Nitrogen from Animal Manures

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Contents

• Introduction
• Characteristics of Manure
• C/N ratio / soil organic matter
• Volatilization
• Manure characteristics
• Leaching
• Runoff
• Estimating manure rates
• Crop selection
• economics
• Summary
Introduction

• Over 1,032,000,000 Mg of manure produced each year.
• 7,570,000 Mg of N released each year.
• This means that on average manure is approximately .7% N by weight:
  \[ \frac{1.032 \times 10^9}{7.57 \times 10^6} = 7.33 \times 10^{-3}. \]
Introduction

• Much is “recycled” through crops
• Nitrogen is often the limiting nutrient for crop production.
  – it is highly mobile.
  – plants need it in large amounts.
  – it is difficult to predict availability
  – High concentrations can lead to environmental problems.
Introduction

Environmental Risks

- Nitrate leaching to groundwater
- Movement to surface water
- Gaseous losses
- Over-application can be a cause of these
Characterization of Manure N

- Estimate of nutrient content
  - Animal species
  - Feeding program
  - Production level
  - Environmental conditions
  - Storage
  - Application
Manure Analysis

• Need to know more than just total N
• Estimate forms that are immediately available, and forms that are slower release
• Very heterogeneous, both temporally and spatially
• Up to 3x difference from spatially different samples
• Long term averages best
Manure Analysis

• Find total N and NH$_4$-N
• NH$_4$-N is used to estimate available N
• Cost $20-$50, and take 1-2 weeks
• Time and cost are prohibitive
• Many on site tests available
Forms and Factors
Mineralization and Immobilization

- One of the most important processes
- Immobilization = inorganic → organic
- Mineralization = organic → inorganic
- The driving force is the energy in the organic bonds, needed by soil microorganisms
- Effected by many factors: temp, moisture, aeration, soil chem, manure composition
- Varies greatly from region to region
C/N Ratio

- Determines if mineralization or immobilization occurs
- Generally < 25:1 will result in net mineralization
- Manure ranges from 13:1 – 25:1
- Manure additions will usually result in net mineralization
Composition of manure plays a large role in the mineralization or immobilization. Plant cell wall components will have a high C/N ratio, but will be resistant to breakdown because of lignification. These are often found in manure, as well as any animal bedding. Typically not much effect on immobilization.
Soil Organic Matter

- Living organisms: <5%
- Fresh residue: <10%
- Stabilized organic matter (humus): 33% - 50%
- Decomposing organic matter (active fraction): 33% - 50%
Soil Make-up

• Soil characteristics also play a role in mineralization rate
• 2x-4x differences in mineralization in different soils
• Higher mineralization rate in coarser textured soil, possibly due to better aeration.
• also factors
  – pH
  – Moisture
  – %Sand
  – Temperature (optimal 30-40 C)
Ammonia Volatization

- Lost as N₂ gas
- Losses can be from 10%-90%
- Concern near large animal lots
- Can travel long distances
- Primary mechanism for NH₃ volatilization: hydrolysis of urea

\[
\text{CO(NH₂)₂} + 3\text{H₂O} \rightarrow (\text{NH₄})₂\text{CO₃} \text{H₂O} \\
(\text{NH₄})₂\text{CO₃} \text{H₂O} \rightarrow 2\text{NH₃} + 2\text{H₂O} + \text{CO₂}
\]
Ammonia Volatization

- Losses are highest where manure is drying
- On a barn floor at a temp of 20C, 40% of the N was lost after 2d
- Lessened by anaerobic conditions (5-20%)
- Higher losses in loose piles
- Liquid storage 3-60% loss
- Unagitated liquid 10-15%
## Ways to slow volatilization

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Reduction of losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acidification</td>
<td>75%</td>
</tr>
<tr>
<td>Adding alum</td>
<td>50-99%</td>
</tr>
<tr>
<td>Ca(H2PO4)2</td>
<td>60%</td>
</tr>
<tr>
<td>Zeolites</td>
<td>60%</td>
</tr>
<tr>
<td>Organic material</td>
<td>47%</td>
</tr>
<tr>
<td>Surface crust/cover</td>
<td>20%</td>
</tr>
</tbody>
</table>
Loss from field application

- During application almost no loss
- Irrigation can increase volatilization
- Following application losses can be up to 90%
- Incorporation will reduce this
- Loss of turkey manure was 23x less after incorporation
- 8x less for urea
- 61% of losses for poultry litter were in the first 72h
Weather effects

• Weather is a major contributor
  – Rain
  – Temp
  – Wind

• Timing of rainfall more important than amount
• Temperature effects the equilibrium constants for \( \text{NH}_3 \)
• Wind increases evaporation and removes \( \text{NH}_3 \) from the surface
• With high winds volatilization can be reduced, because a crust is more quickly formed.
• Diurnal patterns were also observed
Manure characteristics

