Refining Nitrous Oxide Emission Factors – Measurements & Modelling

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Nairobi 24 26Sept. 2012

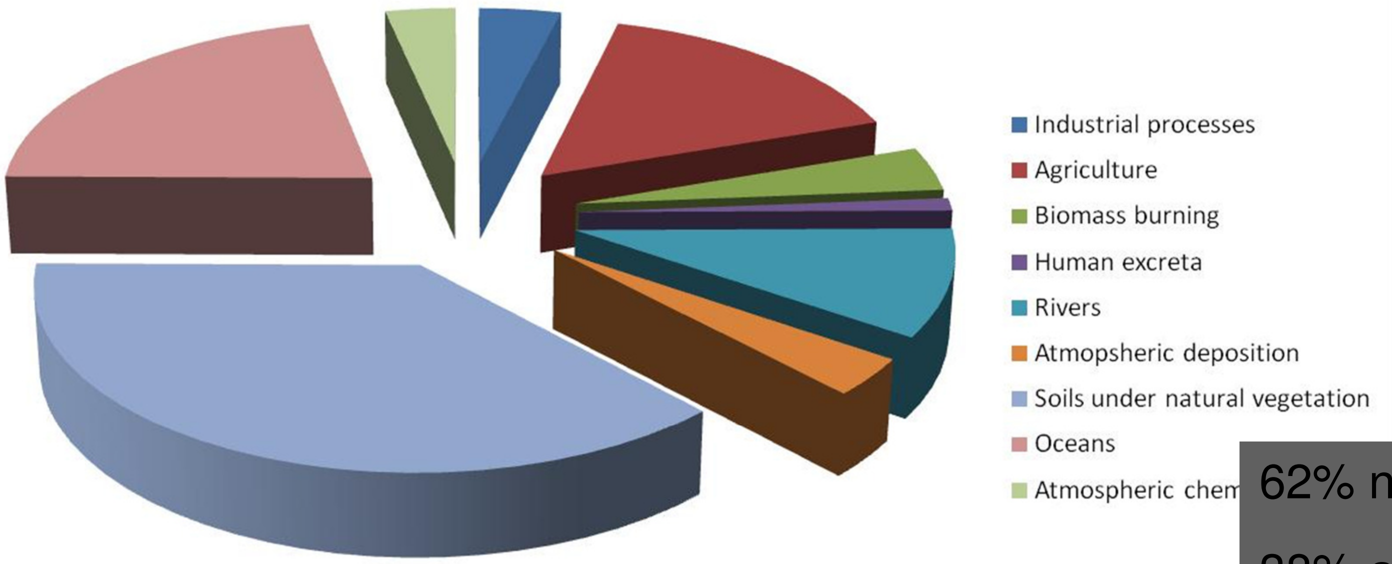
The Irish Agriculture and Food Development Authority

Global N_2O emissions

Agriculture-sourced nitrous oxide contributes to > 5% of global emissions

Principally driven by fertiliser N, animal deposition & indirect emissions

Due to nitrification and *partial* denitrification of mineral N in the soil



62% natural

38% anthropogenic

Total emissions

17.7 (8.5-27.7) Tg N/y

Denman et al 2007, IPCC

Current & projected N_2O emissions

	Population	Current N_2O emission (Gg)	Current per capita emission of N_2O (g)	Projected population growth 2000-2050	Projected N_2O emission 2050 (Gg)
Africa	921073	592	643	2.44	1444
Asia	3936536	2451	623	1.41	3467
Europe	729421	570	781	0.95	542
Latin America & Caribbean	556512	846	1521	1.40	1184
N America	335175	726	2167	1.41	1022

Calculating N_2O emissions

Emissions = Activity Data x Emission Factor

$$Total_{ij} = A_j \times Ef_{ij}$$

Where:

$Total_{ij}$ = the emissions (tonnes) of gas i from a particular livestock type j

A_j = the number of animals per livestock type j ('000/yr)

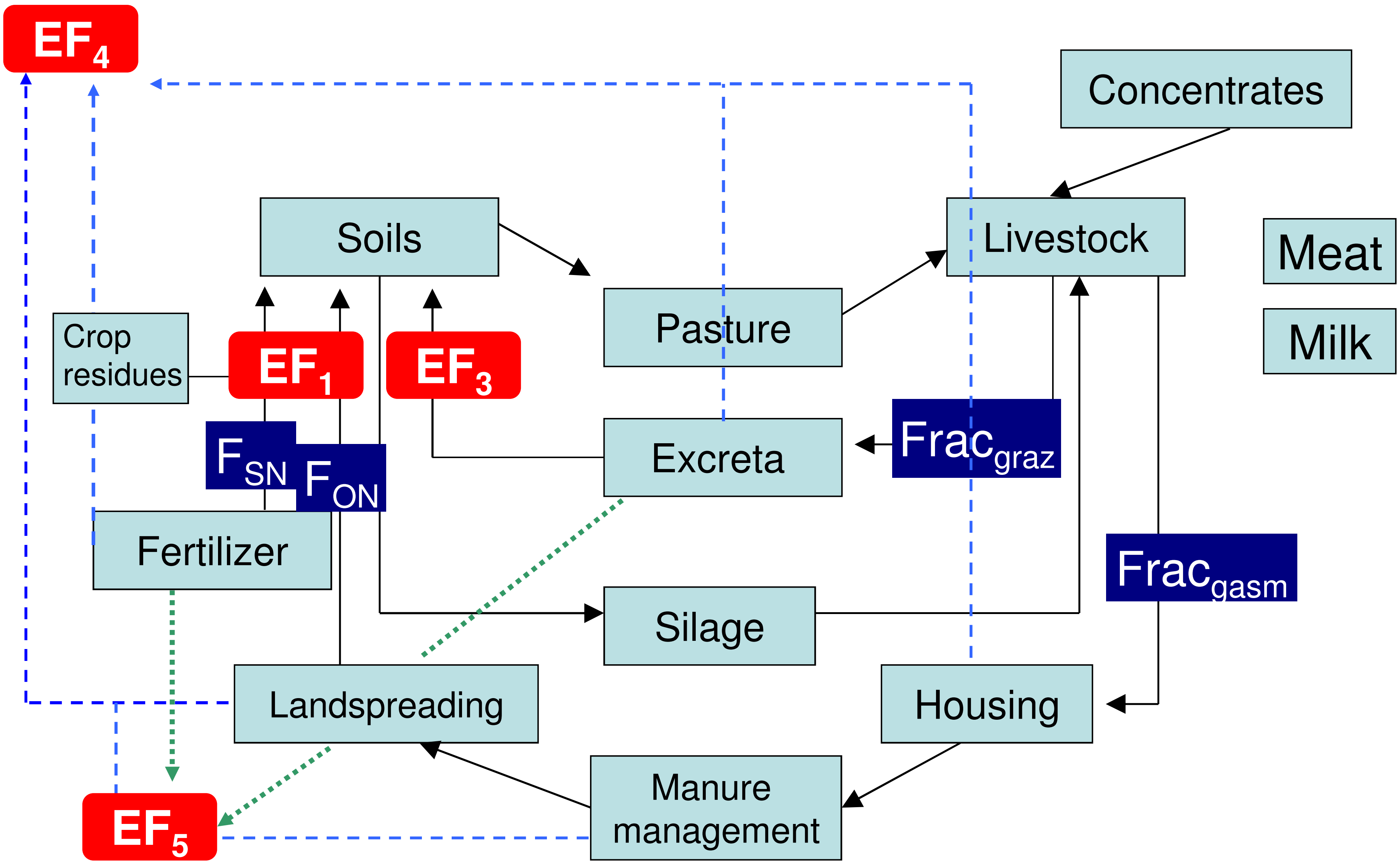
Ef_{ij} = the emission factor associated with gas (kg N_2O-N kg N applied)

Calculating N_2O emissions

$$N_2O_{Direct}\text{–}N = N_2O\text{–}N_{N\,inputs} + N_2O\text{–}N_{OS} + N_2O\text{–}N_{PRP}$$

$$N_2O\text{–}N_{N\,inputs} = \begin{bmatrix} \left[\left(F_{SN} + F_{ON} + F_{CR} + F_{SOM}\right) \bullet EF_1\right] + \\ \left[\left(F_{SN} + F_{ON} + F_{CR} + F_{SOM}\right)_{FR} \bullet EF_{1FR}\right] \end{bmatrix}$$

$$N_2O\text{–}N_{PRP} = \left[\left(F_{PRP,CPP} \bullet EF_{3PRP,CPP}\right) + \left(F_{PRP,SO} \bullet EF_{3PRP,SO}\right)\right]$$


EF4
Concentrates
Soils
Livestock
Meat
Pasture
Crop residues
EF1
EF3
Milk
FSN
FON
Excreta
Fracgraz
Fertilizer
Fracgasm
Silage
Landspreading
Housing
Manure management
EF5

Generating emission factors

$$EF\ (\%) = \frac{N2O\text{-}N\ total\ (treatment) - N2O\text{-}N\ total\ (control)}{Urine\ N\ (applied)}\ x\ 100$$

- Need to cover as many variables as possible – N response, soil texture, climate (temperature & moisture).
- Require at least one year of data
- Sampled frequently enough to cover temporal variation
- Higher tiers introduce more flexibility into inventories – allows more mitigation options to be accounted

Excreted N

Requires N excretion rates for different animal categories

Collect population data from livestock population characterisation;

Determine the annual average nitrogen excretion rate per head (N_{ex}(T)) for each defined livestock species/category T

