Odours from Intensive Livestock Operations

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▪ Take Home Messages on Livestock Manure Odour

- Odour intensity associated with livestock facilities consists of a multitude of organic and inorganic compounds
- Odorous organic compounds result from incomplete anaerobic breakdown of manure; urea in urine is quickly lost as ammonia
- Dispersion greatly reduces exposure to high concentrations but odour can still linger out to 1 km from a livestock facility
- Management strategies can reduce odour and enhance the value of manure as a crop fertilizer

▪ Introduction

A challenge faced by the livestock industry is the utilization of the nutrients in animal manure in a sustainable manner. It has long been recognized that recycling manure back to the land is valuable as a source of nutrients for crop growth. This is especially true for nitrogen (N) where a high yielding dairy cow can excrete as much as 140 kg N annually and a large beef animal upwards of 87 kg N annually (Table 1: ECETOC 1994, van Horn 1995). However, the increased usage of inorganic fertilizer has reduced the demand for organic fertilizers in recent years. Despite this, the application of animal manure to crop land makes sense given the economical constraints of transporting manure long distances and the production of forages and cereals in the immediate area of livestock facilities. There is potentially a problem with the abundance of manure produced by intensive livestock facilities where accumulations of 2.1 tonnes per head annually are generated by feedlots and 16.6 tonnes of slurry (includes urine and wash water) per cow are generated from dairy operations (Bennett and McCarley 1995). The offensive odours associated with livestock facilities are caused by the production of intermediate volatile odorous compounds during the anaerobic microbial breakdown of livestock manure. The exposure of these odorous compounds to air during storage and land applications can contribute to poor air quality in the local region. Odour nuisance complaints are often used to gauge the severity of the air quality issues in a local region resulting from livestock facilities that are not managed in an environmentally sensitive manner. Several approaches exist to control odour, including diluting the odour by mixing with fresh air (use of a minimum separation distance), reducing the generation of odorous compounds by altering the feed, exposure or breakdown process, or by treating the odour.

Table 1. Reported annual excretion of nitrogen from agricultural animals.

Animal	Amount of nitrogen (kg N yr^{-1})
cow (9000 kg milk yr^{-1})	101 to 118
cow (600 kg milk yr^{-1})	101 to 140
beef cattle (<1 yr)	33 to 36
beef cattle (1-2 yr)	76 to 87
sheep	12 to 37
fattening pig	13
sow with piglets	33 to 39
laying hen	1

This paper presents information on the composition, detection, dispersion and some mitigation practices of offensive odour from cattle manure. In particular, data are reported from a study funded by the Canadian Alberta Beef Industry Development Fund on the composition and dispersion of the odour at cattle feedlots near Lethbridge, Alberta. In this area there is a feedlot capacity of 323 thousand head, 12.6 thousand dairy cows, 63 thousand swine and 500 thousand poultry.

■ Origin of Odour from Livestock Manure

The odour emitted from livestock manure is attributed to a multitude of volatile organic and inorganic compounds (upwards of 150 compounds). The main odorants in livestock manure include ammonia, hydrogen sulfide, amines, mercaptans, volatile fatty acids, and phenols. These odorous compounds originate from the breakdown of proteins (e.g., ammonia, hydrogen sulfide, mercaptans), carbohydrates (e.g., alcohols, aldehydes, ketones, organic acids) and fats (e.g., alcohols, acetic acid) (Barth and Polkowski 1974). Ammonia and alcohols combine to form amines while hydrogen sulfide and alcohols form mercaptans.

In the rumen of the animal, ammonia is used by microbes to synthesize amino acids. But if too much rumen-degradable protein is fed, or if lack of energy (carbohydrates) limits bacterial growth, excess ammonia is excreted as urea in urine. Once excreted, urea in the presence of microbes forms ammonium (NH_4^+) that can be converted to nitrate (NO_3^-) and used by plants. Alternatively, ammonium under the right conditions can form ammonia (NH_3) in soil that can volatilize into air. Volatile fatty acids (VFA) originate from the fermentation of carbohydrates. Undigested carbohydrates that are excreted as feces can continue to ferment and form VFA compounds. The main VFA compounds produced in manure are acetic, propionic, butyric, valeric and caproic acids.

