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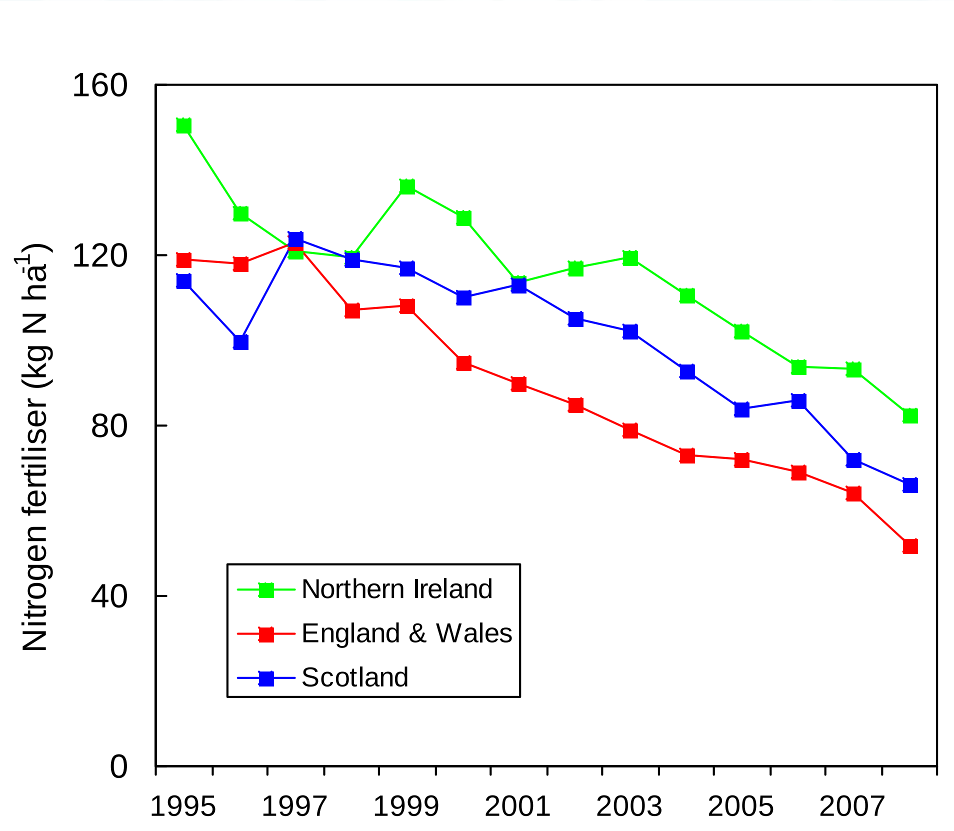
Nitrogen Use Efficiency – Best Management Practices

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

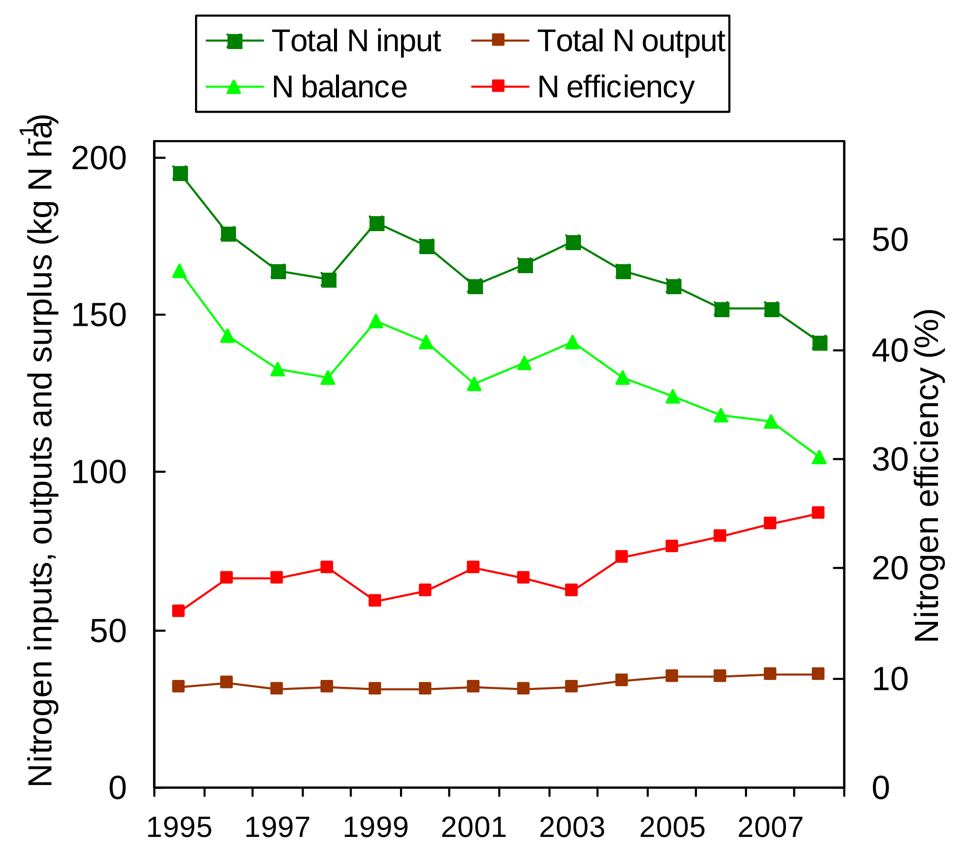


Rates for Scotland and England & Wales are for grassland - source British Fertiliser Survey

Data from Bob Foy, AFBI

- 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

Nitrogen efficiency in Northern Ireland 1995 - 2009

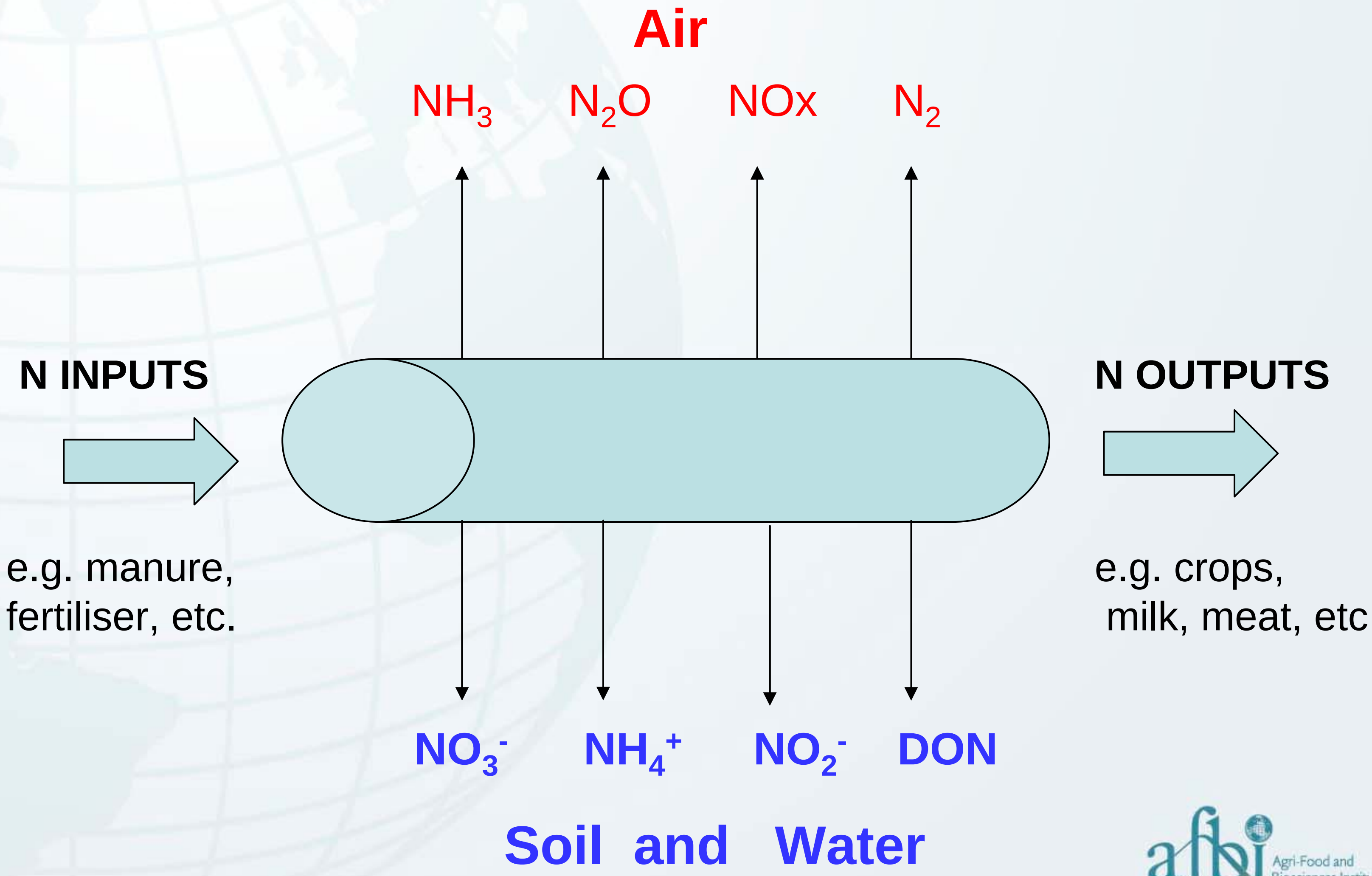


Rates based on area of crops and grass

Data from Bob Foy, AFBI

- 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%

Agriculture & Nitrogen: what goes in must come out



Air

NH_3 N_2O NOx N_2

N INPUTS

e.g. manure,
fertiliser, etc.

