Gaseous emissions from pig-on-litter systems
Pig housing

M. Hassouna (1), P. Robin (1), C. Kermarrec (1), C. Texier (2)

(1) INRA UMR Sol-Agronomie-Spatialisation – 65, rue de Saint-Brieuc – CS 84215 – 35042 Rennes cedex
(2) IFIP – La Motte au Vicomte – 35650 Le Rheu FRANCE
Controlled conditions

3 series of experiments

- the influence of physical structure and chemical composition

4 different types of litter: 2 commercial products (BioPig, straw compacted in small cubes), broken straw, crushed willow

- the influence of using old litter on gaseous emissions

4 different mixtures: old sawdust litter only, old sawdust litter + 1/3 or 2/3 of fresh sawdust, fresh sawdust only

- the influence of turning and excretion input:

4 treatments: with/without excretion x with/without turning
3 pigs/cell 3m²
25-60kg
Standard food Ad libitum
$T_{\text{ins}} \approx 23^\circ \text{C}$

Controlled conditions

Air extraction and treatment

Air renewal

Cooled air

Naturally ventilated cells

Temperature controlled floor

water & food
litter
pigs
Gas concentrations: $\text{N}_2\text{O}$, $\text{H}_2\text{O}$, $\text{CO}_2$, $\text{NH}_3$

CONTROLLED CONDITIONS

- **Computer**
  - Datalogger
  - **Gas concentrations** $\text{N}_2\text{O}$, $\text{H}_2\text{O}$, $\text{CO}_2$, $\text{NH}_3$

**Air speed**

- **Air temperature, humidity**
  - **Outside air**
  - **Inside air**
  - **Air inlet**
  - **Air outlet**

**Litter temperature**

**Eager workshop**

**ALIMENTATION**
**AGRICULTURE**
**ENVIRONNEMENT**

**INRA**
Results

Type of litter

Biopig
- Pig: 33%
- NH3: 26%
- N2O: 1%
- N2: 11%
- Solid manure: 29%

Compacted straw
- Pig: 33%
- NH3: 26%
- N2O: 1%
- N2: 7%
- Solid manure: 33%

Crushed willow
- Pig: 33%
- NH3: 16%
- N2O: 2%
- N2: 13%
- Solid manure: 36%

Broken straw
- Pig: 33%
- NH3: 19%
- N2O: 1%
- N2: 12%
- Solid manure: 35%

Type of litter:
Mixture: old litter/new sawdust

3/3 new sawdust
- Pig: 33%
- Solid manure: 39%
- NH3: 8%
- N2O: 1%
- N2: 19%

2/3 new sawdust
- Pig: 33%
- Solid manure: 40%
- NH3: 11%
- N2O: 1%
- N2: 15%

1/3 new sawdust
- Pig: 33%
- Solid manure: 13%
- NH3: 13%
- N2O: 1%
- N2: 40%

0/3 new sawdust
- Pig: 33%
- Solid manure: 9%
- NH3: 12%
- N2O: 1%
- N2: 45%
maximum effects of turning and excretion input

Lying area, turned or not

- N-final 94%
- N-initial 86%
- N-N\(_2\O\) 5%
- N-NH\(_3\) 1%
- N-deficit +14%

Excretion area, not turned

- N-final 72%
- N-initial 56%
- N-N\(_2\O\) 5%
- N-NH\(_3\) 8%
- N-deficit -15%
- N-excreted 44%

Excretion area, turned

- N-final 54%
- N-initial 54%
- N-N\(_2\O\) 8%
- N-NH\(_3\) 7%
- N-deficit -31%
- N-excreted 46%

100% N conservation

0% N-N\(_2\O\) emission

<5%

N-N\(_2\O\) emission

>10%

Eager workshop


Commercial conditions

⇒ Measurements of gaseous emissions in commercial buildings (pig-on-litter systems):
  
  **Contrasted stocking density**
  **Contrasted building insulation**

Contrasted seasons (winter and summer)

⇒ Validation of a simplified method (weekly / continuous)
### Commercial conditions