Tier 1

$$N_{ex(T)} = N_{rate\ (T)} \times \frac{TAM}{1000} \times 365$$

TAM → Total animal mass

$N_{rate\ (T)}$ → Default excretion rate

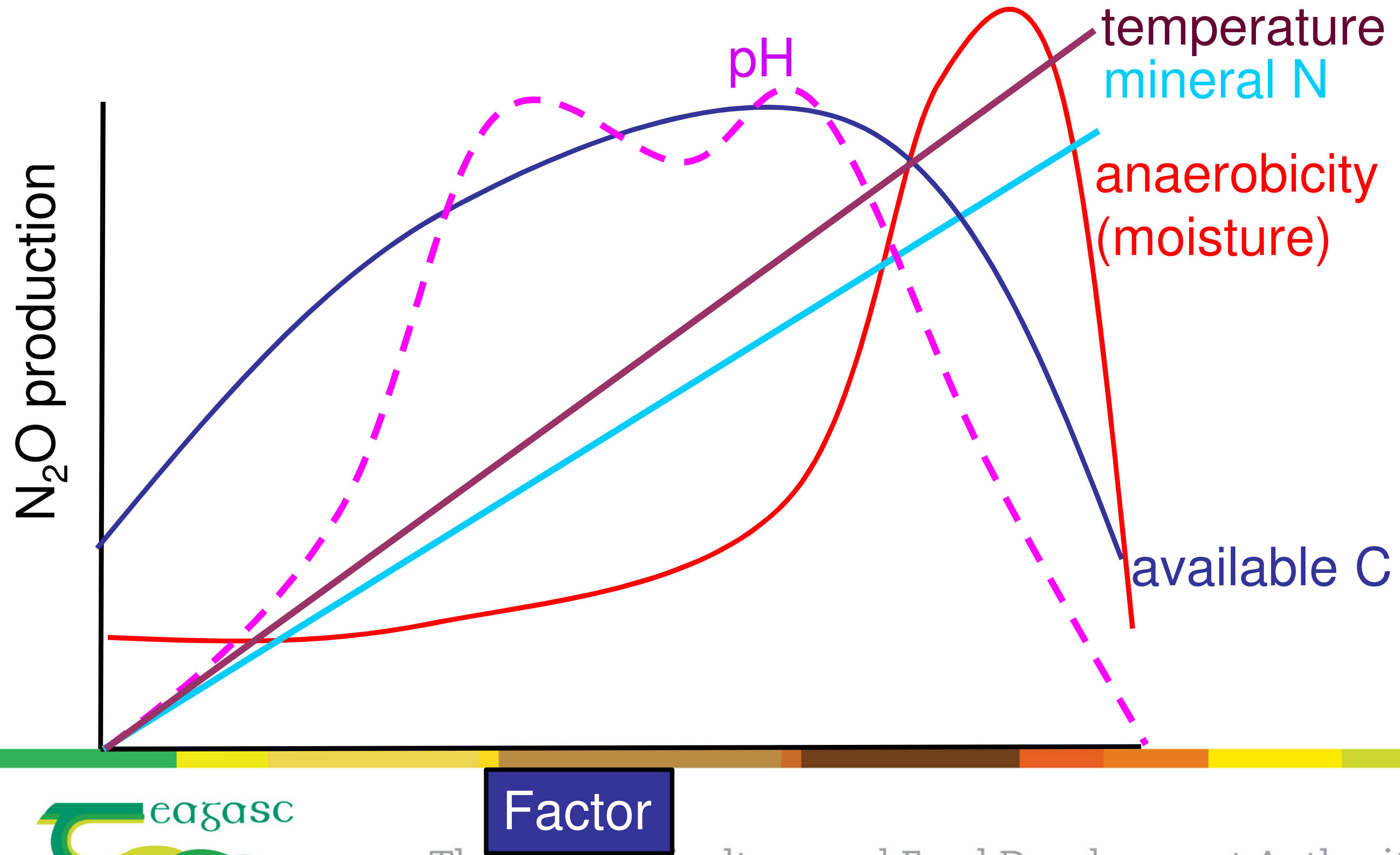
Tier 2

$$N_{ex(T)} = N_{intake\ (T)} \times (1 - N_{retained\ (T)})$$

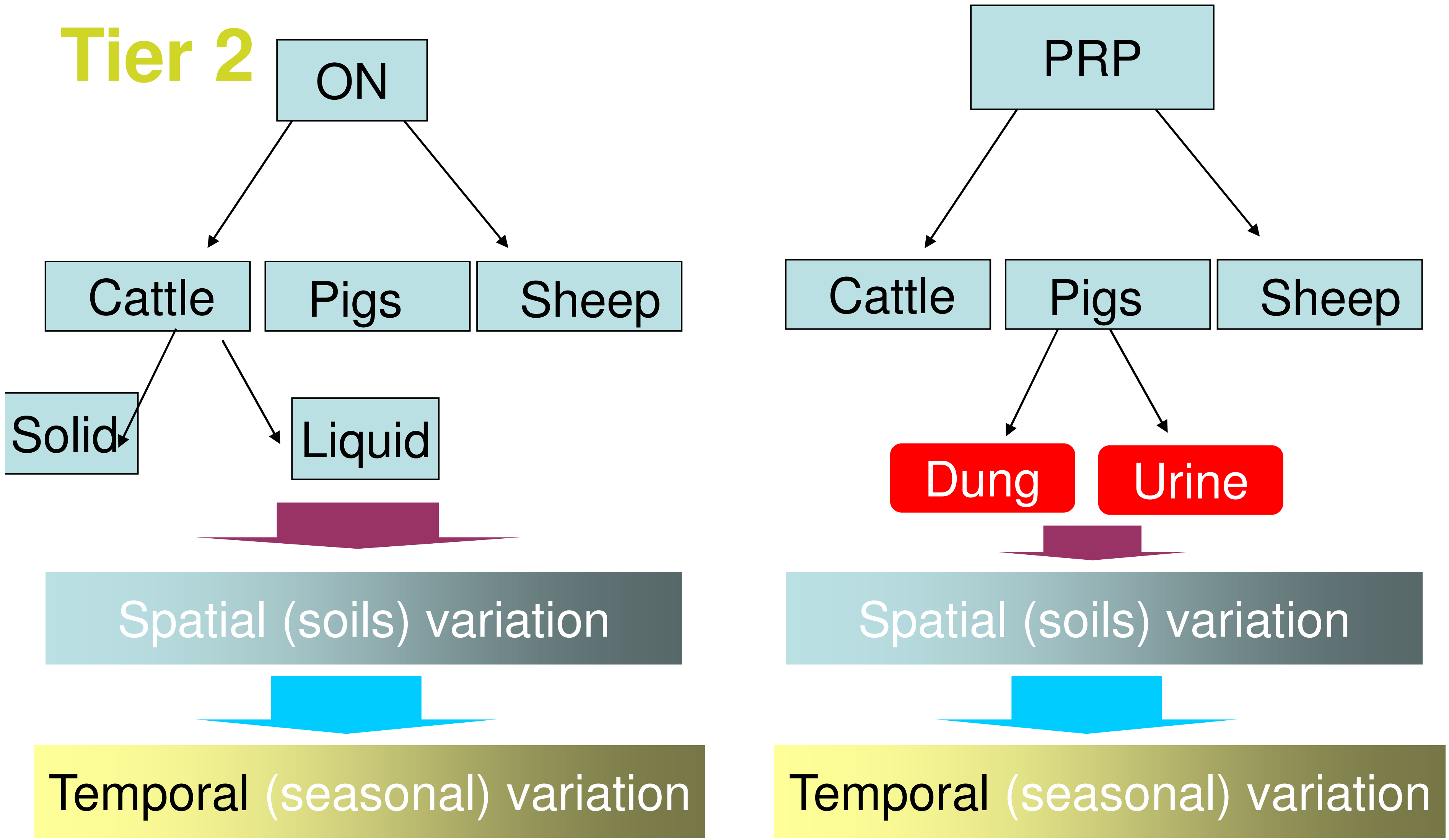
$N_{intake\ (T)}$ → Based on Gross Energy and Crude Protein

$N_{retained\ (T)}$ → Based on milk production/ weight gain

Factors influencing N_2O from agricultural soils



Tier 2


ON
Cattle
Pigs
Sheep
Solid
Liquid
Spatial (soils) variation
Temporal (seasonal) variation
PRP
Cattle
Pigs
Sheep
Dung
Urine
Spatial (soils) variation
Temporal (seasonal) variation

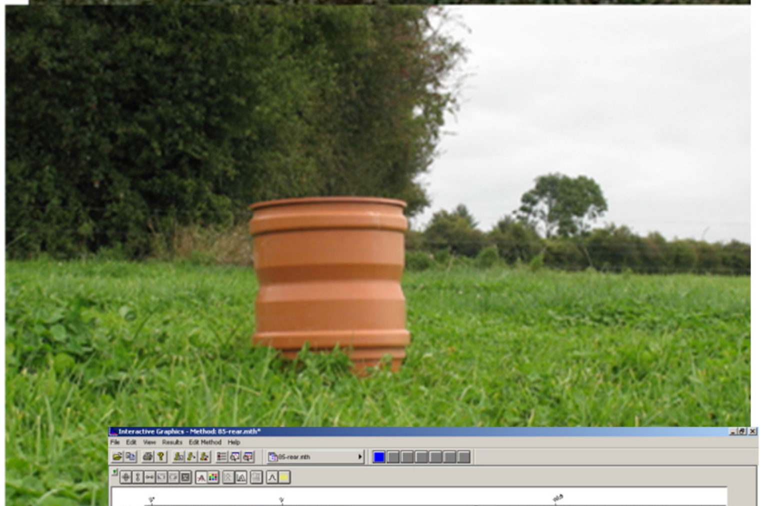
Measurement options

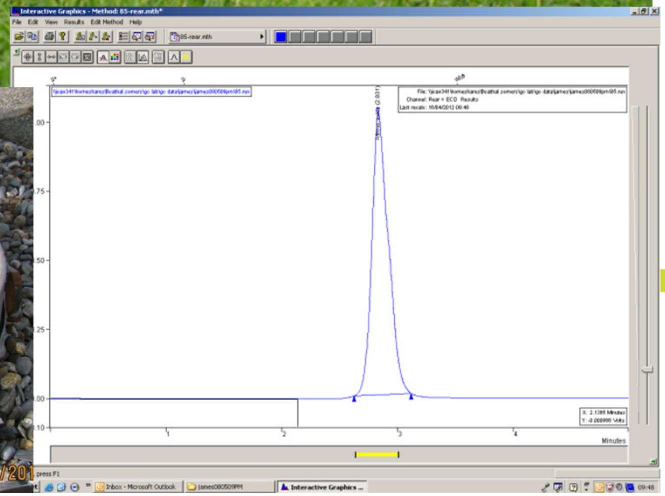
- Static/Automatic Chambers
- Eddy covariance

- Field/plot scale
- Lysimeters & ^{15}N tracing
- Modelling

Chamber techniques

- Chambers placed on collars
- Samples removed by syringe and stored in exetainers
- Analysed post hoc on a gas chromatograph with Electron Capture Detector
- Flux calculated as ΔC/Δt



