Nitrogen Use Efficiency – Best Management Practices

Catherine Watson
Outline of presentation

• Trends in N fertiliser use
• Environmental consequences
• Strategies to improve N use efficiency (N fertiliser management, crop and soil management, livestock management, manure management and modification of N fertilisers)
• Summary of costs and ease of adoption
• Gaps in knowledge
Average N fertiliser applied 1995 - 2008

- Nitrogen rates have declined in all regions of UK
- In Northern Ireland, N fertiliser in 2008 was 82 kg N ha⁻¹
- The lowest rate since 1975
- 45% lower than maximum N rate in 1995
- Saving of 19,350 tonnes N year⁻¹ in 2008

Rates for Scotland and England & Wales are for grassland - source British Fertiliser Survey
Data from Bob Foy, AFBI
Nitrogen efficiency in Northern Ireland 1995 - 2009

- Intensive grassland agriculture operates at low rates of N efficiency.
- Sustaining agricultural output in NI requires improvements in N efficiency.
- Action Programme aims to improve N efficiency and sets maximum rates of N fertiliser for grass.
- A measure of gross N efficiency is the ratio of inputs to outputs.
- Total N output has hardly changed despite lower N inputs.
- Thus ratio of gross N efficiency has increased from 2003 steadily to 25%.

Rates based on area of crops and grass
Data from Bob Foy, AFBI
Agriculture & Nitrogen: what goes in must come out

N INPUTS

- e.g. manure, fertiliser, etc.

N OUTPUTS

- e.g. crops, milk, meat, etc.

Air

NH₃ \quad N₂O \quad NOx \quad N₂

Soil and Water

NO₃⁻ \quad NH₄⁺ \quad NO₂⁻ \quad DON
Emissions from agriculture as a % of total national emissions of GHGs

EU Directive to reduce GHG’s by 20% by 2020

Percentage

New Zealand
Ireland
France
Denmark
EU
Germany
Belgium
UK
Netherlands
USA
Japan
Total UK agricultural emissions of methane and N₂O in 2007 as Mt CO₂ equivalent

- Methane:
  - Enteric fermentation
  - Manure management

- Nitrous oxide:
  - Soils
  - Manure management
EU Water Framework Directive


- Commits member states to restore all water bodies to good ecologic and chemical status by 2015
Good Management Strategies

Match N supply to crop demand

• N Fertiliser management (type, amount & timing of application)
• Crop and soil management (soil drainage, good soil structure etc.)
• Livestock management (production per animal, diet manipulation etc.)
• Manure management (e.g. timing and application method)
• Modification of N fertilisers (urease and nitrification inhibitors)
N Fertiliser management

Good understanding of some factors influencing losses:

Soil factors: organic C, NO$_3$ concentration, moisture, temperature
Management factors: fertiliser type, rate and timing of applications, slurry applications

• Apply lower rates of N (plus emission savings in fertiliser production)
• Time application to avoid heavy rainfall
• Use NH$_4^+$N instead of NO$_3^-$ N based fertilisers under wet conditions
Daily denitrification loss (kg N/ha/d)

Total N$_2$O loss (kgN/ha/d)

% H$_2$O

Feb  Mar  Apr  May  Jun  Jul  Aug  Sep  Oct  Nov  Dec  Jan  Feb
Denitrification loss vs N applied

Total $N_2O$ loss (kg N/ha/y)

N applied (kg N/ha/y)
Effect of form of fertiliser N on N$_2$O emissions

- **N$_2$O-N (g ha$^{-1}$)**
  - 0
  - 2000
  - 4000
  - 6000
  - 8000
  - 10000
  - 12000
  - 14000

- **Fertiliser Types**
  - Control
  - CAN
  - Urea
  - Urea+Agrotain
  - UAS

- **Fertilisation Stages**
  - 1st fertn.
  - 2nd fertn.
  - 3rd fertn.
  - Total

- **Graph Legend**
  - Dual axis

- **Graph Title**
  - Effect of form of fertiliser N on N$_2$O emissions
# N₂O emission factors for each fertiliser-N, and seasonal weighted mean EFs.

