Odour Emissions from Swine Operations in Manitoba

By

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ABSTRACT

Odour emissions were studied on ten (10) hog farms in Manitoba in 1999 and 2000. On each selected farm, odour samples were taken from (i) barn exhaust, (ii) manure storage, and (iii) downwind (50 m to 3.5 km). By following a commercial applicator, odour samples from manure land application were taken three times by using a wind tunnel. Odour levels (concentrations) of collected samples were determined by using a dynamic-dilution olfactometer (AC'SCENT International Olfactometer, St. Croix Sensory Inc., Stillwater, Minnesota) with six screened human assessors. A Jerome meter ® (Model 631-x, Arizona Instrument, Phoenix, Arizona) was used to measure hydrogen sulfide (H_2S) levels of odour samples taken from six farms in 2000. Large variations of odour and hydrogen sulfide levels among farms and within individual farms were observed. Farm-average odour levels and hydrogen sulfide (H_2S) levels from barn exhaust ranged from 131 to 1842 OU on ten farms and from 148 to 927 ppb on six farms, respectively. No apparent correlation was found between the odour level and the general farm characteristics, such as the age and type of operation. However, the emission rates from farrow and nursery barns were statistically higher than that from dry sow barns, and no significant difference in emission rate was found between farrow and nursery barns. Outdoor temperature had a significant effect on odour levels from barn exhaust, but not on odour emission rates (in a range from 12 to 41 °C). The amount of time pigs stayed in nursery barns affected both odour levels and odour emission rates. Farm-average odour levels ranged from 205 to 615 OU near the manure surface in earthen manure storage. There was no apparent correlation between the odour level from manure storage surface and the general farm characteristics. Wind speed affected odour

levels near the surface of manure storages. The higher the wind speed, the stronger the odour levels near the manure surface. Injection of manure into soil caused little odour emission from soil in this study. The emission rate measured from the soil with no manure applied was almost the same as that from the manured soil (3.6 vs. 4.2 $OU \bullet m^3 \bullet s^{-1} \bullet m^{-2}$). A positive correlation was found between odour levels and hydrogen sulfide (H_2S) concentrations for samples from both barn exhaust and lagoon odour. More odour measurements with detailed daily farm information are recommended to better understand the effect of day-to-day farm conditions on odour emission, the correlation between odour emission and barn type, and the variation of odour emission during the day in different seasons.

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1. INTRODUCTION

The swine industry in Manitoba has experienced a rapid expansion during the last few years. Total hog production has grown from 3.2 million head in 1996 to 4.8 million head in 1999. The development of large and intensive swine operations is a trend that is likely to continue in the province. This has caused public concerns regarding the potential impact of intensive swine operations on environment quality. Currently, odour is one of the greatest concerns associated with its nuisance and potential impacts on human health.

Odorous gases are produced at several sites around a swine operation. The most common odour sources are buildings, manure storage facilities, and land applications. Odour from swine operations is a complex mixture of many different odorous compounds resulting from the anaerobic decomposition of swine manure. The gases that pose a concern are ammonia, hydrogen sulfide, volatile fatty acids, p-cresol, indole, skatole, and diacetyl, by either their relatively high concentration or their low detection thresholds (O'Neill and Phillips, 1992; Priest et al., 1994). The odour intensity depends on the concentration of each compound and the combination of these compounds as well. As both the concentration and the combination of these compounds are highly variable upon the environmental conditions and management practices, the intensity and the character of odour vary greatly.

Research on developing technologies for the reduction of swine odour has been maintained as a priority in this field. However, many technologies involve extra cost or are impractical for producers. An effective measure for alleviating odour problems is maintaining adequate setback distance between the swine operations and the residences.

Currently, air dispersion models are used to predict downwind odour levels to establish science-based setback distances. However, the use of air dispersion models relies largely on source emission information (Smith, 1993) which is highly variable with farm characteristics, weather conditions, manure handling systems, and time of day. The application of these models is limited by the inadequacy of source emission information.

In Manitoba, odour is becoming a big issue especially when people consider the siting of new or the expansion of existing swine operations. However, at the present time, there is very little scientific information available as to the level and variability of the odour intensities and emissions that exist around typical confined hog operations in the province. The public concerns about nuisance of swine odour may have been based on information from outside the Province or influenced by a few local examples of poor livestock production stewardship. To some extent, these concerns have become obstacles to the further expansion of swine industry in Manitoba.

2. OBJECTIVES

The objectives of this project were:

(1) to measure odour emissions in typical swine operations in Manitoba and assess the scale of " the odour problem", and

(2) to correlate measured odour levels and odour emissions to the characteristics of swine operations and other environmental factors.

3. LITERATURE REVIEW

3.1. Introduction

Modern swine production systems are characterized by increased confinement and concentration of animals in small areas. In Manitoba, between 1990 and 2000, the number of hog farms has declined by more than 50 percent from 3150 to 1450, while the average number of hogs per farm has more than tripled - increasing from 388 heads to 1290 heads (Tyrchniewicz et al. 2000). At most of the intensive swine operations, pigs are kept in buildings that have well designed ventilation systems to keep the optimum temperature and relative humidity within the building. The pen floors have slots, through which the manure is collected and stored in the underlying storage pits until discharged to outdoor storage. The larger production and more intensive operations require less labour due to highly efficient systems for feeding and waste handling on the farm. However, this intensification also has some negative environmental impacts. Emission of odour from swine operations is one of the major concerns regarding its impact on the environment and public health, and in return, these concerns can also affect the acceptability and development of swine farming.

3.2 The nature of swine odour

3.2.1 Swine odour formation

For most people, 'pigs stink ' seems to be common knowledge. But actually a clean pig has about the same amount of body odour as a clean human being (Anonymous, 1995). It is mostly swine manure along with feed that contributes to malodour release from swine operations (Schaefer, 1977). During the accumulation of manure inside barns and the storage of manure outside barns, odour is produced by the decomposition of organic matter in the manure. The decomposition of manure can be aerobic or anaerobic, depending mainly on the availability of oxygen during the degradation. In pig farms, aerobic decomposition only applies to a few situations such as the decomposition of manure on the exposed surface of pens and pig bodies, as well as the surface layer of manure storage. In contrast, anaerobic decomposition occurs in most of the manure accumulation and storage cases because of the oxygen deprived conditions. In a balanced anaerobic decomposition process, anaerobic bacteria decompose carbohydrates, proteins, and fats during an acid fermentation phase to organic acids. Methane-producing microorganisms break down the organic acids to produce methane and carbon dioxide (Hobson et al. 1974, cited from Hobbs et al. 1997). Spoelstra (1980) described a laboratory experiment he did in 1979 in which a mixture of freshly voided feace and urine was anaerobically incubated. The products were mainly volatile fatty acids and carbon dioxide. Only small amounts of methane and other products were formed. He concluded that the main factors contributing to the low rate of methanogenesis in stored hog waste included low natural temperature during storage, overloading of degradable organic materials and high levels of NH_3 in the waste. This suggested that the imbalance between the processes of acid formation and methane production is the main cause of the accumulation of volatile compounds in the storage of hog waste.

3.2.2 Odourous compounds in swine odour

Many studies have been done to reveal the odorous compounds involved in swine operation systems. O'Neill and Phillips (1992) did a literature review on the identified odorous substances in livestock wastes and in the air around them. A total of over 168 volatile compounds associated with manure decomposition and animal metabolic activities have been identified by different researchers. These compounds can be grouped into eight categories: carboxylic acid, alcohols, phenolics, aldehydes, nitrogen heterocycles, mercaptans, amines, and sulfides. The most frequently reported odorous compounds which cause the most concern seem to be the volatile fatty acids, hydrogen sulfide, p-cresol, insole, sketole, diacetyl, and ammonia, by virtue either of their relatively high concentrations or of their low detection thresholds. The odorous mixture may vary with the microbial activity which is highly dependent on many environmental conditions such as temperature, pH, oxygen concentration, and moisture content (Schmedt and Jacobson, 1995), as well as the nutrient content of the manure (Hobbs et al. 1996; Sutton et al. 1996 (cited from Zhu et al. 1999a)). This leads to the change of both chemical composition and concentration of each composition in odour mixture with the location, the size and type of swine operation, production practices, manure handling practices, season, temperature, humidity, time of day, and wind speed (anonymous, 1995). Therefore, the overall odorous mixture is highly variable.

3.2.3 Odourous compounds and odour sensation

Identifying the presence of odorants in swine odour is not enough to understand the characteristics of the odour since these odorous compounds are interactive and smell differently than pure compounds when mixed together. The combination of odorous compounds may result in five possible results as addition, reduction, independence, synergism, and averaging (Hill and Barth,1976, cited from Feddes et al., 1999). Research with mixtures of odorants of known odour intensity proved that it is not possible to predict the odour intensity of a mixture of even two components (Rosen et al. 1962, cited from Zhu et al. 1999a). Efforts have been made to correlate odour intensity and concentration of some major malodor indicators in swine odour. Barth and Poldowski (1974) identified the odorous components in stored dairy manure and found that the volatile organic acids correlated best with odour intensity. A study conducted by Spoelstra (1977) found that indole and skatole could not be indicators of swine odour because the concentrations of these compounds might decline during storage. He also reported that both ammonia and hydrogen sulfide were not suitable indicators for swine odour (1980). Williams (1984) found that BOD can be applied as an indicator in odour from both aerobic and post treatment manure storages. Pain et al. (1990. cited from Hobbs et al. 1995) reported a correlation between odour concentration and NH_3 concentration in air. but the relationship is not constant for all farm odours and odour is still detectable at zero ammonia concentration. However, other researches have found that odour from swine operations can not be well represented by any single or even a small group of compounds (Hobbs et al. 1999). At present, there is no consistence in the literature regarding the correlation between specific odorant gas emission and the odour sensation.

3.3 Odour and human perception

The perception of odour by humans is a complex process. During normal nose breathing. volatile compounds are inhaled with the air and carried to the olfactory area which contains about 10 million receptors. Odour molecules are then absorbed in the nasal passage and bind to receptors in the olfactory epithelium, which are specific to certain odour molecules. Each reception of odour molecules creates an electrical signal in the olfactory nerves. A summation of these signals are sent to the olfactory center in the brain through nerve fibers, where the signal is interpreted through a comparison to other signal patterns held in the memory and an appropriate response to this odour is generated (Smith, 1999; Sarig, 2000).

The human response to odour is unique from person to person. The response and perception varies with the sensitivity of individual olfactory systems which are affected by genetics and age, physical condition of the individual, and the individual's experience and memory of exposures to the odour (Barth, 1973; Anonymous,98). The expectations and pre-existing attitudes of people about the odour also play an important role in response to, and perception of, an odour (http://www.monell.org/sensation.htm, 1/11/2001 10:58 AM)

3.4 Odour measurement

Currently, many analytical methods are available for the analysis of concentrations of specific gases in odour. These include the gas chromatography (GC) method, high-performance liquid chromatography (HPLC), and mass spectroscopy (MS). However, the quantitative analysis are often inadequate because the compositions and the relative concentrations of the odorous compounds released from swine operations are highly variable, and some constituents are presented at levels below the limit of the instrument. In addition, as odour is defined as human response to chemical compounds, human judgement is the major factor that other measurements have to relate to regarding odour perception and discrimination (Sarig, 2000). Sensory evaluation using the human nose is the basis for most of the experimental measurements of odour and the use of human panels is currently widely of the experimental measurements of odour and the use of human panels is currently widely accepted as the best method for odour evaluation (Riskowski, 1991; Clanton et al. 1999).

The most important parameters for odour evaluation are odour intensity and odour concentration. Odour intensity is the relative strength of the odour above the detection threshold. For an individual odourous compound, the relationship between its odour intensity and its mass concentration follows a power law (Stevens, 1960, cited from McGinley et al. 2000):

$$I = k\,C^n$$

where I is the odour intensity (strength), C is the mass concentration of odourant (mg/m^3), and k and n are constants that are different for different odorous compounds. By measuring the concentration of an odorous compound, the intensity of odour can be calculated. However, as cited before, since swine odour is a mixture of over 168 odorous compounds, and the combination of these compounds is complex and unpredictable, furthermore, odour is not well represented by any individual chemical constituent, therefore, the intensity of swine odour can not be obtained from the measurement of concentration of any odorous compound (Clanton et al. 1999).

Rating is a commonly used method for odour intensity measurement. Odour samples can be presented to human panelists directly for evaluation and rated on a numerical scale, with the higher number representing the more intense odour. A cloth swatch technique has been developed by Zhang et al. (1999) for odour intensity measurement. When odour is drawn through the swatch by using a vacuum pump, it is adsorbed on the swatch. The swatch is then presented to panelists, and odour intensity is quantified by using a modified

The Odour Referencing Scale method serves as a standard method for referencing suprathreshold odour intensity (ASTM, 1999). Panelists are provided a reference odour (butanol) with a series of different concentrations and asked to compare the intensity of tested odour with the references. Two methods can be used in this standard: dynamic-scale method and static-scale method. The dynamic-scale method involves the use of an olfactometer device with a continuous flow of butanol. The static-scale method utilizes a set of water solutions with different dilutions of standard odorant (butanol). The odour intensity of a sample is expressed in parts per billion of butanol.

The odour concentration is defined as the number of dilutions at which 50% of the panel can just detect the odour and is presented as the dilution -to-detection threshold (D/T) or odour unit (OU). The odorous sample is diluted using odourless air in different ratios and presented to an odour panel in an order of ascending concentration. Each panelist is presented with one odour sample and two odourless samples and the panelist is asked to choose the one that is different from the other two. Measurement of odour concentration by using dynamic olfactometry with human assessors has been accepted as the industry standard in the United States and Europe (ASTM, 1991; CEN, 1999).

