined thereafter. Liquid swine manure had a higher initial OC shortly after application compared to solid manure; however, odour declined as the manure infiltrated into the soil. The use of liquid manure on average, for all trials, was found to decrease odour losses by 12%, when compared with solid manure. Higher liquid manure application rates were generally found to produce higher odour emissions; doubling the application rate increased odour by 22% and 5x the application rate increased emissions by 38%. Applying manure after a heavy rainfall was found to increase emissions by 10%. Applying manure before a rainfall however, reduced odour emissions by an average of 14%. Applying manure therefore, at the proper application rate and before a rainfall, can therefore help reduce overall emissions to neighbouring communities.

It is clear that a standard approach for odour assessments in the field must be developed. At present, limited techniques are available for accurate, on-field measurement of odour emissions. Current methodologies measure only concentrations and tend not to quantify emissions. For this reason flux techniques, such as those based on micrometeorology, are needed to help evaluate and quantify odour emissions over time in the field. Currently, there are limited techniques available for measuring odour fluxes and the TPS method offers a good, valid, flux measurement approach for small-scale comparative trials. It provides a useful option for odour assessment; however, its use is limited by the resolution of OC (takes large differences in concentration to see treatment effects). Difficulty in determining treatment effects may be due to the high variability and low sensitivity of the olfactometer. Olfactometry continues to be the challenge and there is a need for improvements in fast response odour assessments (i.e. an electronic nose). Odour measurements in the field may therefore show more pronounced results with fast response techniques, like an electronic nose.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge Agriculture and Agri-Food Canada (AAFC), Matching Investment Initiative (MII) program, Natural Sciences and Engineering Research Council (NSERC), and The Nova Scotia Department of Agriculture (NSDA) Technological Development Program for providing financial support for this research. Special thanks are also extended to Dr. John MacLeod (AAFC), Lloyd Kerry (AAFC), and John McCabe (NSDA) for their research and technical support.

REFERENCES

AC'SCENT. 1999. About AC'SCENT® International Olfactometer. http://www.fivesenses.com/acscent/About acscent.htm (2007/09/20)

ASTM. 1991. E679-91. Standard practice for determination of odor and taste thresholds by a forced-choice ascending concentration series method of limits. In *Annual Book of ASTM Standards*. Philadelphia, PA: American Society of Testing and Materials.

Beauchamp, E.G., G.E. Kidd, and G.W. Thurtell. 1978. Ammonia volatilization from sewage sludge applied in the field. *Journal of Environmental Quality* 7:141-146.

Canada Soil Survey Committee. 1978. The Canadian system of soil classification. Canadian Department of Agriculture Publication 1646. Supply and Services Canada. Ottawa, ON.

Gordon, R., M. Leclerc, P. Schuepp and R. Brunke. 1988. Field estimates of ammonia volatilization from swine manure by a simple micrometeorological technique. *Canadian Journal of Soil Science* 68: 369-380.

Gordon, R., R. Jamieson, V. Rodd, G. Patterson and T. Harz. 2001. Effects of surface manure application timing on ammonia volatilization. *Canadian Journal of Soil Science* 81: 525-533.

Guo, H., J. Feddes, C. Lague, W. Dehod and J. Agnew. 2005. Downwind swine odour monitoring by trained odour assessors-Part I: Downwind odour occurrence as affected by monitoring time and locations. *Canadian Biosystems Engineering* 47:6.47-6.55.

Hanna, H.M., D.S. Bundy, J.C. Lorimor, S.K. Mickelson, S.W. Melvin and D.C. Erbach. 2000. Manure incorporation equipment effects on odor, residue cover, and crop yield. *Applied Engineering in Agriculture* 16(6):621-627.

Hobbs, P.J., T.H. Misselbrook and B.F. Pain. 1995. Assessment of odours from livestock wastes by photoionization detector, an electronic nose, olfactometry, and gas chromatography-mass spectrometry. *Journal of Agricultural Engineering Research* 60(2): 137-144.

Hobbs P.J., T.H. Misselbrook and T.R. Cumby. 1999. Production and emission of odours and gases from ageing pig waste. *Journal of Agricultural Engineering Research* 72: 291-298.

Huijsmans, J.F.M., J.M.G. Hol and G.D. Vermeulen. 2003. Effect of application method, manure characteristics, weather and field conditions on ammonia volatilization from manure applied to arable land. *Atmospheric Environment* 37:3669-3680.

MacDougall, J.I., C. Veer and F. Wilson. 1988. Soils of Prince Edward Island. Research Branch, Agriculture Canada, Land Resource Research Centre. Contribution No. 83-54. Supply and Services Canada. Ottawa, ON.