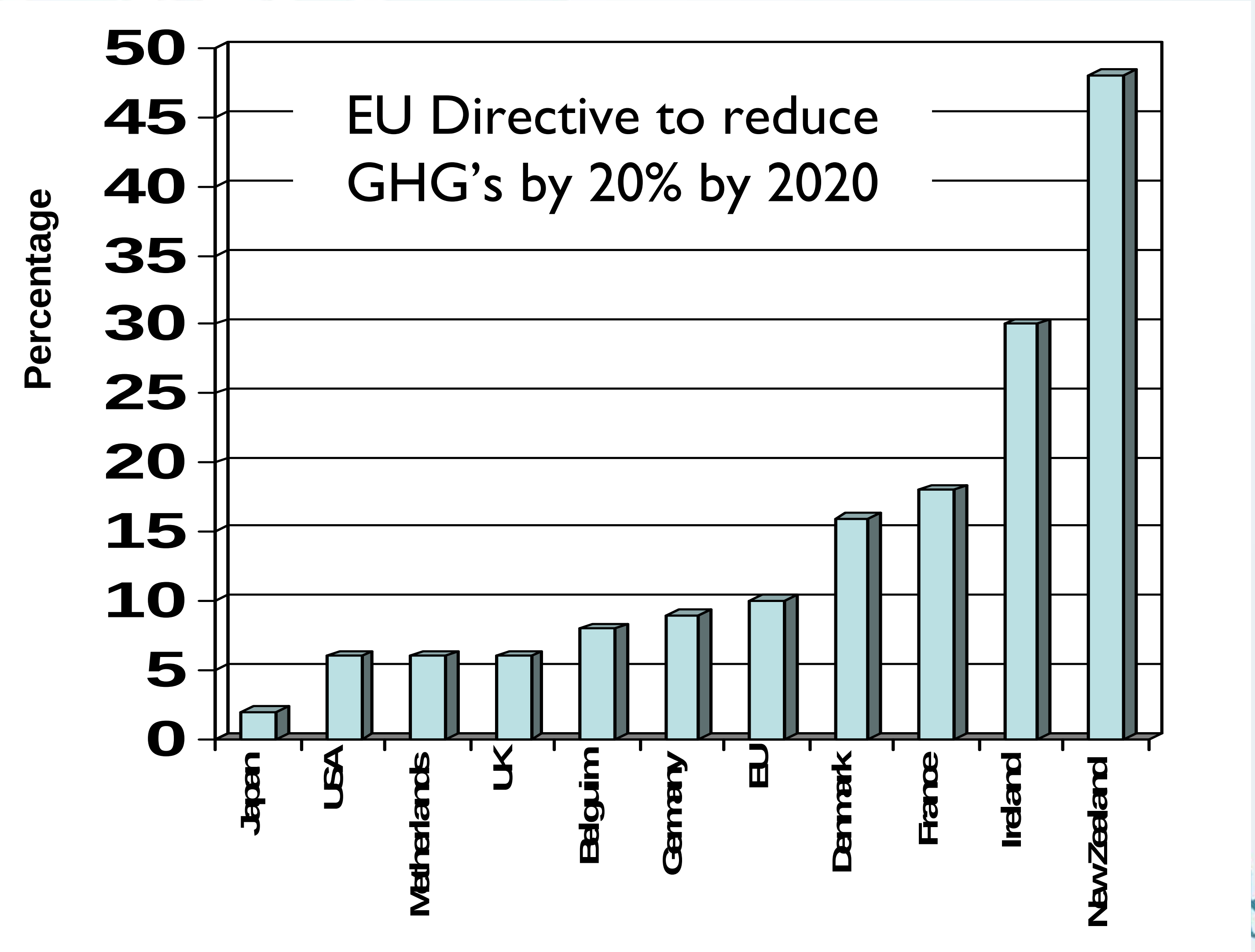
N OUTPUTS

e.g. crops,
milk, meat, etc

NO_3^- NH_4^+ NO_2^- DON

Soil and Water

Emissions from agriculture as a % of total national emissions of GHGs



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

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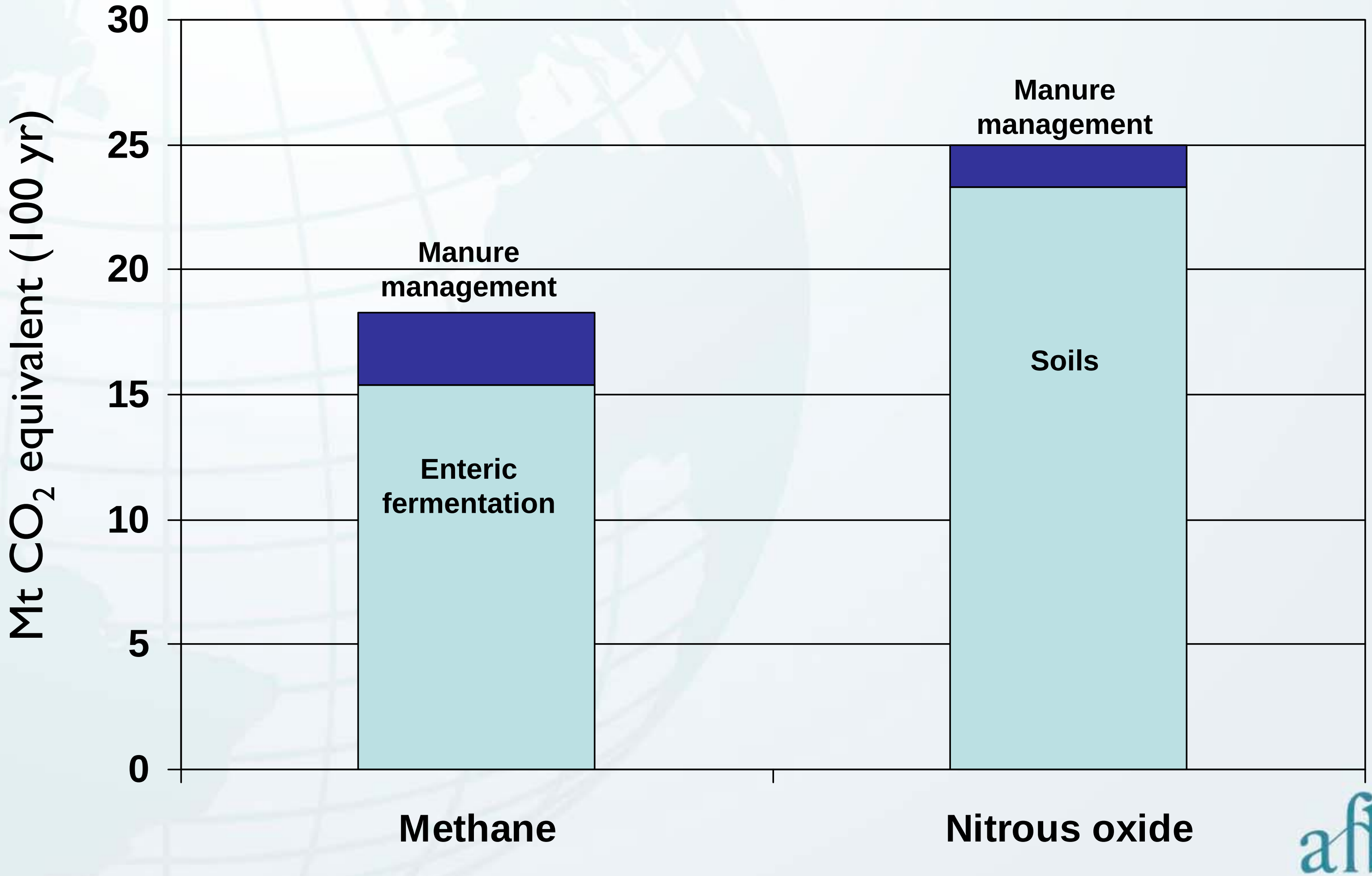
Total UK agricultural emissions of methane and N_2O in 2007 as Mt CO_2 equivalent



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EU Water Framework Directive

Brings together many existing directives related to protecting water quality (e.g. Groundwater Directive 1980, Nitrates Directive 1991, Drinking Water Directive 1991 & Bathing Water Directive 2006)