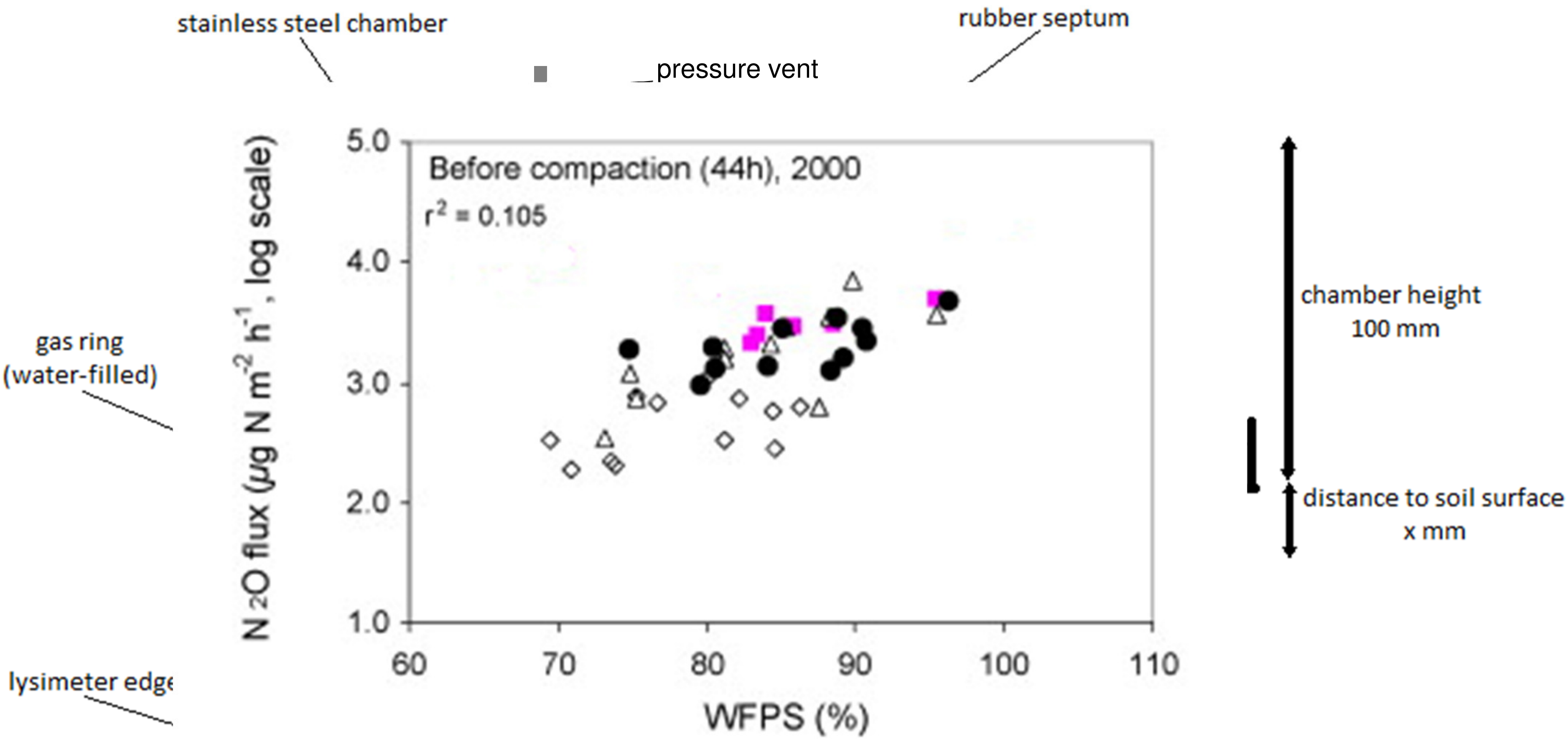


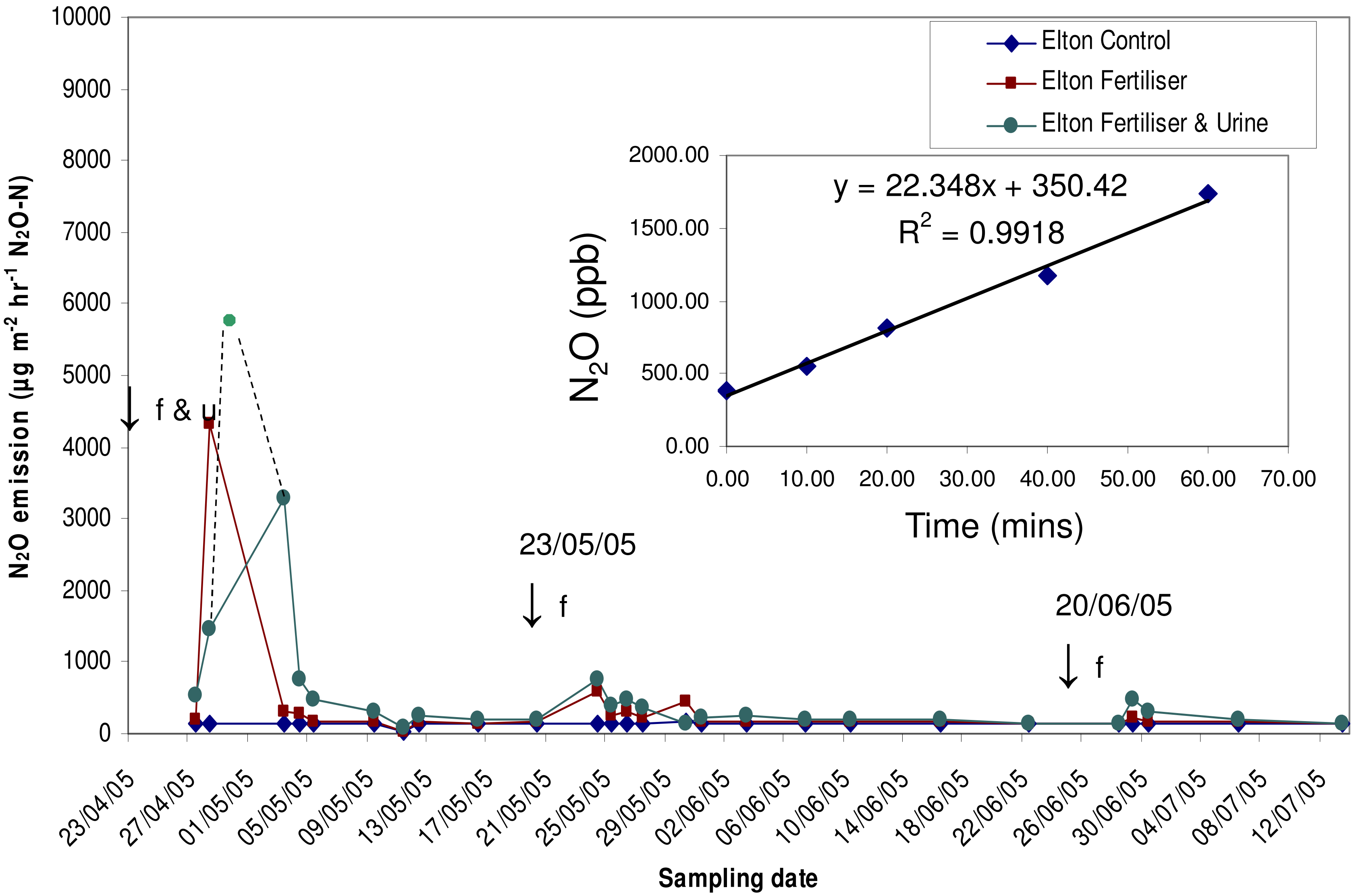
Chamber Techniques

Important: Soil temperature and soil moisture must be measured concurrently

Need to take a minimum of **three** time points for linear slope response, **four** for non-linear response

Keep gaps between measurements to a minimum – **MORE INTERPOLATION = GREATER UNCERTAINTY**





10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
N2O emission (µg m-2 hr-1 N2O-N)
f & u
23/05/05
f
20/06/05
f
Elton Control
Elton Fertiliser
Elton Fertiliser & Urine
2000.00
1500.00
1000.00
500.00
0.00
N2O (ppb)
y = 22.348x + 350.42
R2 = 0.9918
0.00 10.00 20.00 30.00 40.00 50.00 60.00 70.00
Time (mins)
23/04/05 27/04/05 01/05/05 05/05/05 09/05/05 13/05/05 17/05/05 21/05/05 25/05/05 29/05/05 02/06/05 06/06/05 10/06/05 14/06/05 18/06/05 22/06/05 26/06/05 30/06/05 04/07/05 08/07/05 12/07/05
Sampling date

Chamber techniques

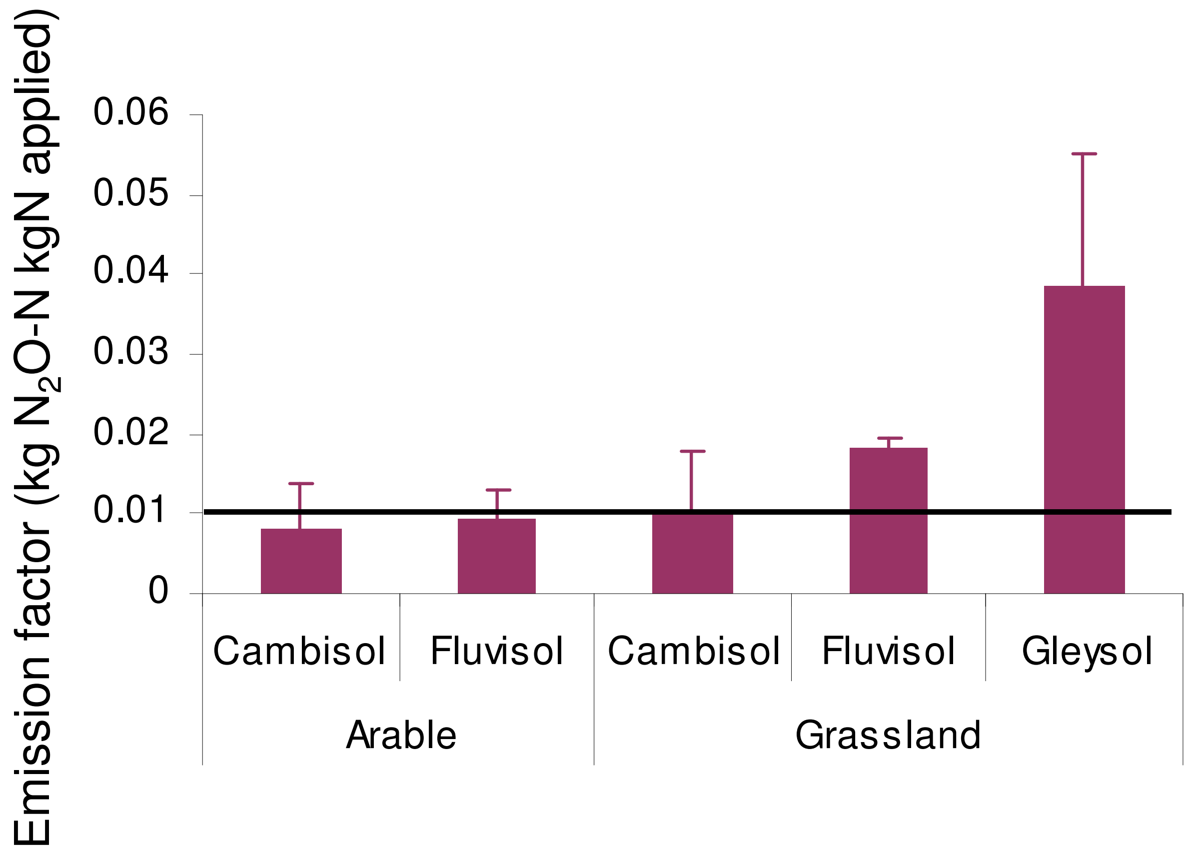
Advantages

- Technically the cheapest and most widespread method
- Samples can be stored – but results not available immediately
- Can cover a large number of treatments