- **NH₄-N content**
  - Higher quantities = more volatilized
  - Percentage doesn’t change

- **Dry matter**
  - Drier = less loss for poultry
  - Cattle and swine losses increase with dryness

- **pH**
  - Direct effect, higher pH = more losses
  - When pH is lowered, volatilization can be reduced up to 85%
Nitrification

- Manure contains very little nitrate
- In warm aerobic soils, easily $\text{NH}_4$ is easily turned into $\text{NO}_3$
- $\text{NO}_3$ levels increase with higher manure application rates
Leaching

- Can contaminate groundwater
  - Harmful to infants
- When applied at optimum rate, 36% lost by leaching
- Still less than safe drinking standards
- May be greater losses from manured in the long term
- Proportional to application rate
Leaching

- Type of manure effects leaching
- Composting can reduce nitrate
- Soils with higher infiltration and percolation rates have higher leaching potential
- Poorly drained soils mineralize N more slowly; less leaching, more denitrification
- Increase in leaching with no-till
- Cover crops can reduce leaching
Denitrification

• \( \text{NO}_3 \rightarrow \text{NO}_2 \rightarrow \text{NO} + \text{N}_2\text{O} \rightarrow \text{N}_2 \)
• NO and \( \text{N}_2\text{O} \) are atmospheric pollutants
• Variable amount of loss, few percent to 11%-37%
• Requires:
  – NO3
  – Decomposable organic matter
  – Anaerobic conditions
  – Microbes use N as an electron acceptor
Denitrification

- Sludge denitrification
- Little denitrification deep in soil, no C
- Manure C can move up to 1 M deep
- Liquid manure can create anaerobic conditions
- Worse when injected
- Greatest losses within 30 days
Runoff

- Important factors:
  - Application timing
  - Incorporation

- High losses when applied on frozen soil

- Minimal when covered with snow

- Runoff losses reduced by 90% after 3 days
Runoff

- Fertilizer compared to manure; mixed results, little difference, or greater loss with fertilizer
- Swine manure, more runoff than poultry
- Can reduce runoff volume, but not lost nutrients
- Riparian zones can reduce runoff losses (sort of)
Application Rate

- Used for centuries
- Based on experience
- Availability refers to what can be taken up by the plant, not what actually is
- Only inorganic forms
Mineral Indices

• Used to estimate manure N availability
• Incubation study using a mixture of soil, and amendment under specific conditions
• Pretreatments can influence results
• A core sample is more representative
• \( \textit{N}_t = \textit{N}_0 \left(1 - e^{-\textit{K} \textit{t}}\right) \)
  – \( \textit{N}_t \) is the cumulative inorganic N at time \( \textit{t} \)
  – K is mineralization rate
  – \( \textit{N}_0 \) is potential mineralizable N
Fertilizer Equivalence

• Determine the amount of inorganic N fertilizer needed to produce the same yield as a given amount of manure

• Using manure will increase the total N in the long term

• Doesn’t take into account other soil benefits of adding manure

• Can be from 5% - 25%
Apparent Recovery of N

• Compares the amount of N taken up, compared to a control

• Apparent N recovery % = (treatment N uptake – control N uptake)X100 total N applied

• Apparent N recoveries are usually lower for higher application rates

• Also manure recovery rates are usually lower than fertilizer rates
Direct recovery using N-15

• Plant recovery of applied N can be traced by analyzing the plant tissue
• Special fertilizer or manure can be traced
• Found that urine and fecal N were lower than other studies had suggested
• Found lower recovery levels than other methods
Table 21–5. Estimates of first-year manure N availability and recovery using various methods, where 36 Mg ha⁻¹ solid dairy manure was applied (Muñoz et al., 2004).

<table>
<thead>
<tr>
<th>Year</th>
<th>n†</th>
<th>$\text{N}^{15}$ recovery</th>
<th>App recov‡</th>
<th>N availability§</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Range</td>
<td>Mean</td>
</tr>
<tr>
<td>1998</td>
<td>12</td>
<td>10</td>
<td>4 to 15</td>
<td>15</td>
</tr>
<tr>
<td>1999</td>
<td>8</td>
<td>17</td>
<td>8 to 16</td>
<td>18</td>
</tr>
<tr>
<td>2000</td>
<td>4</td>
<td>22</td>
<td>7 to 42</td>
<td>17</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>14</td>
<td>-</td>
<td>16</td>
</tr>
</tbody>
</table>

† Number of observations.
‡ Apparent recovery according to the difference method.
§ Rel eff, relative effectiveness; FE, fertilizer equivalence based on whole-plant N uptake.
¶ Across years, weighted by number of observations.
Availability Tests or indices

