CHARACTERISTICS AND EMISSION RATES OF ODOR FROM COMMERCIAL SWINE NURSERIES


ABSTRACT. Odor emission rates and characteristics were evaluated at two commercial swine nurseries in Indiana during the months of March, April, and May. The nurseries, housing 94 to 250 pigs, were mechanically ventilated with long-term manure storage pits under wire floors. Incoming ventilation air at one of the nurseries was tempered in a heated hallway. An eight-member odor panel evaluated odor concentration with a dynamic olfactometer and odor intensity and hedonic tone at full strength. The odor concentration of incoming ventilation air ranged from 7 to 85 odor units per cubic meter (OU m–3) and averaged 18 OU m–3. It ranged from 94 to 635 OU m–3 and averaged 199 OU m–3 in the ventilation exhaust air. The mean odor emission rates of the two nurseries were 18.3 and 62.5 OU s–1 AU–1 (1.1 and 2.7 OU s–1 m–2), respectively. The overall mean odor emission rate was 34 OU s–1 AU–1 (1.8 OU s–1 m–2). The measured emission rates are expected to be lower than those that follow stringent panel sensitivity requirements not currently required by olfactometry standards in the U.S.

Keywords. Odor evaluation, Manure management, Ventilation system, Air flow rate, Air quality.

Odor nuisance continues to be a major issue for the swine industry, which is an important sector of the agricultural economy in the United States. Therefore, a significant amount of research has been initiated to better understand the nature and control of odor emissions from swine production.

The source emission rate is an important input to atmospheric dispersion models (Gryning et al., 1987; Mejer and Krause, 1986; Smith, 1993; Watts, 2000; Zhu et al., 1998). It is also needed for the development and implementation of parametric setback guidelines (Lim et al., 2000; Schaubberger and Piringer, 1997) that are intended to ensure sufficient dilution by atmospheric dispersion between animal facilities and neighboring residences and businesses.

Dilutions to threshold (DT) or odor concentration is assessed by diluting samples with known amounts of odor–free air and presenting the dilutions to a panel of human subjects using an olfactometer, a dilution apparatus. The DT is the number of dilutions with odor–free air required for an odor to be perceived by 50% of the panel (Norén, 1987). One odor unit is defined as the amount of odorant in one cubic meter of air at the panel threshold (Thièle, 1986). The DT of a sample is often expressed as odor units per cubic meter (OU m–3) for calculation of odor emission rate (CEN, 1999). Thus, the gross odor emission rate (OU s–1) from a livestock building is the product of the ventilation airflow rate (m3 s–1) and the odor concentration (OU m–3) in the exhaust air. Because incoming air may be odorous, the difference in odor concentration between ventilation inlet and outlet air is used to calculate the net odor emission or only the odor generated in the room (Miller et al., 2001; Smith and Dalton, 1999; Watts, 1999). To allow comparison with other research results, odor and gas emission rates are normalized to the number and weight of animals by dividing the total emission rate by the number of animal units (AU = 500 kg live weight) (Ni et al., 2000; Oldenburg, 1990; Wathes et al., 1997). Area–specific emission rates are determined by dividing the total emission rate by the floor area (Groop Koerkamp et al., 1998).

Heber et al. (1998) measured odor emission rates from four mechanically ventilated swine finishing houses between April and August. The buildings had long–term manure storage beneath fully slatted floors. The mean odor concentration of 109 measurements was 142 OU m–3, and the mean odor emission rate was 36 OU s–1 AU–1 (5.0 OU s–1 m–2).

Jacobson et al. (1998) measured odor and gas reductions from sprinkling soybean oil in nursery pig rooms located in Minnesota. The mean odor concentrations at the ventilation exhausts of the control and treatment rooms were 461 and 251 OU m–3, respectively. These rooms had pigs weighing 7–16 kg for two 6–week growth cycles between December and March. The mean odor concentration measured in another nursery in Minnesota by Liu et al. (1993) averaged 487 OU m–3. Airflow rates were not reported in either of these studies, so it was not possible to derive odor emission rates.