<table>
<thead>
<tr>
<th>Livestock building</th>
<th>Experimental station</th>
<th>Commercial buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration (weeks)</td>
<td>Winter</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>21</td>
</tr>
<tr>
<td>Number of pigs</td>
<td>Winter</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>35</td>
</tr>
<tr>
<td>Final weight (kg)</td>
<td>Winter</td>
<td>146</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>143</td>
</tr>
<tr>
<td>Measurement technique</td>
<td>Simplified method</td>
<td>Tracer gas</td>
</tr>
<tr>
<td>Initial straw quantity (kg/pig)</td>
<td>Winter</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>16</td>
</tr>
<tr>
<td>Straw supply (kg/day.pig)</td>
<td>Winter</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>0.5</td>
</tr>
<tr>
<td>Litter surface (m²/pig)</td>
<td>Winter</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>1.4</td>
</tr>
</tbody>
</table>
Commercial conditions

Gas concentrations: \( \text{NH}_3, \text{N}_2\text{O}, \text{CO}_2, \text{CH}_4, \text{SF}_6 \)

\( \text{SF}_6 \rightarrow \) Air flow rate

Eager workshop
Emission estimates from tracing and heat production give similar values
Validation of the results

<table>
<thead>
<tr>
<th></th>
<th>Water emission</th>
<th>Carbon emission</th>
<th>Nitrogen emission</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>H₂O</td>
<td>CO₂</td>
<td>NH₃</td>
</tr>
<tr>
<td></td>
<td>(kg H₂O.pig⁻¹)</td>
<td>(kg C-CO₂.pig⁻¹)</td>
<td>(kg N-NH₃.pig⁻¹)</td>
</tr>
<tr>
<td>Gaz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tracing</td>
<td>402</td>
<td>92</td>
<td>1,1</td>
</tr>
<tr>
<td>Heat production</td>
<td>391</td>
<td>84</td>
<td>1,0</td>
</tr>
<tr>
<td>Concentration ratios a</td>
<td>387</td>
<td>91</td>
<td>1,1</td>
</tr>
</tbody>
</table>

a the water emission of 387 kg H₂O.pig⁻¹ is the deficit of the mass balance increased by 10% metabolic water produced, the ratios of gas concentration to water vapor are used to calculate the other emissions.
B1  Summer 2003    1,2 m²/pig
5,4 kg N-food + 0,4 kg N-straw/pig

B2-R1  Summer 2002    2,6 m²/pig
4,5 kg N-food + 0,5 kg N-straw/pig

ITP-R1  Summer 2002    1,4 m²/pig
8,5 kg N-food + 0,4 kg N-straw/pig

ITP-R2  Summer 2002    1,0 m²/pig
6 kg N-food + 0,4 kg N-straw/pig

B1  Winter 2003    1,2 m²/pig
5,4 kg N-food + 0,4 kg N-straw/pig

B2-R1  Winter 2001    2,6 m²/pig
4,5 kg N-food + 0,5 kg N-straw/pig

ITP-R1  Winter 2002    1,4 m²/pig
8 kg N-food + 0,4 kg N-straw/pig

ITP-R2  Winter 2002    1,4 m²/pig
9 kg N-food + 0,4 kg N-straw/pig

N2-N  15%
N2O-N  1%
NH3-N  26%
N-manure  25%
N-pigs  33%

N2-N  24%
N2O-N  5%
NH3-N  10%
N-manure  32%
N-pigs  29%

N2-N  15%
N2O-N  1%
NH3-N  26%
N-manure  25%
N-pigs  33%

N2-N  29%
N2O-N  1%
NH3-N  26%
N2-N  9%
N-manure  35%
N-pigs  29%

N2-N  40%
N2O-N  1%
NH3-N  26%
N2-N  3%
N-manure  25%
N-pigs  29%

N2-N  15%
N2O-N  1%
NH3-N  26%
N2-N  3%
N-manure  25%
N-pigs  29%

N2-N  15%
N2O-N  1%
NH3-N  26%
N2-N  1%
N-manure  25%
N-pigs  33%
Influence of the stocking density:

- Pigs activity
- Gaseous exchange

Influence of solid manure water content

Rather homogenous low nitrogen content in the manure despite the variability in NH$_3$ and N$_2$O emissions
Conclusions

For $N_2O$:

Variations between 0.02 and 0.16kg $N-N_2O/kg$ excreted $N$

Higher than the given reference for pig-on-slatted floor systems: 0.02 $N-N_2O/kg$ excreted $N$ (IPCC)

$$EF(N_2O) = 4 - 12\% \text{ excreted } N \text{ for livestock buildings with less than } 2 \text{ m}^2 \text{ litter/pig}$$

$$EF(N_2O) = 2 - 8\% \text{ excreted } N \text{ for livestock buildings with more than } 2 \text{ m}^2 \text{ litter/pig}$$

These emission factors should be reduced when the litter inputs are over 100 kg litter/pig
For NH₃:

Small influence of the indoor conditions, the rearing conditions or the litter management in the livestock buildings with a normal stocking density (between 1 and 1.4 m²/pig), regular straw supplies and thermal insulation of the building.