3.5 Sources of swine odour

3.5.1 Odour emission from buildings

Swine buildings are often considered major odour sources with large quantities of odorous gases being released continuously. Complaints on nuisance of odour emissions from buildings contribute approximately 10 - 35 percent of the total complaints associated with buildings contribute approximately 10 - 35 percent of the total complaints associated with commercial swine production facilities (Tessier, 2000). Accumulated manure, the pigs themselves, and dust from the feeders and animals are the main sources of odour from animal buildings. Anaerobic decomposition of manure is common in the building when manure remains in gutters or in pits for temporary storage. Research has shown that the concentration of some of the odorous compounds in swine manure may increase over a 24-h period of anaerobic storage (O' Neill and Phillips, 1991). The idea that exposed surface area of slurry plays a role in the emission of odour was suggested by Klarenbeek et al. (1982, cited from O' Neill and Phillips, 1991), according to their observations that reduced building odour emissions resulted from a reduction in slurry surface area. Dirty pigs and pens produce extra odour emissions because they provide an additional area of manure-covered surface for odour release, and when covered with manure, the warm body surfaces of the pigs promote the production of odour (Anonymous, 1998). The activity of animals is another factor that affects the odour emission from buildings (Martinec et al. 1998; Zhu et al. 1999b). Dust also plays a major role in the emission of odour from buildings (Day et al. 1965). Odorous molecules easily adhere to dust particles and may coat the walls, ventilation systems, and surface of the facility, and escape from the buildings in an intensive dose.

It has been found that odour emissions vary significantly among different swine buildings. Jacobson et al. (1999) measured odour concentrations and odour emission rates from building exhausts on 17 swine buildings and the measured data spanned from 24 OU to 1515 OU in odour concentration and from 1 to 30 $OU \cdot m^3 \cdot s^{-1} \cdot m^{-2}$ in odour emission rate. Odour emissions from a pig finishing building measured by Heber et al. (1999) was 20

$OU \cdot m^3 \cdot s^{-1} \cdot m^{-2}$ on average. Factors such as type and age of operation, building design, ventilation rate, manure handling system, barn management, and use of manure treatment technology may all contribute to these variations (O' Neill and Phillips, 1991). There is very little information available to confirm these observations and correlate them with each of the contributing factors.

Odour emissions vary during the day on the same farm. Martinec and Hartung (1998) studied diurnal odour emissions from two swine barns with mechanical ventilation systems. They reported a decrease of odour concentration in the course of the day between 11 a.m. and 7 p.m. which was mainly caused by the increased air flow rate at the same time, and an increase of odour emission rate at 11 a.m. until the following morning at 1 a.m. Zhu et al. (1999b) conducted the research on daily variations in odour and gas emissions from 5 pig barns. They concluded that odour concentration in swine facilities did not change significantly during the daily course for most of the buildings.

3.5.2 Odour from manure storage

Typically, swine manure is flushed or pumped from buildings with water and stored for 6 – 12 months in earthen, concrete, or steel storages. During storage, manure is decomposed under the anaerobic conditions prevailing in the lower layer of storage. The anaerobic decomposition of manure produces a variety of odorous compounds that cause nuisance complaints when released into the air. This contributes to about 20 % of the total nuisance complaints of swine operation (Tessier, 2000).

Volatilization is often the most important mechanism for odour emission from a liquid surface. It occurs when molecules of odorous compounds escape from the liquid surface to the surrounding air. The transfer of odorous gases across the liquid-air interface depends on the concentration and properties of the volatile compounds, characteristics of the liquid phase, and the surrounding environmental conditions (air velocity and temperature) (Tansel and Eyma, 1999). Researchers (Arogo et al. 1999a; Arogo et al. 1999b) have investigated the mass transfer coefficients of some soluble gases in the liquid manure. The results have shown that air velocity, liquid temperature and temperature differences between the liquid and air, and lagoon solid content are factors affecting the mass transfer of soluble gases in liquid manure. For some soluble gases, such as ammonia, the mass transfer coefficient increases with the increase of air velocity and the temperature difference between liquid and air. However, for hydrogen sulfide, the mass transfer coefficient increases when temperature differences increase, but slightly decreases when air velocity increases. Heber et al. (1999) conducted odour emission measurement from a surface-aerated lagoon and found that lagoon odour emissions vary significantly with time of loading, wind speed, slurry temperature, and air temperature.

A significant seasonal trend of odour emission from storage has been revealed by Jacobson (1997) that higher odour levels occur in the spring of the year. They also noticed that factors such as storage type, location, and animal type do not have significant effects on the odour level from the manure storage. The odour levels from manure storage units spanned from 40 to 300 OU measured by Jacobson et al. (1999) on ten swine farms in Minnesota.

3.5.3 Odour from land application of manure

Swine manure is often utilized as fertilizer on cropland due to its high nutrient

During this process, volatile compounds in the manure can escape into the air from the large surface area of applied field and cause odour complaints which contribute to approximately 40 – 70 % of the total complaints from swine operations (Tessier, 2000). The volatilization of manure applied to land depends mainly on the application technique, and most of the volatilization occurs during the first few hours after application (Pain et al., 1991). Pain et al. (1991) showed that efficient injection of manure could reduce odour emission up to 80% compared to manure surface application. Chen et al. (2000) evaluated different techniques for liquid manure application on grassland. In terms of odour emission, significantly lower odour and ammonia emissions were found by using manure injection. Currently, injection of liquid manure is well accepted as the most effective way to control odour emission during land application (Anonymous, 1995).

3.6 Measuring odour emissions from swine operations

3.6.1 Odour emissions from buildings

The odour emission rate is a parameter to quantify the amount of odour emission from an odour source. The odour emission rate from a mechanically ventilated livestock building is the product of the odour concentration in the building exhaust multiplied by the total building ventilation rate. The ventilation rate of mechanically ventilated buildings can be estimated using either fan-wheel anemometers or tracer techniques (Demmers et al. 2000). The use of full-size fan-wheel anemometers is accurate and very common for measuring airflow of building openings, but need a permanent installation that is not suitable for measurement involving a large number of buildings. British Standards Institution (1980) suggested a measurement involving a large number of buildings. British Standards Institution (1980) suggested a standard method to measure the local air velocity at each of a series of points within the fan opening and then to carry out a numerical integration across the whole openings. The summation of airflow from each opening will be the total airflow rate of the building. Another alternative method is to use a tracer gas (CO_2 or NH_3 in animal buildings) to calculate the total ventilation rate of the building without having to measure the ventilation rate. The ventilation rate can be estimated based on the mass balance between the tracer and the air. However, this method requires complete mixing of the tracer within the ventilated space, therefore, the result is not accurate if the internal volume is imperfectly mixed (Demmers et al. 2000).

3.6.2 Odour emission rate from area sources

To measure odour emissions from surface areas such as storage surface and application fields, portable wind tunnels have been commonly used (Schmidt et al. 1999; Smith and Watts, 1994b; Pain et al. 1991). These wind tunnels are open bottom chambers that are placed over the emitting surface. Filtered air is blown or drawn through the tunnel to mix with and transport the emissions away from the emitting surface (Smith and Watts, 1994a). The odorous air mixture is sampled at the outlet of the tunnel and the odour emission rate is estimated by multiplying the outlet stream odour concentration and the airflow rate through the tunnel. Researchers have found that odour emissions increased as tunnel wind speed increased. The power function relationship between odour emission and tunnel wind speed was established by Schmidt et al. (1999) on the emission measurement over manure storage surface, $E_V / E_1 = V^{0.89}$ where V = given bulk tunnel velocity (m/s), E

$_1$ is the emission at 1 m/s and E_v is the emission at velocity V. This result corroborated earlier work by Smith and Watts (1994b) on cattle feedlots odour emissions. However, the correlations between the measured emissions under controlled tunnel velocity and the real emissions at ambient conditions are unknown and more research efforts on the topic is still needed.

4. MATERIALS AND METHODS

4.1 Farm selection

Ten hog farms (A - J) of different types of operations, building ages, sizes, and manure management practices were selected for this study (Table I). Four of the ten farms were located in the Triple S area, five in other areas of southern Manitoba, and one in western Manitoba. Of the ten farms, five were farrow to finish operations, two nursery operations, two farrow-nursery operations, and one grow/finish operation. The ages of these farms ranged from 2 to 40 years. Odour measurements were taken from a total of 23 barns on the selected farms, including 3 farrow, 5 dry sow, 9 nursery, and 6 finish barns. The detailed information on farm characteristics is presented in Appendix I.

Table I: General characteristics of ten selected farms

Farm	Type	Age	Capacity	Exhaust
A	Farrow to finish	5	750 sows	Wall
B	Farrow to finish	10	350 sows	Wall
C	Farrow to finish	35	800 sows	Wall
D	Farrow to finish	40	120 sows	Wall
E	Nursery	3	5000 nurseries	Wall
F	Nursery	4	10000 nurseries	Wall
G	Farrow to finish	4	700 sows	Wall
H	Farrow	2	3000 sows	Wall
I	Finish	4	4000 finishes	Wall
J	Farrow to nursery	2	2500 sows	Roof

4.2 Sample collection

4.2.1 Sampling equipment and procedure

A commercial vacuum chamber (AC'SCENT Vacuum chamber, St. Croix Sensory, Inc., Stillwater, Minnesota) was used to collect odour samples in 10 L Tedlar bags (AC'SCENT Sampling bag, St. Croix Sensory, Inc., Stillwater, Minnesota). When sampling, a bag was placed in the chamber and the inlet of the bag was connected to a teflon probe which was placed close to the odour source. A vacuum pump was used to create a vacuum inside the chamber and odorous air from the odour source was drawn into the bag through the teflon probe by vacuum suction (fig.1). Each sample was taken in two steps: (i) fill the bag with 2 L of sample air and then evacuate to "coat" the bag, and (ii) draw odorous air into the bag at a rate of 1 to 2 L/minute until the bag was 3/4 full.

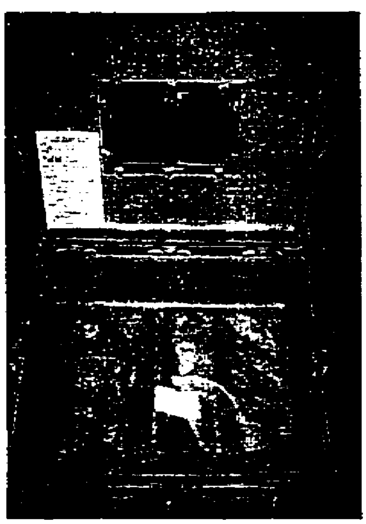

Figure 1 – Vacuum chamber with Tedlar bag for odour sampling

4.2.2 Sampling schedule

Samples were scheduled to be collected three times on each selected farm in a random order between May and September when odour is more concerned by neighbourhood because more outdoor activities occur during this time. However, because Farm J was selected late August in 2000 to replace a pre-selected farm because of a court case, samples on farm J were taken three times at the end of the month (see Appendix II for a summary of sampling activities). In addition, three sets of samples were collected in morning, noon, and evening on Farm H on three separate days in August to examine the variation in odour emissions during the day.

Due to scheduling difficulties, odour measurements from land application could not be taken on the selected farms. Instead, samples were collected three times by following a custom manure applicator.

4.2.3 Sampling location

On each selected farm, odour samples were taken from (i) the barn exhaust, (ii) manure storage, and (iii) downwind (fig. 2). For collecting samples from the barn exhaust, a sampling probe was placed in the mid stream of airflow from the exhaust fans. At the same time, the size of the exhaust fan was measured, and the average velocity of exhaust air from each exhaust fan in the building was also measured with a vane anemometer. The airflow rate from each running fan was estimated as the product of average air velocity and fan area. The total ventilation rate from the building was approximated as the summation of the air flow rate of all exhaust fans in the building (Demmers et al. 1997, cited from Zhu et al. 1999b). Due to the limited of number of samples that could be taken each time, only two odour samples were taken from each building. For lagoon odour, samples were taken by locating the probe closely (within 10 mm) to the manure surface and parallel to the wind direction at the downwind edge of the lagoon. Meanwhile, wind velocity at the same level close to lagoon surface was recorded. Downwind samples were taken in distances from 50 m to 3.5 km, or on the property line of the farm at 1 m height.