Amon et al. (1995) and Verdoes and Ogink (1997) measured odor emission rates from swine buildings using the Dutch NVN 2820 olfactometry standard. The 1995 version of the NVN 2820 standard (NNI, 1995) results in DT values that are 2 to 5 times higher than the draft standard CEN TC264...
(CEN, 1999) currently being followed by many laboratories in Europe, Australia, and Canada (Watts, 1999). Amon et al. (1995) reported a mean exhaust fan odor concentration of 2,800 OU m\(^{-3}\) at 600-pig (8 to 27 kg) nursery buildings located in Slovenia. Airflows were measured by traversing fan outlets with a hot wire anemometer. The experiments were carried out in the autumn with mean inside temperatures of 25\(^\circ\)C. The buildings were mechanically ventilated and equipped with manure pits underneath a fully slatted floor. The mean odor emission rate of all buildings was 488 OU s\(^{-1}\) AU\(^{-1}\). Verdoes and Ogink (1997) measured odor emissions from a partly slatted pig nursery, which was designed for low ammonia emission. The mean exhaust fan odor concentration and odor emission rate were 2,109 OU m\(^{-3}\) and 272 OU s\(^{-1}\) AU\(^{-1}\), respectively. The mean ventilation rate and inside temperature were 9.2 m\(^3\) h\(^{-1}\) pig\(^{-1}\) and 27\(^\circ\)C, respectively.

Zhu et al. (2000) reported the results of odor emission measurements in a 475-head nursery with mechanical ventilation and a deep pit. Seven measurements were made two hours apart during one sampling visit to the nursery. The mean weight of the pigs was 20.5 kg. The means of exhaust fan odor concentration and building odor emission rate were 765 OU m\(^{-3}\) and 149 OU s\(^{-1}\) AU\(^{-1}\), respectively. The mean ventilation rate and inside temperature were 31 m\(^3\) h\(^{-1}\) pig\(^{-1}\) and 27\(^\circ\)C, respectively.

Odor emissions from swine buildings measured in Australia were 2 to 4 times greater in summer than in winter (Watts, 1999). The greatest increase occurred when inside temperatures exceeded 25\(^\circ\)C. The data also showed that increased humidity increases odor emissions. The author also concluded that regular flushing of waste out of buildings reduces odor emissions compared to deep-pit systems. Watts (1999) concluded from an extensive review of Australian research that an appropriate estimate of annual mean odor emission rates for new swine houses (pig type not specified) in Australia with daily manure removal by flushing is 150 OU s\(^{-1}\) AU\(^{-1}\) (NVN 2820 olfactometry). Estimated winter and summer odor emission rates were 100 and 200 OU s\(^{-1}\) AU\(^{-1}\), respectively.

Measurements of odor concentration alone are insufficient to assess human perception of odor (Misselbrook et al., 1993) and additional parameters such as intensity and hedonic tone more thoroughly characterize odor. Odor intensity is the relative perceived psychological strength of an odor and is independent of the knowledge of odor concentration (McGinley and McGinley, 2000). For a single chemical odorant, odor intensity increases as a power function of its concentration (Nicolai et al., 2000). Hedonic tone is the degree to which an odor is subjectively perceived as pleasant or offensive (McGinley et al., 2000) and is more closely related to odor annoyance than any other odor measurement variable. Offensive odors become more offensive at higher concentrations (Sobel, 1972). Such perceptions of hedonic tone are strongly influenced by previous experience, personal preference, and the emotional context in which the odor is perceived. Some odor abatement processes alter an odor’s hedonic tone without significantly changing its concentration.

Stevens (1957) established that a sensation is proportional to the stimulus raised to a power. This relationship is known as Stevens’ Law and has been applied to intensity (sensation) and concentration (stimulus) of livestock odor (Bundy et al., 1997; Misselbrook et al., 1993; Nicolai et al., 2000; Sweeten et al., 1983; Zhu et al., 1998).