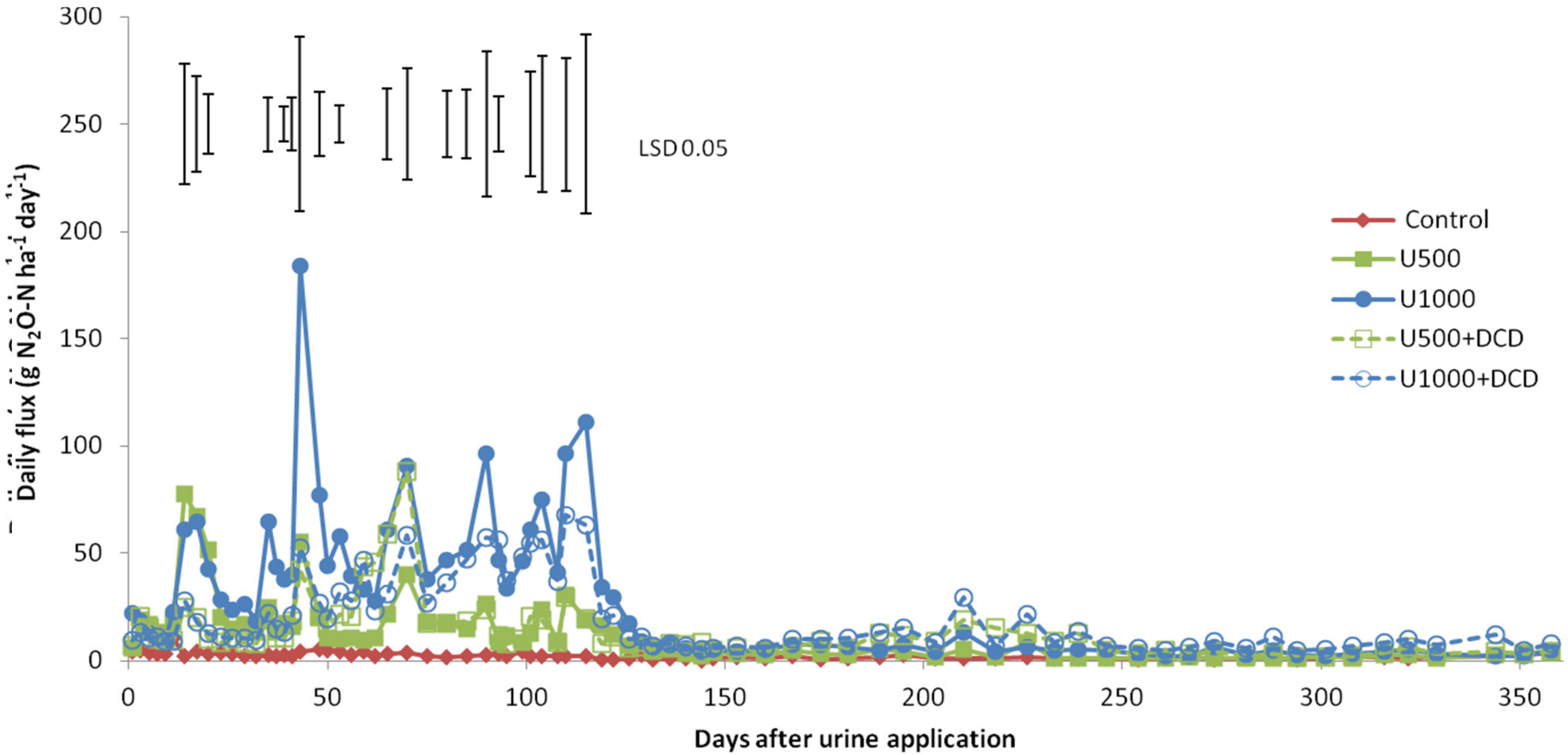
Disadvantages

- Only point measurements – as N_2O is episodic, peaks may be missed
- Non- continuity of measurement means that gaps are linearly interpolated – leading to greater uncertainty
- Unless coupled directly to a GC or other detector – no real time measure of flux
- No spatial integration