- Quantification of one or more compounds in the soil
- Showed N mineralization in the lab and field are not well correlated
- Several indices fail to show significant differences between treatments when actual crop responses occur
- PSNT is useful for organic N sources
<table>
<thead>
<tr>
<th>Animal species</th>
<th>Method†</th>
<th>Manure type</th>
<th>Available N %</th>
<th>Residual year</th>
<th>Comments§</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy</td>
<td>Diff</td>
<td>Liquid</td>
<td>8.8</td>
<td>Second</td>
<td>–</td>
<td>Paul and Beauchamp (1993)</td>
</tr>
<tr>
<td></td>
<td>Diff</td>
<td>Liquid</td>
<td>2.3</td>
<td>Third</td>
<td>–</td>
<td>Paul and Beauchamp (1993)</td>
</tr>
<tr>
<td></td>
<td>FE</td>
<td>Incap</td>
<td>9</td>
<td>Second</td>
<td>Based on N uptake</td>
<td>Klausner et al. (1994)</td>
</tr>
<tr>
<td></td>
<td>FE</td>
<td>Incap</td>
<td>10</td>
<td>Second</td>
<td>Based on yields</td>
<td>Klausner et al. (1994)</td>
</tr>
<tr>
<td></td>
<td>FE</td>
<td>Liquid</td>
<td>10</td>
<td>Second</td>
<td>–</td>
<td>Kelling and Wolkowski (1993)</td>
</tr>
<tr>
<td></td>
<td>FE</td>
<td>Liquid</td>
<td>5</td>
<td>Third</td>
<td>–</td>
<td>Kelling and Wolkowski (1993)</td>
</tr>
<tr>
<td></td>
<td>FE</td>
<td>Incap</td>
<td>3</td>
<td>Third</td>
<td>Based on N uptake</td>
<td>Klausner et al. (1994)</td>
</tr>
<tr>
<td></td>
<td>FE</td>
<td>Incap</td>
<td>3</td>
<td>Third</td>
<td>Based on yields</td>
<td>Klausner et al. (1994)</td>
</tr>
<tr>
<td>Beef</td>
<td>Diff</td>
<td>Solid</td>
<td>3.5</td>
<td>Second</td>
<td>–</td>
<td>Paul and Beauchamp (1993)</td>
</tr>
<tr>
<td></td>
<td>Diff</td>
<td>Feedlot</td>
<td>18.0</td>
<td>Second</td>
<td>–</td>
<td>Eghball and Power (1999b)</td>
</tr>
<tr>
<td></td>
<td>Diff</td>
<td>Solid</td>
<td>7.4</td>
<td>Third</td>
<td>–</td>
<td>Paul and Beauchamp (1993)</td>
</tr>
<tr>
<td>Poultry</td>
<td>$^{15}$N</td>
<td>Fresh chicken</td>
<td>2 to 3</td>
<td>Second</td>
<td>Barley</td>
<td>Thomsen et al. (1997)</td>
</tr>
<tr>
<td>Sheep</td>
<td>$^{15}$N</td>
<td>Fresh</td>
<td>3.6</td>
<td>Second</td>
<td>Barley/ryegrass</td>
<td>Jensen et al. (1999)</td>
</tr>
<tr>
<td></td>
<td>$^{15}$N</td>
<td>Fresh</td>
<td>4.5 to 5.7</td>
<td>Second</td>
<td>Ryegrass</td>
<td>Sørensen et al. (1994)</td>
</tr>
<tr>
<td></td>
<td>$^{15}$N</td>
<td>Fresh</td>
<td>1.4</td>
<td>Third</td>
<td>Barley/ryegrass</td>
<td>Jensen et al. (1999)</td>
</tr>
</tbody>
</table>

† Diff, difference method; FE, fertilizer equivalence; Incub, incubation.
‡ Percentages are N availabilities according to the fertilizer equivalence method, or apparent N recoveries according to the difference or $^{15}$N methods.
§ Field experiments, planted to corn, unless otherwise stated.
Residual Availability

- Not all manure N is available in the first year
- Second year recoveries are from 2%-18%
- Third year recoveries 1%-7%
- Decay series for readily available and slowly available N