Generally, ammonia and hydrogen sulfide are the predominant gases contributing to livestock odours; amines and mercaptans are also reported as significant odorants from beef cattle feedlots. Some gases can contribute to odour intensity (e.g., ammonia) while others contribute more to its offensiveness (e.g., volatile fatty acids, phenols and cresols). As a result, finding specific gases to act as tracers of odour intensity and offensiveness is not straightforward.

Ammonia has been researched extensively because of its economic and environmental importance. Ammonia losses can account for as much as 50% of the total ammonium-N in manure and is a significant economic loss in the nutrient value of the manure. The nutrient loss of ammonia may become more critical if recommended manure application rates change from being based on nitrogen to that of phosphorus content. The net result will be less nitrogen applied on land as manure and therefore maintaining high ammonia to phosphorus ratio will be very important. On the environmental side, ammonia has been identified as one of the major emissions by human activity (>95%; Isermann 1994) and a majority of this is attributed to agriculture. In Canada animal husbandry is identified as the major ammonia source (82%) followed by fertilizer use (18%). Our prior work in Alberta has shown that upwards of 380 kg ammonia per day per hectare is emitted from a swine lagoon while a 25,000 head feedlot emitted 3,445 kg of ammonia per day (0.138 kg per animal). We have no data on dairy operations in western Canada.

■ Detection of Odour from Livestock Manure by People

Gases that can be perceived by humans are first *detected* and at higher concentrations are secondly *recognized* distinctively. Odorants can become an *annoyance* (or nuisance) and eventually a physical *irritation* at ever increasing concentrations. Each type of sensory response is associated with a wide range in concentration due to the range in individual sensitivities.

The more common odorous compounds emitted from livestock manure are listed in Table 2 along with their lowest toxic and odour threshold values. Generally, volatilized compounds are smelled (if an odorant) before their concentration is high enough to be a health risk. The irritation threshold is generally orders of magnitude higher than the detection threshold. However, for ammonia the separation between detection and irritation is not that far apart. Our study, and others, suggests that the ammonia concentration associated with feedlots, and manure applied to land, is less than the threshold concentration required to cause irritation to eyes (25,000 to 50,000 parts per billion, ppb) but above the detectable threshold. While some individuals can detect ammonia as low as 600 to 4,700 ppb, it is reported that discomfort can exist at ammonia concentrations as low as 1,000 ppb. In most countries the occupational exposure limit is around 25,000 ppb. Hydrogen sulfide is detected at a much lower concentration than ammonia, around 0.5 ppb, and becomes toxic at 10,000 ppb.

Table 2. Livestock manure odorants and their threshold values.

Volatile	Toxic Level ppb	Odour Threshold ppb
ammonia	25000	4700
hydrogen sulfide	10000	0.5
acetic acid	10000	1000
butyric acid	5000	1
propionic acid	10000	34
phenol	5000	5
methyl mercaptan	500	2
ethyl mercaptan	500	1
trimethyl amine	10000	0.2
dimethyl amine	10000	47
methyl amine	10000	21
p-cresols	5000	1

Generally gases emitted from livestock facilities quickly disperse in the surrounding air and become diluted with distance from the facility. However, dilution of the emitted odorants below a detectable human level may not always occur for some distance, i.e., due to sources and/or poor dispersion. Within some distance, odorous compounds can be high enough to result in an odour nuisance, which is defined as the presence of offensive odour air at such an intensity, concentration, frequency and duration as to >materially interfere= with the normal use and enjoyment of property.

Evidence on the impact of odours from cattle manure on nearby residences is generally testimonial in nature. Most studies on the subject involve odour from swine operations that is high in hydrogen sulfide gas. Symptoms associated with exposure to livestock manure gases include eye, nose and throat irritations as well as headache and drowsiness (Schiffman 1998). Exposure to odours also coincides with a higher incidence of mood disorders (tension, depression, anger, fatigue and less vigour) for people who experienced odours from a swine operation.