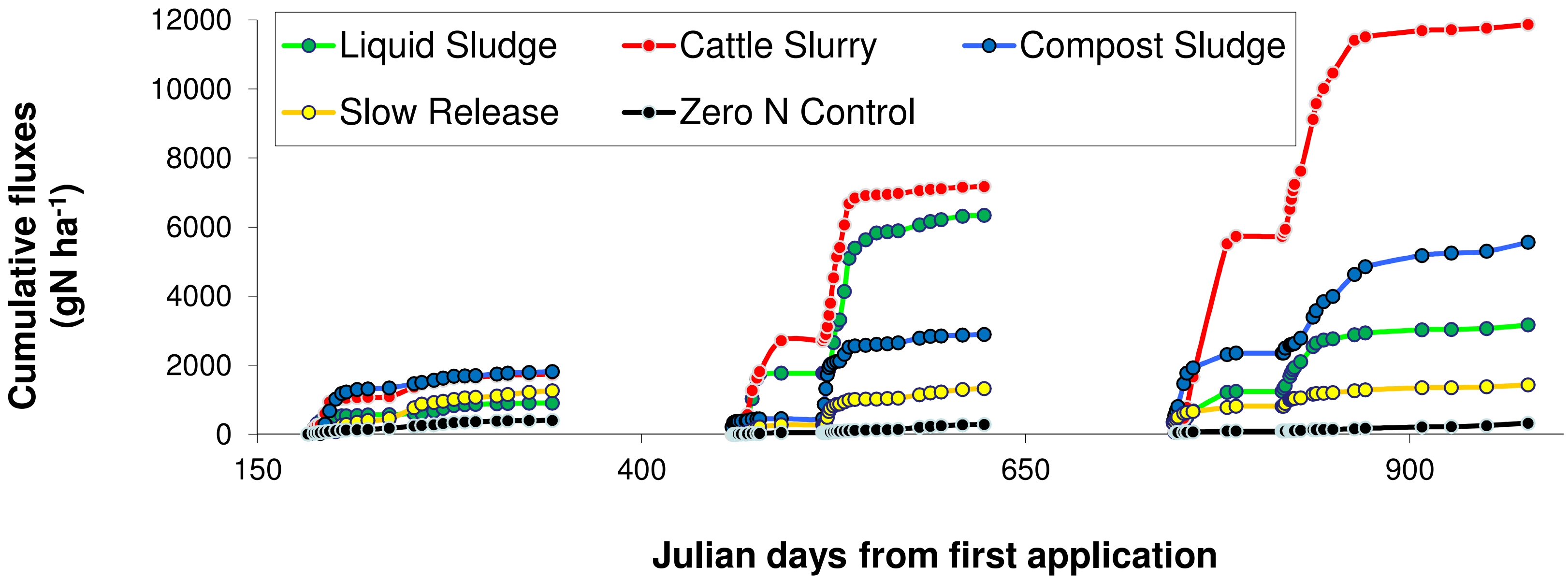
Emission factors – effect of soil type



Do you need to measure across a whole year

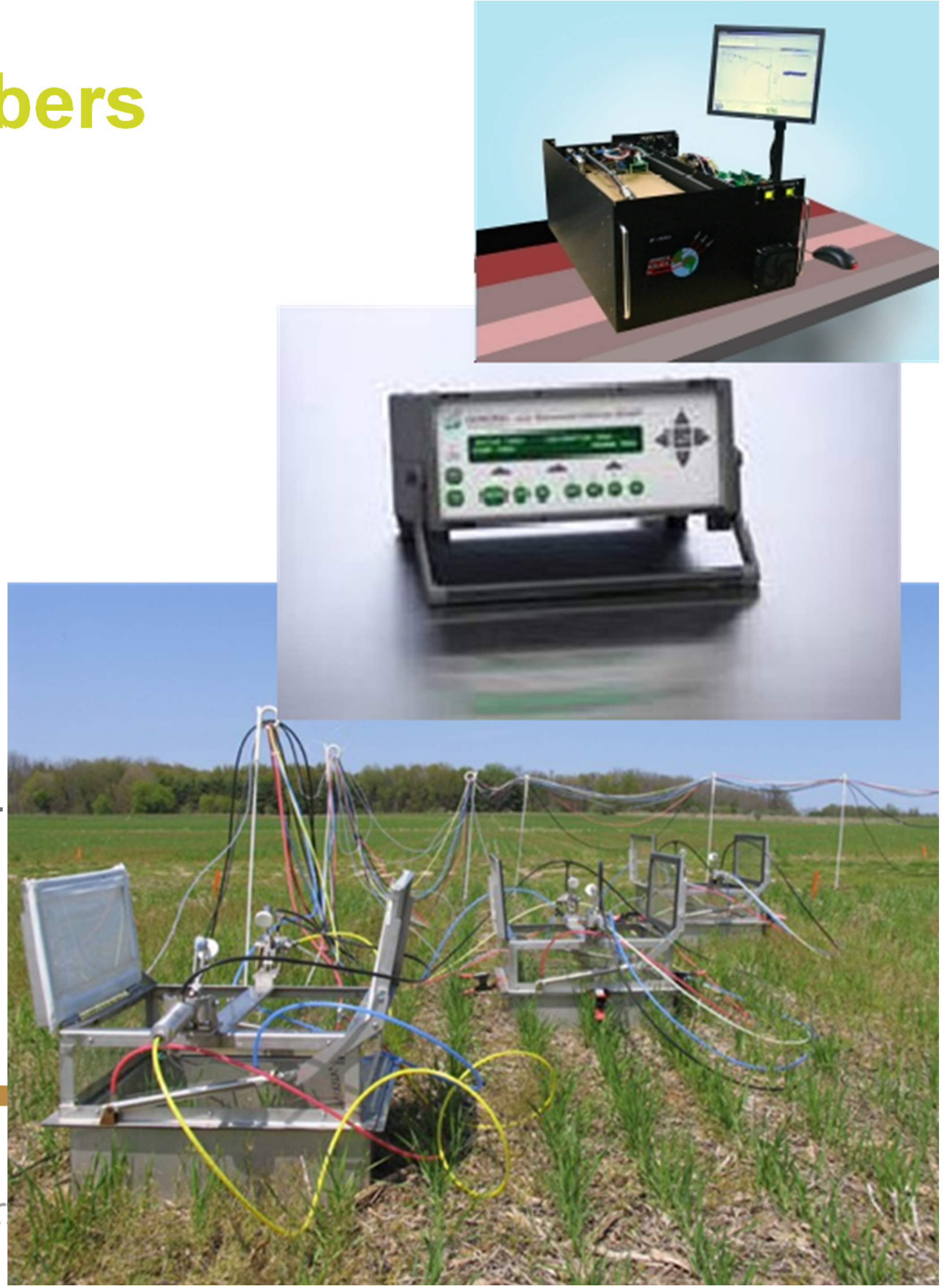


Effect of N type on emission factor

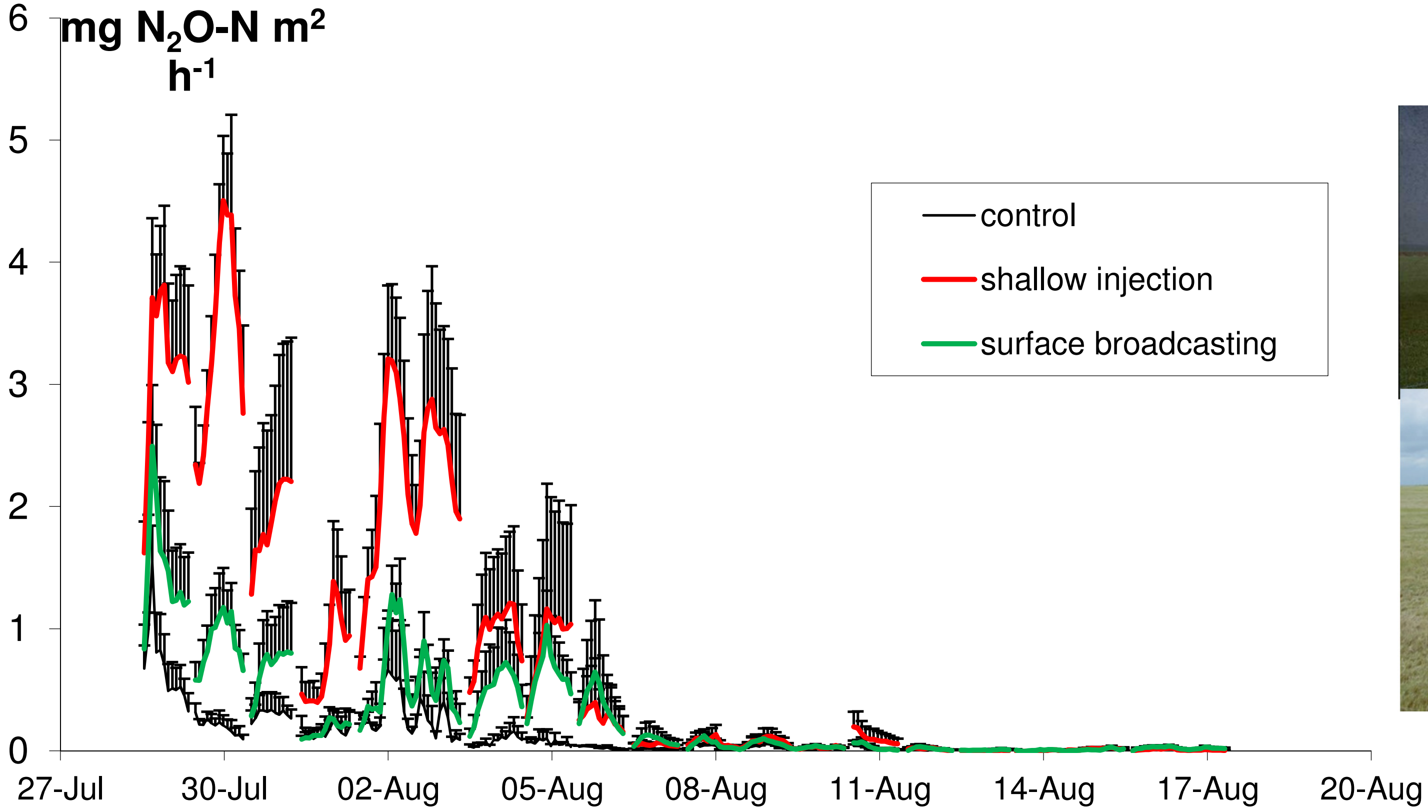


Automated chambers

- Automated chambers – capture temporal variation
- Less issues with interpolation between datapoints
- But more expensive and may reduce number of treatments analysed
- Real time measurements if coupled with photo-acoustic gas analysers or FT-IR QCL or TDL systems
- Samples can be collected in Tedlar bags – integrated value over a longer time period



Slurry and Manure management



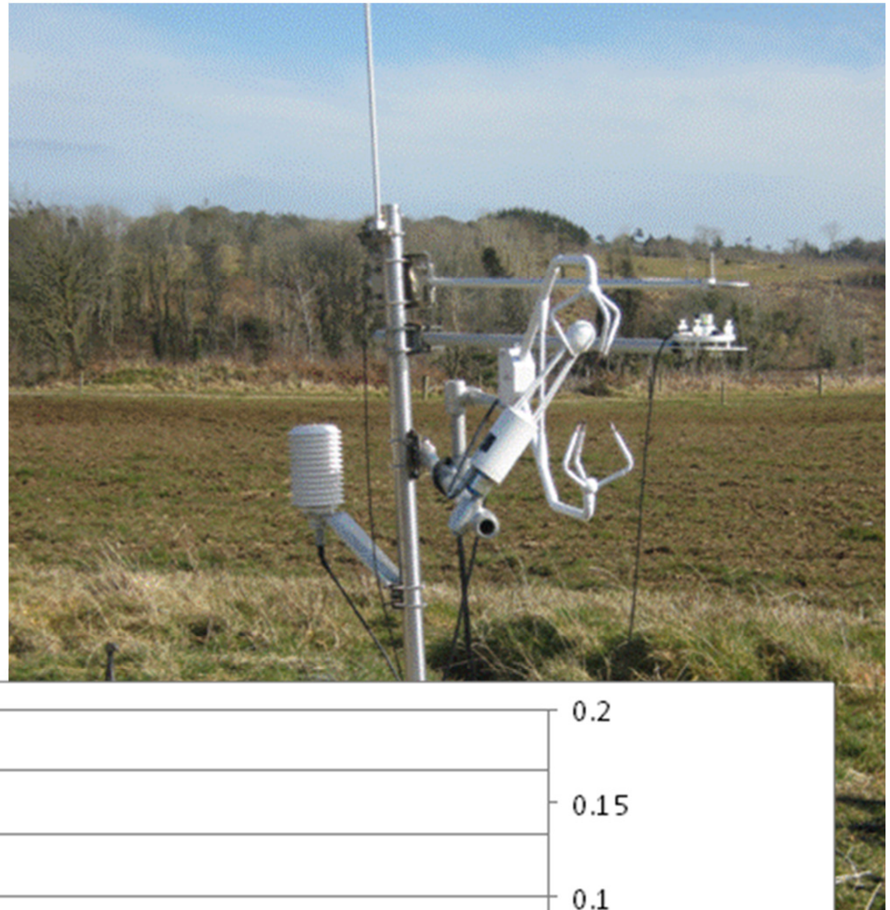
Manure management has a major impact on emissions

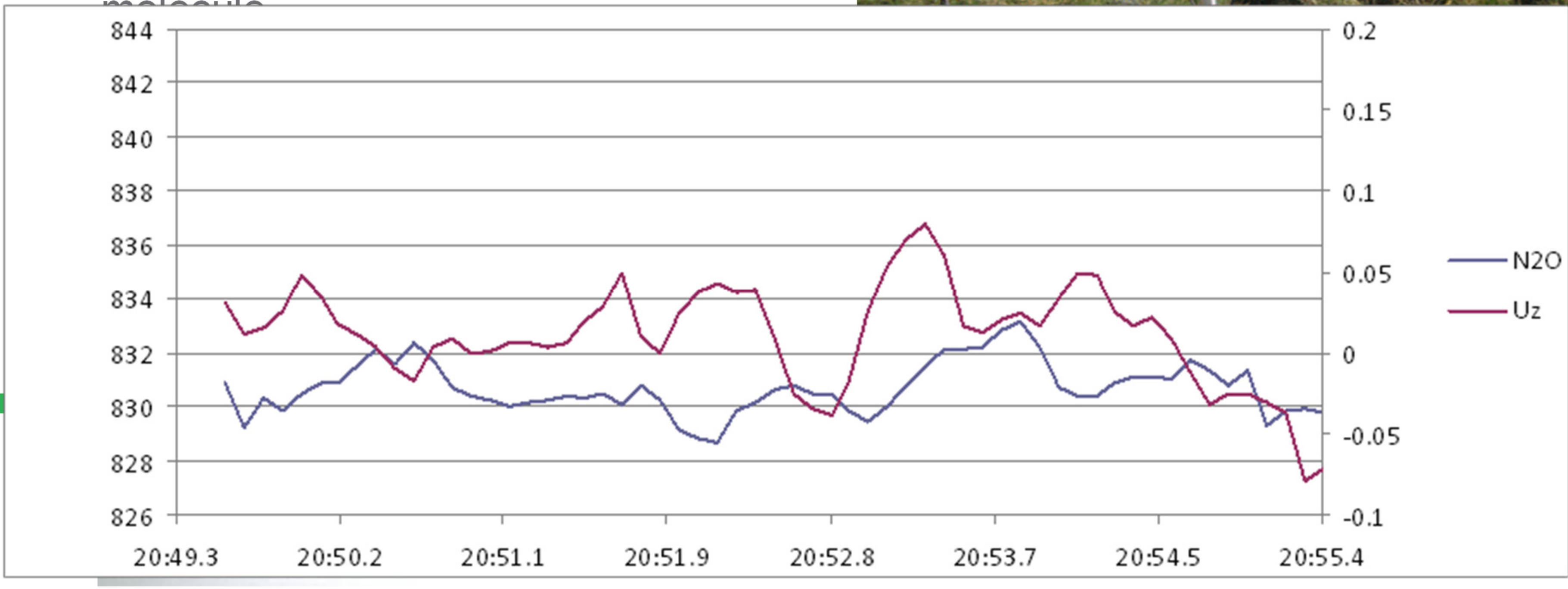
Method of application can significantly reduce NH_3 emissions but increase N_2O emissions

Chadwick et at, 2011. *Animal Feed Science and Technology*, 166, 514– 531.

Eddy Covariance

- Uses the co-variance between vertical windspeed and other factors (CO_2, H_2O, N_2O etc) to calculate a flux
- If 2 molecules of N_2O move down at a given speed in one moment, and 3 move up the next moment, we know the net movement if 1 molecule

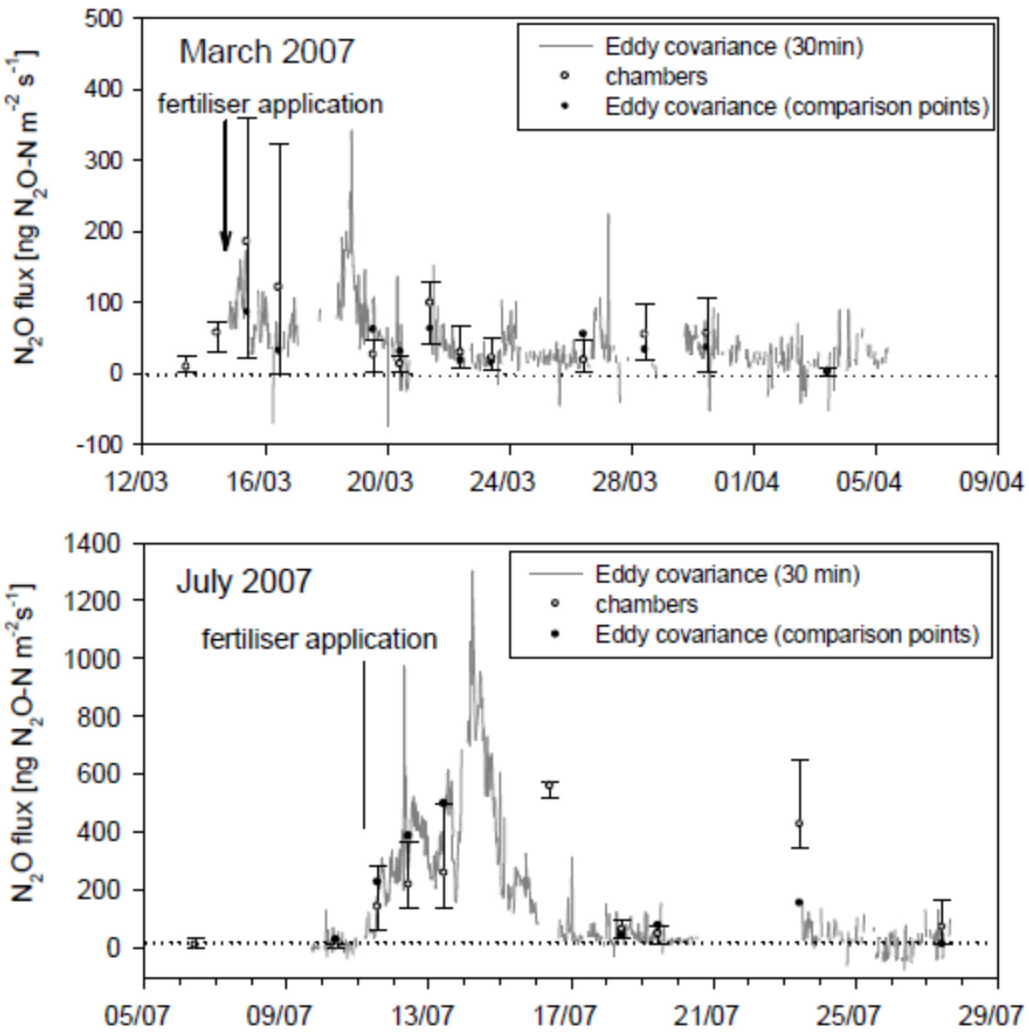




Eddy Covariance

- •Data is high resolution – more accurate cumulative values
- •Spatially integrated over a large area
- •Ideal for model constraint