**IPCC default emission factor = 1.00% (uncertainty range 0.3 – 3.0 %)**

<table>
<thead>
<tr>
<th>Site/Crop</th>
<th>N material</th>
<th>Net N₂O emission factor (%)&lt;sup&gt;a&lt;/sup&gt;</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Spring</td>
<td>Early summer</td>
<td>Mid-summer</td>
<td>Seasonal weighted mean</td>
</tr>
<tr>
<td>Hillsborough (grass)</td>
<td>CAN</td>
<td>0.13</td>
<td>10.99</td>
<td>0.81</td>
<td>3.93 ± 1.17&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Urea</td>
<td>0.06</td>
<td>4.47</td>
<td>0.92</td>
<td>1.74 ± 0.47&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Urea+Ag</td>
<td>0.25</td>
<td>4.63</td>
<td>0.61</td>
<td>1.80 ± 0.48&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>UAS</td>
<td>0.07</td>
<td>3.05</td>
<td>0.96</td>
<td>1.29 ± 0.42&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>Net emission, after subtraction of control value, as % of N applied. Values with different letters are statistically different (p<0.05).
N$_2$O emissions vs soil WFPS

Relationship between N$_2$O emissions and soil water-filled pore space following application of CAN to grassland at Hillsborough
Soils are highly variable with 308 different soil types on 97 parent materials.
Rate of N loss in each catchment due to ‘denitrification’

Denitrification Rate

- < 10 (kgN / ha / yr)
- 10 - 20
- 20 - 30
- 30 - 40
- > 40

Modelled from:
- Soil moisture
- Soil temp
- Soil-NO$_3$N

7,500 t N$_2$O / year
Crop and Soil Management

• Improved drainage so soil is not so wet and prone to denitrification losses
• Sward management (age, species, nutrient balance, soil and plant analysis, improve soil structure, pH, ploughing)
• Clover to partially replace fertiliser N
Livestock management

- Increase production per animal
- Restricted grazing (animal welfare issues?)
- Lower N concentration in urine by diet manipulation
Manure management

• Manure timing
• Separation of slurry into liquid and solid fractions
• Application method
• Storage
• Manure quality – very variable (avg dairy slurry at 6% DM = 2.9 kg total N/m³ but range 1.7 to 7.4 kg/m³)
• Slurry + fertiliser interaction
• Anaerobic digestion
Effect of slurry application method on dry-matter yield

Dry matter yield kg N ha⁻¹

SP=splash plate, TS = trailing shoe and BS=band spreading.

Frost 2007
Cattle slurry increases N$_2$O from KNO$_3$ over 4 days

Stevens et al. 2001
Effect of timing of slurry before nitrate on nitrous oxide flux

Nitrous oxide flux (umol/m²/h)

Time (h)

Control
Day 0
Day -1
Day -2
Day -3
Day -4
LSD

Stevens et al. 2002
Modification of N fertilisers

Slow or controlled release fertilisers
Delays the availability of a nutrient for plant uptake or extends its availability to the plant longer than ‘rapidly available nutrient fertilisers’

Stabilised N fertilisers
Extends the time the N component of the fertiliser remains in the soil in the urea or ammoniacal form

- Urease inhibitors (inhibit hydrolytic action of urease enzyme on urea)
- Nitrification inhibitors (inhibit the biological oxidation of $\text{NH}_4^+$-N to $\text{NO}_3^-$-N)
Urea hydrolysis

$$\text{CO(NH}_2\text{)}_2 + \text{H}^+ + 2\text{H}_2\text{O} \xrightarrow{\text{urease}} 2\text{NH}_4^+ + \text{HCO}_3^-$$

Urease inhibitor
nBTPT is the only commercially available urease inhibitor

- Tradename is AGROTAIN
- AGROTAIN is a clear green solvent containing 20 - 25% nBTPT. This can be:
  - Used to coat urea granules
  - Added to the urea melt during manufacture
  - Added to UAN solutions prior to surface spreading in the field
Daily loss of NH$_3$-N (%)

- **Urea**
- **Urea + Agrotain**
- **CAN**

Loss of NH$_3$-N (% of that applied) vs Days
Maize response to Agrotain in USA (11 years testing)

- Agrotain
- Urea (316 sites)
- UAN (119 sites)

Trenkel, 1997
Economics of Agrotain

Cost of treating urea with Agrotain = $50 per ton urea

Maize averages in US

<table>
<thead>
<tr>
<th>No. of sites</th>
<th>316</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg. response (kg/ha)</td>
<td>892kg</td>
</tr>
<tr>
<td>Value of maize @ $137/metric t</td>
<td>$122/ha</td>
</tr>
<tr>
<td>Cost of Agrotain (200 kgN/ha)</td>
<td>$15/ha</td>
</tr>
<tr>
<td>Net return</td>
<td>$107/ha</td>
</tr>
</tbody>
</table>
Economics of Agrotnain amended urea vs AN

Additional cost of amending urea is $50 per t $\approx$ $109 per t \text{ N } \approx \£66 \text{ stg}$

Current price differential between urea and AN in the UK is £81/t N

Small advantage in using amended urea instead of AN, if DM yields are comparable
Nitrification changes non-mobile NH$_4^+$ into a free reactive species NO$_3^-$, which if produced in excess to plant needs is either leached into ground and surface waters or denitrified to produce N$_2$O and N$_2$.