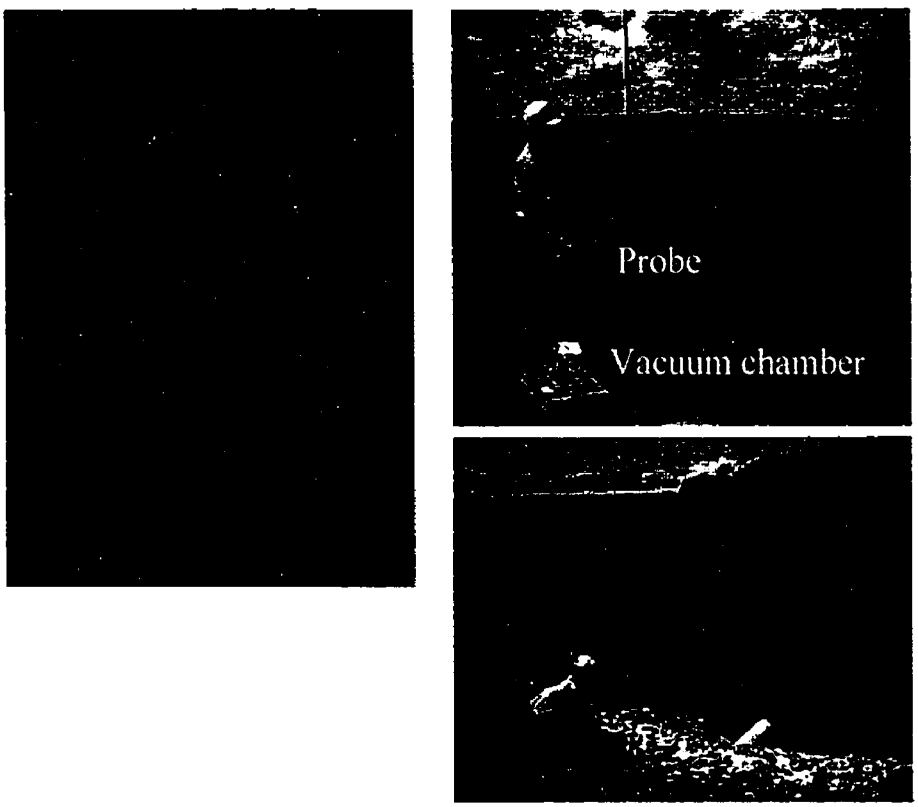

Figure 2 – Odour sampling from barn exhaust, downwind, and manure storage

Odour emissions from land application of manure were measured three times in September 2000 by following a custom manure applicator. The applicator used a manure injection system (Hydro Engineering Corp.), with injector spacing of 508 mm (20 in) and injection depth of 76 to 102 mm (3 to 4 in). The manure application rate was 8.12×10^{-3} – 1.16×10^{-2} m^3/m^2, determined by soil and manure tests, as well as the expected crop yield. A flux hood was constructed to collect odour samples from manured soils (fig.3). The hood covered a soil surface area of 0.3 m^2 (0.75 m x 0.4 m). Fresh air was drawn through a carbon filter, and introduced into the sample collection hood through a 100 mm diameter PVC duct. Airflow rates were measured inside the duct using a hot wire anemometer. Odour samples were collected at the outlet of the hood using a vacuum chamber and Tedlar bags. The odour emission rate from the soil was calculated as the product of the measured outlet odour concentration and the airflow rate through the hood.

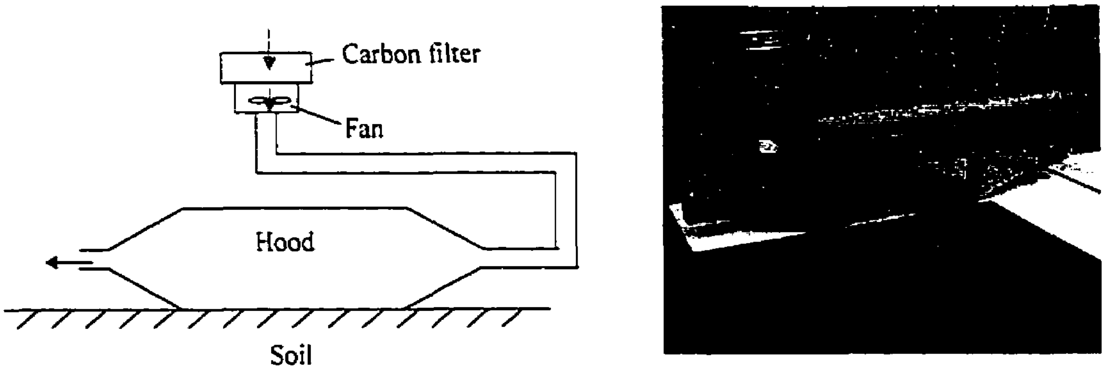

Figure 3 – Flux hood (wind tunnel) for collecting odour samples from manured soil

When samples were being collected, weather conditions (temperature, relative humidity, wind, and sky cloud cover) were also recorded and a site map was sketched on a Sampling Information Sheet (Appendix III).

4.3 Sample evaluation

4.3.1 Equipment and procedure

A Jerome meter (JEROME 631- X, Arizona Instrument Corporation, Phoenix, Arizona) was used to measure the hydrogen sulfide levels of the odour samples collected in the summer and fall of 2000. Samples were drawn over a gold film sensor through an internal pump for a precise period of time. The gold film sensor, in the presence of hydrogen, undergoes an increase in electrical resistance proportional to the mass of hydrogen sulfide in the sample. The sensor adsorbs and integrates the hydrogen sulfide and displays the concentration of detected hydrogen sulfide in parts per million (ppm).

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 the dilution-to-detection threshold (DT), or odour unit (OU), which represented the number of dilutions needed to bring the odour down to the level that could be detected by 50% of a population.

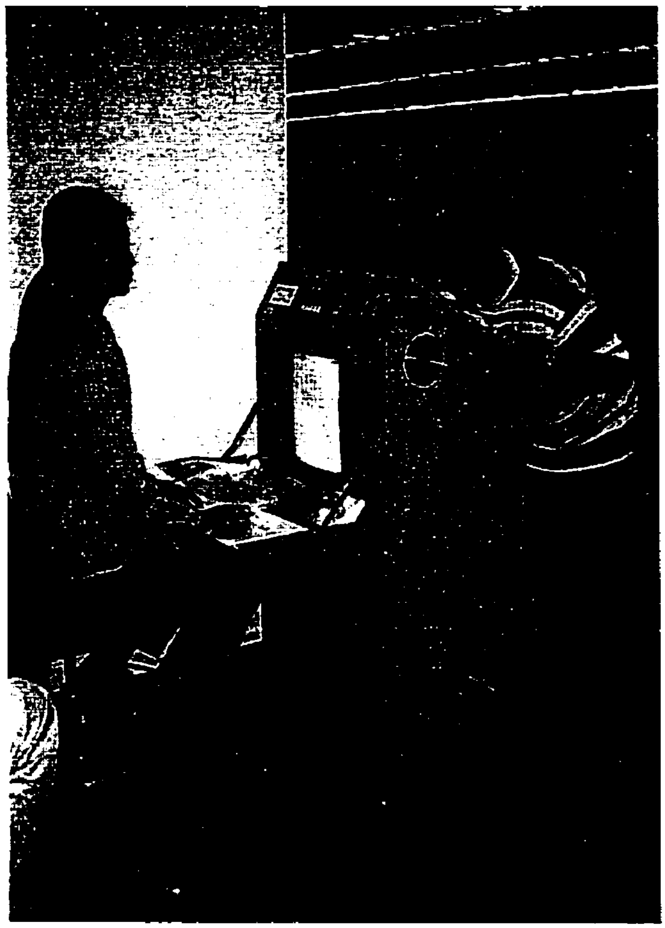

Figure 4 – Assessing odour concentration using a dynamic-dilution olfactometer and human assessors

4.3.2 Sample measurement

Collected samples (in Tedlar bags) were transported to the olfactometry laboratory at the University of Manitoba for odour concentration (level) and hydrogen sulfide concentration evaluation within 24 hours. Odour evaluations were conducted in the Sensory Laboratory of the Canadian Food Inspection Agency, Winnipeg. 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 outliners by comparing assessors' individual threshold estimates with the panel average. The retrospective screening was carried out on the basis of parameter ΔD, the ratio between an individual threshold estimate D_{ITE} and the geometric mean of all individual threshold estimates DT in a measurement :

$$\Delta D = \begin{cases} D_{ITE}/DT & D_{ITE} \geq DT \\ -DT/D_{ITE} & D_{ITE} < DT \end{cases} \qquad (1)$$

If an assessor's ΔD is greater than 5.0 or lower than –5.0, the individual threshold estimate of this assessor will be excluded from the data set for calculation the panel threshold of that measurement. The screening procedure is repeated, after re-calculation of D_{ITE} for that measurement, until all panel members in the data set comply the parameter (CEN, 1999).

4.4 Selection of odour assessors

The panelists were selected through a two level sequential screening procedure. Both levels of screening involved forced choice triangle tests. In the tests, each participant was presented with three flasks of n-butanol solution or water, one of which was different in odour intensity from the other two. Participants were asked to choose the odd sample. The number of correct choices was plotted against the number of triangle tests (Meilgaard, 1991). This would place each participant in one of three regions: reject, continue testing, or accept. h each testing session, participants were presented with six sets of three flasks. At the first level of screening, each participant was given 3 sets of 2 flasks of distilled water and 1 flask of 40 ppm butanol; and 3 sets of 2 flasks of distilled water and 1 flask of 80 ppm butanol. At the second level of screening, the participant was presented with 3 sets of 2 flasks of 10 ppm butanol and 1 flask of 40 ppm butanol; and 3 sets of 2 flasks of 20 ppm butanol and 1 flask of 80 ppm butanol. The order of presentation of the sets and the position of the odd sample within each set were both randomized for each participant. The flasks were randomly assigned three digit numbers and labeled accordingly. For those who fell in the category of continue testing, the tests were repeated on subsequent days until they moved into the accept or reject region. Those participants who moved into the accept region during the first level screening would begin the second level of screening. Participants who were eventually moved to the accept region of the second level screening were selected as panelists.

In May 2001, a re-screening procedure was performed on all of the panelists by following European Standard (CEN, 1999). Two panel selection criteria include: 1) the geometric mean of the individual threshold estimates expressed in mass concentration of the geometric mean of the individual threshold estimates expressed in mass concentration of the butanol gas has to fall between 20 to 80 ppb to meet the required sensitivity, and 2) the antilog of the standard deviation calculated from the logarithms of the individual threshold estimates, expressed in mass concentration of the butanol gas, has to be less than 2.3 to ensure the consistency requirement. Ten individual threshold estimates for the reference 50 ppm n-butanol were performed on each assessor in at least 3 sessions on separate days with a pause of at least on day between sessions. Table II presented the re-screening result for our panelists. It showed that most of the panelists we selected before are qualified to be an odour assessor according to European Standard. Panelist who failed the re-screening test will no longer be used as panelist.

Table II: Result of assessor re-screening following European Standard

Assessor	1	2	3	4	5	6	7	8	9	10	11	12
D/T	31	62.6	33.4	36.1	62.4	87.2	45.1	36.9	27.3	61.6	133	81.3
Std.	1.88	1.56	1.6	2.05	1.58	1.37	1.85	1.72	1.45	1.74	1.48	2.06
Pass/Fail	P	P	P	P	P	F	P	P	P	P	F	F

5. RESULTS AND DISCUSSION

5.1 Odour and H_2S emissions from buildings

5.1.1 Odour levels from building exhaust

Odour levels from building exhaust are summarized in Figure 5 for ten farms (A – J). The mean value of odour level shown for each farm was the average of all barns on that farm, or farm-average. Large variations in odour level were observed among the farms and on individual farms. The farm-average odour level ranged from 131 OU on farm A to 1842 OU on farm G. The variation of odour level within individual farms showed that the least variation occurred on Farm A (79 to 131 OU). and the largest on Farm G (245 to 4635 OU). Multiple comparisons indicated that the ten farms could be divided into three groups according to their odour levels: a low odour level group where odour levels ranged from 131 to 252 OU (Farms A. B. D and I). a medium level group where odour levels ranged from 657 to 823 OU (C, E, F and J). and a high level group where odour levels ranged from 1765 to 1842 OU (G and H). The results from this study were similar to that by Jacobson et al. (1999). They found that the odour levels from hog barns with mechanical ventilation systems ranged from 24 to 1515 OU in Minnesota. As odour emission from building is affected by a variety of factors such as feed ration, manure property, cleanliness of animal and floor, temperature, and ventilation rate, the large variation of odour levels amongst farms suggested that it is necessary to conduct more detailed measurement to reveal the causes of these differences, and to identify good management practice which can reduce odour emissions from swine buildings.

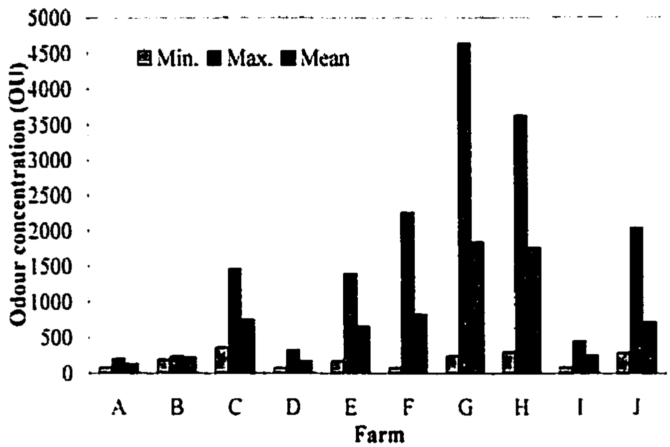

Figure 5 – Farm-average odour levels from barn exhaust on ten farms

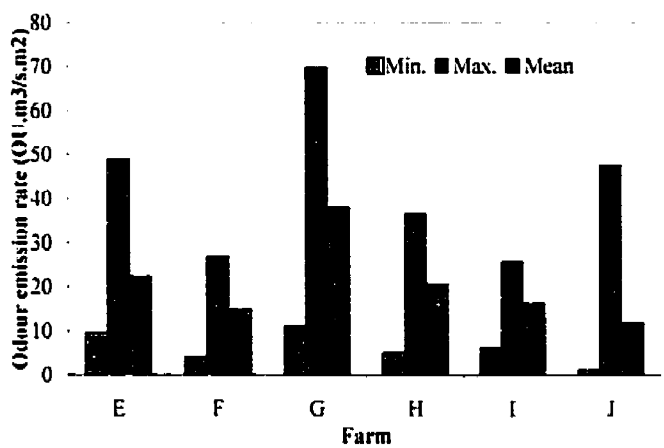

Figure 6 – Farm-average hydrogen sulfide levels from barn exhaust on six farms

5.1.2 H_2S levels from building exhaust

Hydrogen sulfide (H_2S) levels were measured on six farms (E – J) when a Jerome meter was purchased in spring 2000. The patterns of variation in farm-average H_2S level amongst the farms and within individual farms were similar to those of odour level. Among the six farms, Farm I had the lowest H_2S level of 148 ppb and Farm G had the highest of 927 ppb (fig. 6). Similarly, Jacobson et al. (1999) reported H_2S concentrations ranging from 9 to 1156 ppb in swine barns in Minnesota.

