Nitrogen and phosphorus losses from grassland soils and potential abatement strategies

Catherine Watson

Fertilizer Association of Southern Africa - 30th July 2015

Outline of presentation

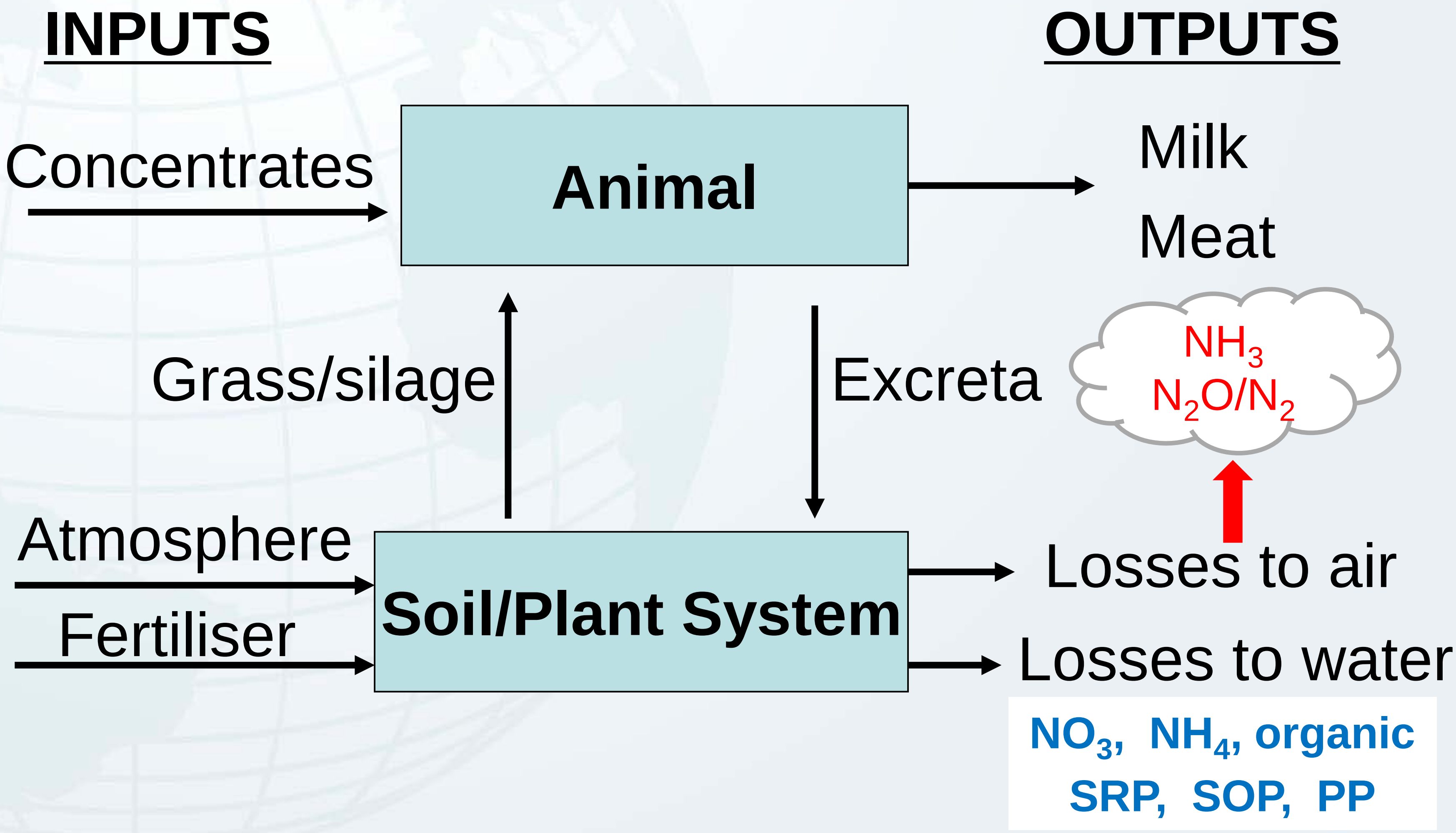
- Overview of N & P cycle and losses
- Good management strategies
- Improving N fertiliser efficiency

  - Slow release-controlled release products
  - Urease inhibitors
  - Nitrification inhibitors

- Phosphorus losses & mitigation
- Conclusions

Agri-Food and Biosciences Institute

Grassland agriculture is part of an open system



Why are losses to water important?

Results in eutrophication

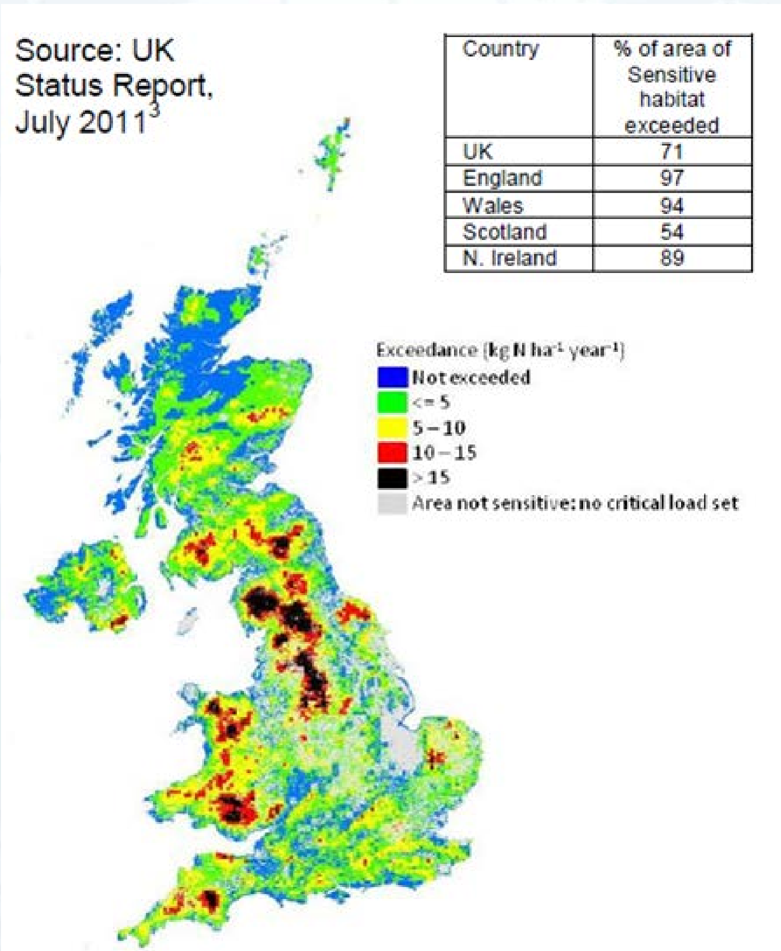
- Increase in algal and weed biomass
- Oxygen depletion of water
- Change in algal and plankton species
- Added costs of water purification
- Change in fish populations

Cost to N.I. £36 - 61m/yr

Why are ammonia losses important?

Contributes to acid rain and leads to deposition of N in sensitive ecosystems

CRITICAL LOAD EXCEEDANCES

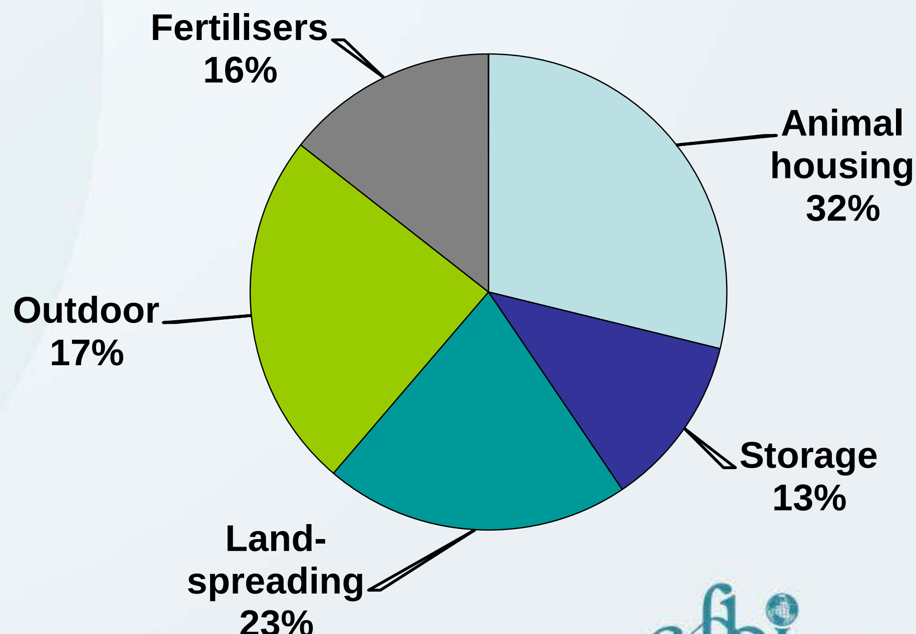


Country	% of area of Sensitive habitat exceeded
UK	71
England	97
Wales	94
Scotland	54
N. Ireland	89

UK agricultural ammonia emissions 2012

237.7 kt NH_3-N

£468m/yr



(Source: DEFRA, 2013)

Effects of acid rain on Bleaklow Moor, Derbyshire

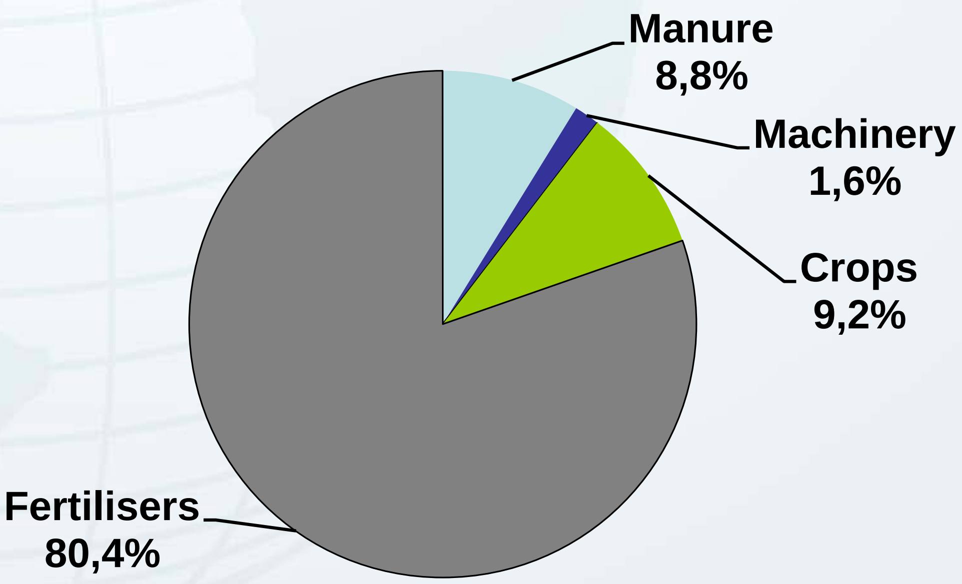
(http://www.bbc.co.uk/news/uk-england-17930662)

Why are nitrous oxide losses important?

N_2O is a potent GHG gas with a global warming potential nearly 300 times that of CO_2

- In Ireland agriculture is responsible for over 30% of total GHG emissions (mainly as CH_4 and N_2O)
- EU Directive to reduce GHG emissions by 20% by 2020 and UK Climate Change Act to reduce GHG emissions by 50% by 2050

N_2O emissions from UK farmed livestock



38.3 kt N_2O/yr

97.5 kt N_2O/yr

£ 738m/yr

(Source: NAEI, 2014)

Agri-Food and Biosciences Institute

Good Management Strategies

Match N & P supply to crop demand

- Fertiliser management (type, rate & timing of application)
- Crop & soil management (improved varieties, use of legumes, good soil drainage, good soil structure, soil & plant testing, control pests and diseases etc.)
- Livestock management (increase production per animal, diet manipulation to reduce N & P excretion)
- Manure management (allow for N & P content of manure, consider storage and timing & method of application)
- Nutrient balance with other essential nutrients (e.g. K, S, trace elements)



Identifying nutrient imbalances

Underuse of sulphur (S)

- Dramatic drop in fertiliser and atmospheric S inputs since 1960's - negative balances
- Currently, more than 20% of silage and grazed swards are testing as sulphur deficient at 1st cut and 1st grazing

Underuse of potash (K_2O)

- More than 20% of 1st and 2nd cut silage swards may be K deficient and under-performing

Sub-optimal sulphur & potash will :

- Reduce DM production &
- Reduce fertiliser N efficiency

AFBI research has developed DRIS analysis to identify nutrient imbalances in grass

Improving the efficiency of fertilisers

<u>Slow or controlled release fertilisers</u>

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

- Slow release – nutrient release pattern is fully dependant on soil and climatic conditions and cannot be predicted

- Controlled release – release pattern, quantity and time can be predicted within certain limits

afbi Agri-Food and Biosciences Institute

Slow and Controlled Release Fertilisers

Type	Description	Examples
Organic-N low solubility compounds	Condensation products of urea-aldehydes (slow-release)	Urea-formaldehyde (UF) Isobutylidene-diurea (IBDU) Cyclo-diurea/ Crotonylidene diurea (CDU)
Physical barrier - coated/encapsulated	Organic polymer coatings (thermoplastic or resins) Inorganic coatings Matrices can be hydrophobic (e.g. polyolefines, rubber etc) or hydrophilic (hydrogels)	Polymer coated sulphur-coated urea (PSCU) Polymer coated urea (PCU) Sulphur-coated urea (SCU) Polyolefin coated urea (e.g. Meister®) and coated NPK(+) compounds (e.g. Nutricote®)
Inorganic low-solubility compounds	Slow release	Eg. Metal ammonium phosphates (struvites), partially acidulated phosphate rock

afbi Agri-Food and Biosciences Institute

Slow and Controlled Release Fertilisers

Advantages	Disadvantages
• N release rate matches crop demand • Increases nitrogen use efficiency • Reduces N loss to the environment • Reduces number of applications/rates/ labour saving	• Synchronizing nutrient release to plant need • High cost per unit N compared to conventional fertilisers • ‘Burst’, damaged granules • Residues of synthetic material in soil