Quantification of odor emissions from typical commercial swine facilities is needed to: (1) assess nuisance potential and setback distances, (2) provide source inputs to odor dispersion models and setback guidelines, (3) compare research results, (4) gain understanding of emission characteristics, and (5) build a database that reveals relationships between building types, design, and management. Swine nurseries with pigs weighing up to 25 kg are typically held at higher temperatures than other buildings and are considered an important source of nuisance odor at swine facilities. Therefore, the objectives of this research were to:

1. Determine typical odor emission rates from pig nurseries.
2. Evaluate effects of total pig mass on odor emission rates.
3. Evaluate nuisance characteristics of odor emitted from swine nurseries.

**MATERIALS AND METHODS**

**DESCRIPTION OF NURSERY ROOMS**

Odor emission rates were measured in two commercial pig nurseries (figs. 1 and 2). The nursery rooms were in buildings separated by 1.6 km and were owned and operated by the same producer. Both rooms were mechanically ventilated and equipped with wire floors, 1.8 m deep manure storage pits, wall exhaust fans, and pit exhaust fans. The ventilation systems were similarly designed and were controlled with integrated environmental control systems (Model DS-2A.2, Fancom BV, Panningen, The Netherlands). The variable-speed pit fans operated continuously. The pits had about 0.3 m of manure remaining after the pits were pumped out in spring and autumn. Both rooms were power washed and disinfected between groups of pigs (growth cycles). The pigs were 3 to 10 weeks old and were fed a standard corn-soybean diet with 17.40% crude protein and 14.64% digestible protein. It included 0.370% calcium, 0.621% total phosphorus, and 0.415% available phosphorus.

Room A (7.5 × 10.9 m) was 19 years old and consisted of a pit exhaust fan and two wall exhaust fans on the east wall, a heater on the west side of the room, and slotted eave inlets on both sidewalls (fig. 1). Room B (6.7 × 8.5 m) was 10 years old and consisted of two fans facing north, and a doorway entrance from a heated hallway in the south end wall (fig. 2). A rigid recirculation duct equipped with a manually controlled fan distributed air from the hallway via an opening above the door. The producer anecdotally characterized room B as the “stuffer” room.

**FIELD SAMPLING PROCEDURE**

Five sampling visits were made to each nursery and nine or ten air samples were collected during each visit. Sampling visits were conducted on March 5 and 17 and April 9, 16, and 23 for room A, and on March 10 and 26 and May 5, 19, and 26 for room B. The first two visits to each room occurred near the end of pig growth cycles. Visits 3, 4, and 5 were conducted during the subsequent growth cycle. Data collection on each day consisted of the following steps:

1. Record variable-speed fan control voltage and set environmental controller to manual control mode to prevent changes in ventilation rate during the sampling procedure.
2. Record time.
3. Measure ambient dry and wet bulb temperatures with a motorized psychrometer.
4. Collect air samples after at least 10 min of step 1.
6. Measure dry and wet bulb temperatures inside the room.
7. Reset fans to automatic control.
8. Collect manure samples and measure depth of manure.
9. Count and record pig numbers.
10. Record average pig mass as estimated by the herdsman.

Odor samples were collected between 10:00 and 11:45 at room A and between 9:45 and 11:20 at room B except for one day when samples were collected between 12:25 and 13:10 at room B. The samples were evaluated on the same day during a 3.5 h (maximum) olfactometry session. Samples were collected using 0.05 mm thick, 10–L, Tedlar bags with stainless–steel fittings. The bags were flushed with either compressed air or nitrogen gas at least three times prior to sampling. New bags were used for each sample collection as recommended by the European draft olfactometry standard CEN TC264 (CEN, 1999). To reduce adsorption losses, 2–3 L of sample air was introduced into each bag and removed before filling the bag with sample air. An air pump (Model 224–PCXR8, SKC, Inc., Eighty–Four, Pa.) created negative pressure inside the air sample collecting chamber (SKC Vac–U–Chamber), causing air to flow directly into the bag.