5.1.3 Odour and H_2S emission rates from buildings

To compare emission rates between different farms, the emission rate is generally expressed as a rate per unit area of the barn floor ($OU \cdot m^3 \cdot s^{-1} \cdot m^{-2}$). Similarly, the hydrogen sulfide emission rate is expressed as $\mu g/s.m^2$. Because building ventilation rates were not measured in 1999 on farms A to D, odour and H_2S emission rates from buildings were only available for farms E to J where odour samples were collected in May to August 2000. Measured farm-average odour and hydrogen sulfide emission rates are presented in fig. 7 and fig. 8, respectively. Unlike odour and H_2S levels, the variation of odour and H_2S emission rates among the six farms were relatively small. Measured odour emission rate ranged from 12 $OU \cdot m^3 \cdot s^{-1} \cdot m^{-2}$ on farm J to 39 $OU \cdot m^3 \cdot s^{-1} \cdot m^{-2}$ on farm G. These rates were slightly higher than those reported by Jacobson et al. (1999) for hog barns in Minnesota (1 to 30 $OU \cdot m^3 \cdot s^{-1} \cdot m^{-2}$). Multiple comparisons of odour emissions from the six farms indicated that among the six farms, farm G had a significantly higher odour emission rate than other farms and farm I had a significantly lower emission rate than the others. The pattern of variation in H_2S emission rate was similar to odour emission rate. The highest H_2S emission occurred on

Farm G (25 $\mu g \cdot s^{-1} \cdot m^{-2}$) and the lowest on Farm J (6 $\mu g \cdot s^{-1} \cdot m^{-2}$). The results are comparable to those from Minnesota (Jacobson et al. 1999) where the building H_2S emission rate ranged from 0.2 to 26.5 $\mu g \cdot s^{-1} \cdot m^{-2}$.

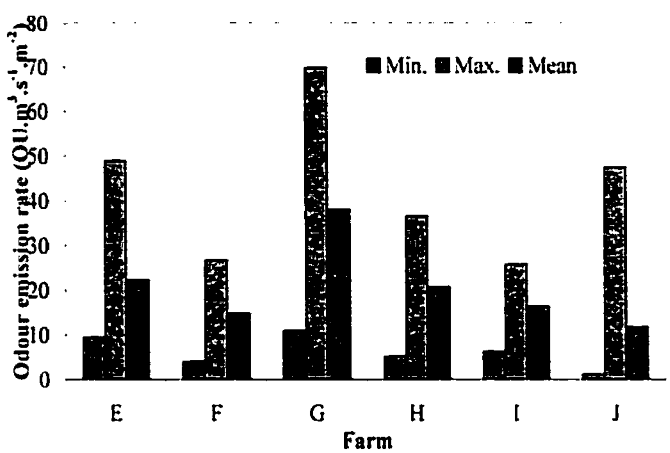

Figure 7 – Farm-average odour emission rate from barn exhaust on six farms

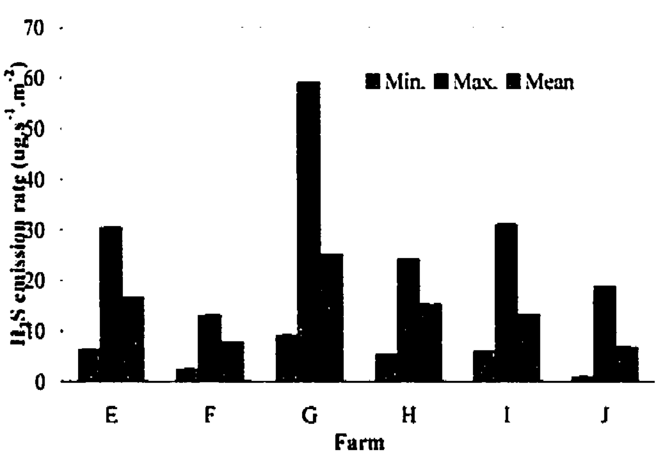

Figure 8 – Farm-average hydrogen sulfide emission from barn exhaust on six farms

5.1.4 Odour level and general farm characteristics

I attempted to find correlations between measured odour levels and general farm characteristics such as age of operation, type of operation, floor type, and manure collection system. Based on the measured results and farm information (Appendix I), no correlations were found between the general farm characteristics and the measured odour levels. For example, Farms A and G were similar in characteristics: both were farrow to finish operations, with Farm A having 50 more sows than G (750 vs. 700 sows); the two farms were 5 and 4 years old, respectively; and both had slatted floors and shallow gutters for manure collection. However, the odour level on Farm A was significantly ($P < 0.05$) lower than that on Farm G. In contrast, farm E and F also have similar characteristics: both were nursery operations, 2 and 4 years old, with wall mounted exhaust fans and the same cleaning schedule, except that F had twice as many pigs as E. But the odour levels on these two farms were statistically the same ($P > 0.05$). Further research is needed to examine the details of day-to-day operations, especially the cleanness of floors, feed rations, and odour abatement measures to determine the causes of large variations in odour level among farms.

5.1.5 Odour emission and sampling period

Most odour measurements in this study were taken between May and September when odour is a main concern due to frequent outdoor activity of neighbours during this time. Figures 9 and 10 show the relative odour levels and the relative odour emission rates at different sampling periods. The relative odour level (odour ratio) was defined as the ratio of measured odour concentration to the farm-average odour concentration of that farm. The relative odour emission rate was the ratio of measured odour emission rate from the farm to the farm-average odour emission rate of that farm. A ratio of 1.0 means that the odour level or odour emission rate in a given sampling time was the same as the farm-average. Statistical analysis indicated that the odour ratios in the sampling period of May 17 to June 14 were significantly ($P < 0.05$) greater than the other sampling periods. Numerically, the odour levels were 76% higher than the farm-average between May 17 and June 14, and the lowest odour level measured in the period of July 19 – August 9 was 70% of the farm-average. Building ventilation rate greatly affected the odour level from buildings. The high odour levels from May 17 to June 14 were attributed to the low ventilation rates due to the low outdoor temperatures during this period, and the high ventilation rates were related to the low odour levels in the period of July 19 and August 9.

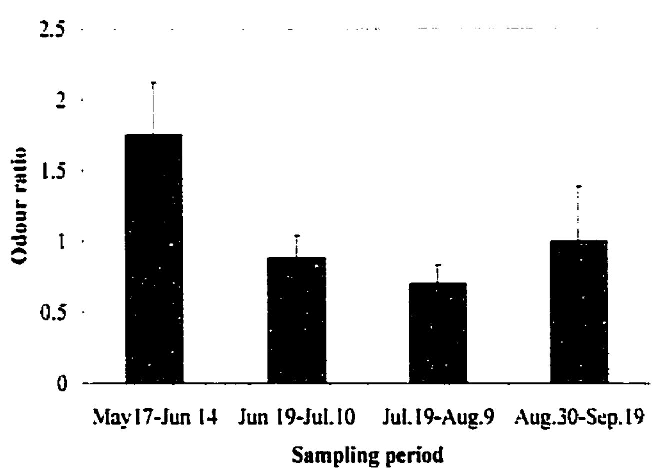

Figure 9 – Measured odour ratios in different sampling periods (T: standard deviation)

The pattern of variation in odour emission rate was different from that of odour concentration. As shown in figure 10, the odour emission ratios did not change significantly during the entire sampling period (P > 0.05). Numerically, the highest emission occurred in the period of July 19 – August 9, which was only 14 % higher than the farm-average. The high emission rate was attributed to the high building ventilation rate due to the high outdoor temperature, even though the odour level was the lowest during this period.

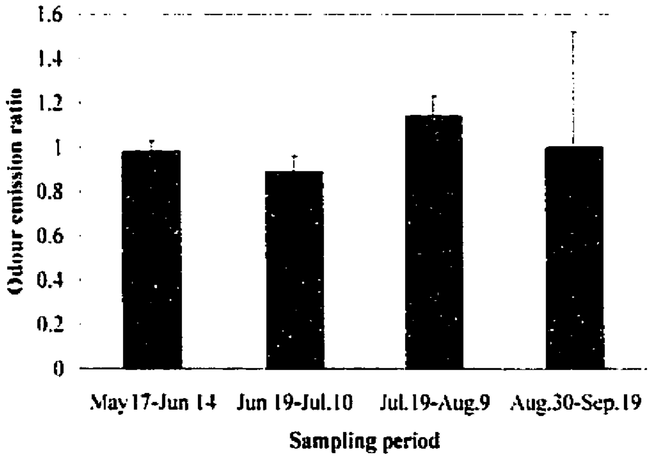

Figure 10 – Measured odour emission ratios in different sampling periods

5.1.6 Odour emission and outdoor temperature

A significant change in odour levels due to outdoor temperatures was observed in this study. Figure 11 shows the relative odour level at different outdoor temperatures. Statistical analysis shows that the odour levels at outdoor temperature 12-20 °C were significantly (P < 0.05) higher than those at other temperatures, and there were no significant (P > 0.05) differences in odour level for temperatures above 20°C. Numerically the highest odour level occurred at outdoor temperature 12 – 14 °C, which was 2.18 times of the farm average odour level. Low ventilation rates at low outdoor temperatures might have contributed to high odour levels from building exhausts as we can see from Figure 13 that the ventilation rate increased with the increase of outdoor temperature.

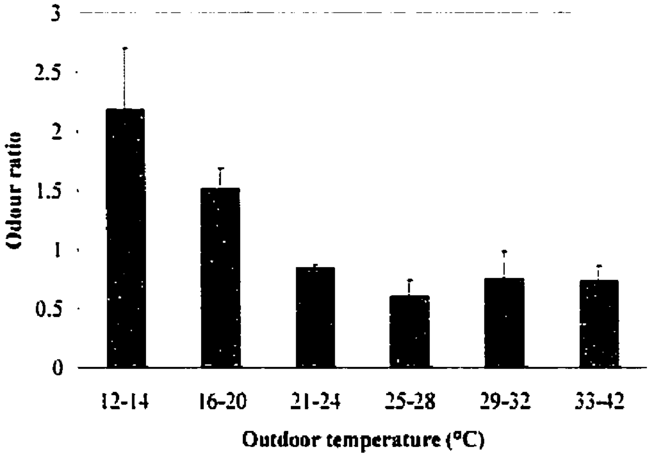

Figure 11 – Measured odour ratios at different outdoor temperatures

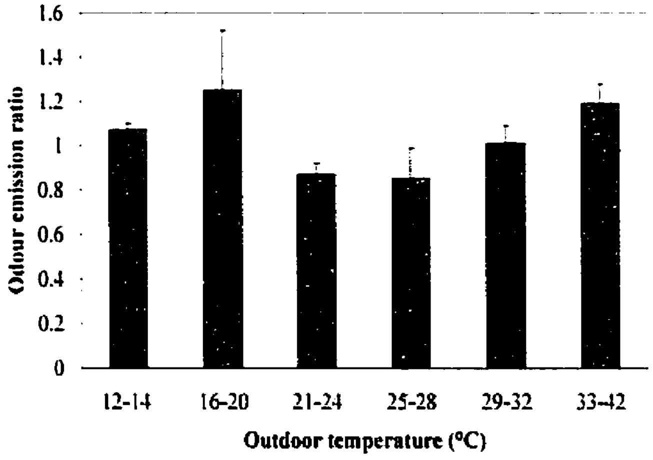

Figure 12– Measured odour emission ratios at different outdoor temperatures

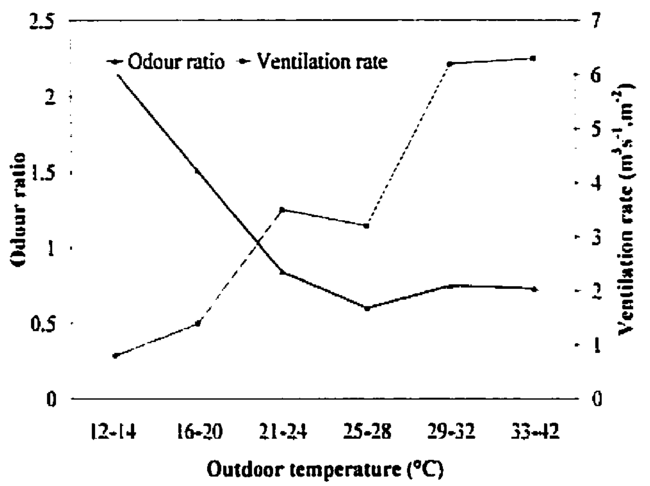

Figure 13- Measured odour ratios and building ventilation rates at different outdoor temperatures

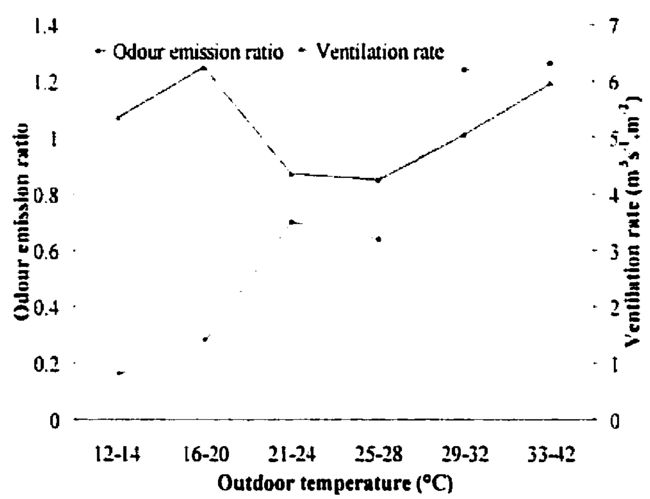

Figure 14 – Measured odour emission ratios and ventilation rates at different outdoor temperatures

Since the odour emission rate depends on both odour level and ventilation rate, the change of odour emission rate with outdoor temperature was found not to be significant in this study ($P>0.05$) (Figures 12 and 14). However, numerically the highest odour emission occurred at outdoor temperature 16-20 °C, which was 25 % higher than the farm average. The lowest emission occurred at outdoor temperature 20-28 °C, which was 85 % of the farm average.