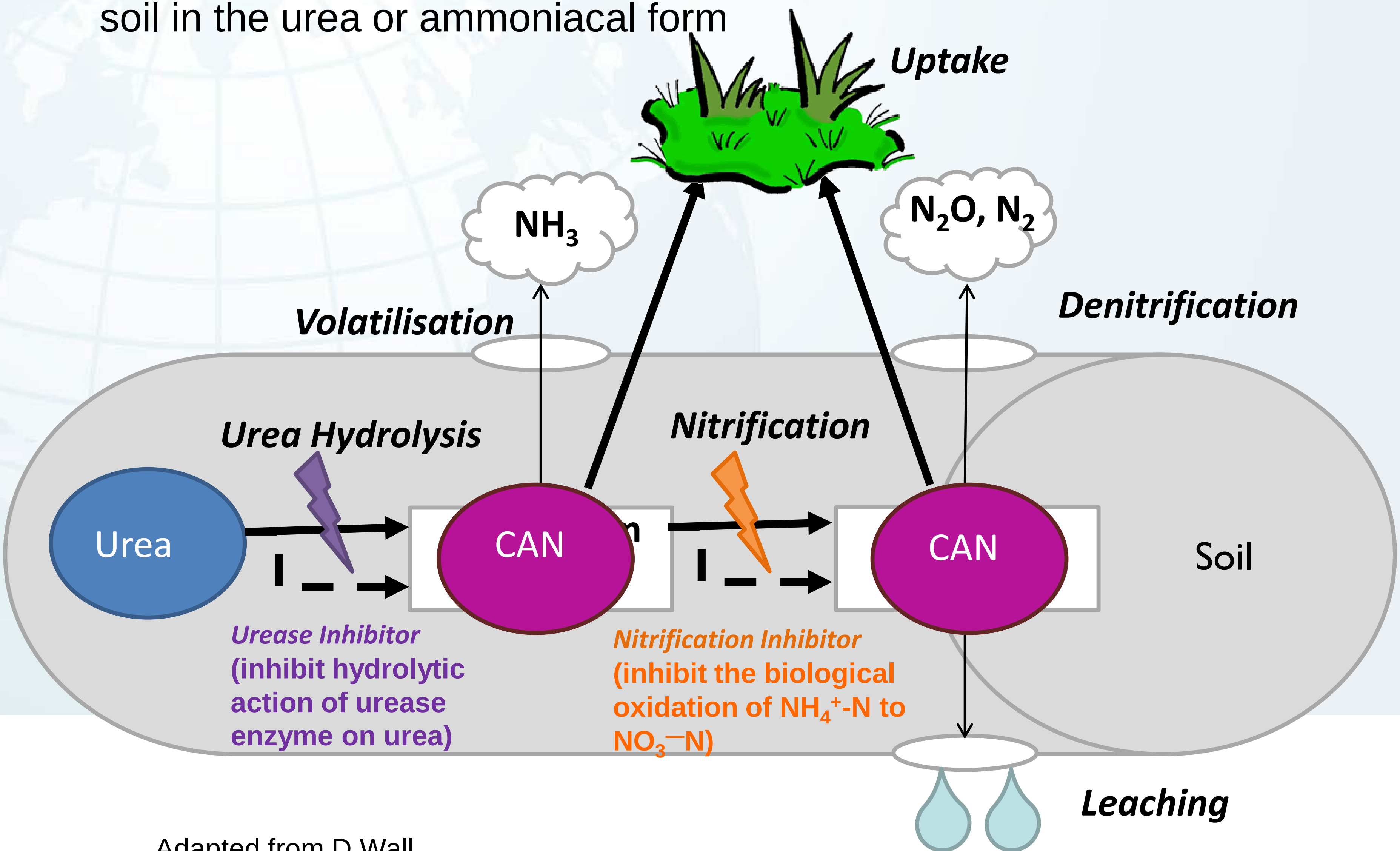
Use

- Limited use < 0.20 – 0.47% of total world fertiliser consumption (Trenkel, 2010)
- High cost compared to conventional fertilisers has limited their use to niche non-agricultural markets
- They are cost-effective for high-value crops
- Recent increase in use due to increased production capacity for SCU in China, and development of new PCU fertilisers (e.g. Environmentally Smart Nitrogen by Agrium) for agricultural crops in USA (profitable in field crops like maize, rice, wheat & potatoes)

afbi Agri-Food and Biosciences Institute

Stabilised N fertilisers

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



Adapted from D Wall

Requirements for successful inhibitors

- Non toxic
- Stable during production, storage and use
- Effective at low concentrations
- Inexpensive
- Compatible with urea or ammoniacal N

Many compounds have been tested but few meet these requirements and are commercially available

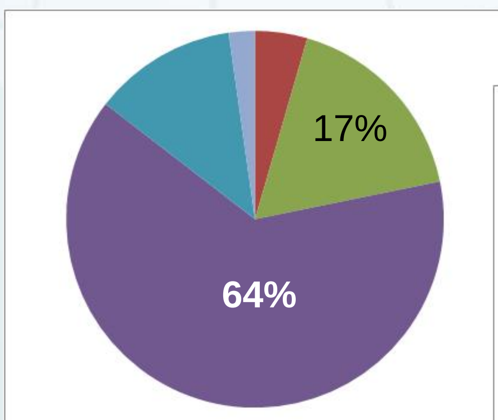
Urea fertiliser

Advantages	Disadvantages
• Most concentrated N fertiliser available (46% N) • Offers transportation advantages over other sources • Less expensive to manufacture	• Loss of N by ammonia volatilisation • Yield response is often lower than that to AN/CAN • Can adversely affect seed germination and seedling growth

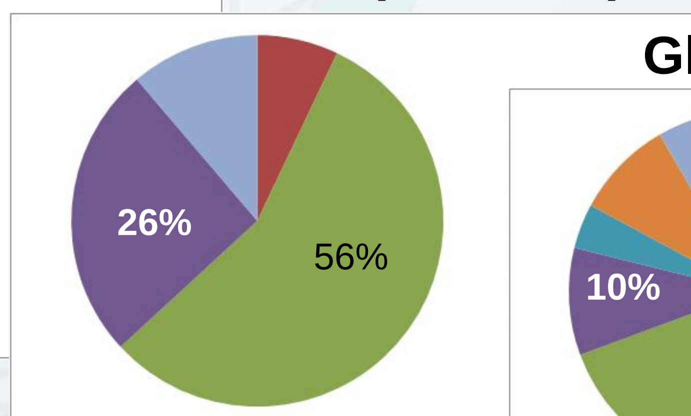
Nitrogen consumption (%) of straight N products

(IFA data 2012)

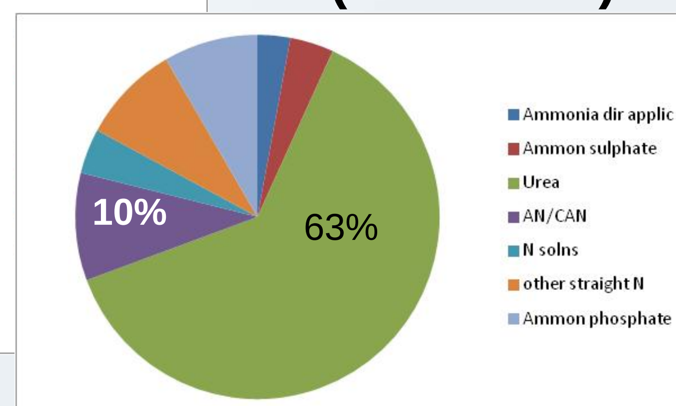
United Kingdom (0.86mt N)



South Africa (0.28mt N)



Global (137.7mt N)



Strategy to reduce ammonia loss from urea

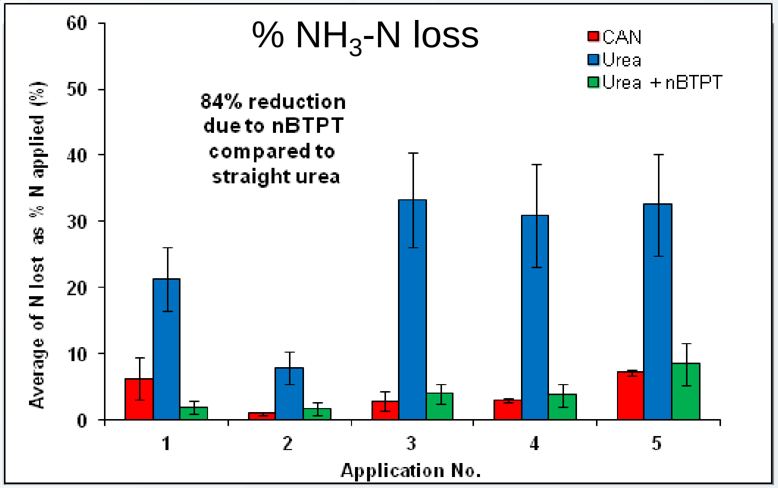
$$CO(NH_2)_2 + H^+ + 2H_2O \xrightarrow{\text{urease}} 2NH_4^+ + HCO_3^-$$

nBTPT is the most effective urease inhibitor – reduces NH_3 loss from urea & increases yield

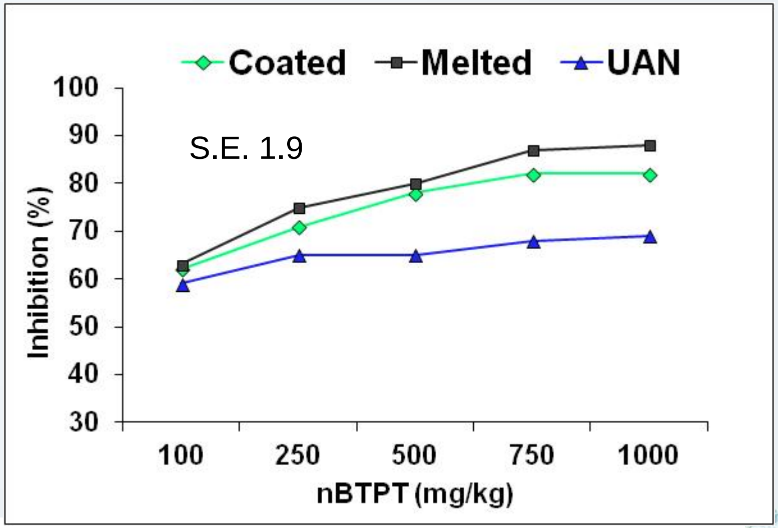
Tradename is AGROTAIN®

Extensive studies on:

- Rate of nBTPT
- Formulation
- Stability
- Effect of soil properties
- Repeated applications
- Short-term plant physiological effects