Ventilation inlet and outlet samples were collected simultaneously during each replication. Air sampling locations at room A included the air at the outlet of the pit exhaust fan and incoming ambient air at the east and west slotted air inlets (fig. 1). Air was sampled in room B at the vent panel in the hallway, the air inlet to the recirculation duct, and the pit fan (fig. 2). Because of low ambient temperatures, the wall exhaust fans did not operate except for a brief time during one of the sampling visits. Outlet samples were therefore only taken at the pit fans.

**Manure Analysis**

Manure samples were collected in triplicate during the last three sampling visits to each nursery. Profile samples were obtained by lowering a sampling probe (Coliwasa Sampler, Animal Environment Specialists, Rossville, Ind.) to collect manure from the top to the bottom of the pit. The contents from several probings were poured into a bucket and thoroughly mixed. A subsample of the mix was taken and stored in a sealed 237 mL plastic bottle, placed in an insulated container with ice, and transported to the laboratory freezer. The dry matter (DM) content was analyzed gravimetrically at 90°C. Total nitrogen (TKN) was determined by the micro–Kjeldahl nitrogen method (Nelson and Sommers, 1972). Ammonium nitrogen (NH₄⁺–N) was determined using the steam distillation method (Bremner and Keeney, 1965). For phosphorous (P) and potassium (K), manure samples were wet ashed by refluxing with concentrated HNO₃ for 2 h prior to analysis of the digest. Analysis of K was determined by atomic absorption spectrophotometry. Analysis of P was evaluated according to Murphy and Riley (1962).

**Calculation of Odor Emission Rates**

Room odor emission rate (E) was determined by multiplying the total airflow rate of the ventilation fans by the increase in odor concentration between the room ventilation inlet and outlet (Smith and Dalton, 1999):

\[
E = Q \Delta C
\]
where

\[ E = \text{net odor emission rate from the nursery, assumed to be equivalent to odor generated inside the room (OU s}^{-1}) \]

\[ Q = \text{room ventilation rate (m}^3\text{s}^{-1}) \]

\[ \Delta C = \text{difference in odor concentrations between ventilation inlet and exhaust air.} \]

For room B, the odor concentration in the hallway exhaust air was used in equation 1 as the ventilation inlet air. Specific emission rates were calculated by dividing E by the number of animal units or by the floor area.

All references to odor emission in this article imply net odor emissions unless explicitly stated otherwise. Gross emission rates were calculated with equation 2 to allow comparison to emission measurements with no corrections for inlet air or background concentrations (Amon et al., 1995; Heber et al., 1998; Jacobson et al., 1998):

\[ E_G = Q C_O \]  

(2)

where

\[ E_G = \text{gross rate of odor emission from the exhaust fans (OU s}^{-1}) \]

\[ C_O = \text{odor concentration of the room exhaust air (OU m}^{-3}). \]

**ODOR EVALUATION PROCEDURE**

**ODOR CONCENTRATIONS**

Odor detection thresholds were measured with a dynamic dilution forced-choice olfactometer (AC’SCENT International Olfactometer, St. Croix Sensory, Stillwater, Minn.) according to U.S. olfactometry standards (ASTM, 1991). The odor panel consisted of eight human subjects who were screened to determine their odor sensing ability (ASTM, 1986). The olfactometer delivered precise mixtures of sample and dilution air to a Teflon-coated presentation mask at a total flow rate of 20 L min\(^{-1}\). The dilution ratio of a mixture was the ratio of total diluted sample flow volume to the odor sample flow volume. For example, a dilution ratio of 10,000 was achieved with 2 cc min\(^{-1}\) of sample flow and 20 L min\(^{-1}\) of total flow.