5.1.7 Odour emission and barn type

To compare odour emissions among different types of barns, three farms (G, H and J), on which at least two types of barn were measured for odour level and emission rate, were analyzed. On Farm G, the strongest odour occurred in the farrow barn (2806 OU), the lowest in the dry sow barn (684 OU), and there was no significant ($P > 0.05$) difference between the farrow and nursery barns (fig. 15). The difference in odour levels between farrow and dry sow barns on Farm H was not significant ($P > 0.05$), nor were the differences between farrow and dry sow barn and between farrow and nursery barn on Farm J. But significant difference in odour level was found between the nursery barn and the dry sow barn on farm J ($P < 0.05$). Analysis of variance performed on data for all three farms indicated that there was significant difference of odour levels between nursery and dry sow barns ($P < 0.05$), but no significant difference between farrow and nursery barn or between farrow and dry sow barn ($P > 0.05$).

Variance analyses showed that odour emission rates were significantly ($P < 0.05$) different among the three types of barn on Farm G (farrow > nursery > dry sow) (fig. 16). On Farm J, the emission rate from the nursery barn was significantly ($P < 0.05$) higher than that from the dry sow barn, while there was no significant difference (P>0.05) between farrow and nursery barns as well as between farrow and dry sow barns. No significant (P > 0.05) difference in odour emission was found between the farrow and dry sow barns on Farm H. Analysis of variance performed on data for all three farms indicated that the emission rates from farrow and nursery barns were significantly (P <0.05) higher than that from dry sow barns and there was no significant (P > 0.05) difference between farrow and nursery barns. Similar result was found by Zhu et al. (1999) that nursery building had the highest odour emission rate compared with farrow and dry sow buildings.

Research on the correlation between odour level and barn type is limited. As odour emission from swine building varies upon many factors, without detailed information on the barn condition, feed ration, and manure property etc., it is hard to explain the variation of odour emission amongst different type of barns.

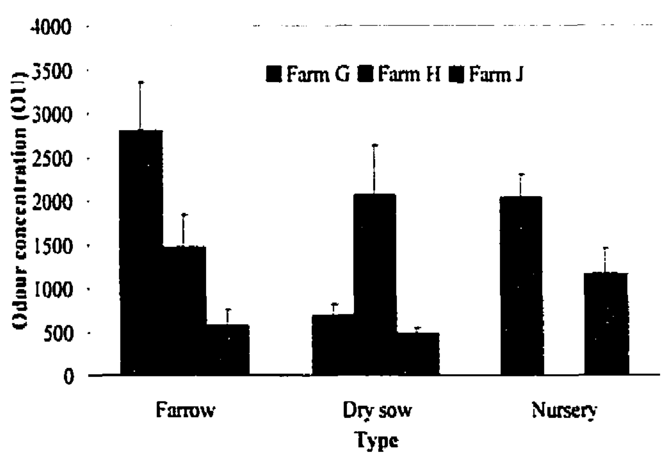

Figure 15 – Comparison of odour levels among three types of barn (T: standard deviation)

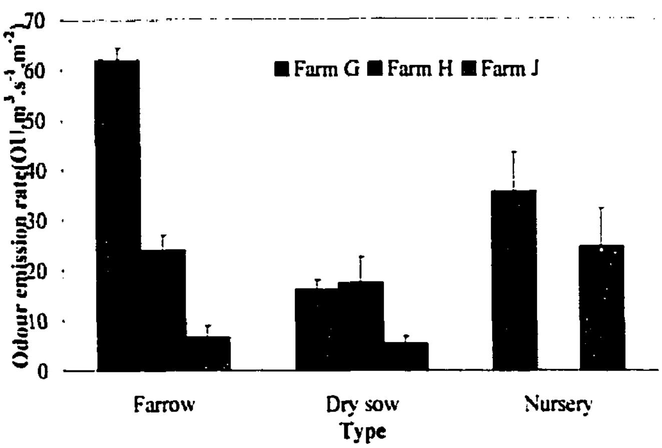

Figure 16 – Comparison of odour emission rates among three types of barn (T: standard deviation)

5.1.8 Odour emission as affected by animal density and stay-time

Two nursery farms (E and F) with a total of six nursery buildings were investigated in this study. An attempt was made to determine factors that affect the odour emission from nursery buildings, as affected by animal density (h/m^2) and stay-time. To eliminate the effect of variances between farms, odour levels and odour emission rates are presented in odour ratio and odour emission ratio respectively, which are the ratio of measured odour levels or odour emission rates to the average odour level or average odour emission rate of each individual farm.

Figure 17 shows the relative odour levels and odour emission rates at different amounts of stay-time. It shows the trend that both the odour level and odour emission rate increase when animals stay longer in the building. Because nursery buildings are generally only cleaned after each batch, as animals stay longer in the building, the pens, floors, walls, as well as animals are getting dirtier, this may cause more odour release. Also because animal weight increases with the stay-time, the heat production by animals will increase as well, which will lead to the increase of ventilation rates in the building and contribute to the increase of odour emission rate.

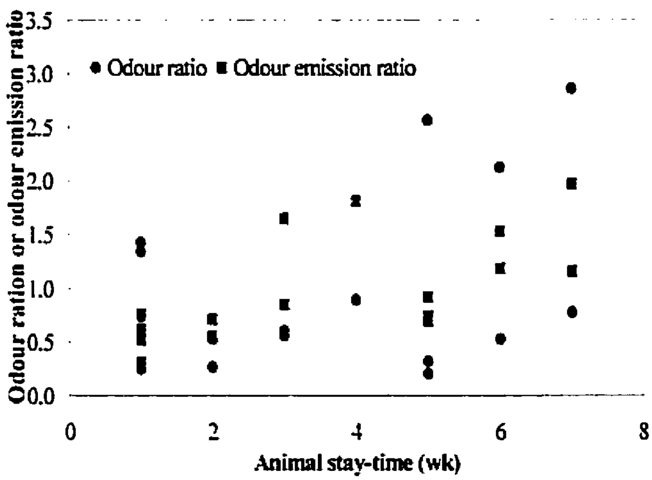

Fig.17- Measured odour ratios and odour emission ratios at different stay-time in nursery barns

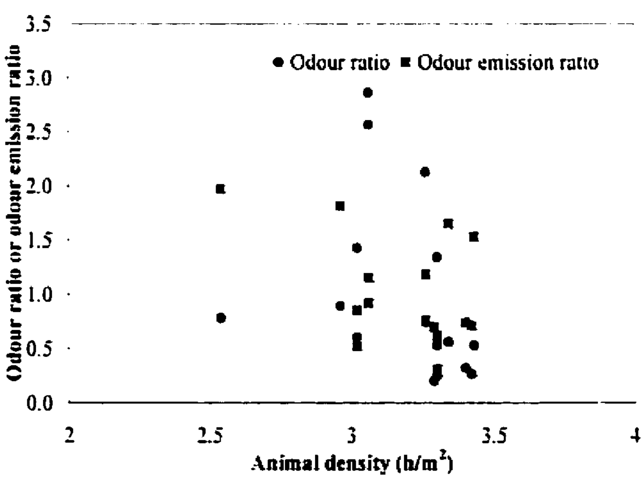

Fig.18 – Measured odour ratios and odour emission ratios at different animal density in nursery barns

Figure 18 shows the relative odour levels and odour emission rates at different animal densities. Both odour levels and odour emission rates did not show an apparent trend of change with the animal density. As the range of animal density in the buildings in this study was very small (mostly between 3.0 and 3.5 h/m^2), animal stay time became the dominant factor affecting odour levels from nursery buildings.

5.1.9 Odour emissions during the day

To investigate odour emissions at different times of the day, odour measurements were taken three times (morning, noon, and evening) on three days in August from one dry sow barn and one farrow barn on Farm H. The results showed that odour levels from the dry sow barn decreased slightly in the evening, and odour levels from the farrow barn increased in the evening (fig.19). Zhu et al. (1999) observed that odour levels did not vary drastically during the daily course for most of the swine buildings. However, Hartung et al. (1998) detected a decrease of odour concentration in the course of the day between 11 a.m. and 7 p.m. in maiden sow and fatteners buildings, which they believed was mainly due to the increased ventilation rate in the afternoon. The effects of animal activity on odour levels from swine buildings were addressed in both research.

The significant increase of odour emission rates in the afternoon and evening was observed in both farrow and dry sow barns ($P<0.05$) (fig. 20) in this study. This was mainly caused by the increase of ventilation rate in the afternoon and evening when outdoor temperature increased. Other researchers found the similar results. Hartung et al. (1998) found that the odour emissions from maiden sow and fatteners buildings increased at 11 a.m. until 1 a.m. in the course of the day, before they started to diminish until the next morning.

Zhu et al. (2000) observed a general trend of increasing odour emission rates for most animal facilities starting from 11:00 a.m. They both agreed that the increase of ventilation rate with the outside temperature rise in the afternoon plays a key role in determining the odour emission rates from animal buildings. Because only two barns at one farm were visited in this study, and both the sample period and the number of samples were limited, therefore variations of odour emissions during the day need to be further studied on more farms and at different seasons (e.g., spring and summer).

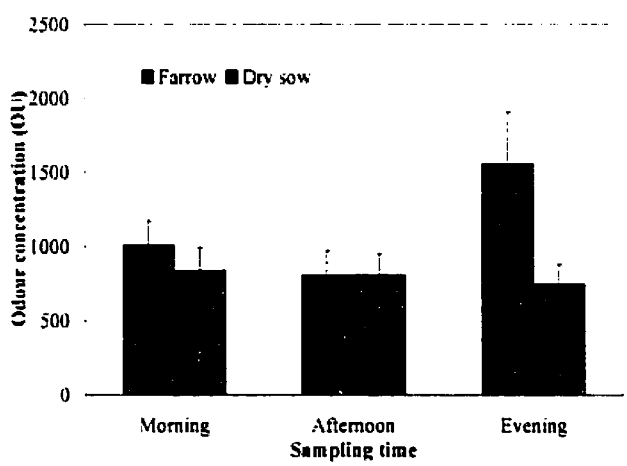

Figure 19 – Measured odour levels from farrow barn and dry sow barn at different times of the day on Farm H (T: standard deviation)

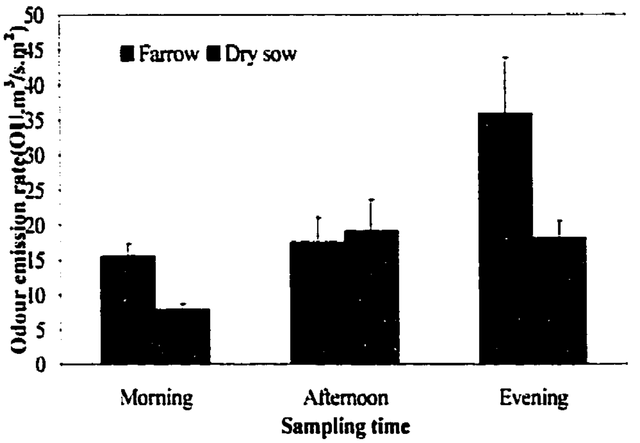

Figure 20 – Measured odour emission rates from farrow barn and dry sow barn at different time of the day on farm H (T: standard deviation)

5.2 Odour emission from earthen manure storage

5.2.1 Odour level and wind speed

An apparent trend was found that the higher the air velocity near the manure surface, the higher the odour level when measured close to the manure surface (fig. 21). It should be mentioned that these wind speeds were measured within 10 cm above the manure surface, and therefore, they should be lower than that measured at weather stations because of the berms and shelterbelts surrounding the storages. The results suggest that lowering the wind speed above the surface of manure storage by using surrounding shelterbelts is an effective measure to reduce odour release from manure storage.

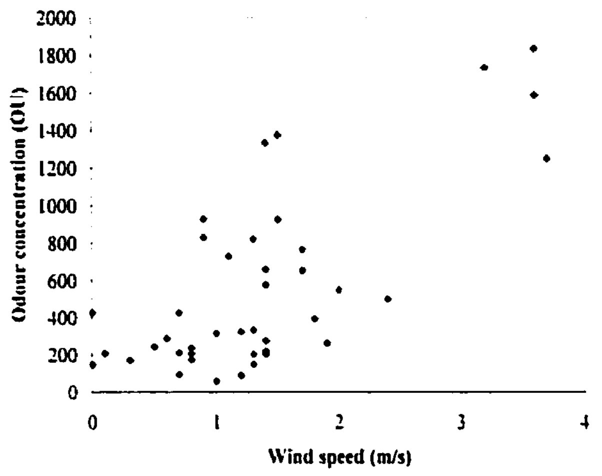

Figure 21– Correlation between wind speed and odour level measured within 10 mm above the manure surface in earthen manure storages (T: standard deviation)

5.2.2 Variation of odour levels among manure storages

Considering the effect of wind velocity on the odour levels from a manure surface. I realized that the air velocity above manure surface has to be taken into account when comparing odour levels among manure storages. As on most sampling days, the wind speed near the manure surface was less than 2.0 m/s, therefore, a sub set of data was selected for wind speeds less than 2.0 m/s for numerical comparisons of odour levels among the six farms. Fig.22 shows the farm-average odour levels measured on the six farms that had earthen manure storages. The highest farm-average odour level was measured on Farm I (697 OU), the lowest on Farm J (205 OU). This range was much less than that from barn exhaust (131 to 1842 OU). A variance analysis was performed on odour levels from the six farms. It showed no significant difference among the six farms in terms of odour levels above the surface of manure storage. Since the total odour emission from manure storage depends on the odour level and the surface area of manure (under certain wind conditions), if the odour level variation is minimal, the surface area becomes the dominant factor influencing the odour emissions from manure storages.