Agreement with English and Danish results: 100 to 400 mg NH₃/h.pig (Groot Koerkamp P.W.G et al., 1998)

EF(NH₃) = 15 - 25% excreted N for pigs reared for at least 10 weeks with a litter input in the range 50-80 kg/pig
Hypothesis: combined Effects explain high variability for pig-on-litter reared for at least 10 weeks, 1,2m²/pig, 50-80kg litter/pig, no turning, normal management (% excreted N):

\[ \text{EF}(\text{NH}_3) = 20\%; \quad \text{EF}(\text{N}_2\text{O}) = 8\%; \quad \text{EF}(\text{N}_{\text{loss}}) = 64\% \]

<table>
<thead>
<tr>
<th>Gas</th>
<th>Litter type</th>
<th>Animal density (m²/pig)</th>
<th>Management</th>
<th>Substrate amount (kg/pig)</th>
<th>Turning</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>straw</td>
<td>sawdust</td>
<td>2</td>
<td>1</td>
<td>0.8</td>
</tr>
<tr>
<td>NH₃</td>
<td>1</td>
<td>1</td>
<td>1.1</td>
<td>0.5</td>
<td>0.8</td>
</tr>
<tr>
<td>N₂O</td>
<td>0.8</td>
<td>1.2</td>
<td>0.8</td>
<td>0.5</td>
<td>0.8</td>
</tr>
<tr>
<td>N_{Loss}</td>
<td>0.88</td>
<td>1.13</td>
<td>1</td>
<td>1.1</td>
<td>0.9</td>
</tr>
</tbody>
</table>

\[ \text{NH}_3 = 0.20 \cdot \frac{17}{14} \cdot \exp \cdot E_{\text{AnimalDensity}} \cdot E_{\text{Maintenance}} \cdot E_{\text{SubstrateAmount}} \]
\[ \text{N}_2\text{O} = 0.08 \cdot \frac{44}{28} \cdot \exp \cdot E_{\text{LitterType}} \cdot E_{\text{AnimalDensity}} \cdot E_{\text{Maintenance}} \cdot E_{\text{SubstrateAmount}} \cdot E_{\text{Mixing}} \]
\[ \text{N}_{\text{Loss}} = 0.64 \cdot \exp \cdot E_{\text{LitterType}} \cdot E_{\text{AnimalDensity}} \cdot E_{\text{Maintenance}} \cdot E_{\text{SubstrateAmount}} \cdot E_{\text{Mixing}} \]
References


RIGOLOT C., ESPAGNOL S., ROBIN P., HASOUSA M., BELINE F., PAILLAT J.M., DOURMAD J.Y. Mathematical modelling of manure production by pigs: part II NH₃, N₂O, and CH₄ emissions and nutrient and matter flows in animal house and during manure storage and treatment. To be submitted
COMPOSTING

J.M Paillat, P. Robin, M. Hassouna
Eager workshop
Mixtures with straw, sawdust, pig slurry, solid manure, molasses, urea, and water. Water content ≈ 70% and free air space ≈ 70%
Material and method

- Gas concentration: $\text{N}_2\text{O}$, $\text{CO}_2$, $\text{NH}_3$, $\text{CH}_4$, $\text{H}_2\text{O}$
- Air speed
- Air temperature, humidity
- Compost temperature
- Inside air
- Outside air
- Air inlet
- Air outlet
- Computer
- Datalogger
Results

- more manure => shorter response time
- more available N => longer emission
- more biodegradable C => lower amplitude