Starting with an extremely high dilution ratio, a step-by-step series of ascending concentrations (step factor = 2) was presented to each panelist. A triangular forced-choice test was conducted whereby the panelist sniffed three sequential sample coded gas streams at each dilution step. One gas stream was randomly assigned to have the odor while the other two gas streams were odor-free. The panelist selected which of the three presentations was “different” (even if no difference was perceived) and thus contained the odor (ASTM, 1991). The panelist declared whether the selection was a “guess” (no perceived difference), “detection” (selection is different from the other two), or “recognition” (selection smells like something). Initial samples were so diluted that they could not be distinguished from odor-free air. Higher and higher odor concentrations (2-fold increases) were presented until the panelist, without guessing, correctly selected the sample in two consecutive steps.

An individual best-estimate DT was calculated by taking the geometric mean of the last nondetectable dilution ratio and the first detectable dilution ratio. The panel DT was reported as the geometric mean of the individual DTs.

**INTENSITY AND HEDONIC TONE**

The odor panel evaluated intensity and hedonic tone directly from full-strength gas samples. Panelists assessed intensity of a sample by objectively matching it to one of a series of n-butanol solutions in water contained in 120–mL wide-necked bottles. This procedure followed the reference scale method (ASTM Standards, 1992). Reference scale solutions were prepared using AR-grade n-butanol (Mal- linckrodt Baker, Paris, Ky.) and odor-free de-ionized water, with concentrations ranging from 10 to 10,240 ppm in geometric series with a factor of 2.

The sample bag was manually compressed, forcing the sample air to flow through a Teflon PTFE tube to a glass funnel (6 cm face diameter). Panelists were instructed to sniff the unknown air sample from the glass funnel and then to sniff the reference solutions beginning with the weakest end of the scale, and to match the unknown to the scale, ignoring differences in odor quality. Panelists were trained to shake reference solutions gently before sniffing them and to recheck the unknown against the reference scale any number of times. Odor intensity was reported as concentration (ppm) of n-butanol in water (BIW). Intensity values were geometric means of panel members’ ratings.

Panelists rated hedonic tone of each sample at the same time as intensity. The hedonic tone scale ranged from −10 (extremely unpleasant) to 0 (neither pleasant nor unpleasant) to +10 (extremely pleasant) (McGinley et al., 2000). The reported hedonic tone was the arithmetic mean of panel members’ ratings. The relationships between odor concentration, intensity, and hedonic tone were evaluated by power function regressions according to Stevens’ Law (Stevens, 1957).
RESULTS AND DISCUSSION

ODOR QUANTITY

The geometric mean odor concentration of incoming ambient air samples was 18 OU m⁻³. It ranged from the lower detection limit of 7 OU m⁻³ to 85 OU m⁻³ (table 1). Occasionally, ambient air has odor from surrounding facilities, causing higher ambient air concentrations. In room B, odor concentrations increased as ambient air flowed through the hallway into the nursery. The hallway, which was used to move pigs and feed, contained residues of odorous organic matter. Odor concentration of ventilation air entering room B from the hallway ranged from 14 to 187 OU m⁻³ and averaged 53 OU m⁻³. Odor increased in both nurseries as air flowed through the room to the pit fans. Odor concentrations at the pit fans ranged from 94 to 635 OU m⁻³ with a mean of 199 OU m⁻³. These exhaust concentrations were similar in