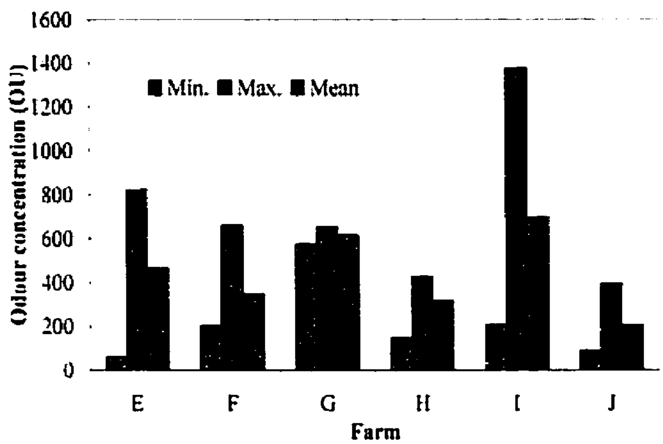

Figure 22 – Odour levels measured within 10 mm above manure surface in manure storages

5.2.3 Odour emission and sampling date

Fig. 23 shows the relative odour level (measured odour level/ farm average odour level) on different sampling dates, as well as the wind speed near the surface of the manure. Variance analysis showed that odour levels measured during May17-29 were significantly higher than those measured during July 1-11 ($P<0.05$), and there were no significant differences among other sampling periods ($P>0.05$). The results agreed with the observation by Jacobson et al. (1997) that odour levels from manure storage in spring is statistically significantly higher than that in summer or fall, because as temperature increases in the spring, combined with the build-up of solids from the winter, the biological activity of bacteria increases drastically at the bottom of the storage and a large amount of odourous gases are generated. When these gases move from the bottom to the surface of the storage, it may lead to the turn-over of the manure in the storage and more odorous gases are released. In the mean time, we have noticed that the wind speeds in the period of May 17 – 29 were also significantly higher than the period of Jul 1-11. Strong wind also plays a role in encouraging the turn-over of manure storage in the spring time.

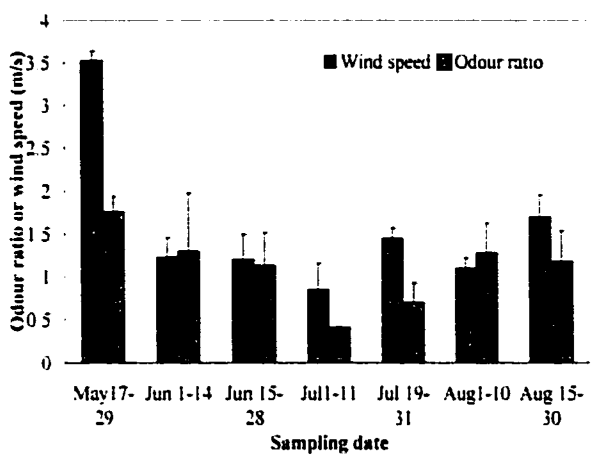

Figure 23 – Mesured odour levels near the manure storage surface in different sampling periods (odour ratio was defined as the odour level divided by the farm-average odour level) (T: standard deviation)

5.2.4 Variations of odour emission during the day

The odour levels near the surface of manure storage appeared to be higher in the evening than in the morning and at noon, even though the wind in the evening was not stronger than at other sampling times (fig.24). The possible reason could be that the temperature of manure in the storage tended to be higher in the evening than in the morning and at noon. This encouraged the bacterial activity in the manure and promoted the release of odorous gases.

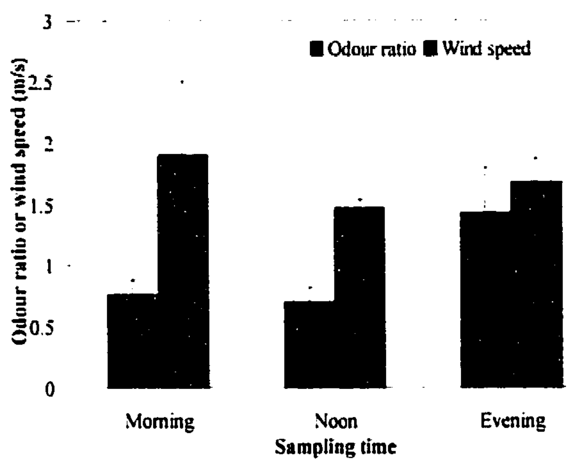

Figure 24– Measured odour levels near manure surface in erathen manure storages at different times of the day in August on Farm H

5.3 Downwind odour levels

Odour dissipated quickly with the distance downwind (fig. 25). Odour levels over 150 m away from the facilities were close to background odour level (20 – 60 OU). It should be pointed out that the downwind odour levels reported here were time-averaged odour levels, not instantaneous odour levels, because of the sampling method used in this study. The olfactometer is considered an industry standard for odour measurement. However, with unstable atmospheric conditions, changing wind speed and direction, obtaining downwind odour samples that are representative to what is actually "felt" by the receptors becomes impractical. When 10 L Tedlar bags were used to collect odour samples for olfactometry measurement, it took 5 to 10 minutes to fill a bag. The collected sample, therefore, reflected the odour level "averaged" over the sampling time. Instantaneous bursts of strong odour may be more of a concern than the average odour strength. Therefore, no conclusions could be drawn from this study with regard to the downwind odour levels from hog operations. Further research should be conducted to develop suitable methods for measuring instantaneous downwind odour levels.

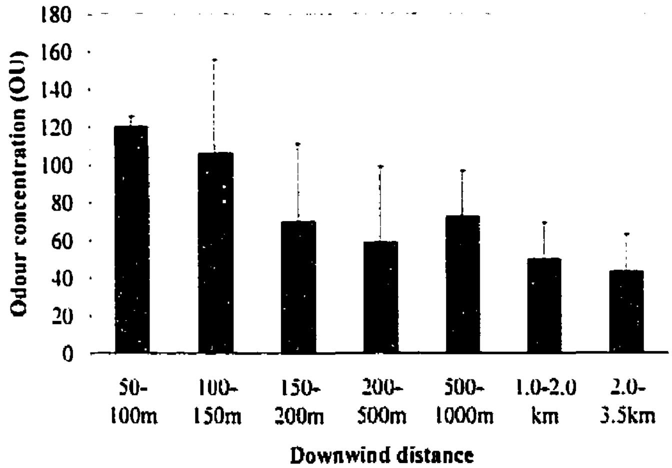

Figure 25 – Measured downwind odour levels (time-averaged) (T: standard deviation)

5.4 Odour emission from land application of manure with injection

To determine the odour emission from fields with applied manure, air samples were taken from fields both with and without manure applied. The emission rate measured on the soil with manure applied was 4.0 $OU \cdot m^3 \cdot s^{-1} \cdot m^{-2}$ which was not significantly different from that on the unmanured soil ($OU \cdot m^3 \cdot s^{-1} \cdot m^{-2}$) ($P > 0.05$) (fig. 26). For unmanured soil, the odour comes from soil itself, which unfortunately could not be differentiated from manure odour by the olfactometer. Air samples collected downwind at the ends (or sides) of the field on which manure was being applied also showed very low odour levels (average odour and H_2S

levels were 60 OU and 4 ppb, respectively). Other research (Pain et al.1991; Chen et al. 2000) have demonstrated that application of manure by injection can reduce odour emission from soil surface effectively. Our observation confirmed that manure injection caused little odour emission from soil.

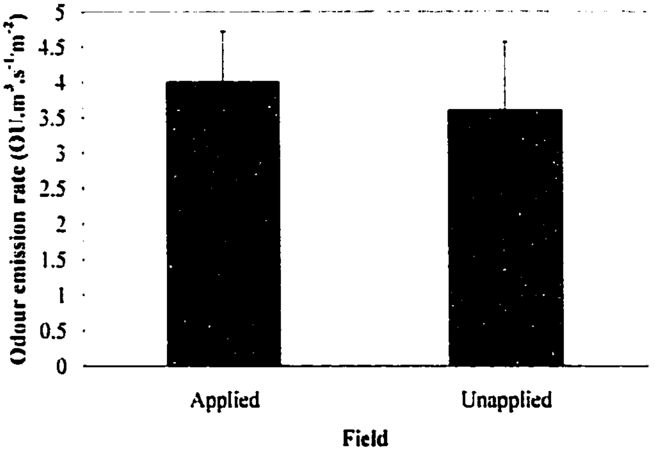

Figure 26 – Measured odour emission rate from the surface of manured and unmanured soil (T: standard deviation)

5.5 Odour and H_2S

Hydrogen sulfide (H_2S) is one of the main gases produced by anaerobic decomposition of swine manure. It draws a lot of attention from researchers, because it may not only cause health problems to both animals and farm workers in confined swine buildings (De Boer et al., 1991 (cited from Arogo et al. 1999b)), but also cause ecological damage by forming acid rain when released into the atmosphere (Arogo et al. 1999b). Hydrogen sulfide has been used by some researchers and regulatory agencies as a swine odour indicator (Miner, 1995), while other researches have found little correlation between swine odour and hydrogen swine odour and hydrogen sulfide (Jacobson et al. 1997). The data collected in this study showed that there appeared to be a positive correlation between the odour level and the H_2S concentration for both barn exhaust and lagoon odours (figs.27 and 28). The coefficients of correlation were 0.75 and 0.70 for barn exhaust and lagoon odours, respectively.

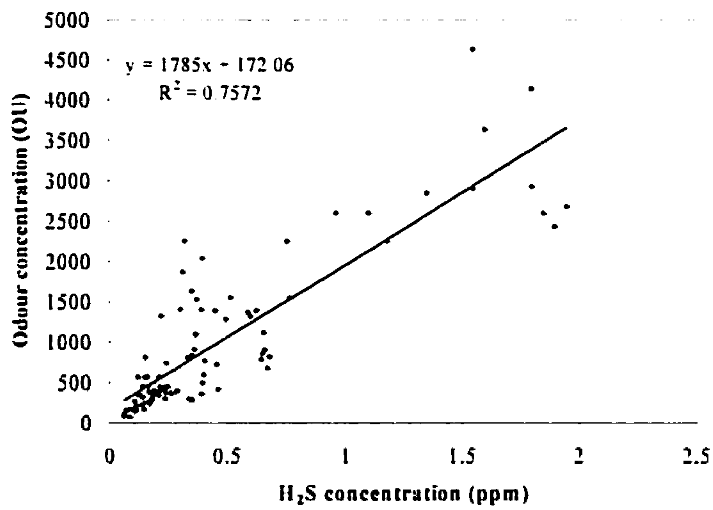

Figure 27 – Correlation between hydrogen sulfide concentration and odour level – barn exhaust

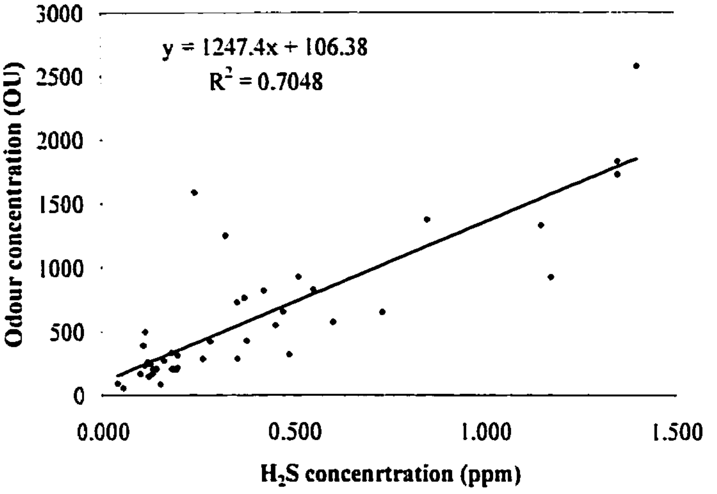

Figure 28 – Correlation between hydrogen sulfide concentration and odour level – manure storage

6. SUMMARY AND CONCLUSIONS

A large amount of odour data was collected in this study to compile baseline information on the characteristics of odour levels and odour emissions from typical hog operations in Manitoba. Samples were taken from building exhaust, manure storage, downwind, and land application of manure, and measured in hydrogen sulfide concentration by using a Jerome meter and odour concentration by using a dynamic-dilution olfactometer. Odour levels and odour emission rates were compared amongst the selected farms and within each individual farms. The variations of odour level and odour emission rate as affected by sampling date, outdoor temperature, barn type, and sampling time during the day were analyzed. Odour emission from manure injected soil was measured and compared with the emission from unmanured soil. Correlations were found between odour concentration and H_2S concentration for samples from both buildings and manure storages. Conclusions can be drawn from the study as follows:

Primary conclusions:

1. Odour levels from barn exhaust varied greatly among the ten farms and within some individual farms in the study. The farm-average odour level spanned from 131 OU to 1842 OU, and the greatest difference between the lowest and the highest odour levels measured on individual farm was from 245 to 4635 OU. No correlations were found between the odour level and the general farm characteristics, such as the age and type of operation, ventilation system, and manure handling system.
2. Farm-average odour emission rates from swine buildings ranged from 12 to 39

$OU \cdot m^3 \cdot s^{-1} \cdot m^{-2}$ on six farms included in the study.