Eager workshop
## Results

### Heap identification

<table>
<thead>
<tr>
<th>Heap identification</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N--/C</td>
<td>N-/C</td>
<td>N-/C</td>
<td>N++/C-</td>
<td>N/C</td>
<td>N+/C-</td>
<td>N/C+</td>
<td>N+/C</td>
</tr>
<tr>
<td><strong>N-NH₃ (g kg⁻¹ totalN)</strong></td>
<td><strong>165</strong></td>
<td><strong>275</strong></td>
<td>387</td>
<td><strong>489</strong></td>
<td><strong>362</strong></td>
<td><strong>479</strong></td>
<td><strong>248</strong></td>
<td><strong>249</strong></td>
</tr>
<tr>
<td><strong>C:N</strong></td>
<td><strong>29.0</strong></td>
<td><strong>24.7</strong></td>
<td>17.6</td>
<td>19.0</td>
<td>19.5</td>
<td>21.2</td>
<td><strong>19.6</strong></td>
<td>19.5</td>
</tr>
<tr>
<td><strong>Wheat straw</strong></td>
<td>18.5</td>
<td>28.1</td>
<td>10.0</td>
<td>26.0</td>
<td>21.0</td>
<td>12.7</td>
<td><strong>15.3</strong></td>
<td>19.4</td>
</tr>
<tr>
<td><strong>Sawdust</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>10.6</td>
<td>-</td>
<td>2.2</td>
</tr>
<tr>
<td><strong>Sugarcane molasses</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>7.5</td>
<td>10.9</td>
</tr>
<tr>
<td><strong>Pig manure</strong></td>
<td>45.0</td>
<td>15.3</td>
<td>80.1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Pig slurry</strong></td>
<td>36.5</td>
<td>-</td>
<td>-</td>
<td>72.8</td>
<td>78.9</td>
<td>52.9</td>
<td>71.9</td>
<td>15.6</td>
</tr>
<tr>
<td><strong>Urea</strong></td>
<td>-</td>
<td>0.5</td>
<td>0.4</td>
<td>1.2</td>
<td>0.1</td>
<td>0.6</td>
<td>-</td>
<td>0.8</td>
</tr>
<tr>
<td><strong>Water</strong></td>
<td>-</td>
<td>56.2</td>
<td>9.5</td>
<td>-</td>
<td>-</td>
<td>23.2</td>
<td>5.3</td>
<td>51.1</td>
</tr>
</tbody>
</table>

Composition (% on wet weight basis) of the composting mixtures
After 2 months of storage, the emissions observed ranges were:

- **EF(C-CO$_2$)** = 19-61% of the initial carbon content
- **EF(CH$_4$)** = 0.02-0.29% of the initial carbon content
- **EF (N-NH$_3$)** = 9-48% of the initial nitrogen content
- **EF (N-N$_2$O)** = 0.4-1.2% of the initial nitrogen content
NH₃-N emitted at 56 d = 16.38 SN – 0.903 SH₉₃ + 643.7
\[ (N=8; P<0.05 ; R^2 = 0.82) \]

\( \text{CO}_2\text{-C emitted at 28 d} = 0.683 \text{ SH} \_\text{VS} - 58.92 \)
\[ (N=8; P<0.01 ; R^2 = 0.84) \]

with NH₃-N expressed in g kg⁻¹ TN, CO₂-C in g kg⁻¹ TC, SN and SH-VS en g kg⁻¹ DM. NH₃.

SN : Soluble Nitrogen
SH₉₃ : Soluble + Hemicellulose-like fractions from the Van Soest analysis

These relations are valid for heaps with water content \( \approx 70\% \) and free air space \( \approx 70\% \)
Équations « dynamiques » de Jean-Marie pour C,N,O₂,H₂O

SN : Soluble Nitrogen
SH<sub>VS</sub> : Soluble + Hemicellulose-like fractions from the Van Soest analysis
Conclusion

Biodegradable C, available N influence NH$_3$ emissions; O$_2$ content influence NH$_3$ and CO$_2$ emissions

NH$_3$-N and CO$_2$-C potential emission can be calculated for the thermophilic phase

The model describing the 5 main influencing factors (C, N, O$_2$, H$_2$O, time) on N-NH$_3$, C-CO$_2$, H$_2$O potential emissions during composting of animal manure will be published

Other experiments have been done for model validation with various climate, cover sheet, bovine or poultry manure

High uncertainty: N$_2$O after thermophilic phase


http://www.rennes.inra.fr/umrsas/documentation