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

R. Rosell

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

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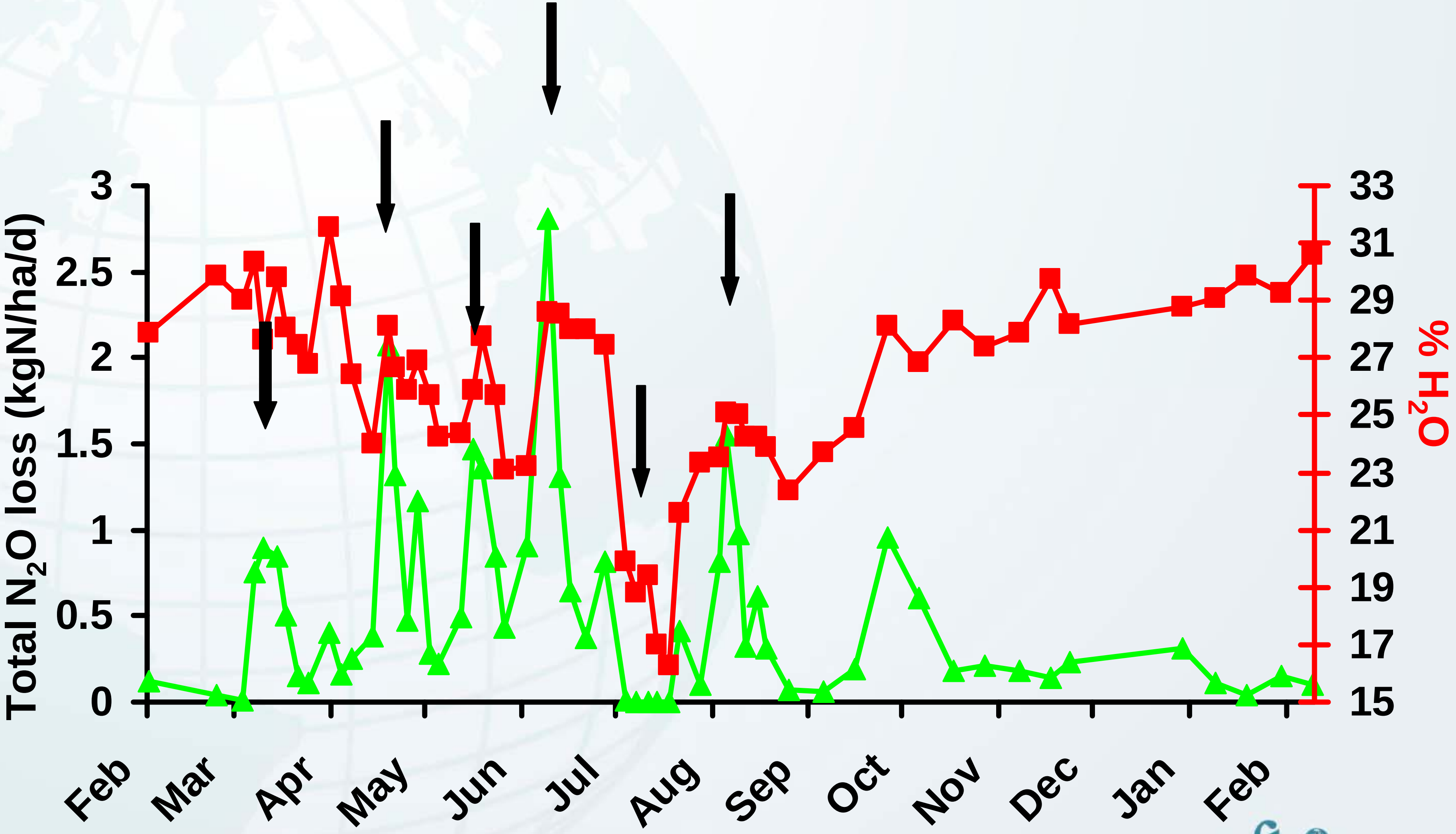
Daily denitrification loss (kg N/ha/d)



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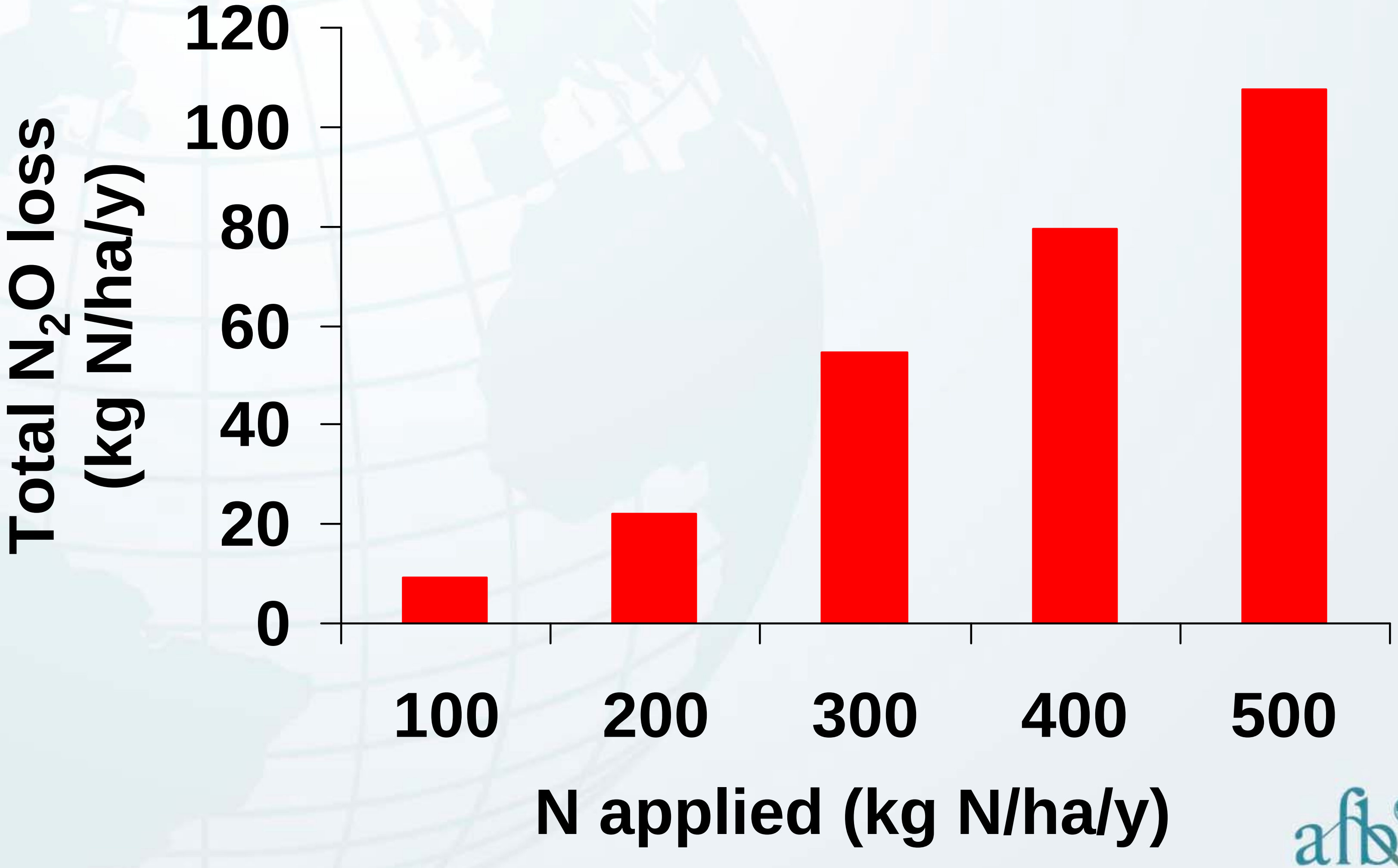
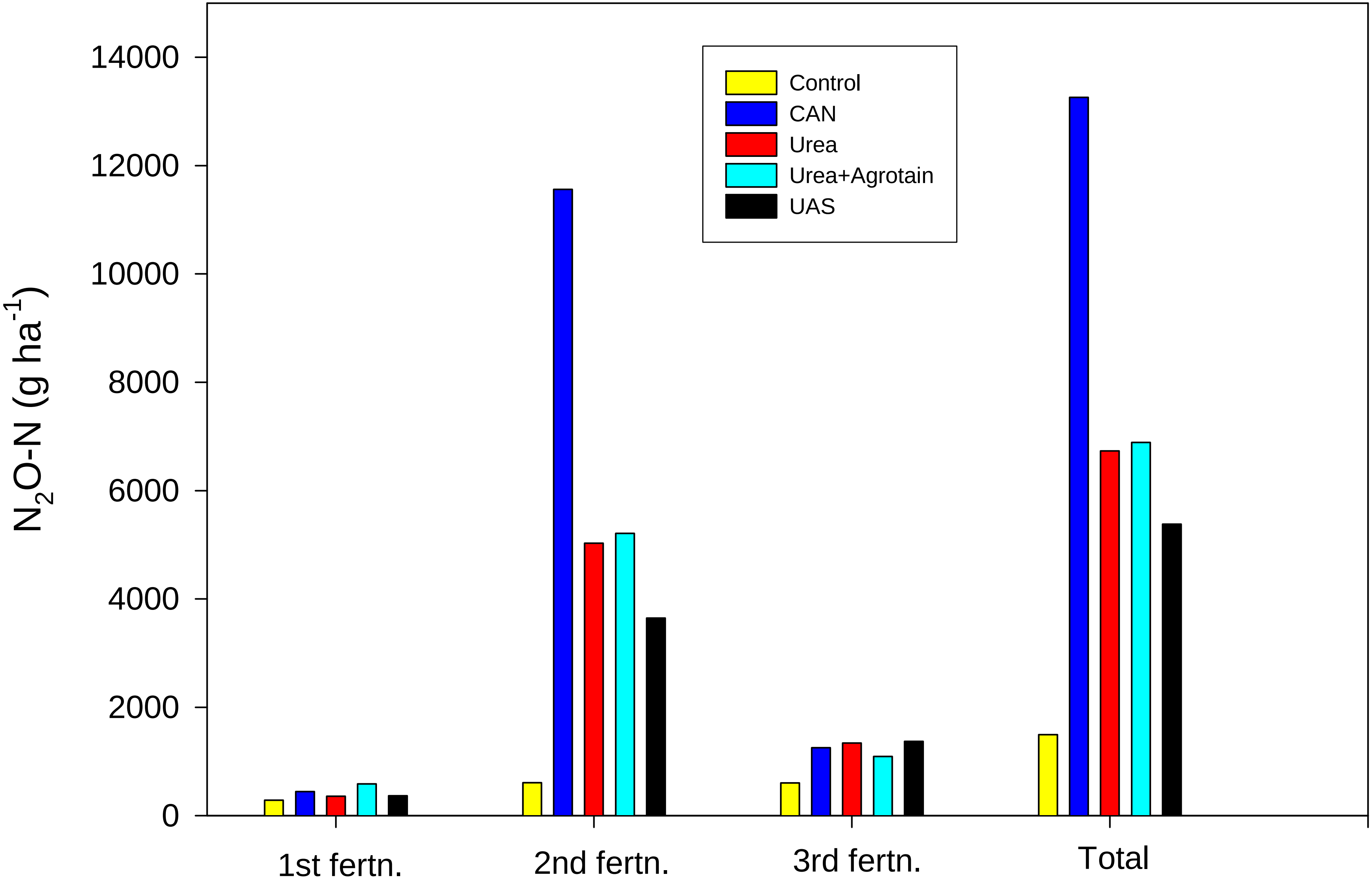
Denitrification loss vs N applied



Effect of form of fertiliser N on N_2O emissions



N_2O emission factors for each fertiliser-N, and seasonal weighted mean EFs.