Secondary conclusions:

1. Odour levels from building exhausts varied with the sampling time. Generally odour levels measured between May 17 and June 14 were significantly higher than other sampling periods (June 19 to September 19). However, there was no significant difference in odour emission rate during the entire sampling period.
2. Odour levels from barn exhaust were higher at lower outdoor temperatures. Odour emission rate was not significantly affected by outdoor temperature in the range measured in this study (12 – 42 ° C).
3. Odour levels did not vary drastically during the daily course, while odour emission rate increased significantly in the afternoon and evening.
4. Odour emission rates from farrow and nursery barns were higher than that from dry sow barns and no significant difference in emission rate was observed between farrow and nursery barns.
5. Animal stay time affected odour levels and odour emission rates from nursery buildings: odour level and odour emission rate increase when animals stay longer in the building.
6. Wind speed affected the odour level near the manure surface in storages: the higher the wind speed, the higher the odour level. Odour levels measured within 10 mm above the manure surface in six lagoons ranged from 205 to 615 OU when wind speed was less than 2 m/s. There was no significant difference of odour level among six studied storages when wind speed was under 2 m/s. Odour level above manure surface was stronger in the evening than in the morning and afternoon.

7. Land application of manure by injection caused little odour emission. There was no significant difference between the emission rates measured from the manured soil and that from the soil with no manure applied.
8. Farm-average H_2S levels from barn exhaust varied from 148 to 927 ppb and H_2S emission rates spanned from 6 to 25 $\mu g/s.m^2$. There were positive correlations between the odour level and the H_2S concentration for samples from both barn exhaust and manure storages.

7. RECOMMENDATIONS FOR FURTHER RESEARCH

Because there are many variables that affect odour from hog operations, and the data from this study was not sufficient for performing detailed statistical analyses to answer some practical questions. Furthermore, the olfactometer used in this study was not effective in measuring instantaneous downwind odour levels. Further research is recommended as follows.

1. Conduct detailed odour measurements in barns of the similar type to determine the effects of day-to-day barn conditions on odour emissions. The specific barn characteristics that should be examined include: pen (floor) cleanliness, washing frequency, manure properties, feed ration, and any measures for odour control.
2. Develop suitable methods for measuring instantaneous downwind odour levels.
3. Collect more odour data for comprehensive statistical analyses to compare odour levels and emissions among different types of barn, and to determine the effect of time of day on odour emissions in different seasons.

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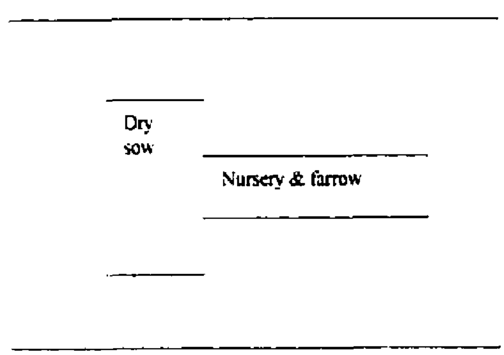
APPENDIX I
Description of Farms Included in This Study

FARM A



General Information
Type of Operation: farrow to finish
Age of Operation: 5 years
Capacity: 750 sows

Geography
Topography around Operation: flat prairie
Shelterbelt or Windbreak:
    Location: surrounding the operation
    Type: mature trees and bushes
    Distance from facility: 60 m

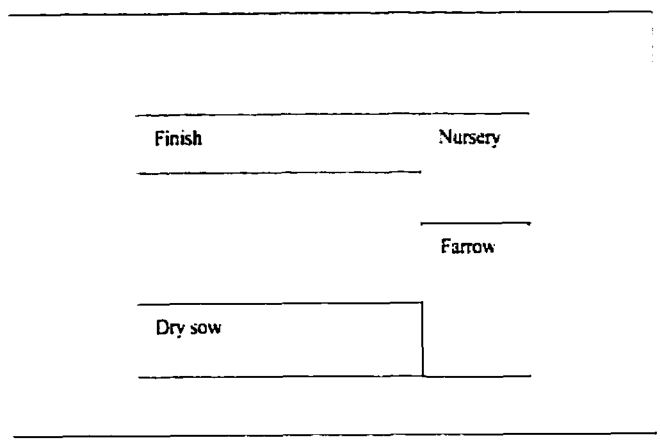
Building and Ventilation
Number of Buildings: 2
Building Size: dry sow: 20 x 90 m; farrow and nursery: 24 x 240 m
Floor Type (Material): slatted
Type of Ventilation: roof and wall mounted vents and fans
Filtration for Exhaust: none

Manure Management
Barn Washing Frequency: ~10 times/year
Hog Manure Handled as a Liquid/Slurry: yes
Collection/Storage Systems (Capacity):
    Indoor: shallow gutter
    Outdoor: above ground storage tank
Solid Manure Storage: no
Feed or Manure Additives: none
Area Used for Spreading Manure (acres): 1200
Season Applied & Percentage: storage emptied in Spring and Fall
Application Method: injection (4" deep)
Ground Conditions for Spread Area: stubble and tillage
Facility Proximity to Neighbours: 1.6 km

FARM B

General Information
Type of Operation: farrow to finish
Age of Operation: 10 years
Capacity: 350 sows

Geography
Topography around Operation: flat prairie
Shelterbelt or Windbreak:
    Location: around barns
    Type: oak and willow bushes
    Distance from Facility: 9 – 30 m



Building and Ventilation
Number of Buildings: 3
Building Size: grow/finish: 60x27 m; dry sow: 60x15 m; farrow & nursery: 30x24 m
Floor Type (Material): slatted
Type of Ventilation: wall mounted vents and fans
Filtration for Exhaust: no

Manure Management
Barn Washing Frequency: weekly
Hog Manure Handled as a Liquid/Slurry: yes
Collection/Storage Systems (Capacity):
    Indoor: scraper to push manure through floor opening
    Outdoor: open earthen storage
Solid Manure Storage: no
Feed or Manure Additives: none
Area Used for Spreading Manure (acres): 220 - 240
Season Applied & Percentage: Fall (100%)
Application Method: injection (4")
Ground Conditions for Spread Area: stubble
Facility Proximity to Neighbours: 200 m

FARM C

General Information
Type of Operation: farrow to finish
Age of Operation: 35 years
Capacity: 800 sows

no. 2

Geography
Topography around Operation: flat prairie
Shelterbelt or Windbreak:

Barn no. 1

Location: around barns
Type: mature trees

Building and Ventilation
Number of Buildings: 2
Building Size: barn no. 1: 45 x 8.4 m; barn no. 2: 10.8 x 14.4 m
Floor Type (Material): slatted (25%), solid (75%)
Type of Ventilation: negative pressure, ceiling inlets and wall mounted fans
Filtration for Exhaust: no

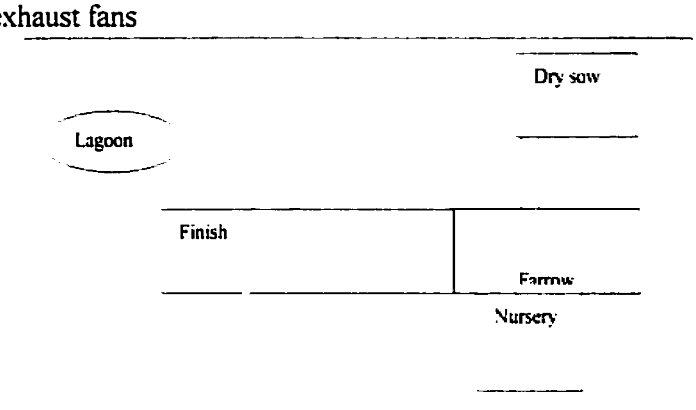
Manure Management
Barn Washing Frequency: 3 times/year
Hog Manure Handled as a Liquid/Slurry: yes
Collection/Storage Systems (Capacity):
Indoor: pits
Outdoor: tanks
Solid Manure Storage: no
Feed or Manure Additives: none
Area Used for Spreading Manure (acres): 500
Season Applied & Percentage: Fall (100%)
Application Method: injection
Ground Conditions for Spread Area: stubble
Facility Proximity to Neighbours: ~1.6 km

FARM D

General Information
Type of Operation: farrow to finish
Age of Operation: 40 years
Capacity: 120 sows

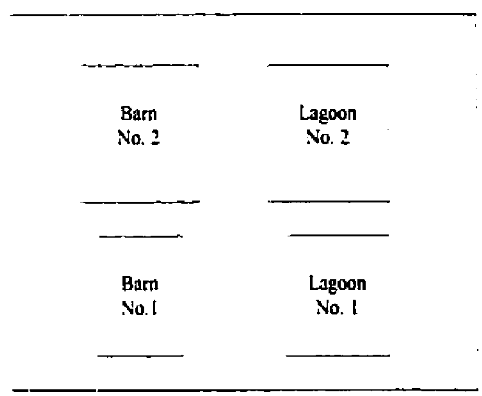
Geography
Topography around Operation: flat prairie
Shelterbelt or Windbreak:
Location: around barn and manure storage
Type: mature trees and bushes
Distance from Facility: 25 m

Building and Ventilation
Number of Buildings: 1 (three sections)
Building Size: farrow and finish: 10.8 x 63.6 m, nursery: 9 x 21 m. dry sow: 6 x 21 m
Floor Type (Material): slatted (55%), solid (45%)
Type of Ventilation: wall mounted vents and exhaust fans
Filtration for Exhaust: no



Manure Management
Barn Washing Frequency: weekly
Hog Manure Handled as a Liquid/Slurry: yes
Collection/Storage Systems (Capacity):
Indoor: pits (1 month capacity)
Outdoor: uncovered earthen storage
Solid Manure Storage: no
Feed or Manure Additives: none
Area Used for Spreading Manure (acres): 400
Season Applied & Percentage: Fall (100%)
Application Method: injection (4" deep)
Ground Conditions for Spread Area: stubble
Facility Proximity to Neighbours: < 0.8 km

FARM E



General Information
Type of Operation: nursery
Age of Operation: 3 years (old barn); 0.5 year (new barn)
Capacity: 2 x 2500

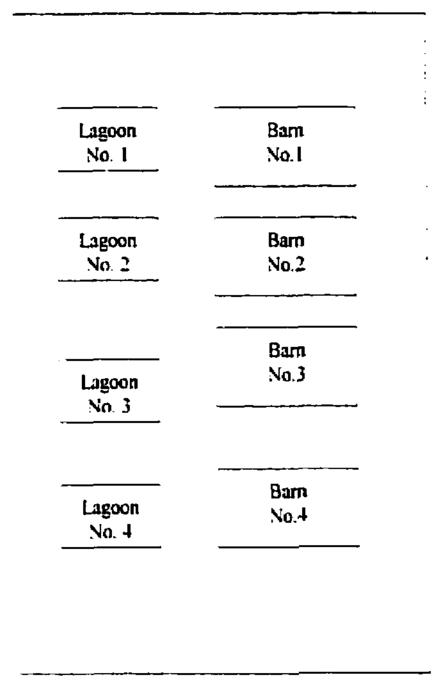
Geography
Topography around Operation: flat prairie
Shelterbelt or Windbreak:
- Location: around barns and manure storage facility
- Type: mature and young trees
- Distance from facility: 15 m and closer

Buildings and Ventilation
Number of Buildings: 2
Building Size: barn no. 1 (old): 46 x 17 m; barn no. 2 (new): 33 x 26 m
Floor Type (material): 20% solid (concrete), 80% plastic slatted
Interior Wall Finish Material: 60% plywood, 40% concrete
Type of Ventilation: wall mounted vents and exhaust fans
Filtration for exhaust: no

Manure Management
Barn washing frequency: 8 - 9 times/year
Hog manure handled as liquid/Slurry: yes
Collection/Storage Systems (Capacity):
- Indoor: shallow gutters (1-3 months)
- Outdoor: straw covered earthen storage (>12 months)
- Lagoon size: lagoon no.1: 30 x 18 m; lagoon no. 2: 30 x 30 m

Feed or Manure Additives: both used to reduce solids and odour
Area Used for Spreading Manure (acres): 50
Season Applied & Percentage: Fall (100%)
Application Method: injection
Ground Conditions for Spread Area: stubble
Facility Proximity to Neighbours: 0.8 km

FARM F



General Information

Type of Operation: nursery
Age of Operation: 4 years
Capacity: 10,000

Geography

Topography around Operation: flat prairie
Shelterbelt or Windbreak:

- Location: around barns and manure storage
- Type: young trees planted in 1998
- Distance from facility: 90 – 120 m

Buildings and Ventilation

Number of Buildings: 4
Building Size: 48 x 17 m each
Floor Type (Material): 10% solid, 90% slatted
Interior Wall Finish Material: 100 % plywood
Type of Ventilation: wall mounted vents and exhaust fans
Filtration for Exhaust: no

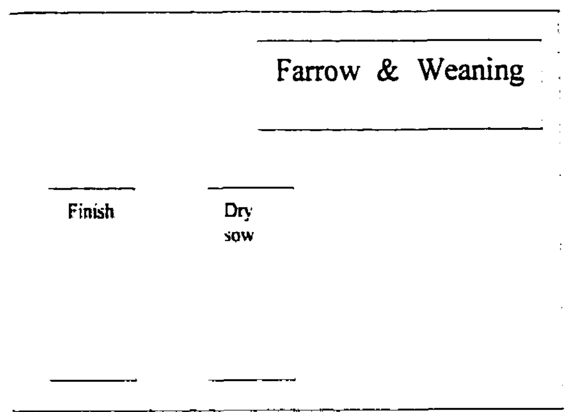
Manure Management

Barn Washing Frequency: 6.5 times/year (pressure wash and disinfect)
Hog Manure Handled as a Liquid/Slurry: yes
Collection/Storage Systems (Capacity):

- Indoor: shallow gutter (1-3 months)
- Outdoor: 4 uncovered earthen storages (>12 months)
- Lagoon size: 40 x 40 m each