Some effort has been made to document toxic thresholds of individual gases and the resulting symptoms of exposure, while little data have been gathered on validating the reported health effects of low concentrations or the mixture of gases on human health. Generally, it has not been established whether exposure to a compound in the *annoyance* range (odour nuisance at concentrations high enough to elicit *detection* but below the *irritation* threshold) should be deemed a health concern, and if so, what importance to place on it. One reason for the lack of research has been due to the difficultly in validating reported symptoms.

In our study of feedlot odorous emissions, only ammonia and butyric acid (out of 14 compounds measured) were close to or above the odour threshold (Table 3), suggesting that these contributed to the odour intensity adjacent to feedlots. For butyric acid, the concentration was nine times the odour threshold adjacent to the feedlot and 28 times the odour threshold adjacent to a field where manure from the feedlot was applied.

Table 3. Averaged maximum concentration of odorous compounds adjacent a feedlot and manure amended field.

Compound	Adjacent Feedlot ppb	Adjacent Field ppb
ammonia	863 (1047)	-
acetic acid (VFA)	45.4	21.7
propionic acid (VFA)	11	19.5
butyric acid (VFA)	9.2	28.5
isobutyric acid (VFA)	1.4	5.4
valeric acid (VFA)	1.5	2
isovaleric acid (VFA)	1.6	6.8
caproic acid (VFA)	1.2	1.2
phenol	0.1	>0.1
p-cresol	>0.1	>0.1
o-cresol	>0.1	0
m-cresol	>0.1	0
indole and skatole	0	0

( ) indicates values during cleaning of the pens

It is expected that the concentration of odorous compounds will vary over the day as the stability of the boundary layer changes. For example, higher concentrations were monitored during the night and morning when the air next to the ground does not mix readily and therefore dilution is poor. This is illustrated for ammonia in Fig. 1 (June 28 1999) where a peak downwind concentration (at 200 m) of 810 ppb was recorded at 10:00 am which quickly dropped off to the minimum value of 280 ppb at 2:00 pm as the air became well mixed. As the evening approached, the dispersion became poor again as indicated by the increase in ammonia concentration. A similar pattern was reported by Luebs et al. (1974) for dairies.

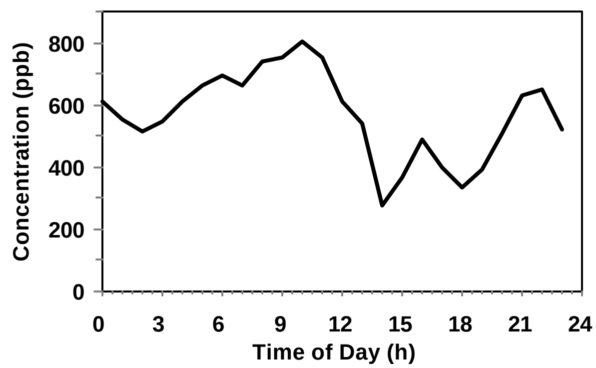

Figure 1. Diurnal variability in ammonia concentration (ppb) recorded 200 m downwind of a feedlot with a laser sensor.

■ Odour Dispersion Around Livestock Facilities

Determining the odour offensiveness or intensity by monitoring single (or several) odorous compounds is an indirect measure which can underestimate the air quality. Therefore, quantifying odour is commonly done either by directly scaling the odorous air against a known concentration of an odorous compound, or by using a dilution scale. In both cases, a selected panel of individuals is used to provide an average value of intensity. In our study of feedlot odours, an olfactometer was used based on the dilution approach. The intensity of the odour sample is characterized based on the number of times a very diluted air sample is concentrated before reaching a level where 50% of the observers register detection. The unit of measurement is called the dilutions-to-threshold value, DT. The offensiveness of the odour can also be characterized at a given DT value, where the sample is rated against a standard odorant.