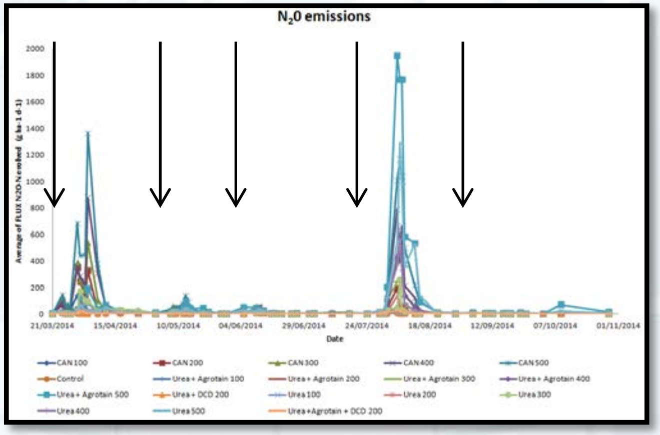
% inhibition in total NH_3-N loss

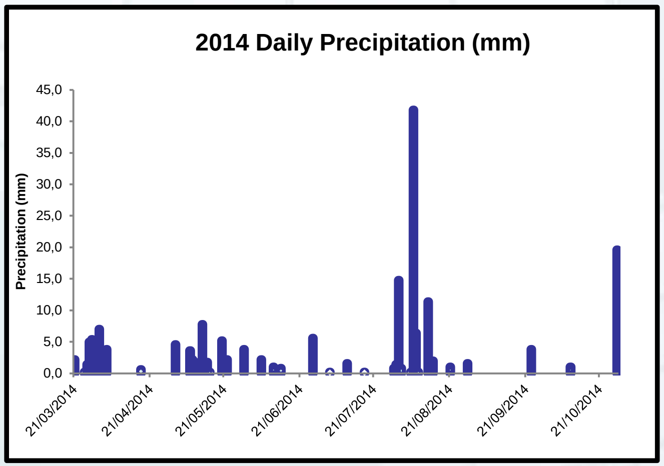


Agrotain treated urea is now marketed in over 70 countries worldwide

Understanding factors controlling N_2O emissions

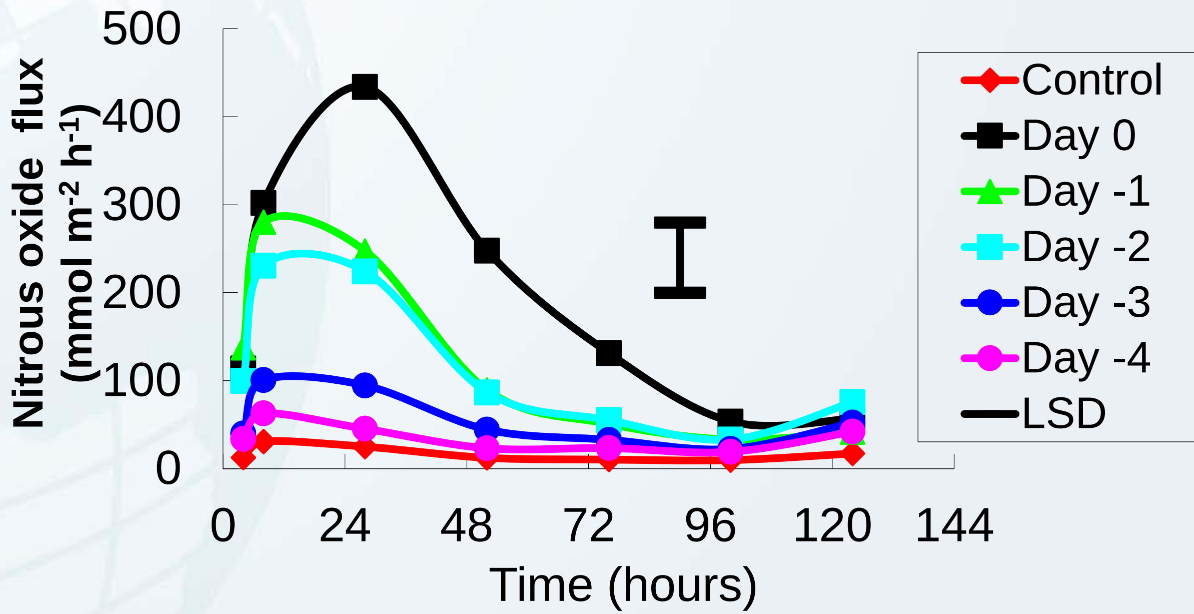
Daily N_2O emissions





Soil moisture, rainfall, temperature, soil type, carbon source, rate & form of N

Effect of timing of nitrate fertiliser application after slurry on N_2O fluxes

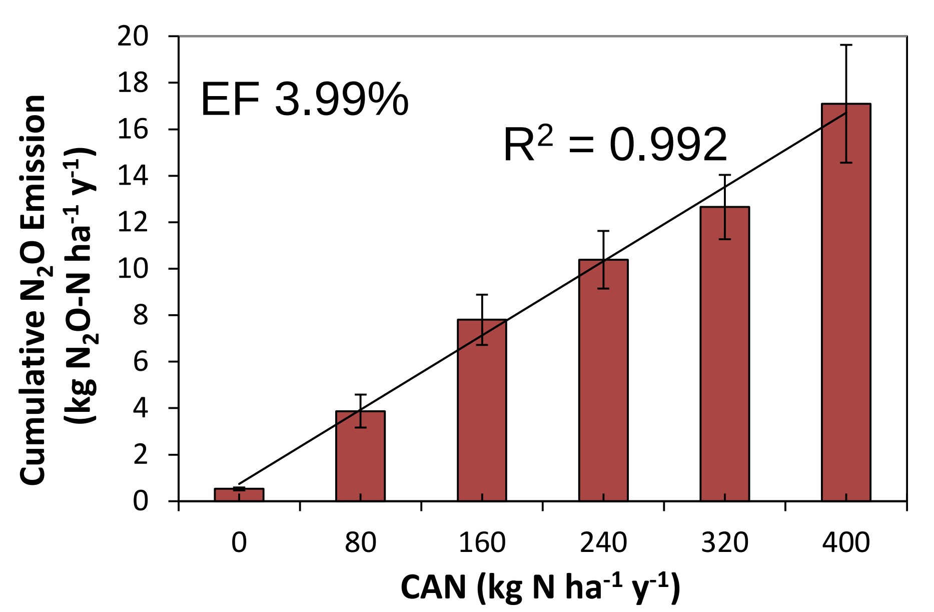


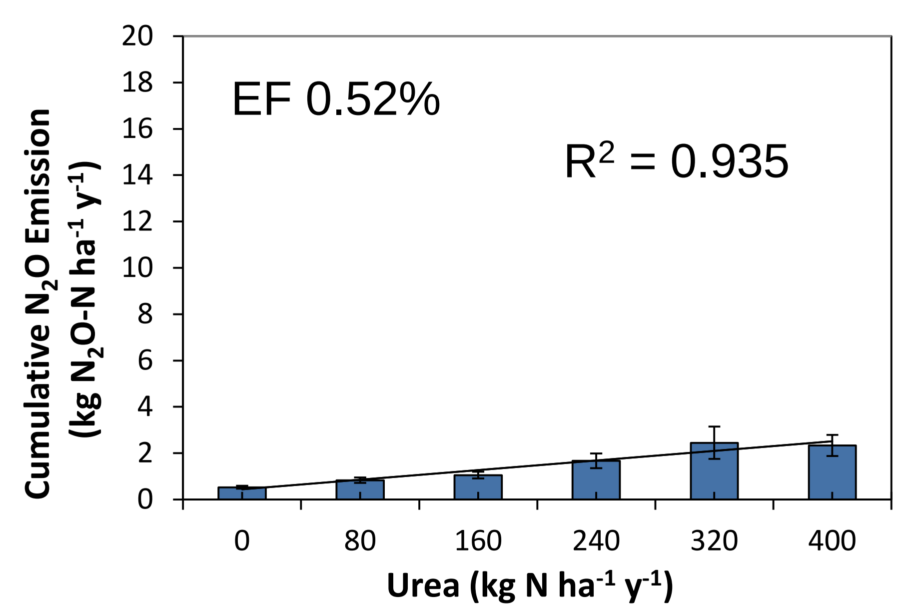
- Delaying nitrate fertiliser application for 4 days after slurry is applied can lower N_2O emissions

Effect of rate and form of N on N_2O emissions

CAN

Urea



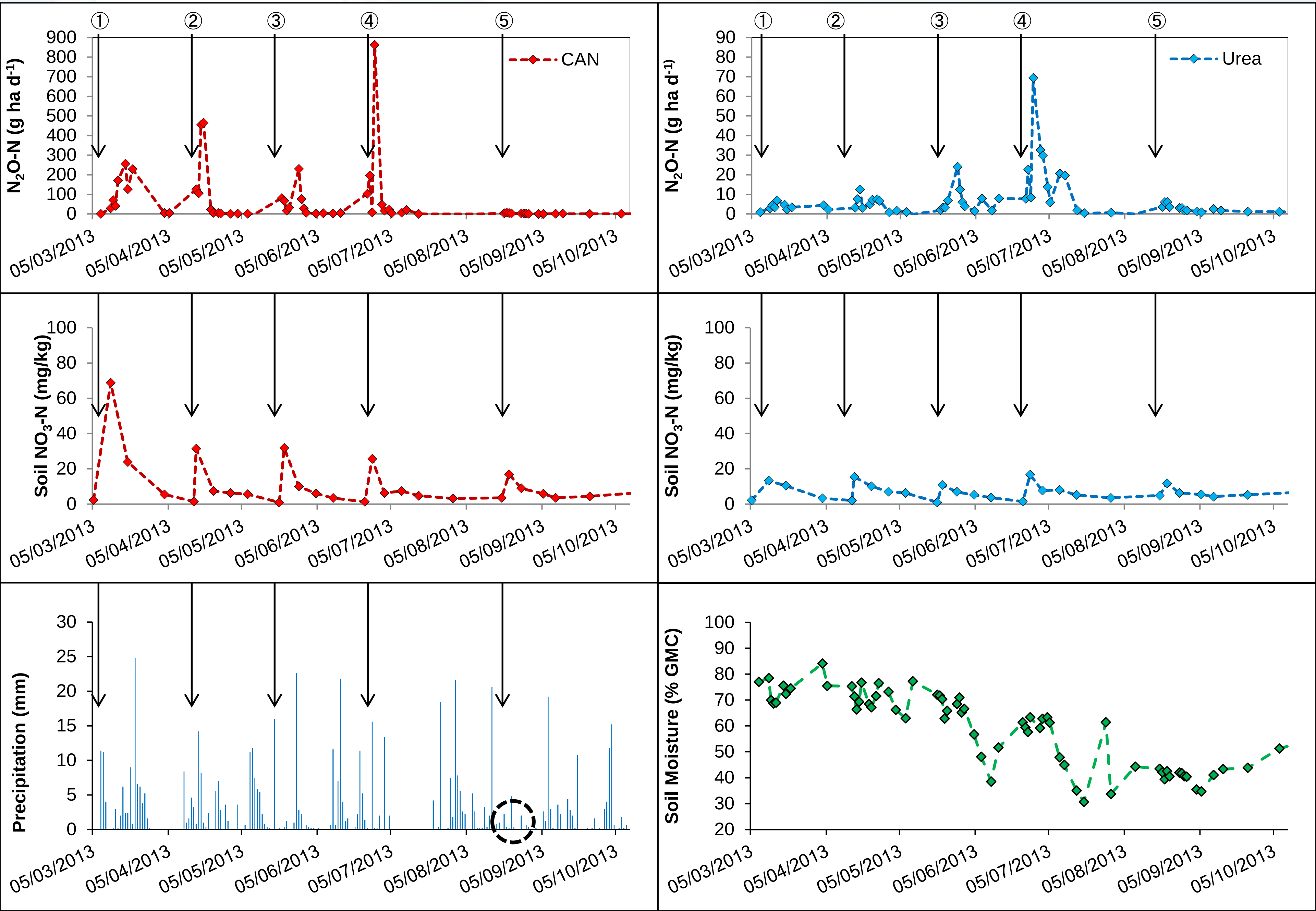


Challenge: *Manipulate soil N transformations to produce N_2 gas*

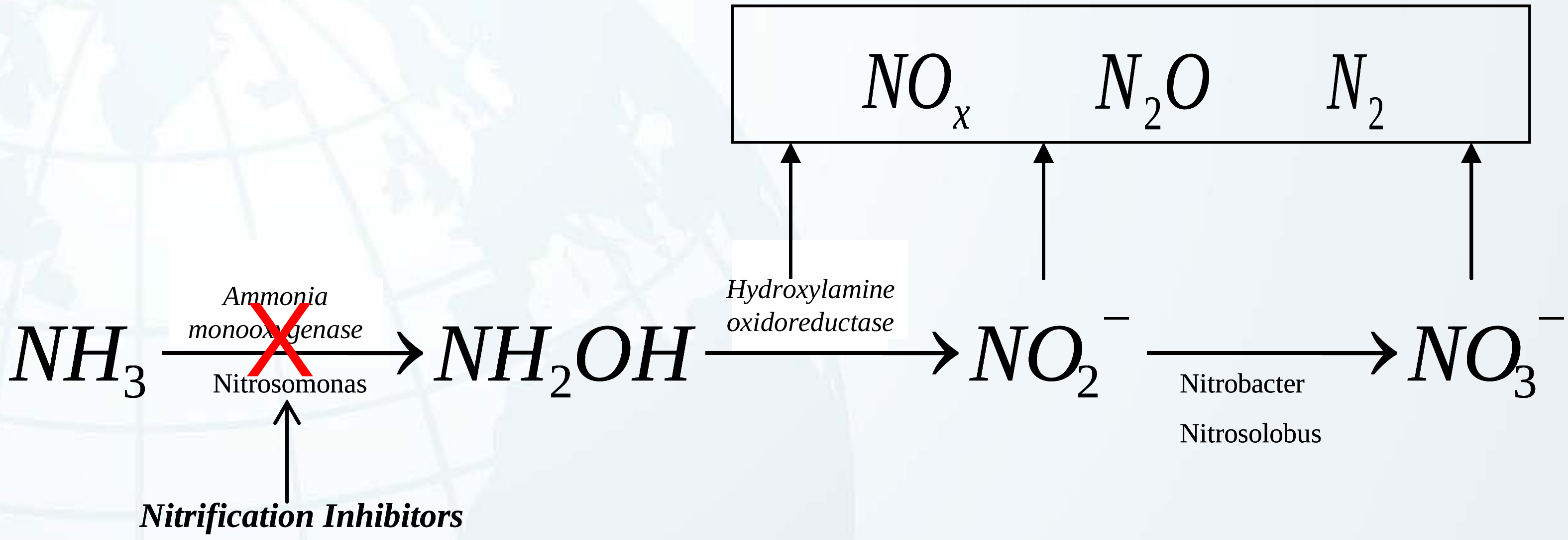
($N_2O \longrightarrow N_2$)

Agri-Food and Biosciences Institute

Peak N_2O emissions linked to soil nitrate



Strategy to reduce N_2O emissions



- Our expertise in ^{15}N isotope techniques has shown that the dominant process generating N_2O in Northern Ireland soils is denitrification
- We have shown that grassland soils are fungal dominated