Misselbrook, T.G., C.R. Clarkson and B.F. Pain. 1993. Relationship between concentration and intensity of odours for pig slurry and broiler houses. *Journal of Agricultural Engineering Research* 55:163-169.

Misselbrook, T.H., P.J. Hobbs and K.C. Persaud. 1997. Use of an electronic nose to measure odour concentration following application of cattle slurry to grassland. *Journal of Agricultural Engineering Research* 66:213-220.

Moseley, P.J., T.H. Misselbrook, B.F. Pain, R. Earl and R.J. Godwin. 1998. The effect of injector tine design on odour and ammonia emissions following injection of bio-solids into arable cropping. *Journal of Agricultural Engineering Research* 71:385-394.

Ogink, N.W.N., C. ter Beek and J.V. Klarenbeek. 1997. Odor emission from traditional low-emitting swine housing systems: Emission levels and their accuracy. ASAE Paper No. 97-4036. St. Joseph, MI: ASABE

Oh, I.H., J. Lee and R.T. Burns. 2004. Development and evaluation of a multi-hose slurry applicator for rice paddy fields. *Applied Engineering in Agriculture* 20(1):101-106.

O'Neill, D.H. and V.R. Phillips. 1992. A review of odour nuisance from livestock buildings: properties of the odorous substances which have identified in livestock wastes or in the air around them. *Journal of Agricultural Engineering Research* 53(1):23-50.

Pahl, O., R.J. Godwin, M.J. Hann and T.W. Waine. 2001. Cost-effective pollution control by shallow injection of pig slurry into growing crops. *The Journal of Agricultural Engineering Research* 80:381-390.

Pain, B.F., C.R. Clarkson, V.R. Phillips, J.V. Klarenbeek, T.H. Misselbrook and M. Bruins. 1991. Odour emission arising from application of livestock slurries on land: Measurements following spreading using a micrometeorological technique and olfactometry. *Engineering Research* 48:101-110.

Parker, B.D., M.B. Rhoades J. Koziel and J. Spinhirne. 2003. Background odours in Tedlar® bags used for CAFO odour sampling. ASAE Paper No. 034144. St. Joseph, MI: ASABE.

Qu, G., J.J.R. Feddes, W.W. Armstrong, R.N. Coleman and J.J. Leonard. 2001. Measuring odor concentration with an electric nose. *Transactions of the ASAE* 44(6):1807-1812.

Rahman, S., Y. Chen, Q. Zhang, S. Tessier and S. Baidoo. 2001. Performance of a liquid manure injector in a soil bin and on established forages. *Canadian Biosystems Engineering* 43:2.33-2.40.

Rahman, S., Y. Chen, Q. Zhang and D. Lobb. 2005. Evaluation methods on manure exposure from liquid manure injection tools. *Canadian Biosystems Engineering* 47: 6.9-6.16.

Smith, R.J. and P.J. Watts. 1994. Determination of odour emission rates from cattle feedlots. Part I, A Review. *Journal of Agriculture Engineering Research* 57:145-155.

Sommer, S.G. and N.J. Hutchings. 2001. Ammonia emissions from field applied manure and its reduction. *European Journal of Agronomy* 15:1-15.

Statistics Canada. 2001. 2001 Census of Agriculture. http://www.statcan.ca/english/freepub/95F0301XIE/index.htm (2007/09/20)

Stevens, S.S. 1960. The psychophysics of sensory functions. *American Scientist* 48: 226-253.

Trabue, S.L., J.C. Anhalt and J.A. Zahn. 2006. Bias of tedlar bags in the measurement of agricultural odourants. *Journal of Environmental Quality* 35:1668-1677.

Watts, P.J., M. Jones, S.C. Lott, R.W. Tucker and R.J. Smith. 1994. Feedlot odor emissions following heavy rainfall. *Transactions of the ASAE* 37:629-636.

Williams, A.G. 1984. Indicators of piggery slurry odour offensiveness. *Agricultural Wastes* 10:15-36.

Wilson, J.D., G.W. Thurtell, G.E. Kidd and E.G. Beauchamp. 1982. Estimates of the rate of gaseous mass transfer from a surface source plot to the atmosphere. *Atmospheric Environment* 16:1861-1867.

Zhang, Q., J.J.R. Feddes, I.K. Edeogu and X.J. Zhou. 2002. Correlation between odour intensity assessed in n-butanol reference scale and odour concentration measured with olfactometers. *Canadian Biosystems Engineering* 44:6.27-6.32.

Zhou, X. and Q. Zhang. 2003. Measurements of odour and hydrogen sulphide emissions from swine barns. *Canadian Biosystems Engineering* 45:6.13-6.18.