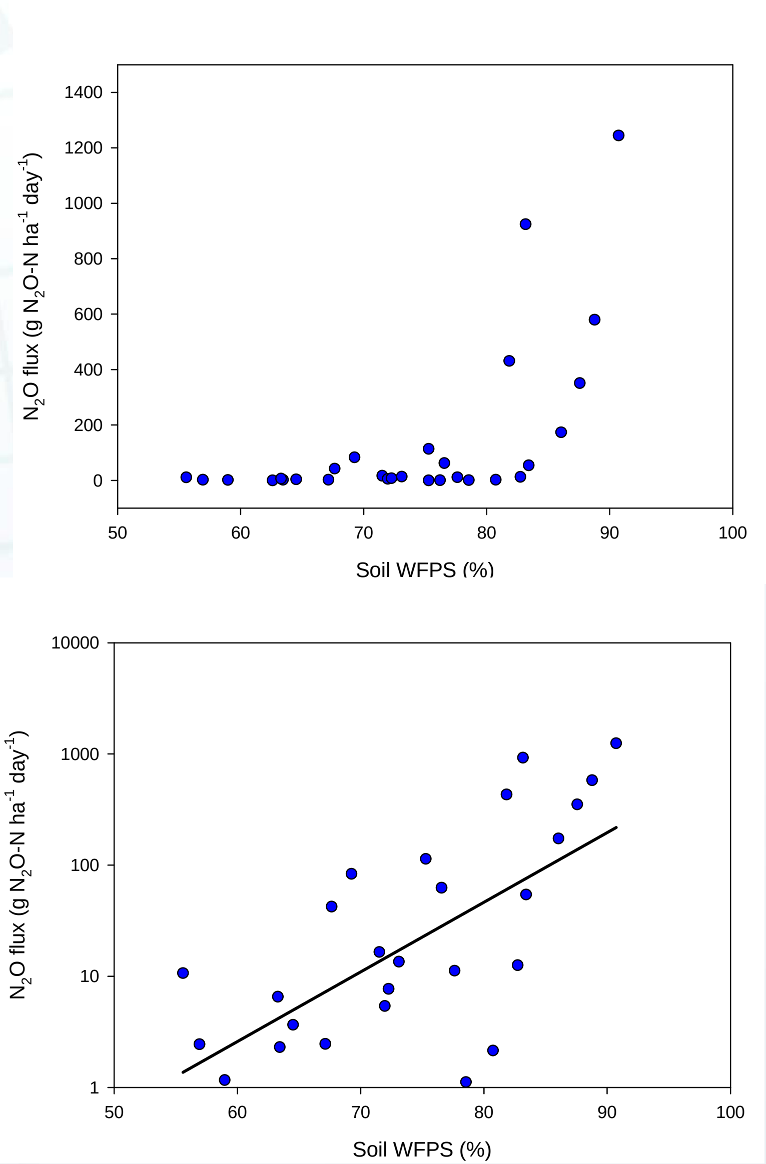
IPCC default emission factor = 1.00% (uncertainty range 0.3 – 3.0 %)

Site/Crop	N material	Net N_2O emission factor (%)[a]			
		Spring	Early summer	Mid-summer	Seasonal weighted mean
Hillsborough (grass)	CAN	0.13	10.99	0.81	3.93 ± 1.17^{b}
	Urea	0.06	4.47	0.92	1.74 ± 0.47^{a}
	Urea+Ag	0.25	4.63	0.61	1.80 ± 0.48^{a}
	UAS	0.07	3.05	0.96	1.29 ± 0.42^{a}

[a] Net emission, after subtraction of control value, as % of N applied.
Values with different letters are statistically different ($p<0.05$).

Defra 2006

N_2O emissions vs soil WFPS



Relationship between N_2O emissions and soil water-filled pore space following application of CAN to grassland at Hillsborough

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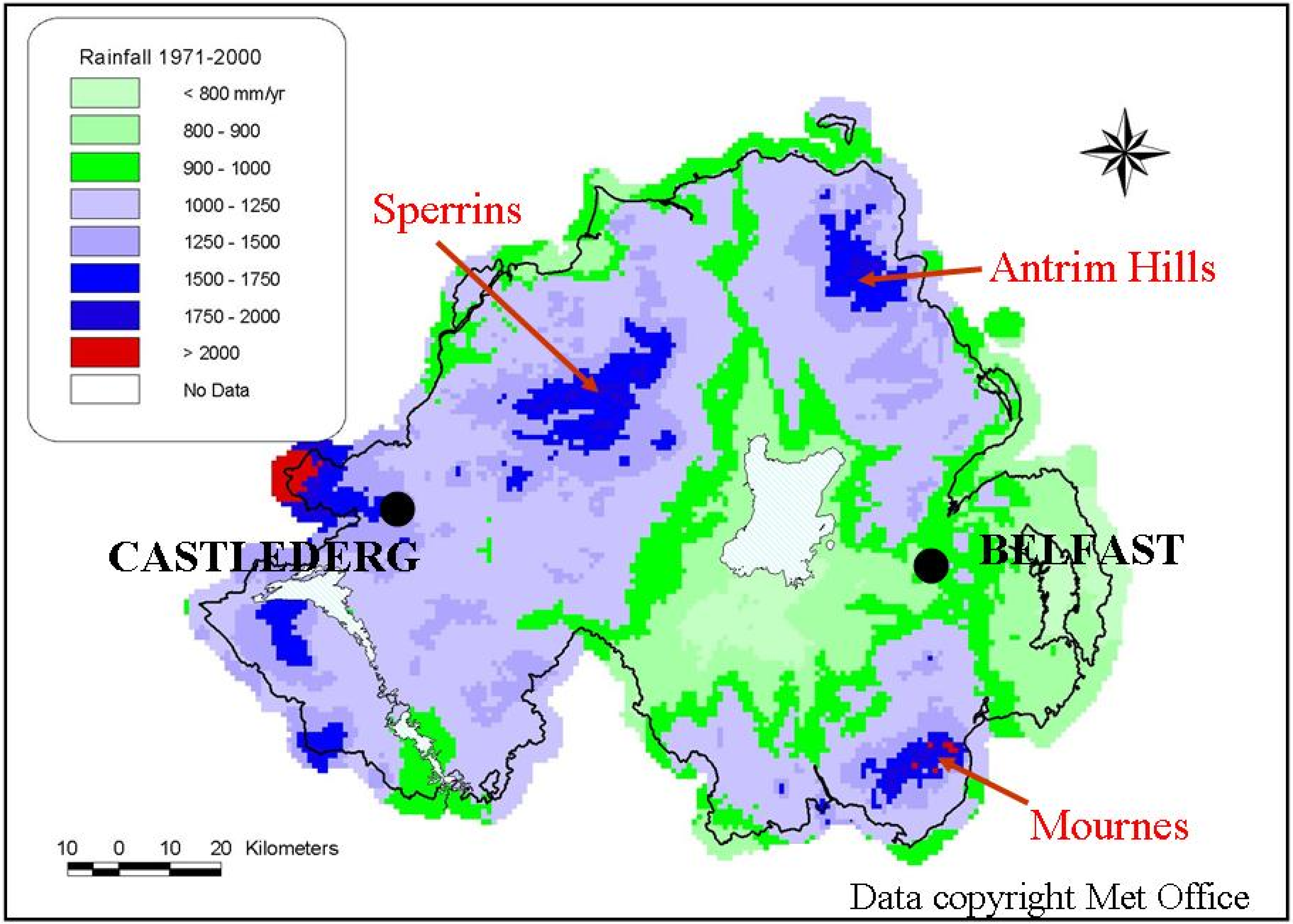
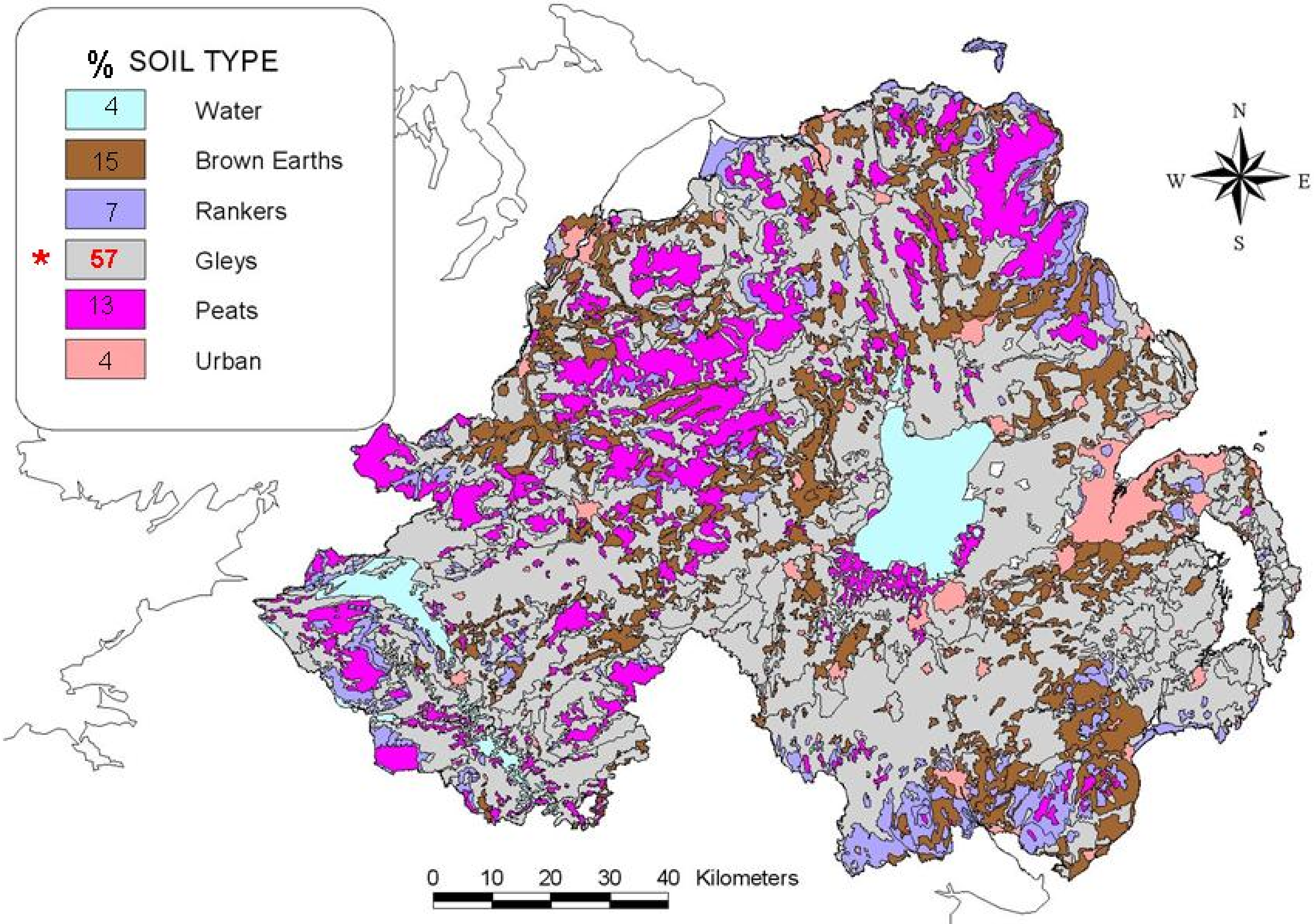