- •Expensive
- •Area or 'footprint' being measured over can be very large
- •Must be flat!
- •Cannot look at many variables
- •Data interpretation can be difficult



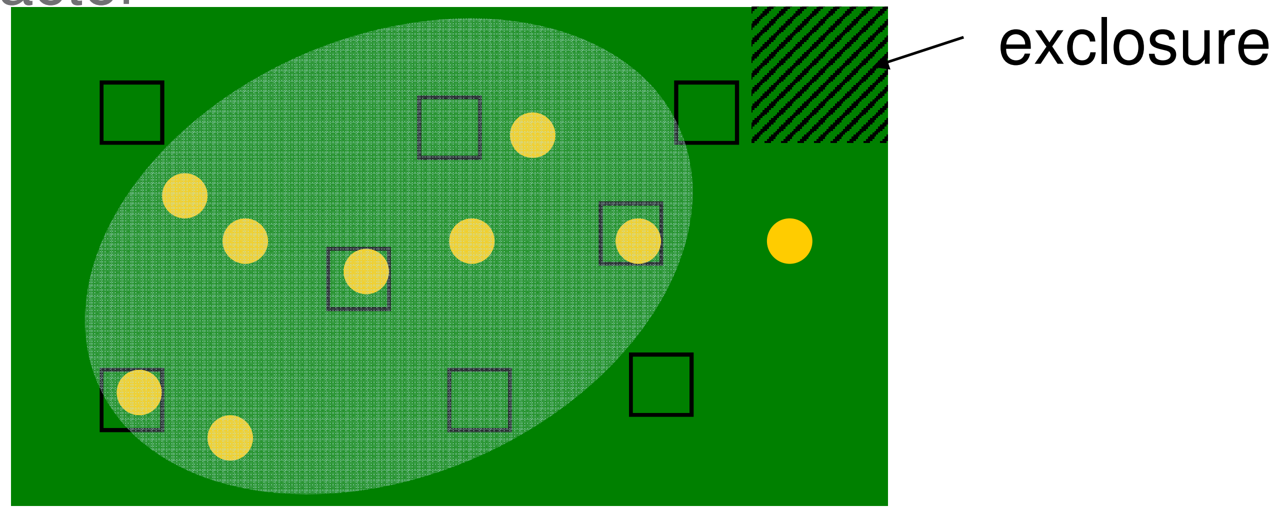
Jones et al. 2011
Atmos. Meas. Tech. Discuss., 4, 1079–1112

Pasture, paddock and range emissions

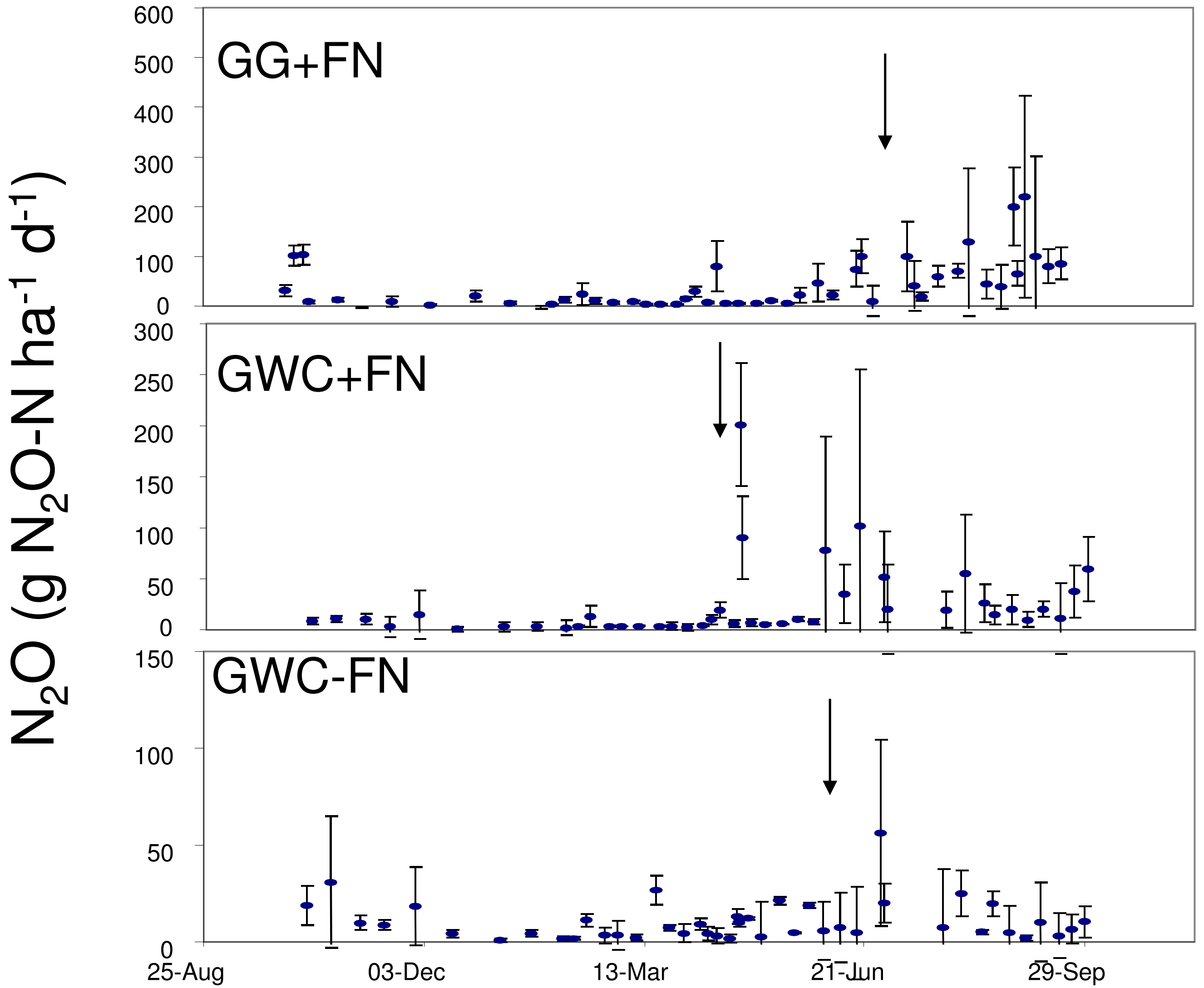
- Spatial and temporal variability in these systems are very high

Two approaches:

- Deploy enough chambers to capture variability
- Need to know rate of excreted N to generate emission factor



Temporal Emissions Profile – Grazed plots



Li et al 2011

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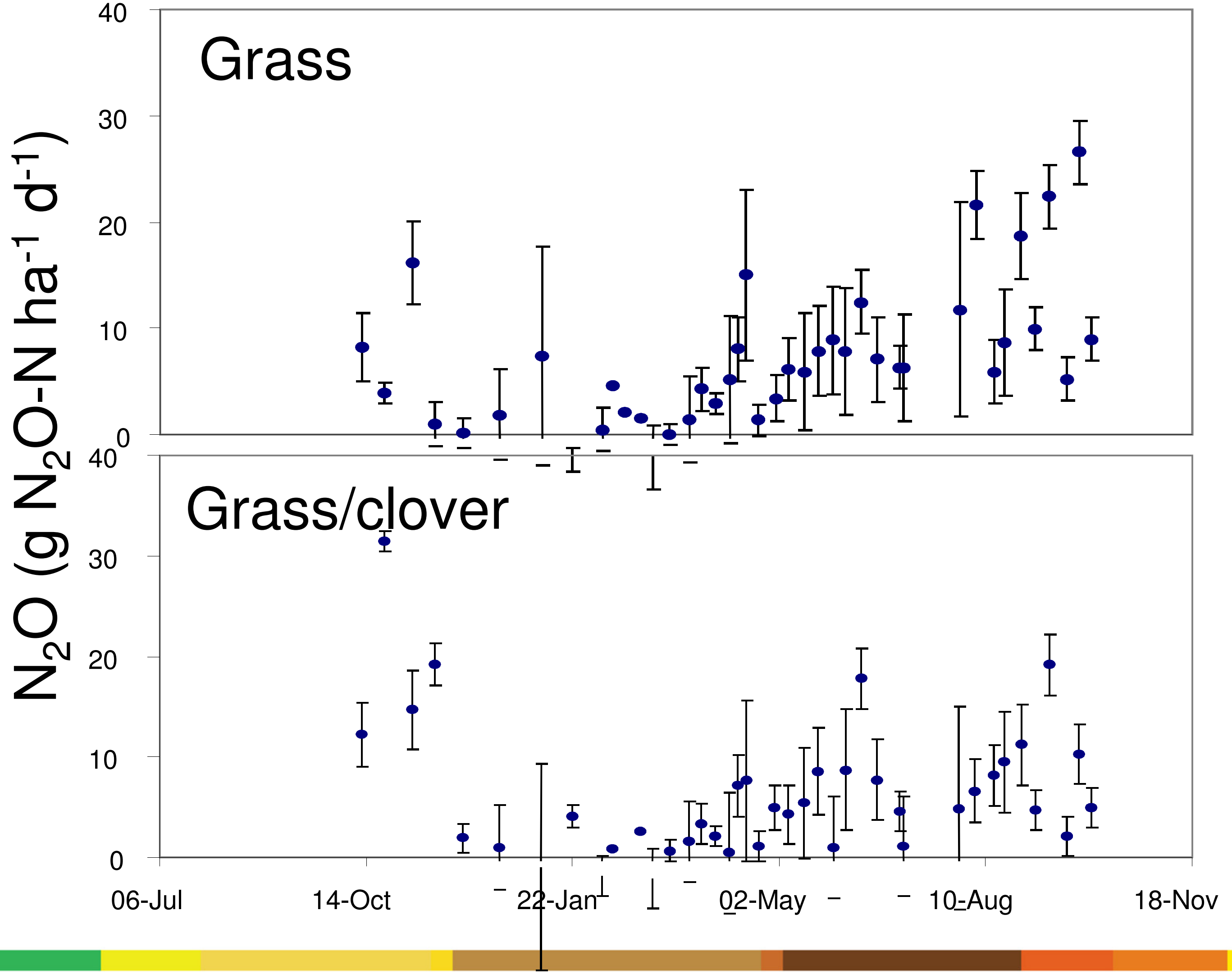
Temporal profile – background emissions