Key is to manage the soil nitrate pool

<u>Form of N</u>
CAN vs Urea

<u>Inhibitors</u>
urease and nitrification

Agri-Food and Biosciences Institute

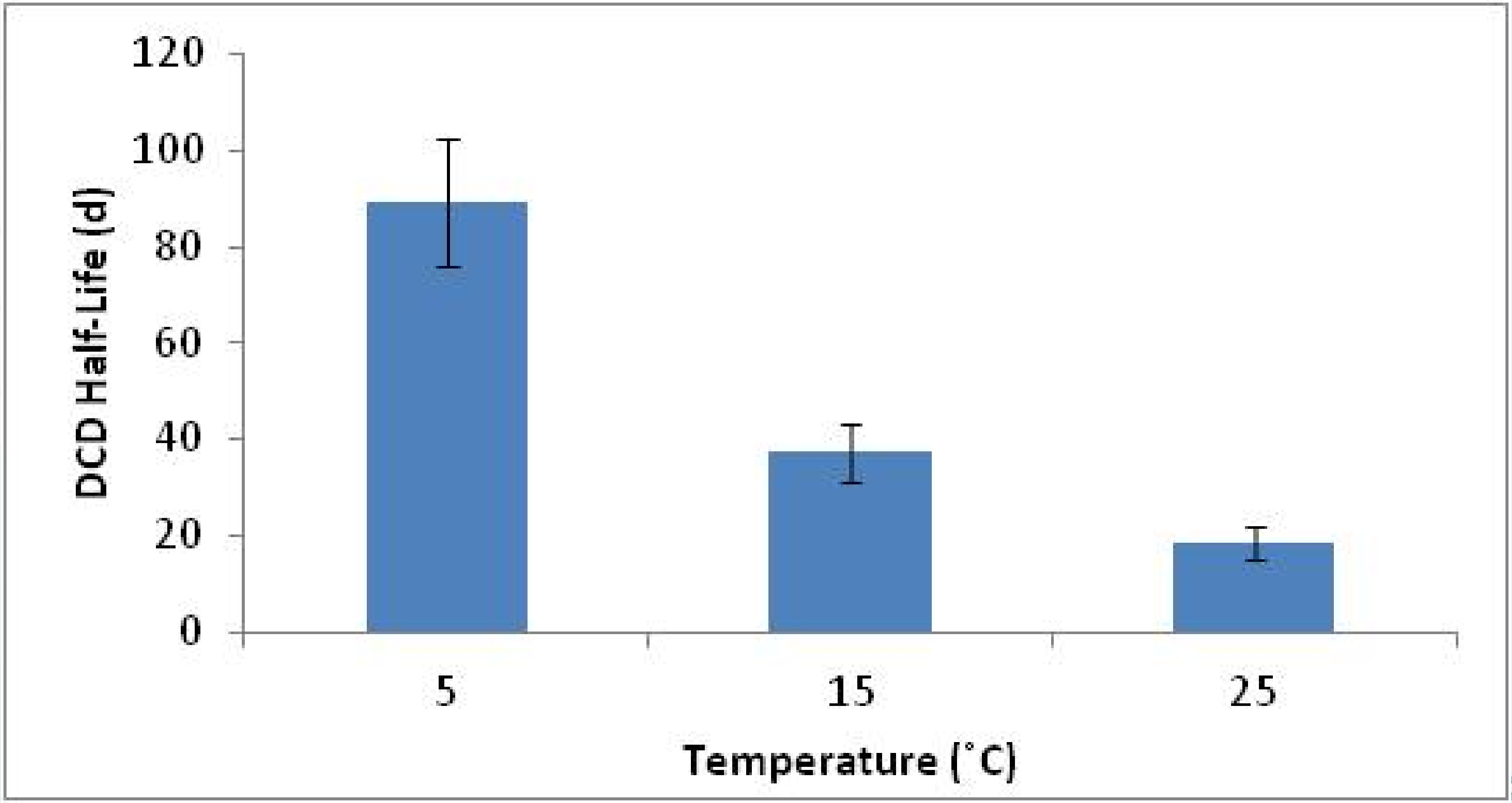
Commercially available nitrification inhibitors

Inhibitor	Rate	Relative volatility	Solubility in water	Mode of application
Nitrapyrin/ N-serve	1-2 mg/kg	High (Corrosive)	Low	Suitable with anhydrous ammonia with injection into soil
DCD	20 mg/kg (10 kg/ha)	Low	High	Use in solid, liquid fertilisers & slurry
DMPP	0.5–1.5 kg/ha	Low	Low	Use in solid, liquid fertilisers & slurry

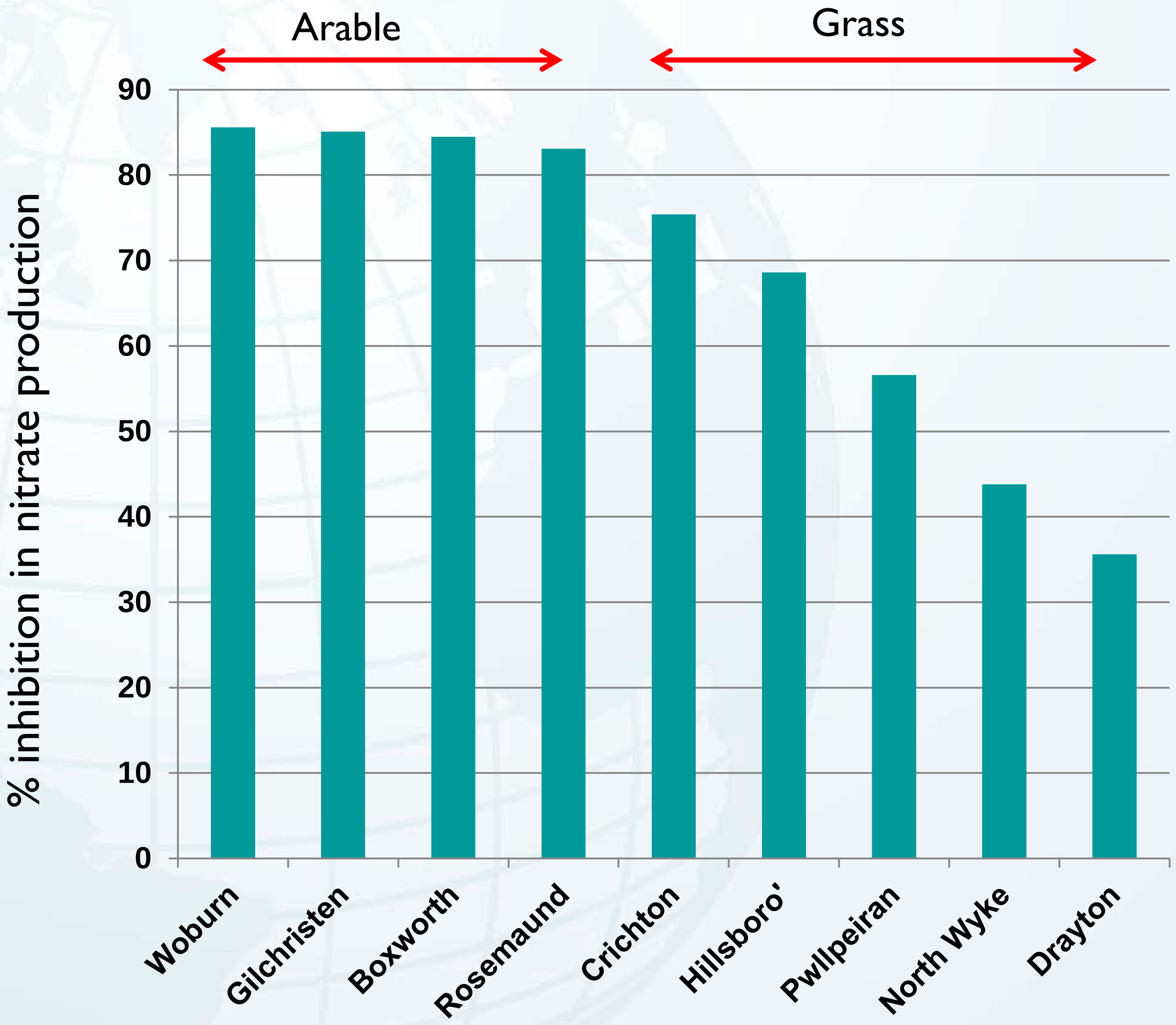
Agri-Food and Biosciences Institute

High temperatures affect the persistence of DCD

Half Life of DCD at 5, 15, and 25˚C (1st order kinetics) – average of 9 soils, data for 3 reps



Soil properties affect the efficacy of DCD



Greatest % inhibition on arable soils: average TN = 0.13%

Grass soils: average TN = 0.49%

DCD is less effective in soils with high % clay and high organic matter content

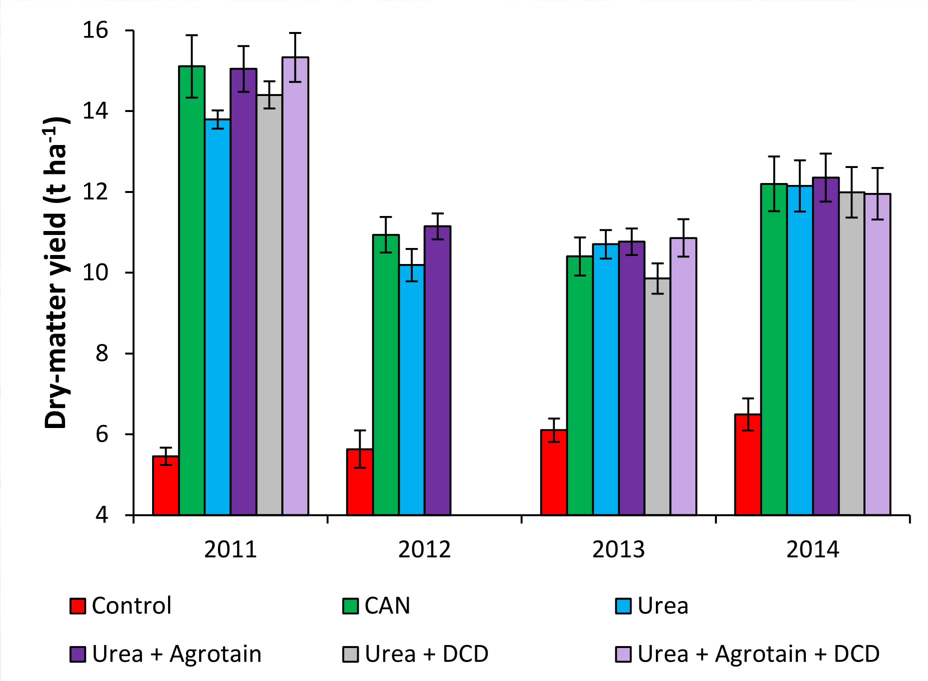
Strategy to reduce N_2O emissions

Direct & indirect N_2O EFs at Hillsborough

	Year				
Fertiliser Form	2011	2012	2013	2014	Average
CAN	0.46	3.50	3.82	1.69	2.37
Urea	0.54	0.67	0.53	0.72	0.62
Urea + n-BTPT	0.47	0.29	0.40	0.41	0.39
Urea + n-BTPT + DCD	0.09	-	0.11	0.20	0.13
Urea + DCD	0.26	-	0.25	0.35	0.29

Strategy to reduce N_2O emissions

Dry-matter yield (t ha^{-1})



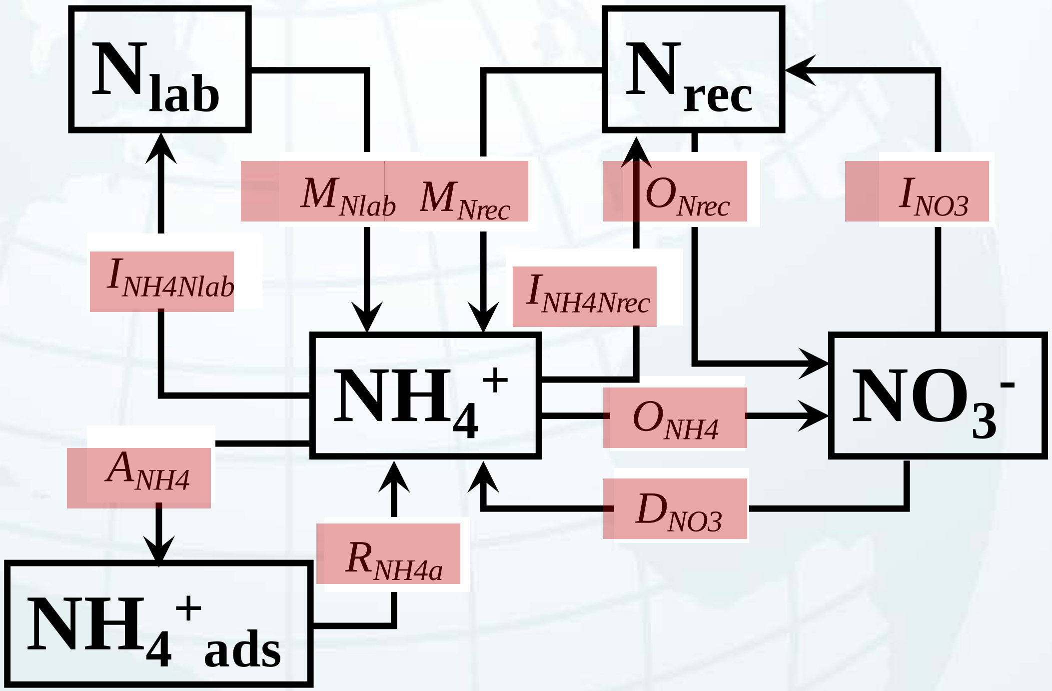
Replacing CAN with urea + urease inhibitor is a potential mitigation strategy to reduce N_2O emissions under Irish conditions, whilst maintaining grass production

Impact: *Stabilised urea is now commercially available in the UK and Ireland as an alternative to CAN & is cheaper*

Agri-Food and Biosciences Institute

Use of ^{15}N stable isotopes

^{15}N Tracing Model



(Müller *et al.*, 2007)