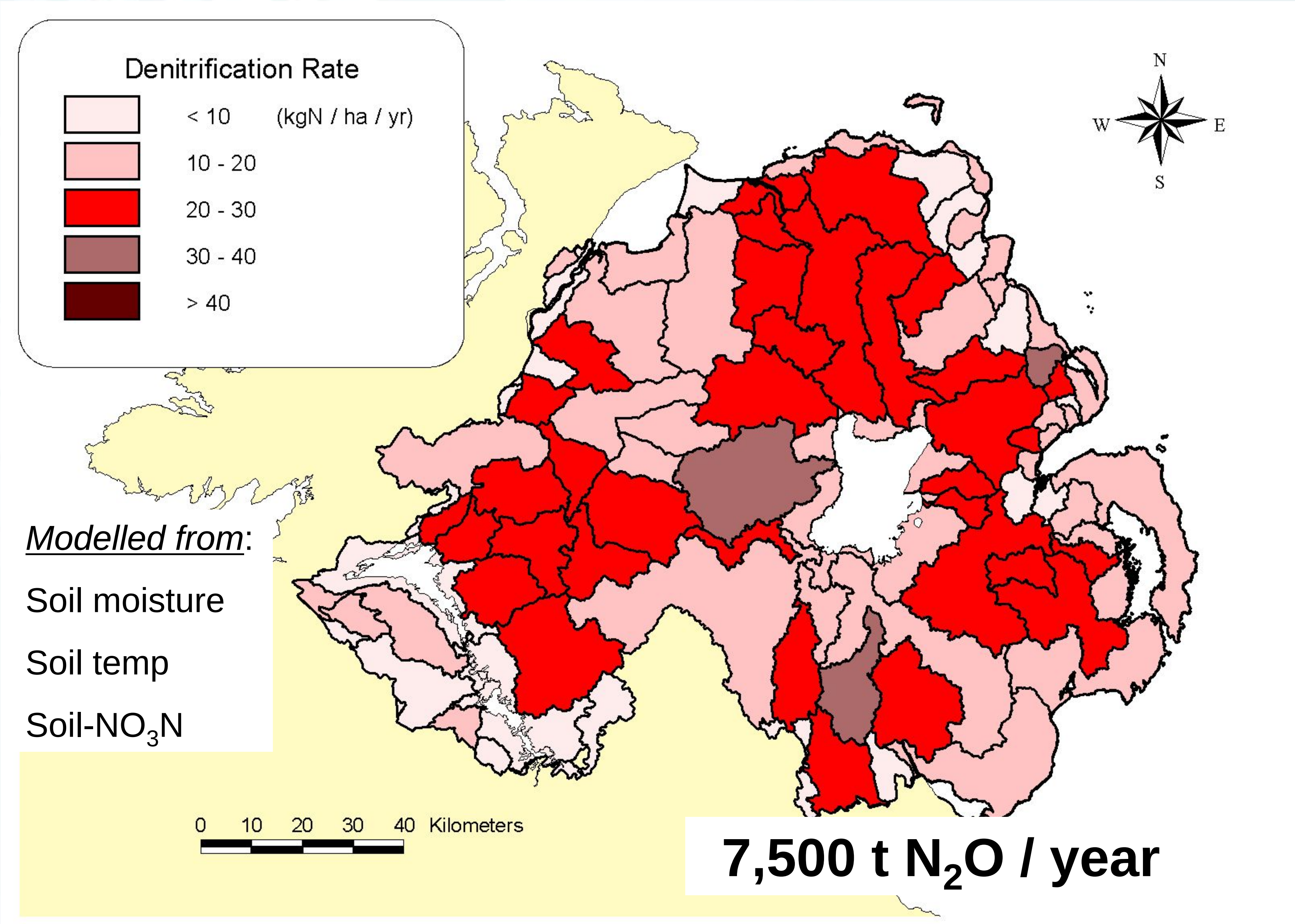
Data copyright Met Office

Major Soil Types



Soils are highly variable with 308 different soil types on 97 parent materials

Rate of N loss in each catchment due to ‘denitrification’



Modelled from:

Soil moisture

Soil temp

Soil-NO_3N

7,500 t N_2O / 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

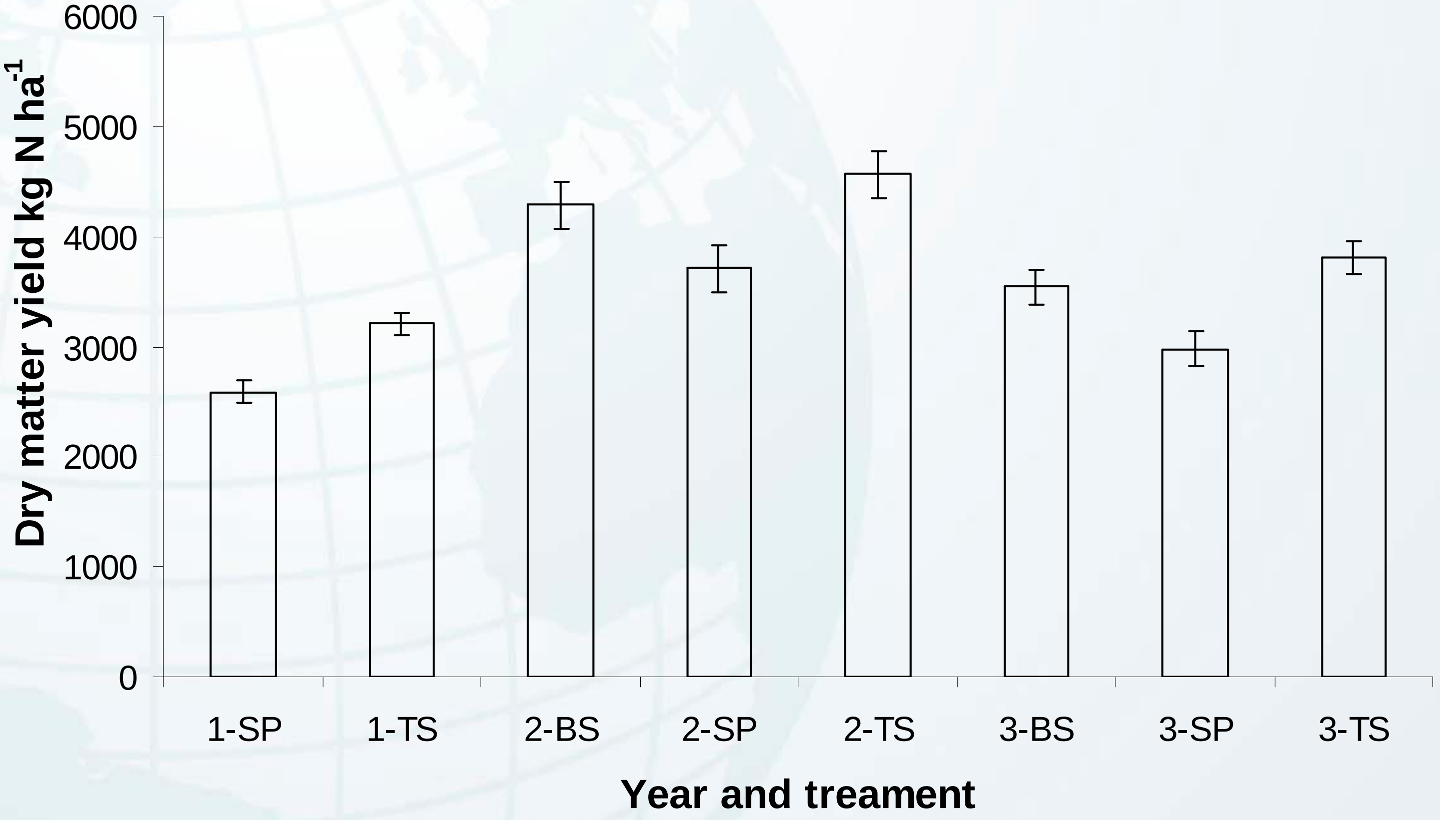
Livestock management

- 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/m^3 but range 1.7 to 7.4 kg/m^3)
- Slurry + fertiliser interaction
- Anaerobic digestion