Feed or Manure Additives: not anymore
Area Used for Spreading Manure (acres): 160 - 200
Season Applied & Percentage: fall
Application Method: 50% injection (4"-6" deep), 50% aerator roller (onto alfalfa)
Ground Conditions for Spread Area: 50% stubble, 50% hay or silage
Facility Proximity to Neighbours: 3.2 km

FARM G



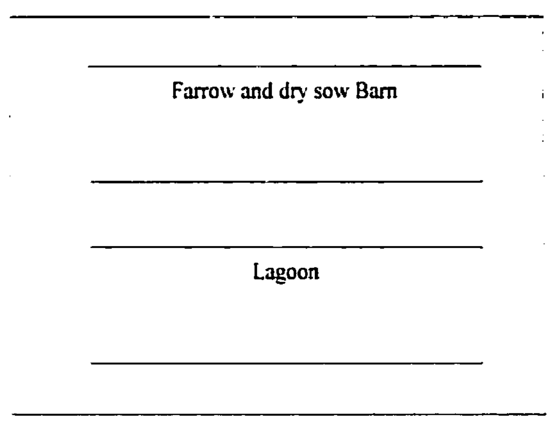
General Information
Type of Operation: farrow to finish
Age of Operation: 4 years
Capacity: 700 sows

Geography
Topography around Operation: flat prairie
Shelterbelt or Windbreak:
Location: around barns
Type: mature trees, bushes and fences
Distance from Facility: 60 m

Buildings and Ventilation
Number of Buildings: 3
Building Size: dry sow: 84 x 20 m; farrow and weaning: 114 x 30 m; finish: not included in this study
Floor Type (Material): dry sow: 50% slatted; farrow and weanling 100 % slatted
Interior Wall Finish Material: 35% plywood, 65% concrete
Type of Ventilation: wall mounted vents and exhaust vents
Filtration for Exhaust: no

Manure Management
Barn Washing Frequency: pull plugs monthly
Hog Manure Handled as a Liquid/Slurry: yes
Collection/Storage Systems (Capacity):
Indoor: shallow gutter (<1 month)
Outdoor: uncovered two cells lagoon (>12 months)
Lagoon size: 90 x 90 m each cell
Feed or Manure Additives: used to reduce odour
Area Used for Spreading Manure (acres): 240
Season Applied & Percentage: Fall (100%)
Application Method: Injection (4"-6" deep)
Ground Conditions for Spread Area: stubble
Facility Proximity to Neighbours: 0.8 km

FARM H



General Information

Type of Operation: farrow to early wean
Age of Operation: 2 years
Capacity: 3000 sows

Geography

Topography around Operation: flat prairie
Shelterbelt or Windbreak:

Location: around barn and manure storage
Type: bushes and trees planted in 1998
Distance from Facility: 90 –120 m

Buildings and Ventilation

Number of Building: 1
Building Size: 238 x 36 m
Floor Type (Material): farrow: 35 % solid and 65% slatted; breeding & gestation: 65% solid and 35 % slatted (concrete)
Interior Wall Finish Material: 100% plywood
Type of Ventilation: wall mounted vents and exhaust fans
Filtration for Exhaust: no

Manure Management

Barn Washing Frequency: pressure wash quarterly
Hog Manure Handled as a Liquid/Slurry: yes
Collection/Storage Systems (Capacity):

Indoor: shallow gutter (1-3 months)
Outdoor: uncovered earthen storage (>12 months)
Lagoon size: 238 x 36 m

Feed or Manure Additives: use to reduce manure odour
Area Used for Spreading Manure (acres): 640
Season Applied & Percentage: Fall (100%)
Application Method: injection (4" - 6" deep)
Ground Conditions for Spread Area: stubble
Facility Proximity to Neighbours: 2 km

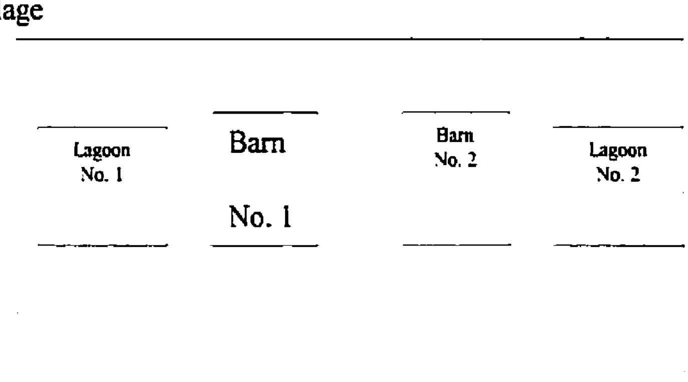
FARM I

General Information
Type of Operation: grow/finish
Age of Operation: 4 years
Capacity: 4000

Geography
Topography around Operation: flat prairie
Shelterbelt or Windbreak:
    Locations: around barns and manure storage
    Type: mature trees
    Distance from Facility: 12 – 45 m

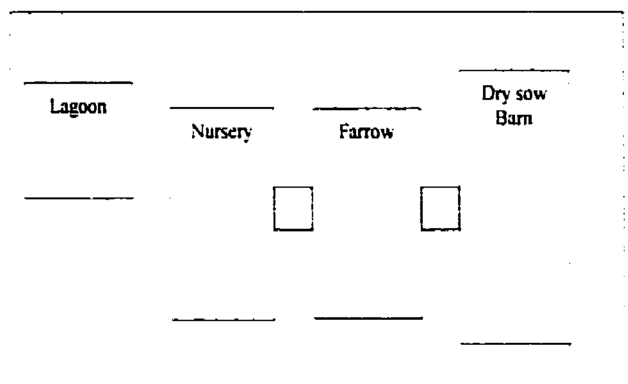
Buildings and Ventilation
Number of Buildings: 2
Building Size: 60 x 27 m each
Floor Type (Material): 80% solid, 20% slatted
Interior Wall Finish Material: 80% plywood, 20% concrete
Type of Ventilation: wall mounted vents and exhaust fans
Filtration for Exhaust: no

Manure Management
Barn Washing Frequency: pressure wash and disinfect 3 times/year
Hog Manure Handled as a Liquid/Slurry: yes
Collection/Storage Systems (Capacity):
    Indoor: shallow gutter (<1 month)
    Outdoor: uncovered earthen storage (>12 months)
    Lagoon size: lagoon no.1: 60 x30 m; no.2: 60 x 40 m
Feed or Manure Additives: used to reduce solids
Area Used for Spreading Manure (acres): 200
Season Applied & Percentage: Summer (100%)
Application Method: Aerway applicator and splash plate
Ground Conditions for Spread Area: hay or silage
Facility Proximity to Neighbours: 0.8 km



FARM J

General Information
Type of Operation: farrow to wean
Age of Operation: 2 years
Capacity: 2500



Geography
Topography around Operation: flat prairie
Shelterbelt or Windbreak:
  Location: around barn & manure storage
  Type: bushes & trees combination
  Distance from Facility: 200 feet

Buildings and Ventilation
Number of Buildings: 3
Building Size: nursery: 32 x 108 m; farrow: 32 x 108 m; dry sow: 32 x 178 m
Floor Type (Material): solid /slated
Interior Wall Finish Material: concrete
Type of Ventilation: roof mounted exhaust fans (chimneys)
Filtration for Exhaust: no

Manure Management
Barn Washing Frequency: pressure wash and disinfect: farrow: 3 times/year; dry sow: 2 times/year; nursery: 8 times/year
Hog Manure Handled as a Liquid/Slurry: yes
Collection/Storage Systems (Capacity):
  Indoor: shallow gutter (2 months), emptying once a week
  Outdoor: straw covered two-cell earthen storage (500 days)
  Lagoon size: cell 1: 60 x60 m; cell 2: 172 x 60 m
Feed or Manure Additives: yes
Area Used for Spreading Manure (acres): 1500 acres available. 800 acres used annually
Season Applied & Percentage: 50% fall and 50% spring
Application Method: injection
Ground Conditions for Spread Area: stubble/ fallow/ hay silage
Facility Proximity to Neighbours: 1.2 km

APPENDIX II
Summary of Odour Measurement Activities

Date	Farm	Sampling times and location
29-Apr-99	A	2 x dry sow exhaust; 2 x finish exhaust; 2 x downwind
13-May-99	D	1 x dry sow exhaust; 2 x finish exhaust; 2 x manure storage
20-May-99	B	2 x manure storage; 4 x downwind
27-May-99	C	2 x manure storage; 3 x downwind
3-Jun-99	D	3 x manure storage; 2 x downwind; 2 x nursery exhaust
17-Jun-99	B	2 x manure storage; 2 x downwind; 1 x finish exhaust
24-Jun-99	B	2 x manure storage; 4 x downwind; 2 x finish exhaust
5-Aug-99	C	2 x manure storage; 4 x downwind; 2 x finish exhaust
12-Aug-99	C	2 x manure storage; 4 x downwind; 2 x finish exhaust
9-Sep-99	A	2 x dry sow exhaust; 1 x manure storage; 4 x downwind
16-Sep-99	A	2 x dry sow exhaust; 6 x downwind
6-Oct-99	E	2 x nursery exhaust; 6 x downwind
21-Oct-99	H	2 x farrow exhaust; 6 x downwind (25 – 100 m)
18-Nov-99	I	2 x finish exhaust; 6 x downwind (25 – 100 m)
18-May-00	F	4 x nursery exhaust; 2 x manure storage; 4 x downwind (50 –120 m)
25-May-00	G	2 x nursery exhaust; 2 x dry sow exhaust; 2 x farrow exhaust; 2 x manure storage; 2 x downwind (150 m)
1-Jun-00	H	2 x farrow exhaust; 2 x dry sow exhaust; 2 x manure storage; 2 x downwind (200 m)
14-Jun-00	E	4 x nursery exhaust 1; 2 x manure storage; 2 x downwind (200 m)
19-Jun-00	I	4 x finish exhaust (2); 4 x manure storages (2); 2 x downwind (120 m)
21-Jun-00	G	2 x farrowing exhaust; 2 x nursery exhaust; 2 x dry sow exhaust; 2 x downwind (200 m)
26-Jun-00	E	4 x nursery exhaust (2); 4 x manure storages (2); 2 x downwind (300 m)
28-Jun-00	H	2 x farrow exhaust; 2 x farrow exhaust; 2 x manure storages; 2 x downwind (100 m)
5-Jul-00	F	8 x nursery exhaust (4); 2 x manure storage; 2 x downwind (100 m)
11-Jul-00	I	4 x finish exhaust (2); 4 x manure storages (2); 2 x downwind (100 m)
19-Jul-00	H	2 x farrow exhaust; 2 x dry sow exhaust; 2 x manure storage; 2 x downwind (150 m)
25-Jul-00	E	4 x nursery exhaust (2); 4 x manure storages (2); 2 x downwind (150 m)
31-Jul-00	G	2 x nursery exhaust; 2 x dry sow exhaust; 2 x farrow exhaust; 2 x manure storage; 2 x downwind (200 m)
2-Aug-00	F	8 x nursery exhaust (4); 2 x manure storage; 2 x downwind (800 m)
9-Aug-00	I	4 x finish exhaust (2); 4 x manure storages (2); 2 x downwind (260 m)
14-Aug-00 (Morning)	H	2 x farrow exhaust; 2 x dry sow exhaust; 2 x manure storage

14-Aug-00 (Noon)	H	2 x farrow exhaust; 2 x dry sow exhaust; 2 x manure storage
14-Aug-00 (Evening)	H	2 x farrow exhaust; 2 x dry sow exhaust; 2 x manure storage; 4 x downwind (150 – 380 m)
21-Aug-00 (Morning)	H	2 x farrow exhaust; 2 x dry sow exhaust; 2 x manure storage; 2 x downwind (120 m)
21-Aug-00 (Noon)	H	2 x farrow exhaust; 2 x dry sow exhaust; 2 x manure storage; 4 x downwind (670 – 2510 m)
21-Aug-00 (Evening)	H	2 x farrow exhaust; 2 x dry sow exhaust; 2 x manure storage; 4 x downwind (670 – 2510 m)
23-Aug-00 (Morning)	H	2 x farrow exhaust; 2 x dry sow exhaust; 2 x manure storage; 4 x downwind (900 – 1610 m)
23-Aug-00 (Noon)	H	2 x farrow exhaust; 2 x dry sow exhaust; 2 x manure storage; 4 x downwind (900 – 1610 m)
23-Aug-00 (Evening)	H	2 x farrow exhaust; 2 x dry sow exhaust; 2 x manure storage; 4 x downwind (900 – 1610 m)
30-Aug-00	J	2 x farrow exhaust; 2 x dry sow exhaust; 2 x nursery; 2 x manure storage; 4 x downwind (1820 – 3480)
31-Aug-00	J	2 x farrow exhaust; 2 x dry sow exhaust; 2 x nursery; 2 x manure storage; 4 x downwind (1900 – 3200 m)
19-Sep-00	J	2 x farrow exhaust; 2 x dry sow exhaust; 2 x nursery; 2 x manure storage; 4 x downwind (1900 – 3200 m)
4-Nov-99	Land	8 x downwind (0 – 100 m)
4-Nov-99	Land	8 x downwind (0 – 100 m)
1-Oct-00	Land	2 x right after application; 2 x 1-hour after application; 2 x open area; 2 x background; 2 x downwind
18-Oct-00	Land	4 x right after application; 2 x 1-hour after application; 2 x background; 2 x downwind
1-Nov-00	Land	2 x right after application; 2 x open area; 2 x background

APPENDIX III
Odour Sampling Information Sheet

Date ________________ Time ___________________ Operator ______________

General description of facility (size; locality; surroundings, eg, buildings. trees, etc) (use sketches)

Sketches

Distance (m)	Bag (sample) No.			Temp (°C)	RH (%)	Wind		Sky (% cloud)	Note
						Direction	Speed (m/s)		