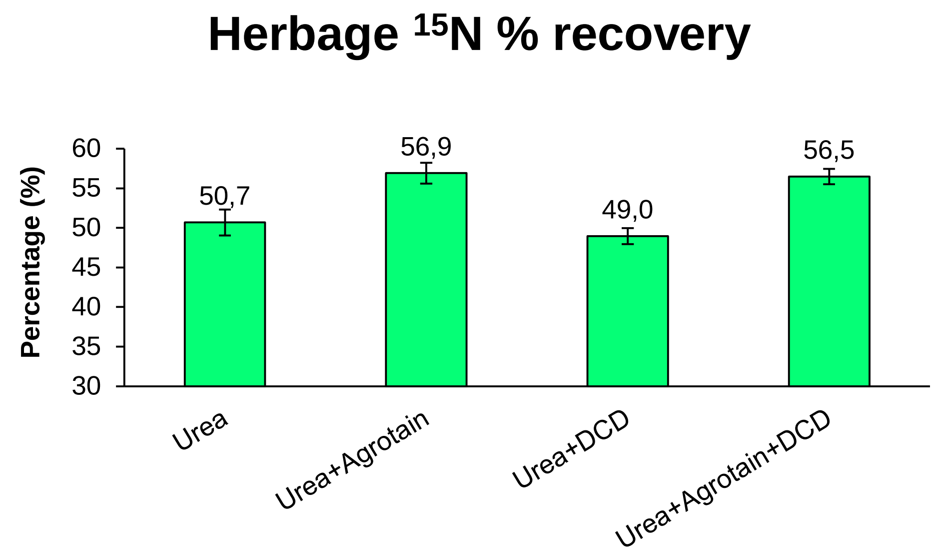
<u>5 soil N Pools</u>

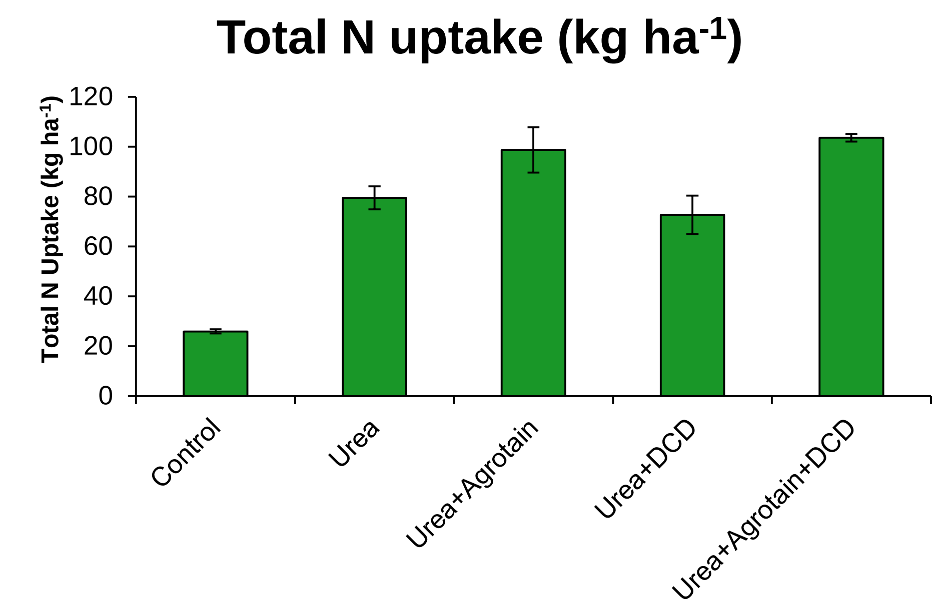
N_{lab}	Labile soil organic N
N_{rec}	Recalcitrant soil organic N
NH_4^+	Ammonium
NO_3^-	Nitrate
$NH_4^+{}_{ads}$	Adsorbed ammonium

Isotope ratio mass spectrometer

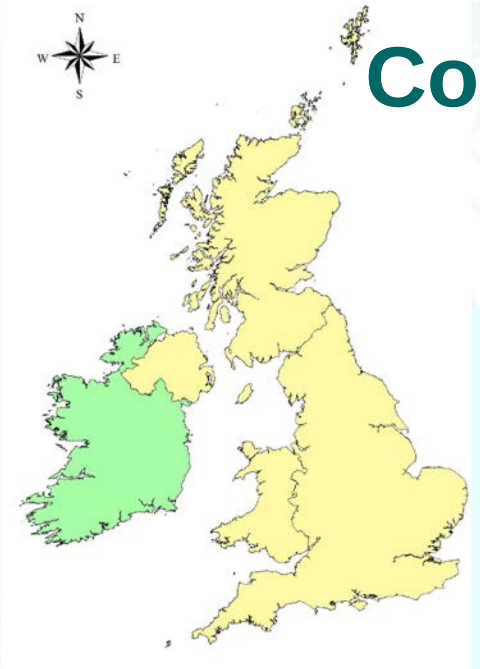
Impact: Providing insights into the effect of inhibitors on soil N transformations

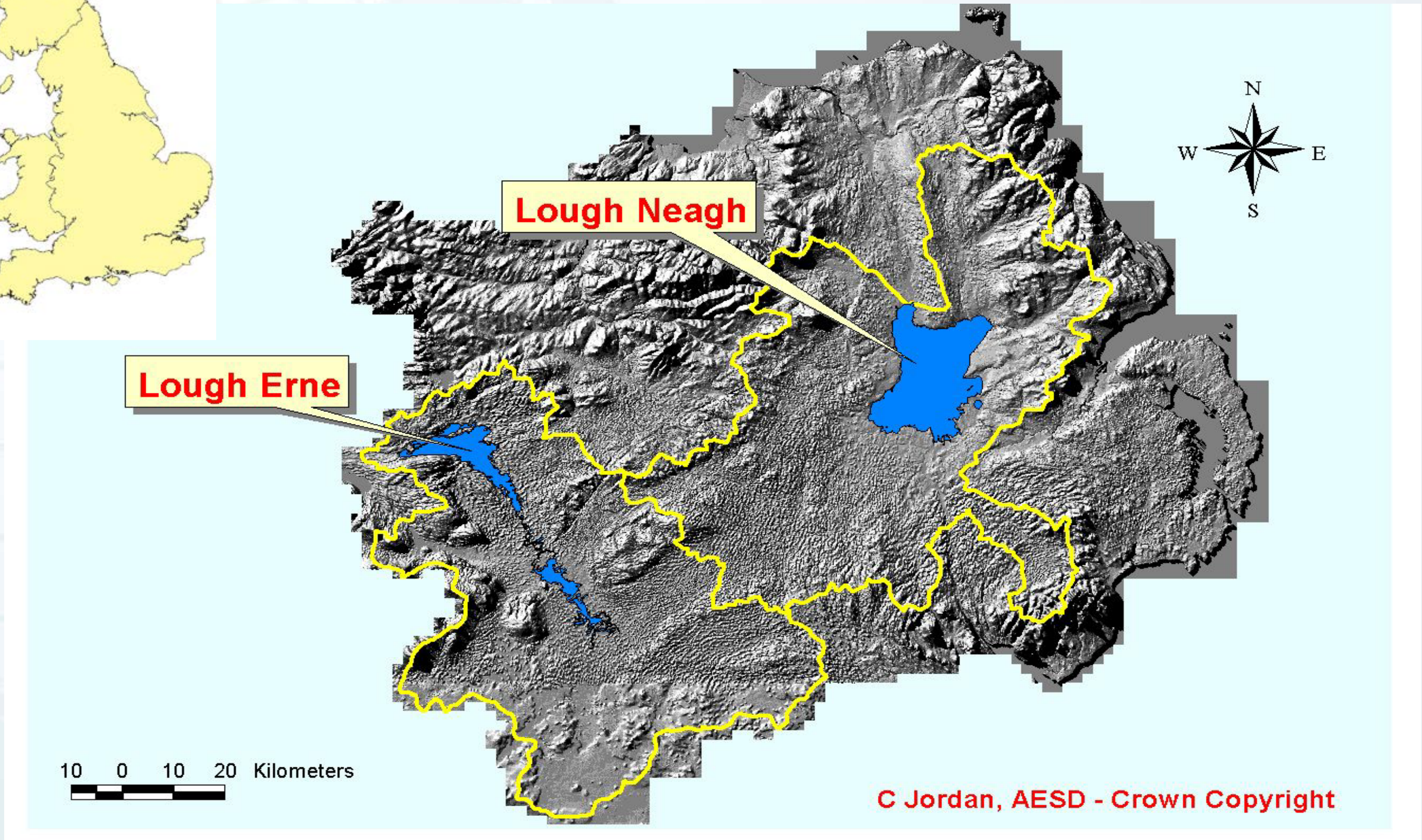
^{15}N field Micro-plot study





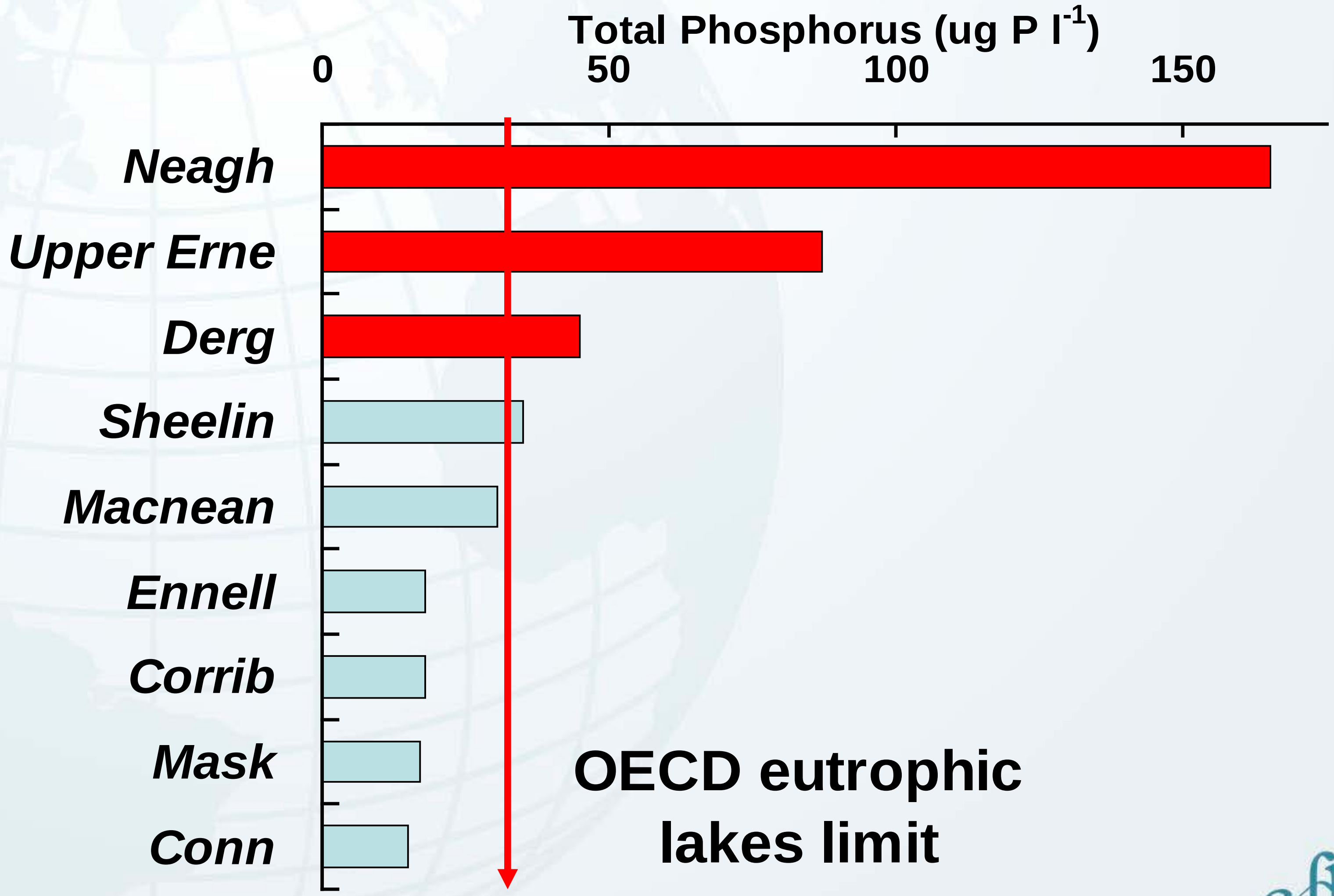
Controlling phosphorus losses in Northern Ireland



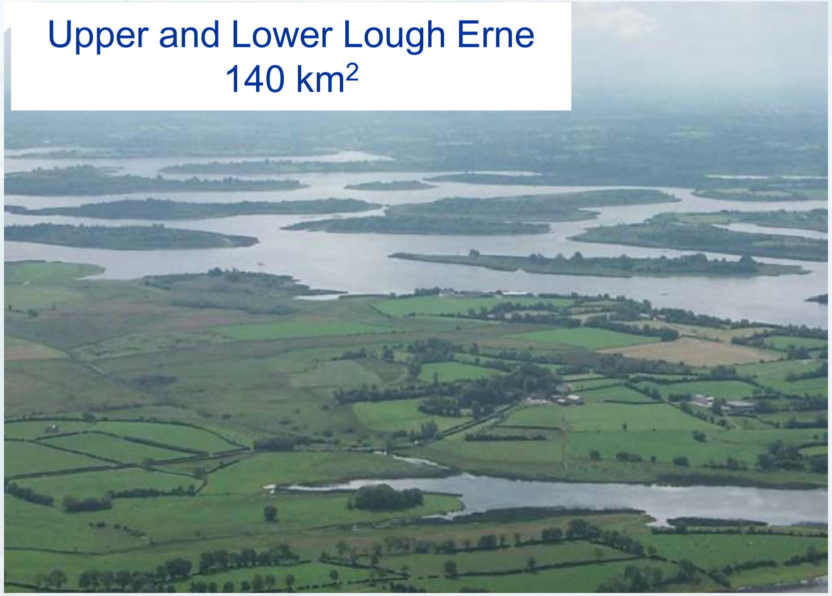


Agri-Food and Biosciences Institute

P concentrations of Irish lakes



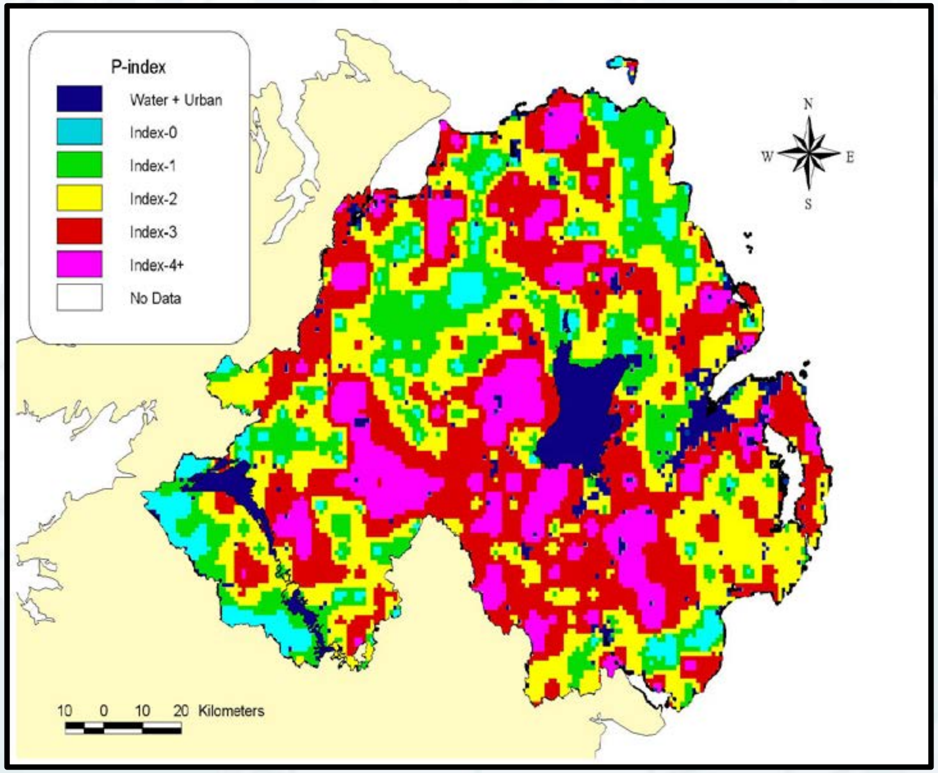
Impact of excess nutrients on water quality