Effect of slurry application method on dry-matter yield



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

Frost 2007

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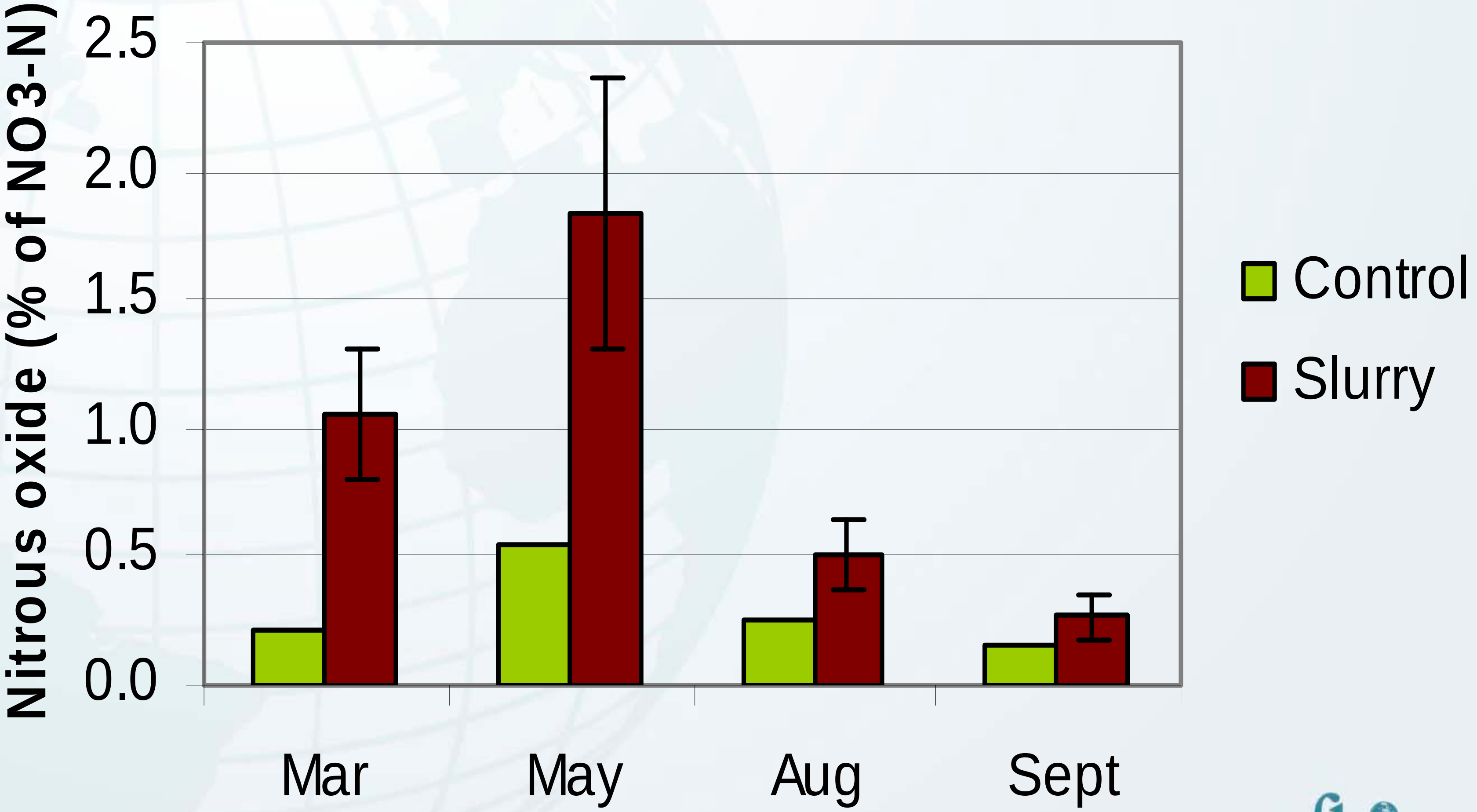
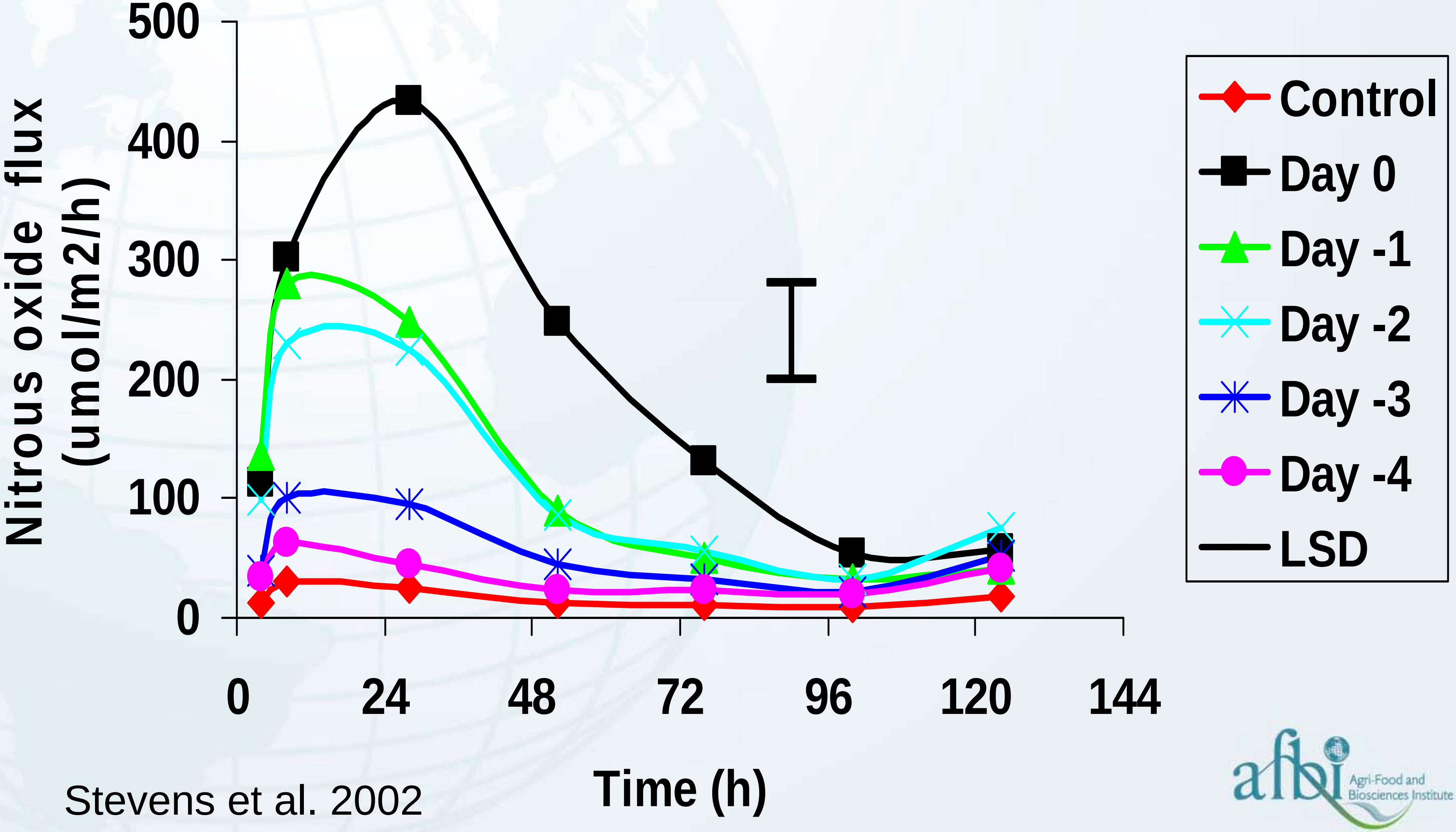
Cattle slurry increases N_2O from KNO_3 over 4 days



Stevens et al. 2001

Effect of timing of slurry before nitrate on nitrous oxide flux



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 NH_4^+-N to NO_3^--N)