<table>
<thead>
<tr>
<th>Species</th>
<th>Decay constants</th>
<th>Comments</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy</td>
<td>0.75–0.15–0.10–0.05</td>
<td>Fresh</td>
<td>Pratt et al. (1973)</td>
</tr>
<tr>
<td></td>
<td>0.50–0.15–0.05</td>
<td>Fresh</td>
<td>Willrich et al. (1974)</td>
</tr>
<tr>
<td></td>
<td>0.30–0.06–0.07–0.05</td>
<td>Anaerobic</td>
<td>Willrich et al. (1974)</td>
</tr>
<tr>
<td></td>
<td>0.30–0.10–0.05–0.02</td>
<td>Liquid, stored</td>
<td>Kelling and Wolkowski (1993)</td>
</tr>
<tr>
<td></td>
<td>0.21–0.09–0.03–0.03</td>
<td>Organic fraction</td>
<td>Klausner et al. (1994)</td>
</tr>
<tr>
<td></td>
<td>0.24–0.15–0.11–0.06</td>
<td>—</td>
<td>Sullivan et al. (1997)</td>
</tr>
<tr>
<td>Beef</td>
<td>0.35–0.15–0.10–0.05</td>
<td>65% N</td>
<td>Pratt et al. (1973)</td>
</tr>
<tr>
<td>Swine</td>
<td>0.00–0.04–0.02</td>
<td>—</td>
<td>Willrich et al. (1974)</td>
</tr>
<tr>
<td>Poultry</td>
<td>0.90–0.10–0.05</td>
<td>Hen</td>
<td>Pratt et al. (1973)</td>
</tr>
<tr>
<td></td>
<td>0.75–0.05–0.05</td>
<td>Broilers</td>
<td>Willrich et al. (1974)</td>
</tr>
</tbody>
</table>
Crop selection

• Research has been done on many different crops, but can still vary from area to area
• Legumes vs nonlegumes
• Annual vs perennial
• Often overall cropping system and management are more important than crop choice
Application to non-legumes

- Usually applied to grain crops
- Direct economic correlation

Table 21–8. Selected research studies evaluating manure applications on grass forages.

<table>
<thead>
<tr>
<th>Grass</th>
<th>Location</th>
<th>Manure type</th>
<th>Yield increase over control</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reed canarygrass</td>
<td>Minnesota, Wisconsin, Iowa</td>
<td>Liquid dairy</td>
<td>213</td>
<td>Schmitt et al. (1999a)</td>
</tr>
<tr>
<td>Perennial ryegrass</td>
<td>United Kingdom</td>
<td>Beef cattle slurry</td>
<td>170</td>
<td>Tunney and Molloy (1986)</td>
</tr>
<tr>
<td>Coastal bermudagrass</td>
<td>Texas</td>
<td>Broiler poultry litter</td>
<td>169</td>
<td>Evers (1998)</td>
</tr>
<tr>
<td>Tall fescue</td>
<td>British Columbia</td>
<td>Dairy slurry</td>
<td>147</td>
<td>Bittman et al. (1999)</td>
</tr>
</tbody>
</table>
Fig. 21–3. Risks considered in the manure management decision-making process.
Application to legumes

- Manure producers have more than they can apply to their fields
- Environmental concern about over applying to non-legumes
- Good if there is an abundance of manure
- Can reduce total N on farms
- Can get same benefit by only using starter fertilizer
Timing

- Optimum manure application time is when nutrient losses are minimized and crop yields are maximized.
- Very difficult
Annual grains

- Application during spring before planting
- Also in fall after harvest, but much can be lost over winter
- Spring = 40% efficiency
- Fall = 24% efficiency
- In season application would be best for uptake, many logistical problems
Perennial forages

- Higher probability to burn crops
- For established forages, a late spring application is best
- Immediately after a harvest, apply manure
Application Methods

- Influences:
  - N availability
  - Loss potential
  - Crop injury potential

- Different methods can result in different harvest values
Row crops

- Surface or injection
- Incorporation reduces environmental losses
- Can reduce volatilization losses 35%-95%
- Needs to be incorporated quickly
- Injection accomplishes the same thing with only one piece of equipment, and only liquid manure
- Better placement in rooting zone
Forage and Perennial

- Most common application method is broadcasting
- Try to reduce burning by banding under foliage, 80% reduction in volatilization
- Manure injection also feasible, agronomic and environmental benefits outweigh negative impacts of equipment damaging plants or roots
Nutritive Additives

• Retain N
• Inhibit nitrification
• Commercial fertilizer N additions
• $\text{AlSO}_4$ can reduce volatilization in litter
• Inconsistent results for nitrification inhibitors
  – Can slow nitrification in some cases
  – Can help retain organic N in soil
• Additions of N to improve the N/P ratio
Effects on Economics

- Can be positive or negative, depending on many variables
- To be positive, cost of moving, storing, applying etc. must be less than the cost of fertilizer
- Other positive effects on soil quality improve long term soil viability
- Several researchers report increased yields more than the amount of nutrients alone
Summary

• Most manure produced in the US is applied to fields
• Can be a serious threat to the environment
• Very complicated soil interactions that are not completely understood
• Economic variables can cause a farmer to be unable to predict the costs of using nitrogen as a fertilizer