Inhibiting nitrification can potentially reduce leaching and denitrification N gas losses.
## Commercially available nitrification inhibitors

<table>
<thead>
<tr>
<th>Inhibitor</th>
<th>Rate</th>
<th>Relative volatility</th>
<th>Solubility in water</th>
<th>Mode of application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrapyrin</td>
<td>1-2 mg/kg</td>
<td>High (Corrosive)</td>
<td>Low</td>
<td>Suitable with anhydrous ammonia with injection into soil</td>
</tr>
<tr>
<td>DCD</td>
<td>20 mg/kg (10-30 kg/ha)</td>
<td>Low</td>
<td>High</td>
<td>Use in solid, liquid fertilisers &amp; slurry</td>
</tr>
<tr>
<td>DMPP</td>
<td>1 kg/ha</td>
<td>Low</td>
<td>Low</td>
<td>Use in solid, liquid fertilisers &amp; slurry</td>
</tr>
</tbody>
</table>
Reduction in $\text{N}_2\text{O}$ Emissions

Ammonium sulphate nitrate

Source: Weiske et al., 2001
(barley, maize, wheat)
Reduction in Nitrate Leaching

Hydrologically isolated grazed dairy pastures in New Zealand

Source: Monaghan et al., 2009
Economics of nitrification inhibitors

A cost benefit analysis is difficult due to fluctuations in the price of standard fertilisers, the target crops and the marketing strategies of national/local sales departments (e.g. high volume or high market share).


To be economic the long-term average losses must exceed 40-50 kg N/ha.

C credits for reduced N$_2$O emissions to offset incurred costs?
Summary of inhibitors

• Urease and nitrification inhibitors can reduce N losses, increase yields, improve crop quality and management flexibility

• Variable effects are due to crop, soil properties, climatic and management factors

• Urease inhibitors are likely to be most beneficial on soils where loss of NH$_3$ from urea fertiliser is high (cost effective)

• Nitrification inhibitors likely to have greatest benefit on soils where N losses (leaching or denitrification) are large (cost effective??)
## Summary of mitigation strategies

<table>
<thead>
<tr>
<th>Category</th>
<th>Cost</th>
<th>Ease of adoption</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>N fertiliser management</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rate, time, form</td>
<td>Minimal</td>
<td>Easy</td>
</tr>
<tr>
<td><strong>Crop &amp; Soil management</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drainage</td>
<td>Expensive</td>
<td>Moderate</td>
</tr>
<tr>
<td>Soil, plant &amp; manure analysis</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>Improve soil structure</td>
<td>Minimal</td>
<td>Easy</td>
</tr>
<tr>
<td>Use of grass-clover systems</td>
<td>Minimal</td>
<td>Mod/difficult</td>
</tr>
<tr>
<td><strong>Livestock management</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increase production/animal</td>
<td>Minimal?</td>
<td>Mod/difficult</td>
</tr>
<tr>
<td>Housed vs grazed systems</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>Reduce manure N by diet manipulation</td>
<td>Minimal</td>
<td>Easy/Mod</td>
</tr>
<tr>
<td><strong>Manure management</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time of application</td>
<td>Minimal/moderate</td>
<td>Easy</td>
</tr>
<tr>
<td>Application method</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>Anaerobic digestion</td>
<td>Expensive</td>
<td>Difficult</td>
</tr>
<tr>
<td><strong>Nitrification Inhibitors</strong></td>
<td>Unproven?</td>
<td></td>
</tr>
</tbody>
</table>
Gaps in knowledge

- Timing of slurry and fertiliser applications after silage harvest
- Slurry spreading techniques
- Effect of anaerobic digestion of slurry on emissions.
- Use of grass-clover systems
- Role of nitrification and urease inhibitors
- Role of different soil microbes (e.g. fungi, bacteria) on GHG emissions
- Scaling up measurement of GHG emissions to improve inventories (laser diode technology)