In a 4,000 head feedlot in Texas (Sweeten et al. 1977), the DT value of odour was reported to range from 1.5 (weak odour) to nearly 170 (very strong odour). A more typical value was 31 DT (moderately strong odour) that was reduced to less than 2 DT (weak odour) within 380 to 500 m downwind. Studies have suggested that odour is generally decreased by a factor of 10 within the first 500 m. Catchment ponds were also significant sources of odour where DT values ranged from 46 to 68.

In our feedlot study, odour intensity was sampled downwind of feedlots at 10, 100, 200 and 1,000 m (Fig. 2). Adjacent the feedlot on May 27, odour intensity approached 24 DT and dropped to 9 DT at 1,000 m. On June 8, lower values were recorded (15 to 2 DT).

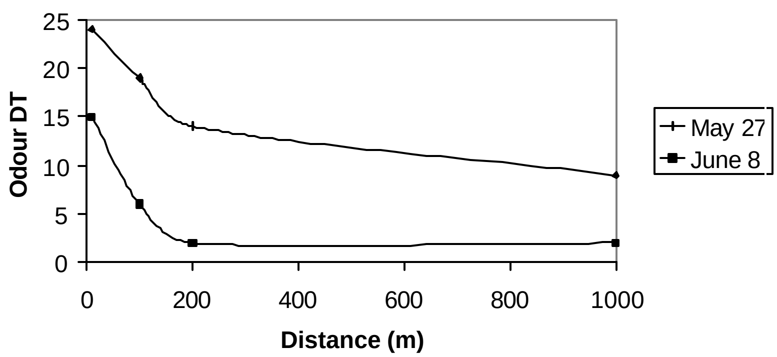

Figure 2. Odour dispersion downwind of a feedlot on two different days in 1999.

The downwind odour dispersion is expected to change as a function of surface moisture and temperature, and wind speed. A typical downwind dispersion curve found in our feedlot study is shown in Fig. 3 for ammonia and three predominant VFA compounds. There was considerable variability in the dispersion curves between days (Fig. 3a) but, in general, concentrations approached the background concentration (found upwind of the feedlot) within 200 m. For example, the ammonia concentration dropped from 504 to 32 ppb over 200 m (May 25-26) and from 188 to 52 ppb (June 9-10) over this same distance. Of the three VFA compounds (Fig. 3b) acetic acid (45 ppb adjacent the feedlot) was found at the highest concentration followed by propionic acid (11 ppb) and butyric acid (7 ppb). However, only butyric acid exceeded the odour threshold (1 ppb) out to distance of about 150 m.

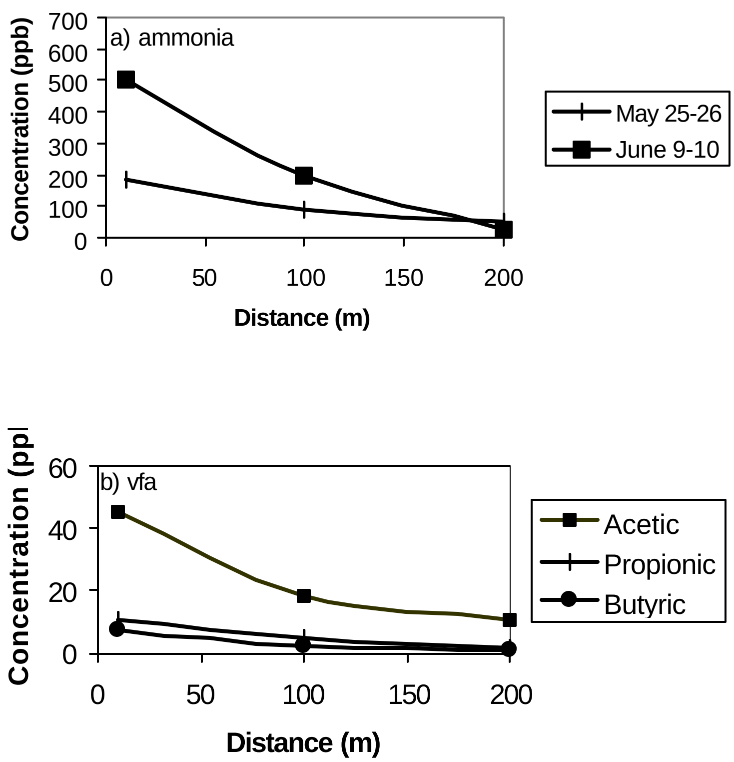

Figure 3. Dispersion of a) ammonia and b) volatile fatty acids downwind of a feedlot.