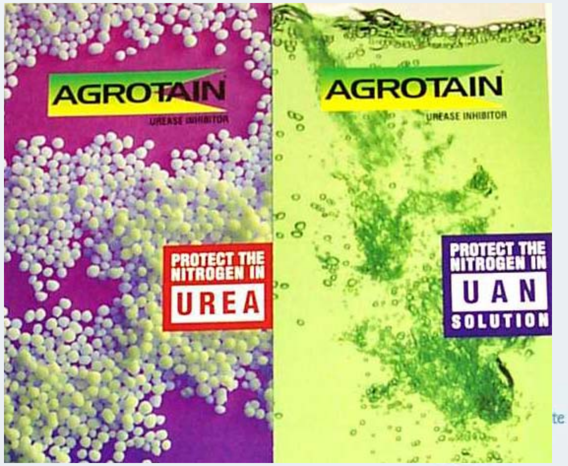
Urea hydrolysis

$$\mathrm{CO(NH_2)_2 + H^+ + 2H_2O \xrightarrow{urease} 2NH_4^+ + HCO_3^-}$$

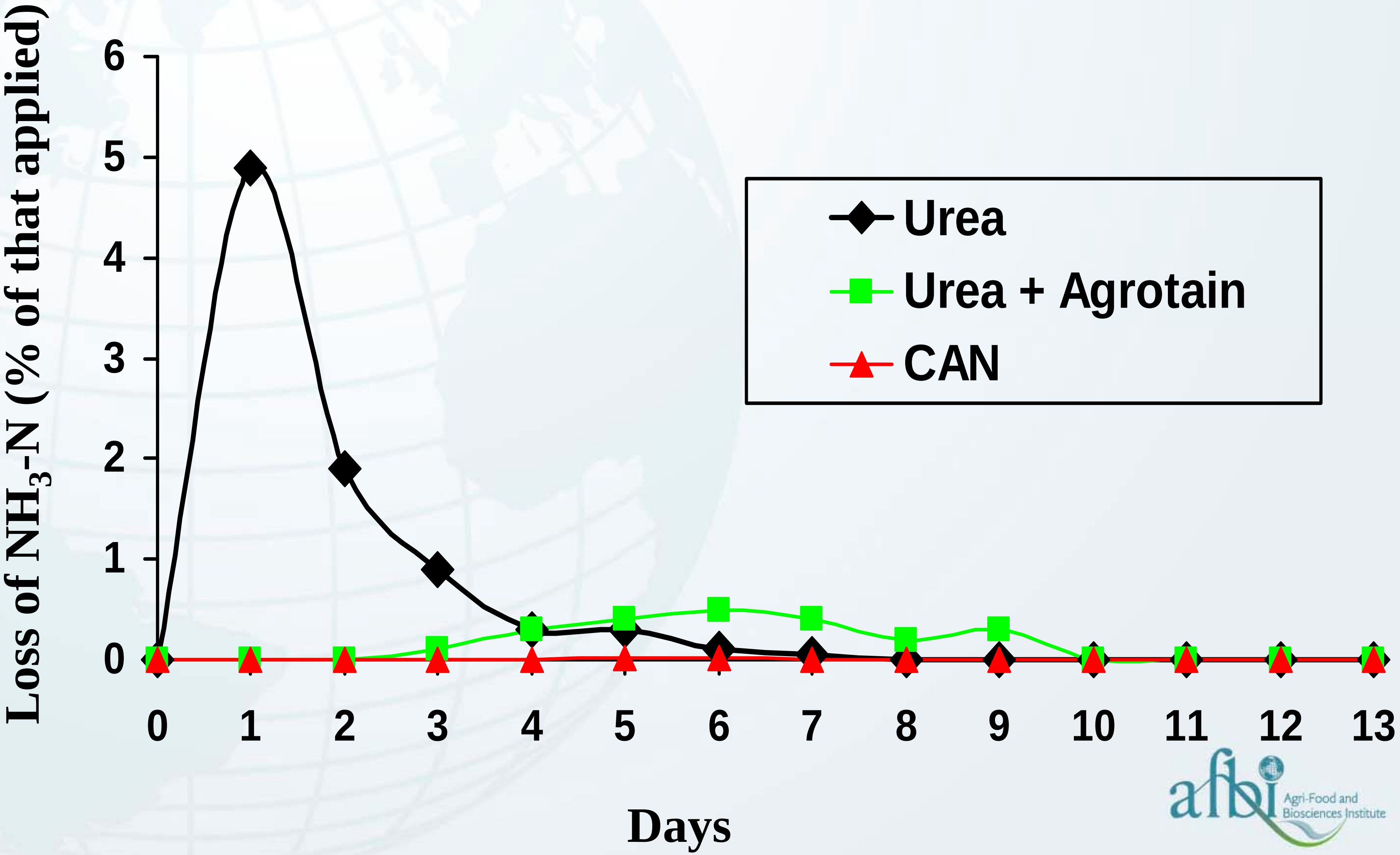
Urease inhibitor

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 (%)



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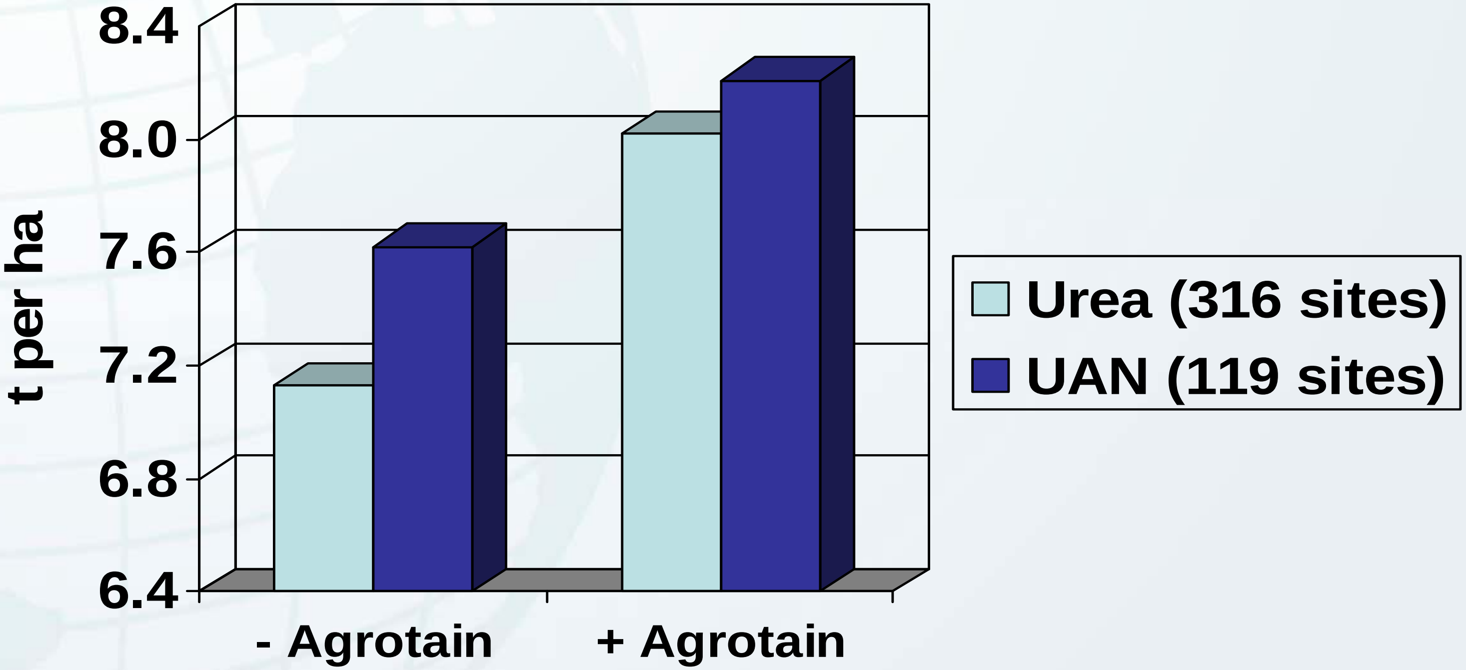
Maize response to Agrotain in USA (11 years testing)



Trenkel, 1997

Economics of Agrotain

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

Maize averages in US

No. of sites	**316**
Avg. response (kg/ha)	**892kg**
Value of maize @ $137/metric t	**$122/ha**
Cost of Agrotain (200 kgN/ha)	**$15/ha**
Net return	**$107/ha**

Economics of Agrotain amended urea vs AN

Additional cost of amending urea is \$50 per t ≅ \$109 per t N ≅ £66 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

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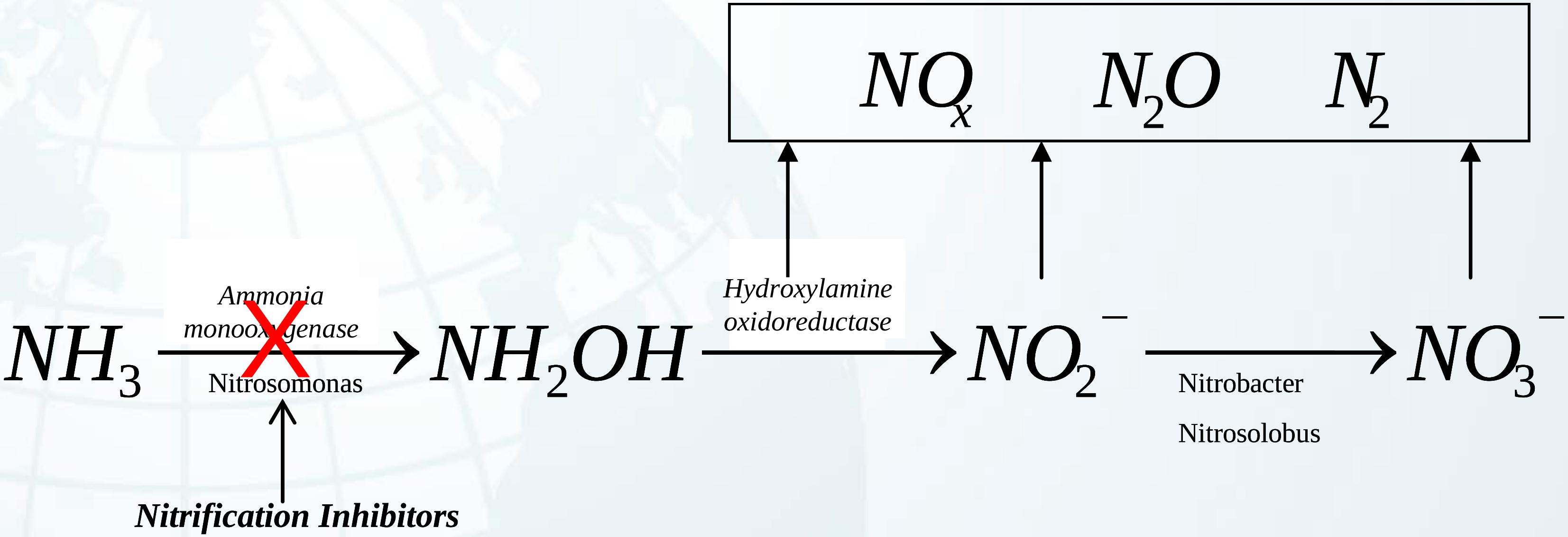
Nitrification



$NO_x \quad N_2O \quad N_2$

$$NH_3 \xrightarrow[\text{Nitrosomonas}]{\text{Ammonia monooxygenase}} NH_2OH \xrightarrow{\text{Hydroxylamine oxidoreductase}} NO_2^- \xrightarrow[\text{Nitrobacter Nitrosolobus}]{} NO_3^-$$

Nitrification Inhibitors

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_2O and N_2.