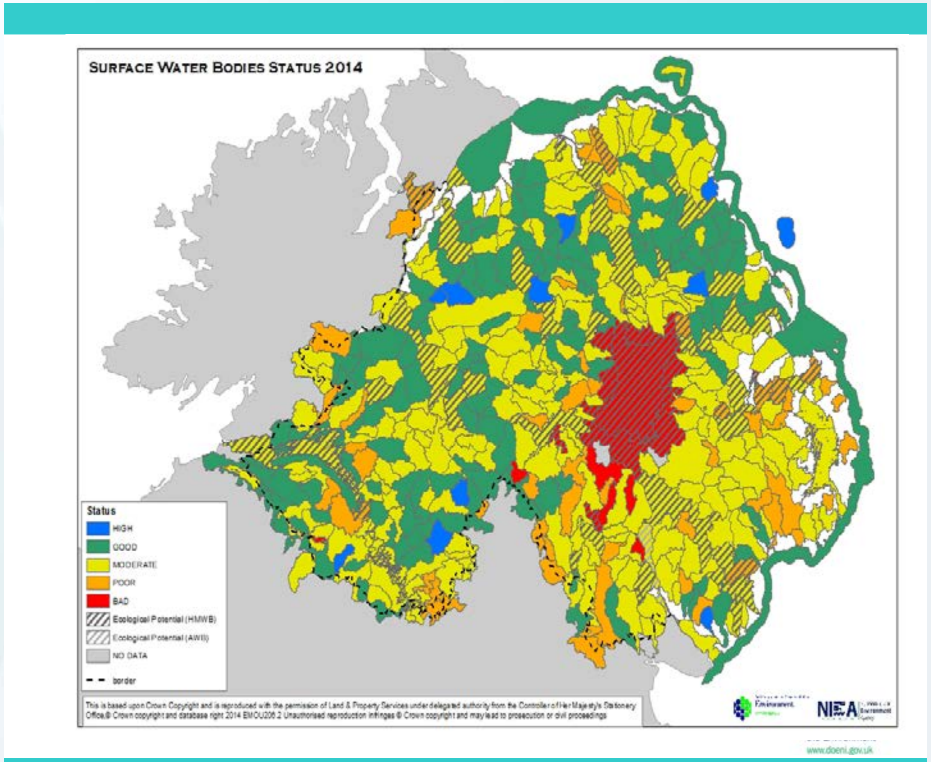


74% of monitored lakes classed as eutrophic or hypertrophic.

- Lough Neagh is hypertrophic
- Lough Erne is eutrophic

Impact of high soil P?





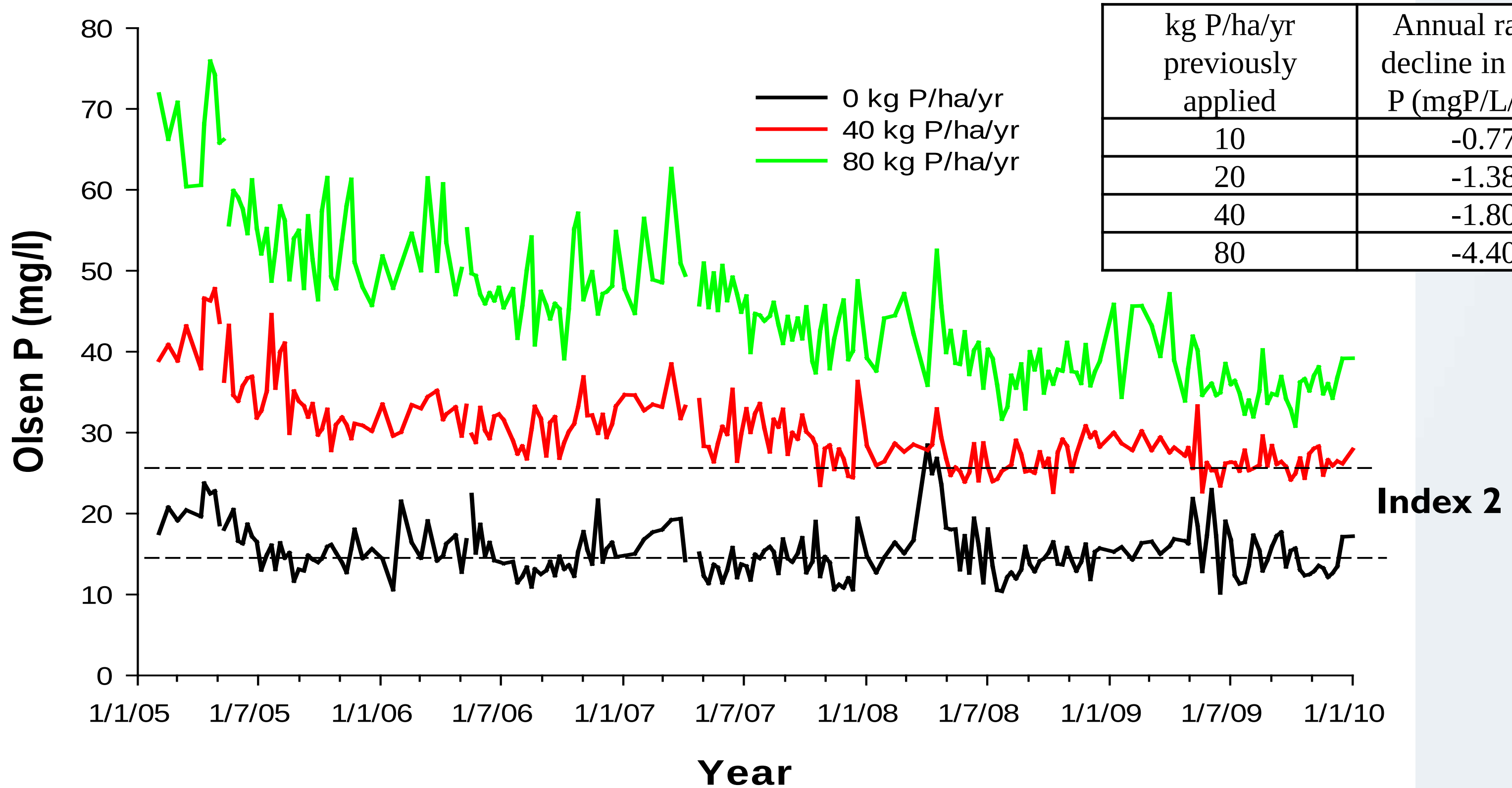
Courtesy of NIEA

Challenge: Reducing high P status soils

afbi Agri-Food and Biosciences Institute

Curtailing phosphorus fertiliser applications

Leads to a decline in soil P status



kg P/ha/yr previously applied	Annual rate of decline in Olsen P (mgP/L/year)
10	-0.77
20	-1.38
40	-1.80
80	-4.40

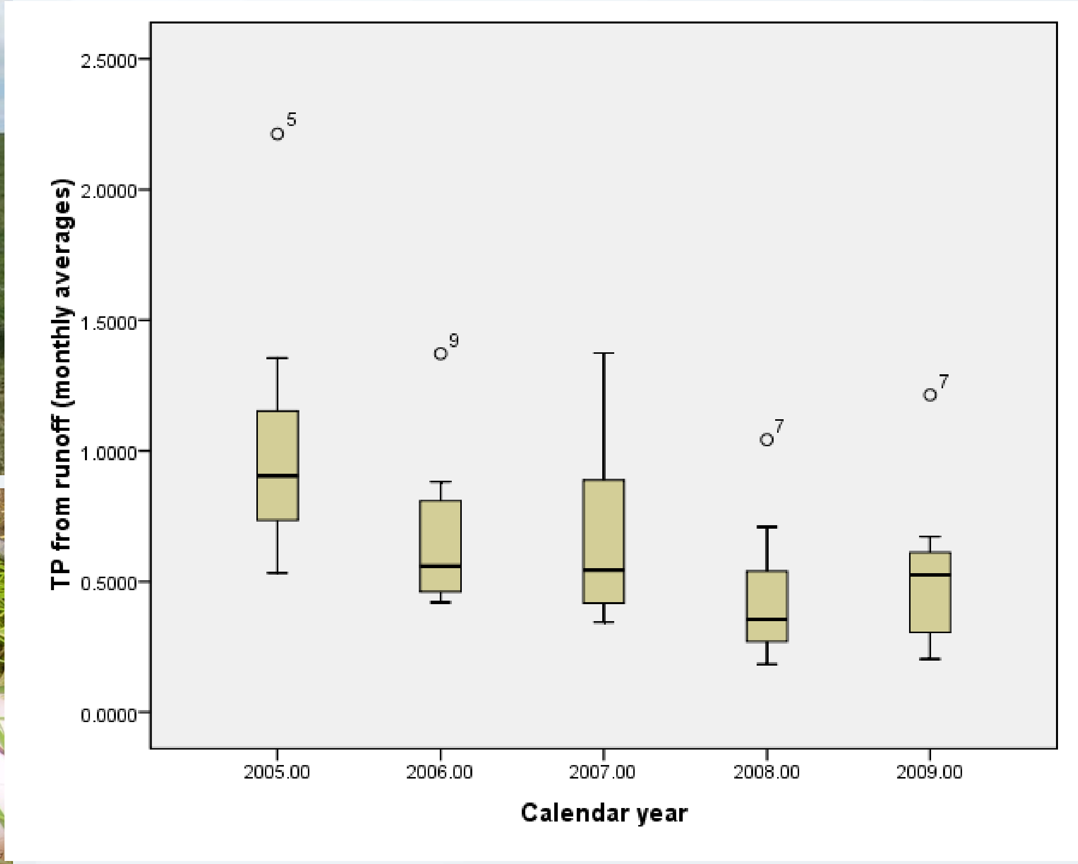
<u>Research Impact</u>

- 13 years for Index 4 soil to decline to Index 2 at a P balance of -8 kg P/ha/yr, under grazing management
- P balance of -8 kg P/ha/yr is not compatible with intensive dairy farming

afbi Agri-Food and Biosciences Institute

Curtailing phosphorus fertiliser applications

Leads to a decline in P concentrations in runoff



Annual decline = 99 μg P/L/year

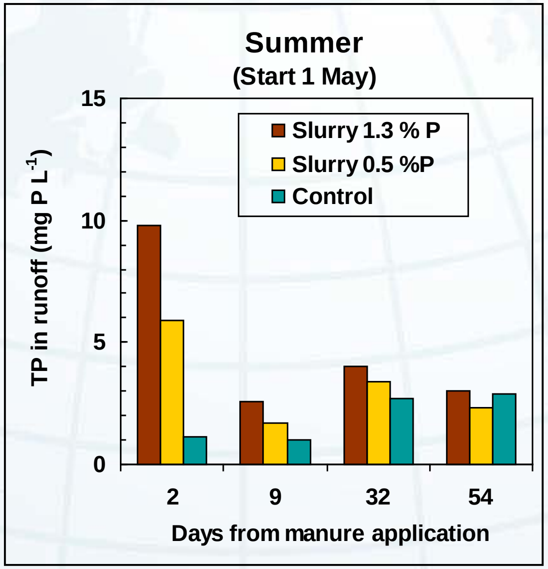
Agri-Food and Biosciences Institute

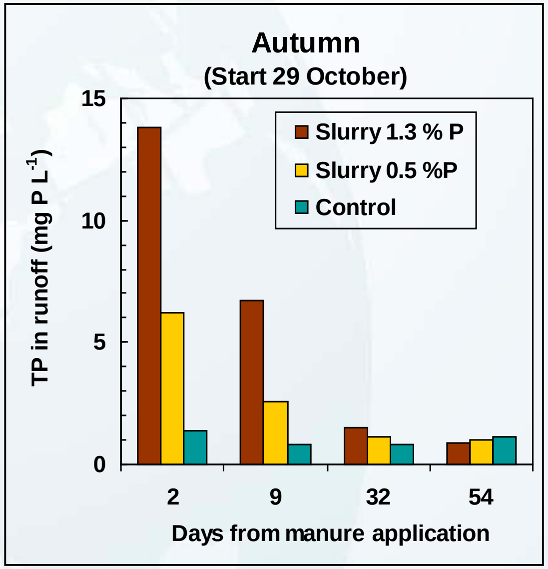
Reducing dietary P on total P losses in runoff following manure application