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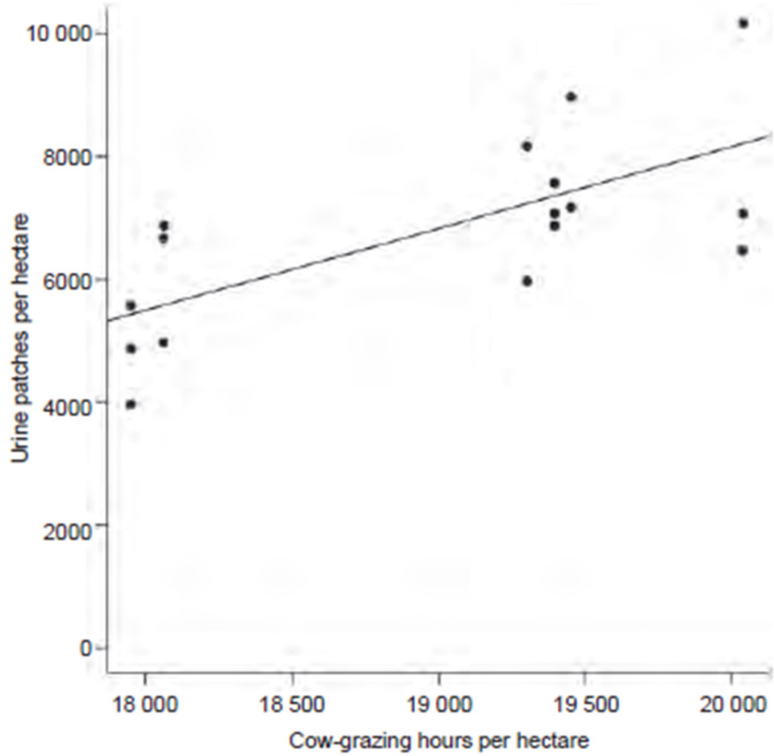
Pasture, Paddock & Range

- Apply urine and faecal N of different rates to an area
- Combine with a urine distribution model



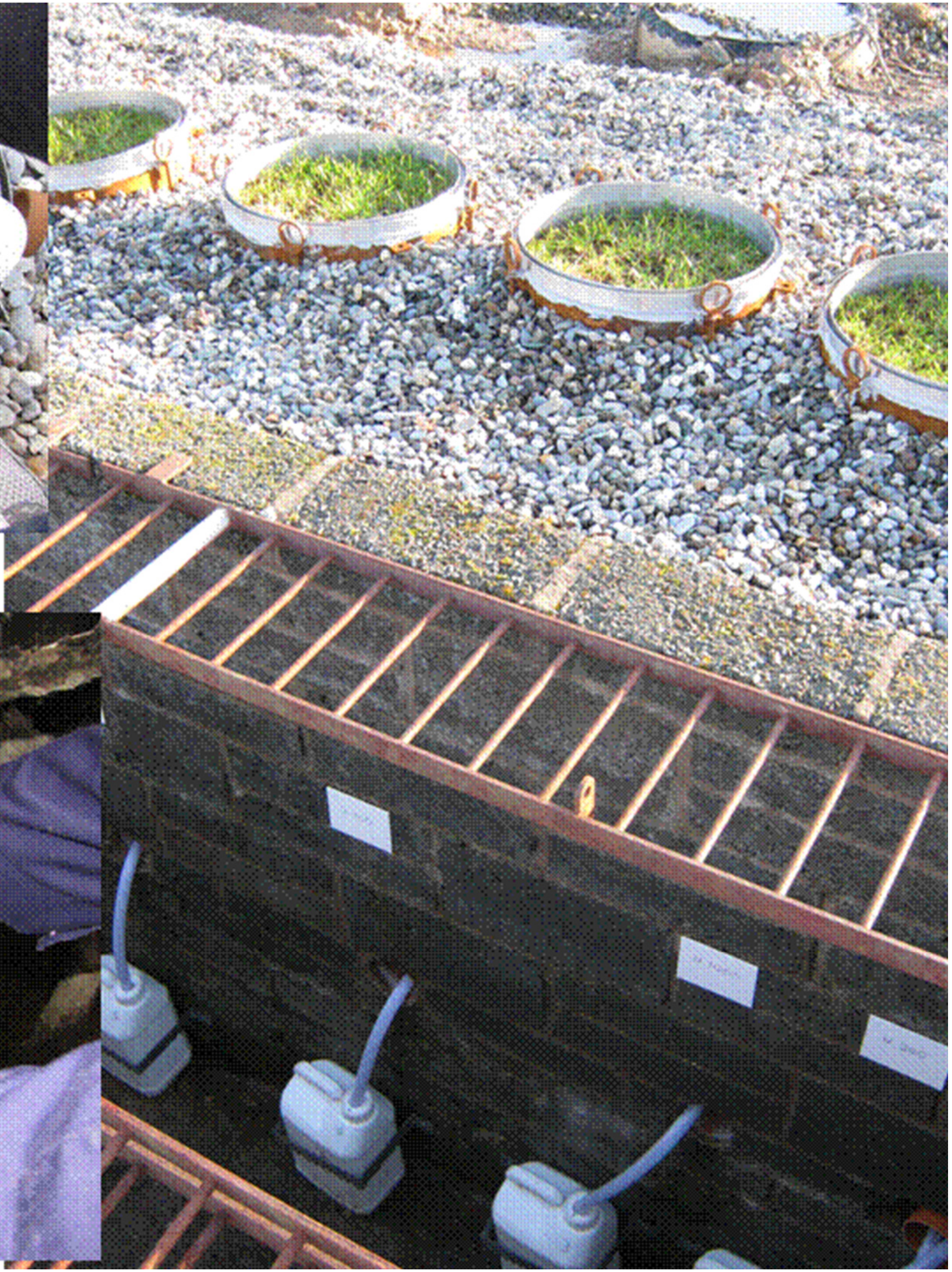
Dennis et al. 2011

$$Y = -1849 + 1.322\,X$$

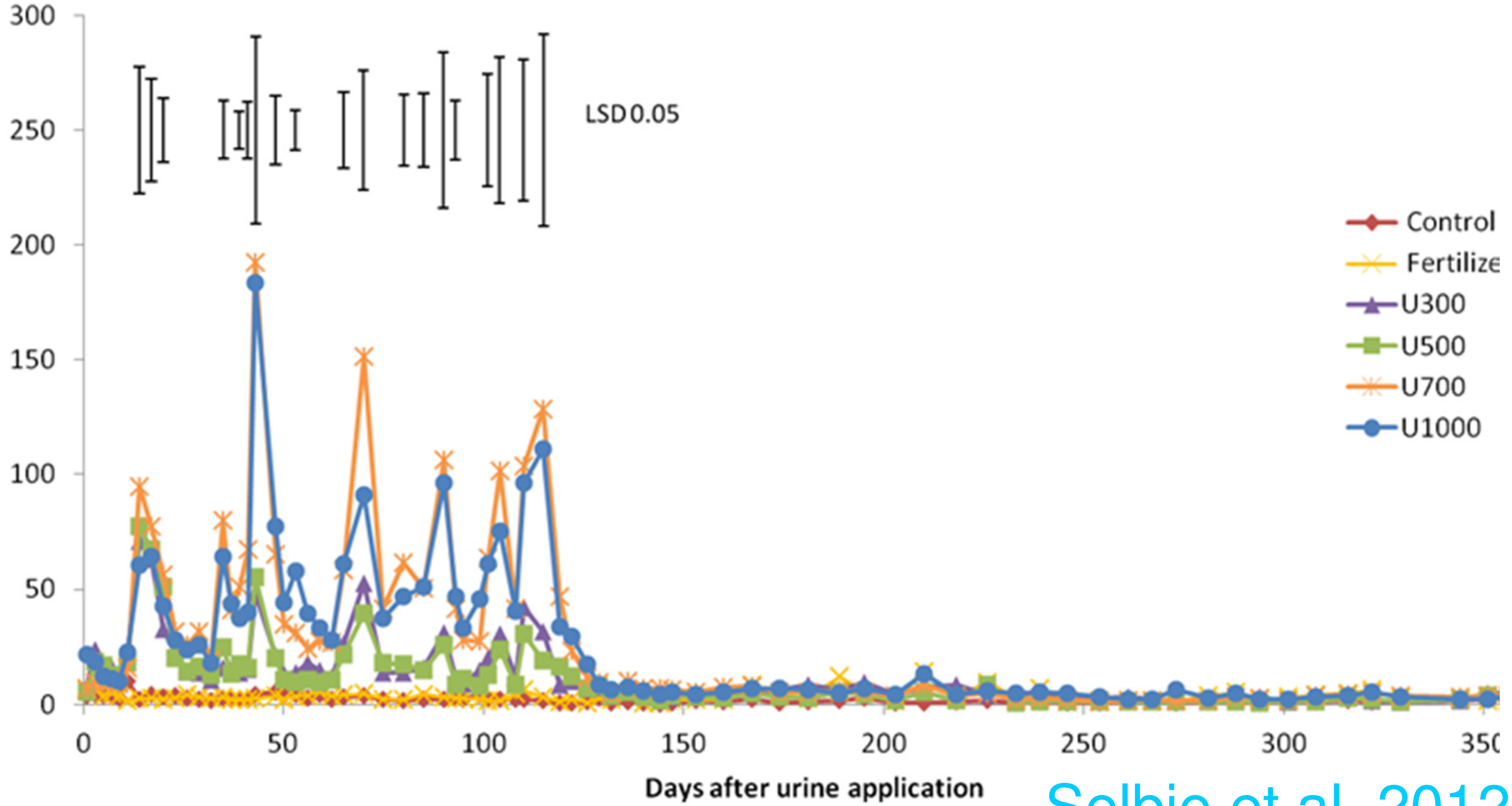
Lysimeters

- Enable measurement of leach N – which is a source of indirect emissions
- Allows for a full N balance
- Powerful tool when used in conjunction with ^{15}N isotope techniques