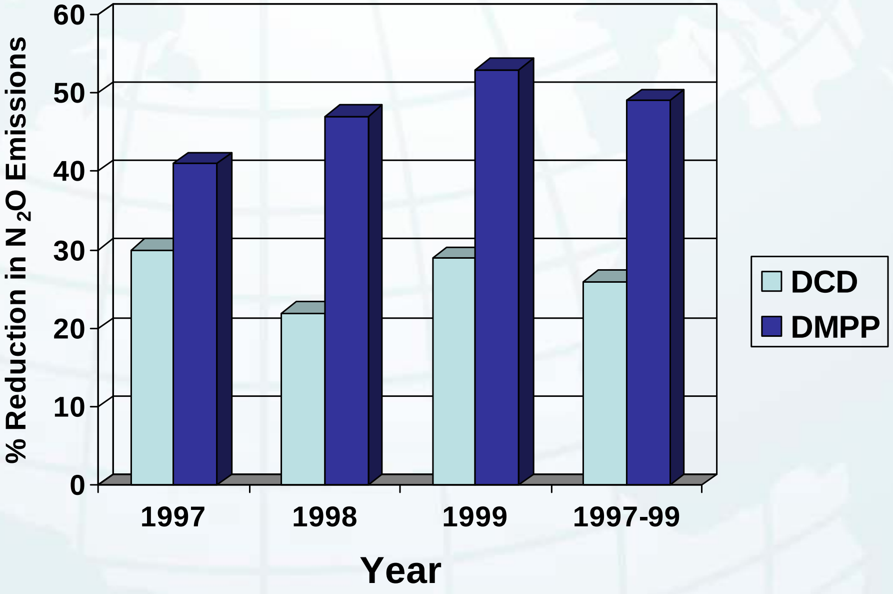
Inhibiting nitrification can potentially reduce leaching and denitrification N gas losses.

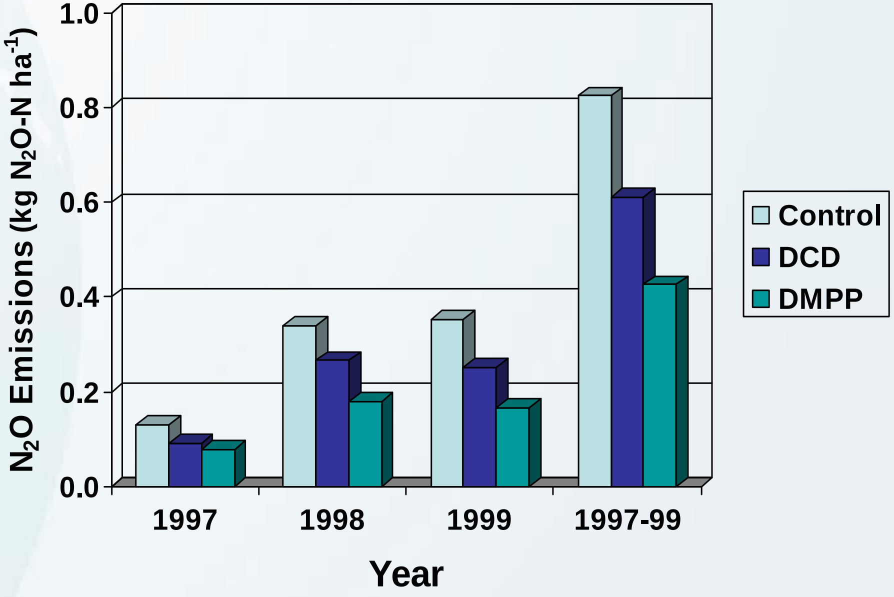
Commercially available nitrification inhibitors

Inhibitor	Rate	Relative volatility	Solubility in water	Mode of application
Nitrapyrin	1-2 mg/kg	High (Corrosive)	Low	Suitable with anhydrous ammonia with injection into soil
DCD	20 mg/kg (10-30 kg/ha)	Low	High	Use in solid, liquid fertilisers & slurry
DMPP	1 kg/ha	Low	Low	Use in solid, liquid fertilisers & slurry

Reduction in N_2O Emissions

Ammonium sulphate nitrate

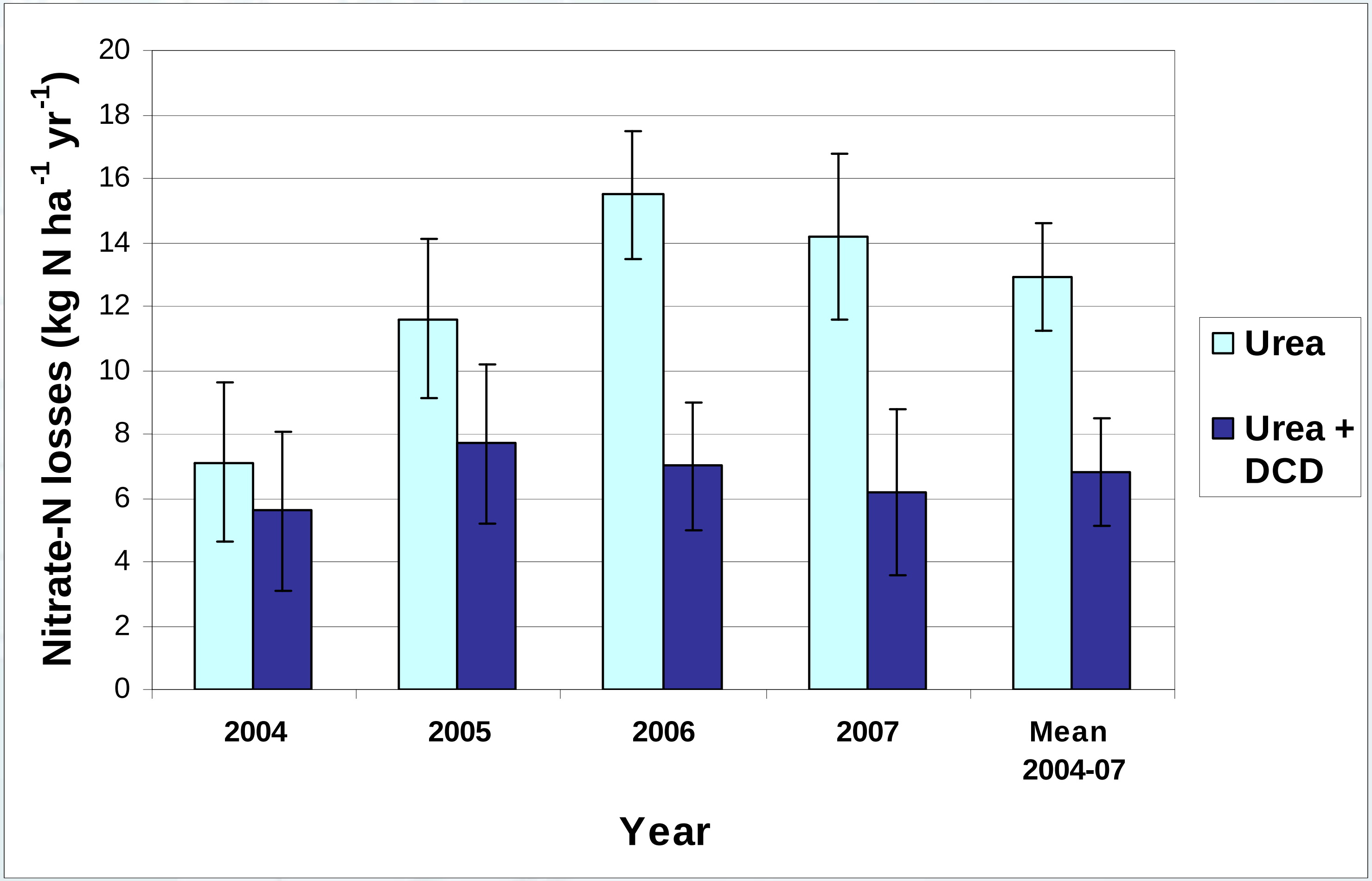




Source: Weiske et al., 2001
(barley, maize, wheat)

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)

Subbarao et al (2006) estimated the cost of nitrapyrin or DCD to be ~ US$ 25-35/ha.

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

C credits for reduced N_2O emissions to offset incurred costs?

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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

	Cost	**Ease of adoption**
N fertiliser management		
Rate, time, form	Minimal	Easy
Crop & Soil management		
Drainage	Expensive	Moderate
Soil, plant & manure analysis	Moderate	Moderate
Improve soil structure	Minimal	Easy
Use of grass-clover systems	Minimal	Mod/difficult
Livestock management		
Increase production/animal	Minimal?	Mod/difficult
Housed vs grazed systems	Moderate	Moderate
Reduce manure N by diet manipulation	Minimal	Easy/Mod
Manure management		
Time of application	Minimal/moderate	Easy
Application method	Moderate	Moderate
Anaerobic digestion	Expensive	Difficult
Nitrification Inhibitors	Unproven?	

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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)

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