Our feedlot study suggests that within a few hundred metres, dispersion is adequate to reduce the odour intensity below the odour threshold of individual compounds. However, on some days a high odour intensity was monitored out to a distance of 1,000 m. There is some evidence from other studies that this discrepancy may be attributed to the additive nature of odorous compounds with regard to their combined concentration being detectable.

■ Mitigation of Odour Emissions

The best methods of reducing odour nuisances involve careful site selection, good facility design and management, and positive relations with local residences. Some odour control can be gained by altering manure decomposition or by using practices to reduce the exposure of manure to air. Some of the methods that can be used to reduce odours are listed in Table 4 and are discussed below. Most of these methods have been developed to reduce ammonia volatilization.

Table 4. Methods identified which can reduce odour emissions.

Strategy		Reduction % (NH_3)
feeding	minimise protein over-consumption (dairy).	10-25
	feed additives e.g., calcium bentonite.	
housing/pens	flush floor frequently (dairy).	50-80
	well designed pens (feedlots) with 2-6% slope for drainage for rapid drying.	
	adjust stocking rate to reduce manure moisture content during wet season (feedlot).	
	use of biofilters on exhaust air (dairy).	
	reduce biological activity, e.g., use of urease inhibitors to reduce ammonia production .	
storage pits /lagoons	rigid lid or roof	80
	flexible or floating cover	60
	artificial crust (e.g., straw)	40
	natural crusts	35
	acidification of slurry (lowers NH_3 but can increase H_2S)	40
	reduce biological activity, e.g., use of lime, formaldehyde, hydrogen peroxide	
	use of salts or absorbent material	
	aeration of system (lagoon)	
land application	band spreading of slurry	30
	injection of slurry (open slot)	60
	injection of slurry (closed slot)	80
	incorporate solids (within 4 h)	80
	incorporate solids (within 24 h)	40
	increase infiltration into the soil (irrigation, diluting, removing solids)	
	apply on cool and wet day	14

Minimum Distance Separation Guidelines

At the forefront of strategies for reducing odour, are guidelines on the distance between livestock operations and residential areas, referred to as the minimum distance separation (MDS) criteria. The odour, perceived as an annoyance by the downwind residences, is reduced by dispersing the odour plume. In Alberta, MDS guidelines take into account animal type and weight, number of animals, typical manure handling practice, and the surrounding land use (sensitivity). For example, the Alberta MDS for a typical 10,000 head feedlot near Picture Butte, Alberta, and a large-scale country residence development is 1,470 m. Using a comprehensive approach developed for farms in Austria, the MDS is comparable at 1,166 m (Schauberger and Piriniger 1997). In many US states, MDS is fixed by experience and is generally less than 1,600 m. For a dairy facility the Alberta guidelines are based on the number of milking cows and type of surrounding land use; for a 200-herd facility in proximity to a large-scale development, the MDS is 513 m.

Our feedlot study suggests that dispersion varies throughout the day and hence so to does the exposure at downwind locations. In addition, estimating odour intensity is best done using a direct measure of odour as opposed to monitoring individual compounds. Although individual compounds may be below their odour threshold, lingering odour intensity may exist due to odorous gases acting in an additive fashion with regard to odour intensity.