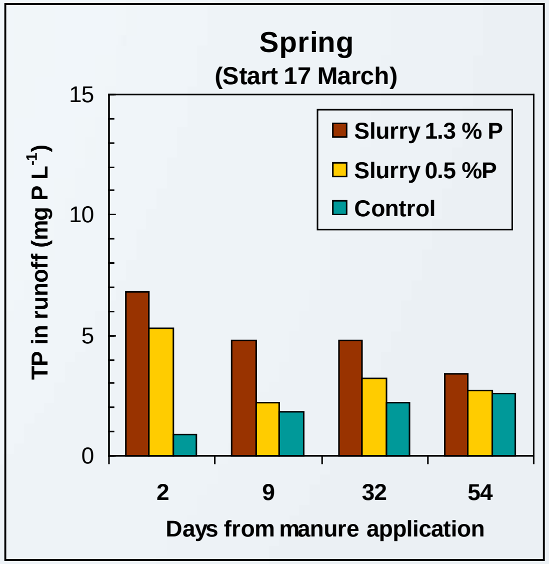
- Manure from dairy cows fed with variable P diets
  - produced high P (1.3%P) and low P (0.5%P) manures
- Rainfall simulation studies were undertaken to determine the impact of manure spreading on:
  - TP concentrations in runoff
  - Persistence of the P signal after manure application
- A rainfall simulator was used for a standard & reproducible rainfall event
  - High intensity rain 40 mm/hour for 30 minutes
  - Results in infiltration excess surface runoff
- Standard slurry application of 50 m^3/ha

Reducing dietary P on total P losses in runoff following manure application

High P (1.3% P) vs low P (0.5% P) manure







- Two days after slurry applications very high P concentrations were measured in runoff.
- Persistence of P signal was less in summer than in autumn
  - In autumn slurry effect evident > 9 days after application
- Avoiding runoff has benefits as great as or better than lowering manure P.

afbi Agri-Food and Biosciences Institute

O'Rourke et al. (2010) J. Environ Qual. 39: 2138-2146

Managing dirty water

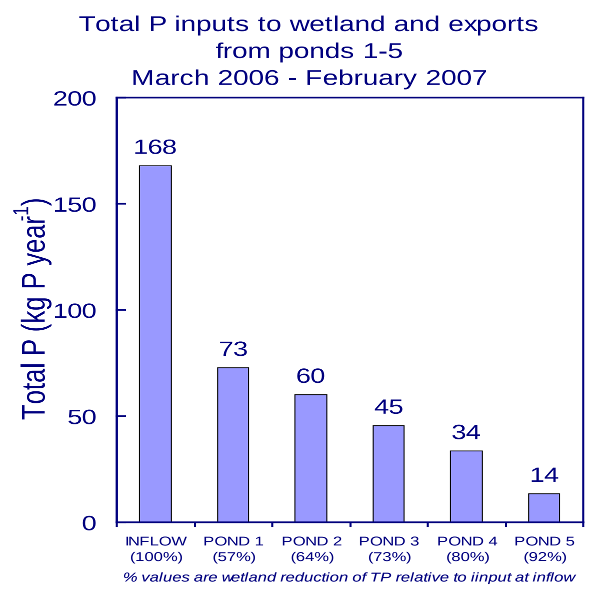
Greenmount Constructed Wetland

The Wetland designed and scaled to treat dirty water from 180 dairy cows containing:

- Parlour washings
- Winter runoff from unroofed grass silage pits
- Dirty water runoff from lightly contaminated livestock yards

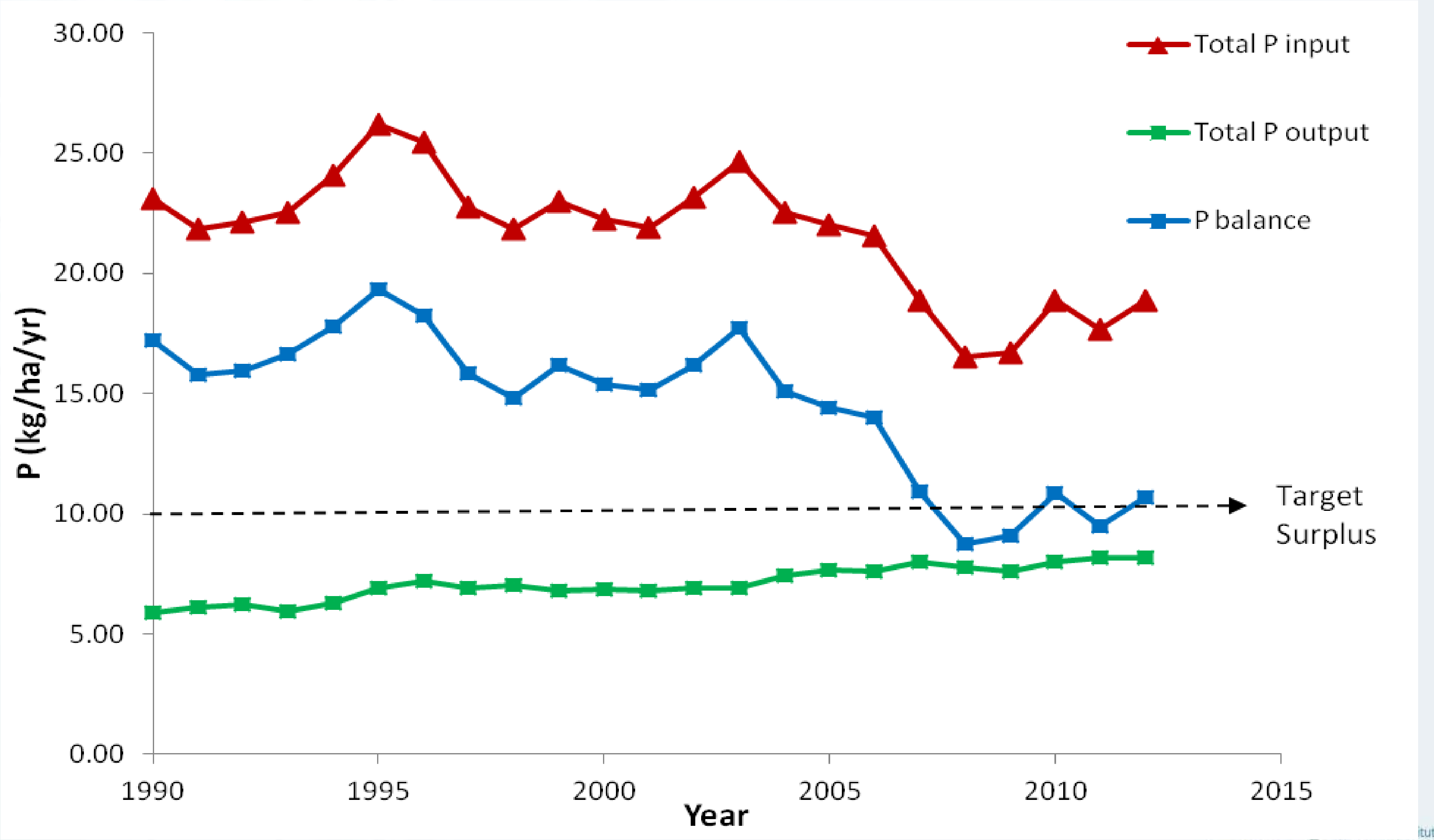
Research has shown:

- Pollutant removals > 95% - Biochemical Oxygen Demand (BOD) > 99%.
- Virtually 100% treatment efficiency in summer.
  - high plant evaporation ensures very little discharge from May to October
- Winter phosphorus retention (82% to 95%) – least in February.



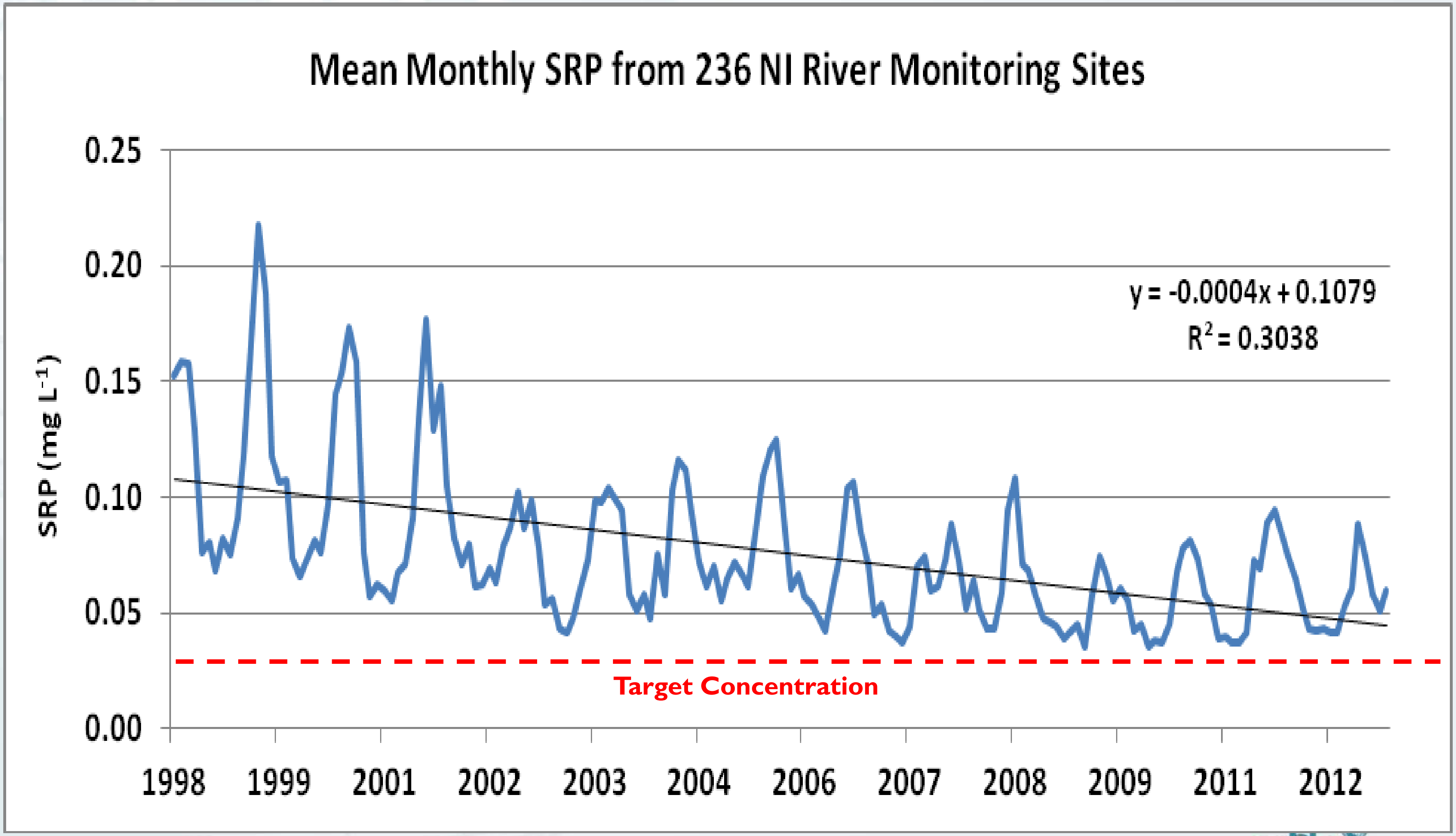
Reducing the P surplus of NI Agriculture

Challenge: Maintain soil fertility and stocking rates



AFBI Research – quantifying P Balance

Improvements in water quality in NI

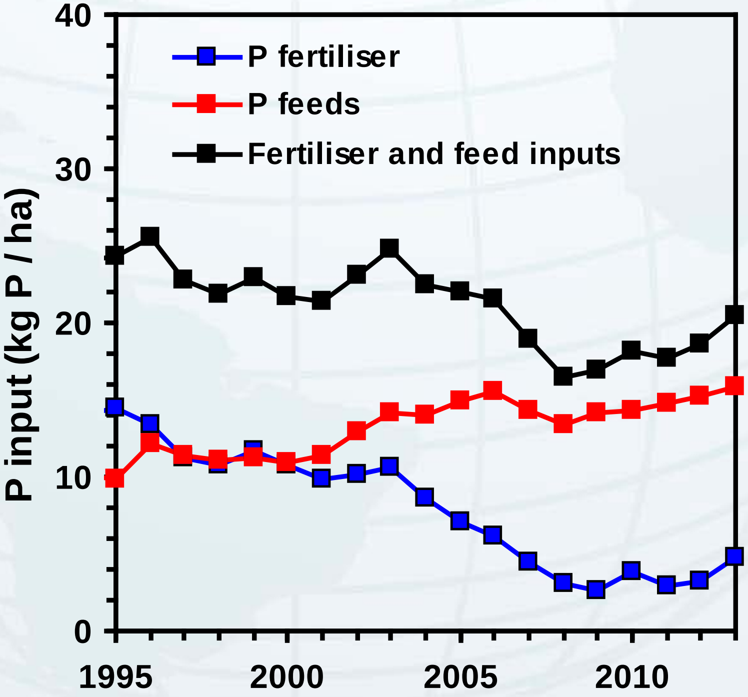


Courtesy of NIEA, Northern Ireland

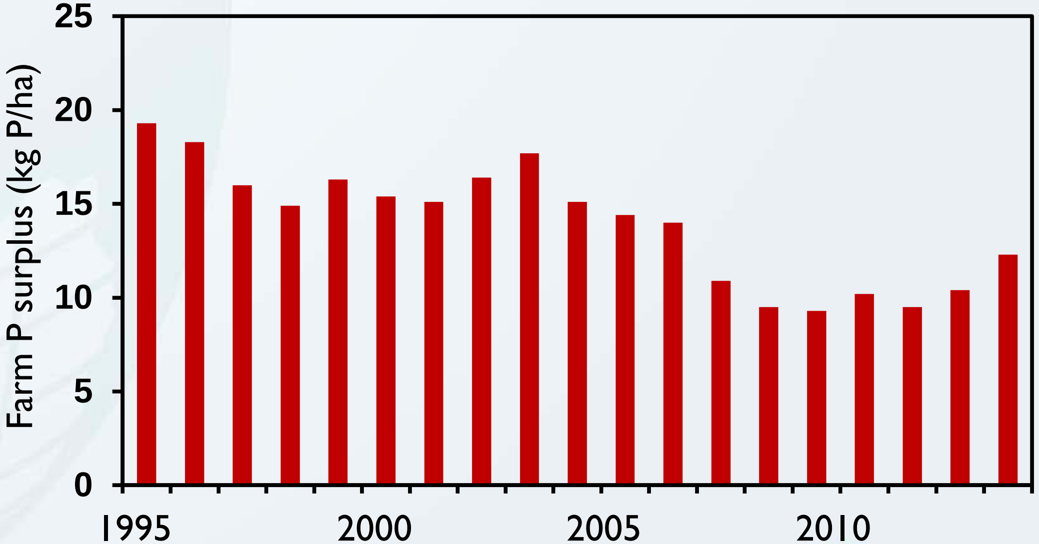
Overuse of P in land based livestock production