Table 1. Means and 95% confidence intervals of variables (visit means) measured in the two swine nurseries.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Room A (mean ±95% ci)</th>
<th>Room B (mean ±95% ci)</th>
<th>Both (mean ±95% ci)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of pigs</td>
<td>229 ±22</td>
<td>100 ±6</td>
<td>164 ±47</td>
</tr>
<tr>
<td>Mean pig mass (kg)</td>
<td>13.5 ±0.4</td>
<td>13.8 ±0.2</td>
<td>13.6 ±0.5</td>
</tr>
<tr>
<td>Stocking density (kg m⁻²)</td>
<td>37.1 ±2.5</td>
<td>23.7 ±0.8</td>
<td>30.4 ±1.2</td>
</tr>
<tr>
<td>Ventilation rate (m₃ h⁻¹ AU⁻¹)</td>
<td>659 ±286</td>
<td>1030 ±415</td>
<td>844 ±259</td>
</tr>
<tr>
<td>Inside temperature (°C)</td>
<td>21.3 ±1.3</td>
<td>21.8 ±1.5</td>
<td>21.6 ±0.9</td>
</tr>
<tr>
<td>Inside relative humidity (%)</td>
<td>57.2 ±4.8</td>
<td>61.6 ±7.9</td>
<td>59.4 ±4.4</td>
</tr>
<tr>
<td>Ambient temperature (°C)</td>
<td>11.3 ±5.4</td>
<td>12.4 ±9.9</td>
<td>11.9 ±5.0</td>
</tr>
<tr>
<td>Outside relative humidity (%)</td>
<td>67.8 ±25.8</td>
<td>53.8 ±9.9</td>
<td>60.8 ±13.2</td>
</tr>
<tr>
<td>n-butanol ODC (ppb)</td>
<td>916 ±406</td>
<td>813 ±284</td>
<td>865 ±212</td>
</tr>
<tr>
<td>Odor concentrations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incoming ambient air at building ventilation inlet</td>
<td>log OU m⁻³</td>
<td>1.28 ±0.34</td>
<td>1.24 ±0.20</td>
</tr>
<tr>
<td></td>
<td>OU m⁻³</td>
<td>19.0</td>
<td>17.4</td>
</tr>
<tr>
<td>Room ventilation inlet from hallway</td>
<td>log OU m⁻³</td>
<td>—</td>
<td>1.72 ±0.35</td>
</tr>
<tr>
<td></td>
<td>OU m⁻³</td>
<td>—</td>
<td>52.5</td>
</tr>
<tr>
<td>Odor characteristics of pit exhaust air</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Concentrations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>log OU m⁻³</td>
<td>2.13 ±0.08</td>
<td>2.47 ±0.28</td>
</tr>
<tr>
<td></td>
<td>OU m⁻³</td>
<td>134</td>
<td>296</td>
</tr>
<tr>
<td>Hedonic tone</td>
<td>–6.03 ±0.79</td>
<td>–5.73 ±2.07</td>
<td>–5.88 ±0.99</td>
</tr>
<tr>
<td>Intensity, log BIW</td>
<td>2.76 ±0.15</td>
<td>3.07 ±0.37</td>
<td>2.91 ±0.21</td>
</tr>
<tr>
<td>Odor emission rate (net)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>per building</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>log OU s⁻¹ (eq. 1)</td>
<td>1.97 ±0.14</td>
<td>2.19 ±0.32</td>
</tr>
<tr>
<td></td>
<td>OU s⁻¹ (eq. 1)</td>
<td>93</td>
<td>156</td>
</tr>
<tr>
<td></td>
<td>log OU s⁻¹ (eq. 2)</td>
<td>2.05 ±0.13</td>
<td>2.35 ±0.34</td>
</tr>
<tr>
<td></td>
<td>OU s⁻¹ (eq. 2)</td>
<td>113</td>
<td>223</td>
</tr>
<tr>
<td>per animal unit</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>log OU s⁻¹ AU⁻¹ (eq. 1)</td>
<td>1.26 ±0.21</td>
<td>1.80 ±0.20</td>
</tr>
<tr>
<td></td>
<td>OU s⁻¹ AU⁻¹ (eq. 1)</td>
<td>18.3</td>
<td>62.5</td>
</tr>
<tr>
<td></td>
<td>log OU s⁻¹ AU⁻¹ (eq. 2)</td>
<td>1.35 ±0.26</td>
<td>1.95 ±0.23</td>
</tr>
<tr>
<td></td>
<td>OU s⁻¹ AU⁻¹ (eq. 2)</td>
<td>22.4</td>
<td>89.4</td>
</tr>
<tr>
<td>per unit area</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>log OU s⁻¹ m⁻² (eq. 1)</td>
<td>0.055 ±0.144</td>
<td>0.435 ±0.320</td>
</tr>
<tr>
<td></td>
<td>OU s⁻¹ m⁻² (eq. 1)</td>
<td>1.14</td>
<td>2.72</td>
</tr>
<tr>
<td></td>
<td>log OU s⁻¹ m⁻² (eq. 2)</td>
<td>0.143 ±0.129</td>
<td>0.590 ±0.338</td>
</tr>
<tr>
<td></td>
<td>OU s⁻¹ m⁻² (eq. 2)</td>
<td>1.39</td>
<td>3.89</td>
</tr>
<tr>
<td>Depth of manure in pit (m)</td>
<td>0.65 ±0.37</td>
<td>0.60 ±0.41</td>
<td>0.63 ±0.25</td>
</tr>
<tr>
<td>Manure characteristics (last three visits only)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Kjeldahl nitrogen (mg L⁻¹)</td>
<td>5235 ±789</td>
<td>2999 ±371</td>
<td>4117 ±895</td>
</tr>
<tr>
<td>AmmoniacaF nitrogen (mg L⁻¹)</td>
<td>3289 ±321</td>
<td>1963 ±136</td>
<td>2626 ±506</td>
</tr>
<tr>
<td>Dry matter (%)</td>
<td>5.74 ±1.94</td>
<td>3.23 ±0.49</td>
<td>4.49 ±1.25</td>
</tr>
<tr>
<td>Phosphorus (mg L⁻¹)</td>
<td>1153 ±345</td>
<td>1745 ±386</td>
<td>1449 ±307</td>
</tr>
<tr>
<td>Potassium (mg L⁻¹)</td>
<td>1844 ±88</td>
<td>979 ±63</td>
<td>1411 ±319</td>
</tr>
<tr>
<td>pH</td>
<td>5.91 ±0.27</td>
<td>7.42 ±0.07</td>
<td>6.67 ±0.56</td>
</tr>
</tbody>
</table>