Additives to Feed

Research on diet formulation has indicated the potential for reducing ammonia volatilization while maintaining cattle weight gains. One approach is to use feeds appropriately balanced for type and level of dietary protein. Some feed additives, such as ionophores, can have an impact on the volatile fatty acids produced in the rumen by shifting fermentation patterns toward propionic acid and away from more objectionable fatty acids such as butyric acid. There is also the potential to use by-pass protein to reduce urea content in urine and thereby reduce ammonia volatilization. A more balanced intake of protein for dairy cows has been shown to reduce nitrogen excreted by 33% and hence the potential conversion of this nitrogen to odorous compounds. Bentonite in beef cattle feed was also shown to slightly reduce the odour (Sweeten et al. 1977). Combining feeding strategies which reduce volatile compounds in feces and urea in urine, with manure management controls which reduce the odour, will ensure that the value of the manure is retained while reducing feed costs and overall odour from cattle facilities and land-applied manure.

Our feedlot study also involved comparing treatments of feedlot cattle fed a control diet, and two types of supplemental protein, i.e., urea, which is totally degraded in the rumen, and blood meal, which is high in rumen undegradable protein. The chambers were designed and used to monitor differences in volatilized gases over five-day periods throughout the summer. A second study looked at antibotic additives in the diet. In both trials, air samples were collected periodically and analysed for odour intensity and composition. Results to date suggest little effect of treatment in reducing odour emission. It follows that in our study, the controlling factor on odour emissions was the state of anaerobic conditions in the feedlot pens as related to moisture content of the manure and not necessarily the composition of the manure in the pen.

Stored Manure

Wet feedlot pens promote anaerobic conditions and more odorous emissions. The use of straw in bedding enables more air to permeate the manure, creating more aerobic conditions for decomposition and therefore creating less odour. Wetting pens for dust control may have a negative impact if the manure becomes saturated and anaerobic decomposition dominates. It is suggested that the optimum moisture content to minimize both dust and anaerobic conditions is between 25 to 40% in the feedlot situation. For dairy, the use of straw cover (5 cm thick) on storage lagoons was shown by Xue et al. (1999) to reduce ammonia and hydrogen sulphide losses by 95% by the third week after applying. Any cover that reduces exposure to air will reduce odorous gas emissions.

The volatility of some compounds depends on whether the manure is acidic or alkaline. Managing pH is more common is swine slurry where a balance is struck between the release of hydrogen sulfide (acidic conditions) and ammonia (alkaline conditions). Generally, altering pH affects the type of odour and does little to reduce the odour intensity. Other additives can modify the decomposition process to promote fewer odorants. For example, urea is rapidly hydrolysed to ammonia by microbial urease. Inhibitors can be added to retard this conversion thus reducing ammonia production and volatilization. Other products containing bacteria or enzymes are intended to alter decomposition but this is a difficult task given the abundant numbers of microbes naturally occurring in manure.

Applying Manure to Land

Weather conditions at the time of manure application can be used as an effective management tool to reduce ammonia losses. For example, periods with a high drying index would generally enhance volatilization of gases and cause an increase in odours. Rain can act to dilute manure and ensure infiltration into soil. In one study, it was shown that ammonia loss during a warm and windy period was 56% of applied ammonium-N while during a cool and rainy period this was reduced to 42% (Bless et al. 1991). Although there are many methods available for incorporating and injecting slurries, for solid beef cattle manure few of these are practical. In our feedlot study, surface applied manure ammonia losses accounted for 20% of ammonium-N; irrigation with 6 mm following application reduced this loss to 10% while incorporating manure with tillage lost 4% of the ammonium-N as ammonia.

■ Conclusion

In our preliminary data from last summer, cattle feedlots were identified as a source of odour consisting of at least ammonia, VFA compounds, cresols and phenol. However, there was generally good dispersion downwind so that at a distance of 1 km, odours often approached the background level. On some occasions, there was still a lingering odour at 1 km. The background ammonia concentration was within the range expected for an area with livestock, and was well below the toxic threshold. Although concentrations were not found at toxic levels, there are a number of survey studies reporting health symptoms due to the presence of odour alone. Further work is needed to address possible health issues at sub-toxic level exposure. Where odour nuisance issues exist, strategies are available to help producers with reducing odour from their operations. However, in western Canada there has been little work to date on either quantifying odours or developing strategies to reduce these odours from dairy operations.

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