- A dramatic decline in P fertiliser usage since 2003 caused a significant decline in mean farm P surpluses on NI farms
- A progressive increase in concentrate P usage, however, has recently begun to reverse this decline in farm P surplus
- Currently, farm P surpluses on 50% of dairy farms (non-derogated) are between 10 and 40 kg P/ha/yr

Phosphorus inputs to NI farmland



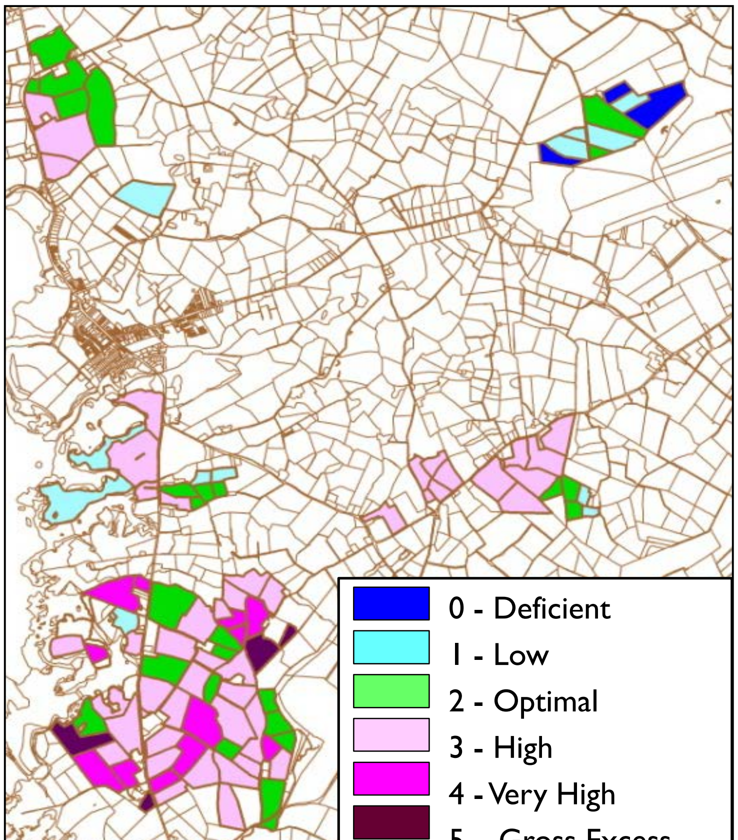
Average farm P surpluses for NI: 1995-2013

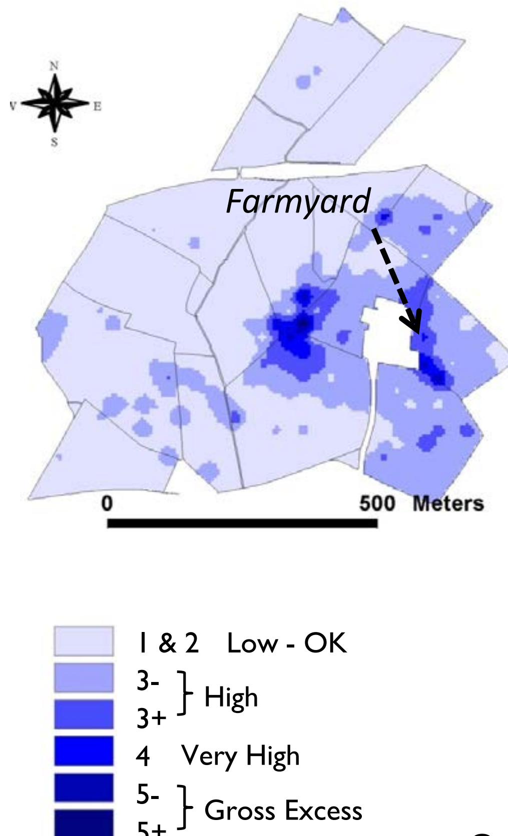


Courtesy of John Bailey, AFBI

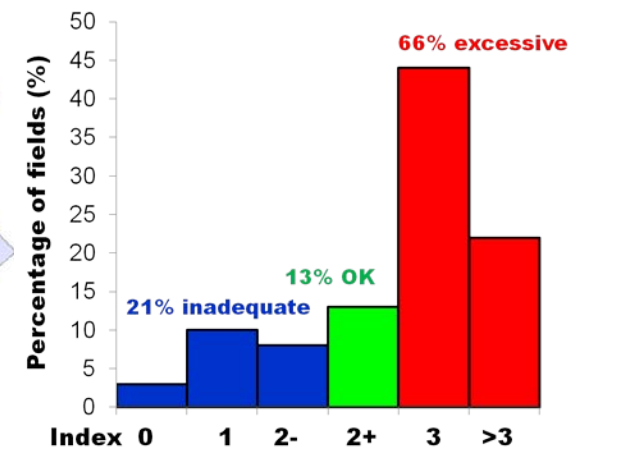
Unbalanced distribution of P

- Lack of soil testing and manure application in fields close to farm yards
- As a result, on average 66% of land on intensive dairy farms is over-supplied with P and on some 100% of fields have P indices > index 2





Soil P index distribution on intensive dairy farms



Courtesy of John Bailey, AFBI

Water Framework Directive

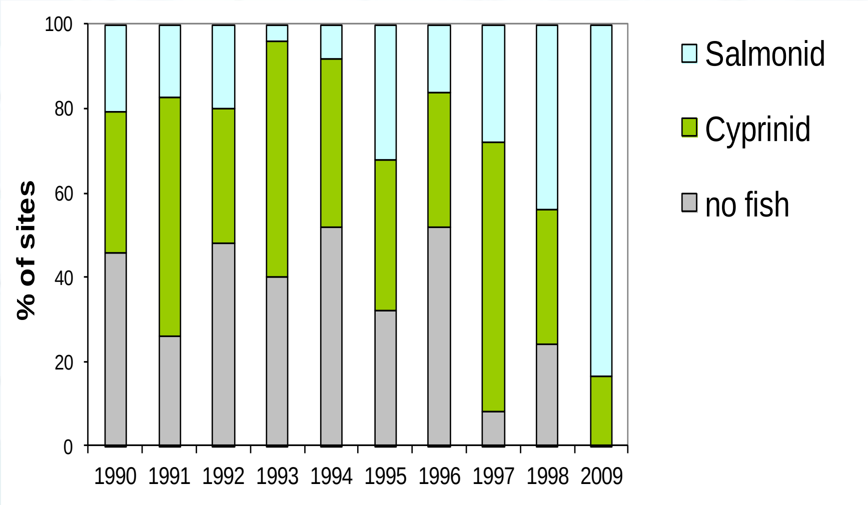
Directive 2000/60/EC

Target is to restore all surface water to good ecological and chemical status by 2027

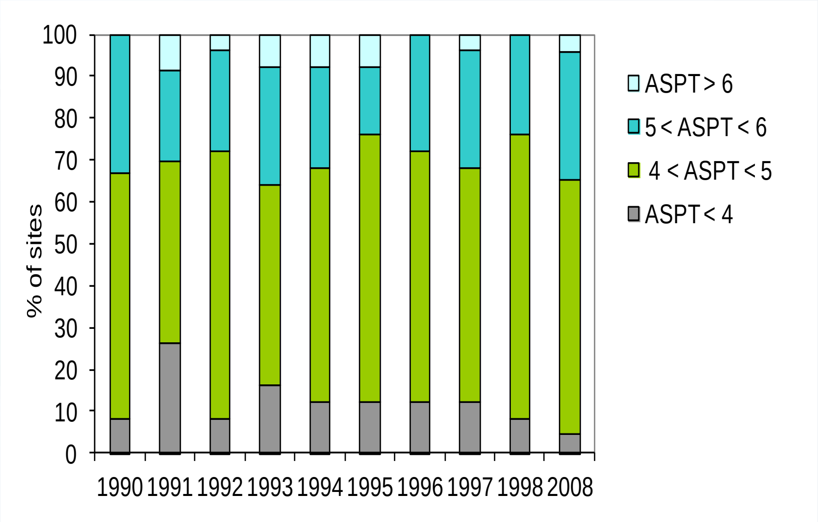
Ecological targets are NOT being met

Challenge: Need for Additional Measures & Setting Realistic Targets

Chemical Water Quality



Biological Water Quality



Why is there no improvement in biological water quality?

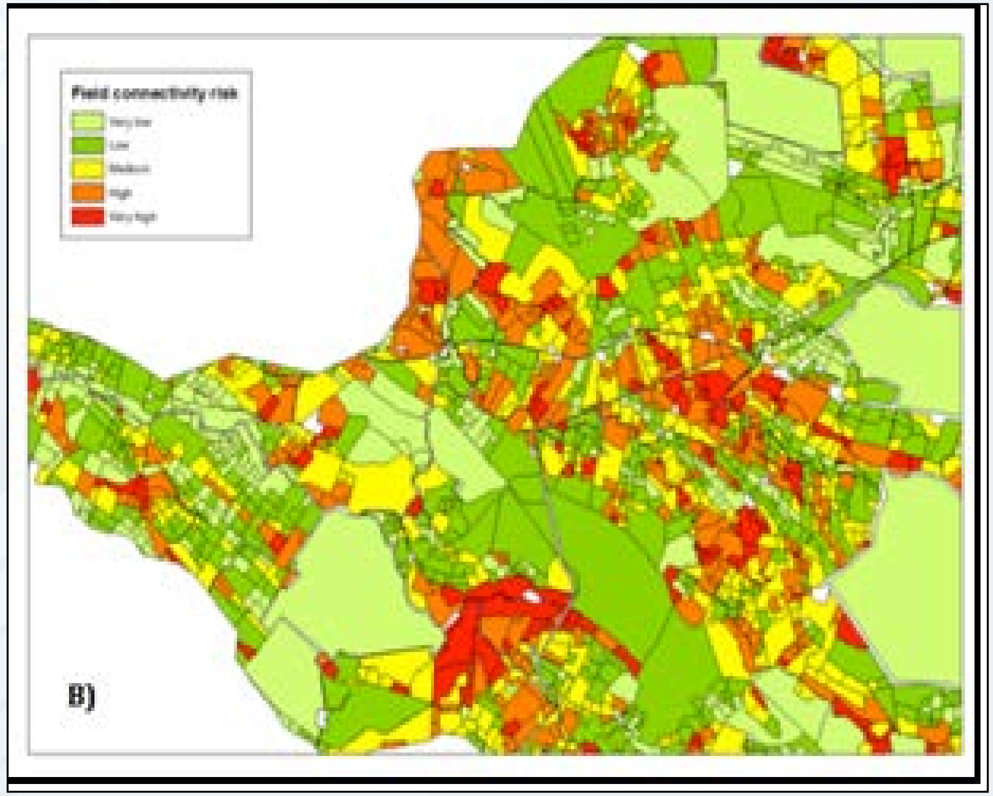
Requirement for long term monitoring programmes of lakes and river networks

Courtesy of Chris Barry, AFBI

afbi Agri-Food and Biosciences Institute

How can we move forward?
Further options to reduce P losses

- Target high risk areas with:
  - Wetlands
  - Riparian zones
  - Willows
  - Vegetated ditches
  - Absorption resins
  - Zone land
  - Plough/Reseed



- Reduce the P surplus and improve manure distribution (incl. manure separation)

afbi Agri-Food and Biosciences Institute

Conclusions

Key issues:

- Growth in demand for agricultural products
- Increased dependence on concentrate feeds (mainly cereals) in livestock systems
- Increasing concerns regarding the environmental impacts of intensive farming systems (e.g. GHGs & ammonia emissions, water quality, ecological impacts)
- Compliance with EU Directives (e.g. Nitrates Directive and WFD) and environmental targets




Sustainable Agricultural Production

Innovation is required

afbi Agri-Food and Biosciences Institute

Thank you for listening

Acknowledgements:
John Bailey, Rachael Carolan, Donnacha Doody, Suzanne Higgins, Ronnie Laughlin, Karen McGeough and all the Agri-Environment field and lab staff

Agri-Food and Biosciences Institute