[a] Computed based on entire floor area.
[b] Mean of last three visits of each nursery.
[c] Significantly different at P < 0.05 level
[d] Significantly different if pig mass included as covariate.
magnitude to the 461 OU m⁻³ mean concentration measured in a Minnesota nursery (Jacobson et al., 1998). The mean pit fan odor concentration of room B (296 OU m⁻³) was 121% higher (P < 0.05) than that of room A (134 OU m⁻³) (table 1). The mean n–butanol ODC of the last six odor measurement sessions was 865 ppb (table 1). Thus, the olfactory sensitivity of the odor panel (selected and managed according to existing U.S. standards) was lower than that required by the CEN TC264 olfactometry standard (CEN, 1999) by a factor of 22. This difference is too large to make a normalizing adjustment of odor concentrations to the CEN standard.

The mean odor emission rate of both nurseries was 33.8 OU s⁻¹ AU⁻¹ or 1.76 OU s⁻¹ m⁻². Net odor emission rates (eq. 1) were about 40% lower than gross odor emissions (eq. 2). Thus, caution should be taken in comparing net odor emissions to gross emissions often reported by other research. The overall mean gross odor emission rate was 44.7 OU s⁻¹ AU⁻¹ or 2.3 OU s⁻¹ m⁻² as compared to 36 OU s⁻¹ AU⁻¹ or 5.0 OU s⁻¹ m⁻² at swine finishing buildings with deep pits (Heber et al., 1998). Based on these two studies using different olfactometry laboratories, pig nurseries with deep pits emit about 25% more odor per animal unit and about 50% less odor per unit floor area than finishing pigs. Although both studies followed U.S. olfactometry standards, measurements using olfactometry that is proven to give comparable results are needed to confirm these relationships between nursery and finishing buildings.

The mean odor emission rate of 63 OU s⁻¹ AU⁻¹ from room B was significantly higher (P < 0.05) than the 18 OU s⁻¹ AU⁻¹ from room A (table 1). The difference between mean area–specific odor emission rates from rooms A and B (1.1 and 2.7 OU s⁻¹ m⁻², respectively) was statistically significant based on an analysis of variance conducted with pig mass as a covariate (fig. 3). Each nursery showed increasing area–specific odor emissions with larger pigs (P < 0.05), confirming the results of Amon et al. (1995).

The more odorous nursery (room B) had only 3.2% dry matter of manure in the pit as compared to 5.7% dry matter in the less odorous nursery (room A) (table 1). Corresponding to higher solids content, the mean concentrations of total Kjeldahl nitrogen, ammonium nitrogen, and potassium were 75%, 68%, and 89% higher (P < 0.05) in room A. This trend was consistent with the results of a controlled laboratory experiment (Heber et al., 2000a) that showed significantly higher odor emission rates from diluted (1:1) finishing pig slurry after two weeks in simulated pits (Heber et al., 2000a).

This phenomenon may be due to ammonia or acid inhibition of odor–producing bacteria in manure with higher solids content. The relatively low manure pH of 5.9 in room A gave some evidence of acid inhibition, while the mean manure pH in room B was 7.4. The pH in room A was similar to measurements of pH 5.6 to 6.4 in simulated pits charged with nursery pig manure (Taraba et al., 2000).

Another difference between the two nursery rooms was that a hallway was used in room B to preheat incoming ventilation air. The resulting higher temperature of incoming air may have contributed to a greater release of odor from surfaces near the inlets.

**ODOR QUALITY**

The overall mean odor intensity and hedonic tone of exhaust air samples were 813 ppm BIW and −5.9, respectively. The nursery means of both variables were similar (P < 0.05) (table 1). The combined data set shows good correlation between intensity and concentration. Among all odor samples, the relationship between intensity (I, ppm BIW) and concentration (C) was represented by the following regression:

\[
I = 3.67 \cdot C^{0.978} \quad (3)
\]

\[
(R^2 = 0.74)
\]

Equation 3 is nearly linear on a log–log scale (fig. 4), agrees with Stevens’ Law (Stevens, 1957), and is similar to regressions reported by Zhu et al. (1998). Nicolai et al. (2000) evaluated 72 swine building odor samples using reference–scaled intensity. The data resulted in the following regression: \(I = 80 \exp(1.186C^{0.198})\), which was characterized by much lower odor concentrations than equation 3 for given intensities (fig. 4). This difference may have been due to a difference in panel sensitivities (n–butanol results not provided) and/or because ambient and hallway samples were included in equation 3.

Hedonic tone (HT), for all odor samples, was also related to odor concentration:

\[
HT = -0.33 \cdot C^{0.523} \quad (4)
\]

\[
(R^2 = 0.59)
\]

As expected, a negative relationship was found. That is, as odor concentration increases, hedonic tone decreases (fig. 5).
Literature that relates reference–scaled odor intensity and hedonic tone of swine odor does not exist. An empirical relationship relating odor intensity and hedonic tone was therefore developed:

$$HT = -0.20 I^{0.498} \quad (R^2 = 0.69)$$  \hspace{1cm} (5)

A negative relationship between hedonic tone and intensity occurred: as intensity decreased, hedonic tone increased (fig. 6). Sobel (1972) found a similar relationship between hedonic tone and category–scaled odor intensity in a study of poultry manure treatment.

CONCLUSIONS

- Mean odor concentrations of ambient and ventilation exhaust air were 18 and 199 OU m$^{-3}$, respectively.
- The mean net odor emission rate from the two nursery rooms was 34 OU s$^{-1}$ AU$^{-1}$ or 1.8 OU s$^{-1}$ m$^{-2}$. The mean gross odor emission rate was 45 OU s$^{-1}$ AU$^{-1}$ or 2.3 OU s$^{-1}$ m$^{-2}$.
- Odor intensity (ppm BIW) increased with odor concentration (OU m$^{-3}$).
- Hedonic tone was inversely proportional to odor concentration (OU m$^{-3}$) and intensity (ppm BIW) raised to the 0.52 and 0.50 powers, respectively.

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