DCD



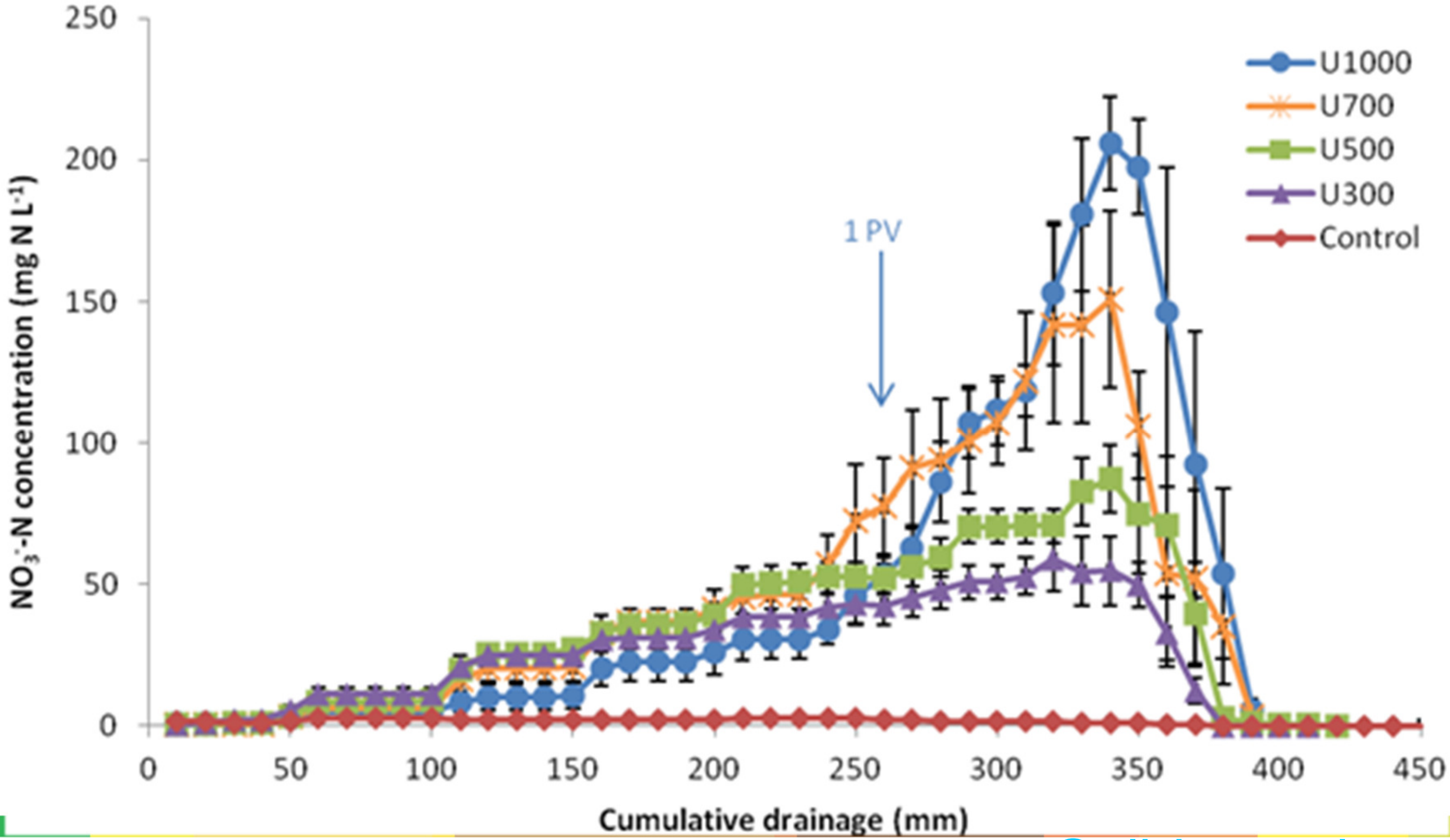
Urine N response curve – N_2O



Selbie et al. 2012

Urine N response curve – leached N

Important in order to quantify indirect emissions

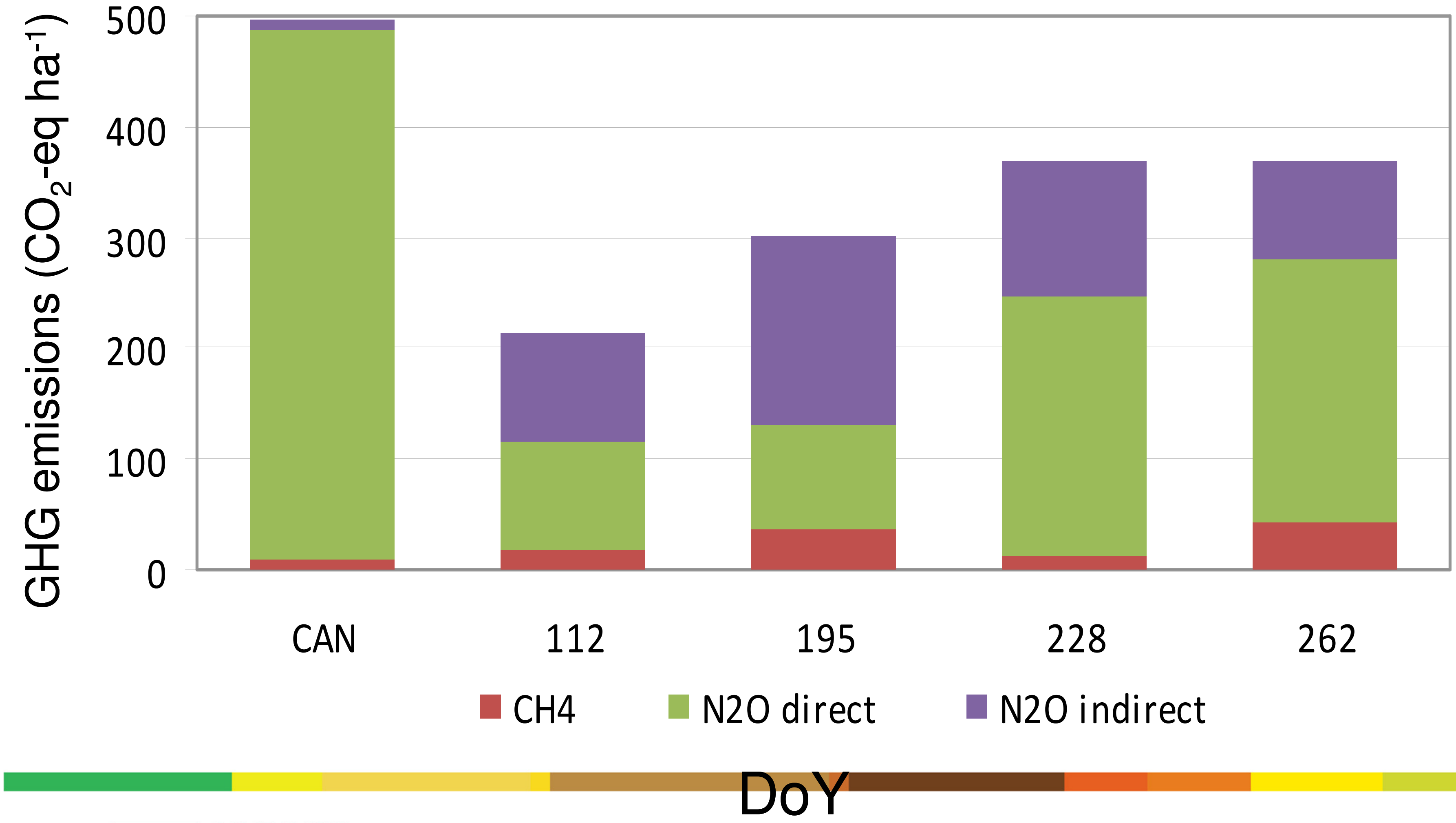


Selbie et al. 2012

Landspreading – accounting for indirect emissions (volatilisation)

- Ammonia – source of indirect emissions
- To measure volatilisation rates – acid trapping – micromet. Techniques or dynamic chambers

Landspreading – accounting for indirect emissions (volatilisation)



Models

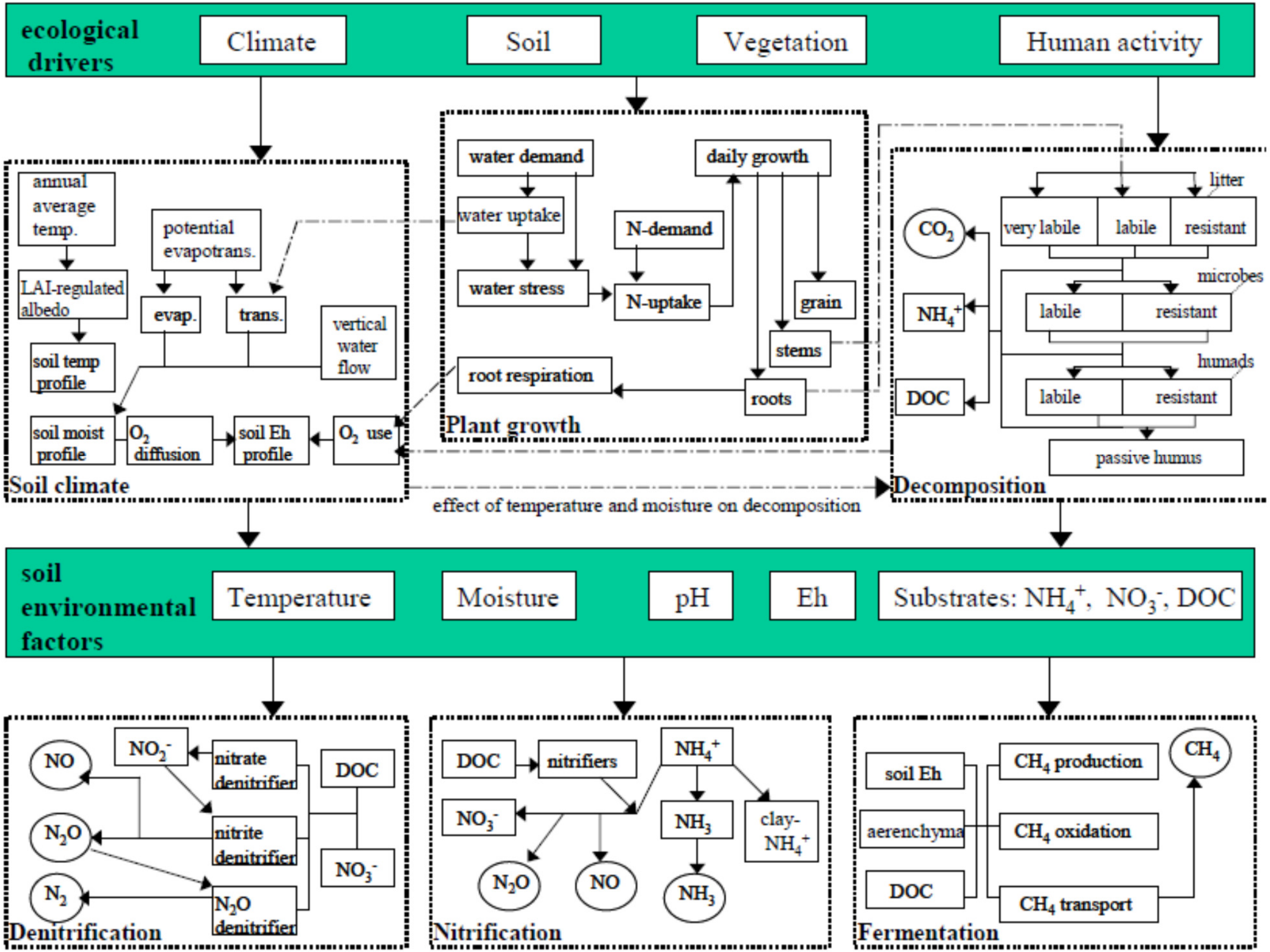
- Process-based computer models of soil C and N biogeochemistry allow us to mathematically simulate the C and N cycles

- These models operate at a daily time step and consist of two components.

- The first component, consisting of the soil climate, crop growth and decomposition submodels, predicts soil temperature, moisture, pH, redox potential (Eh) and substrate concentration profiles driven by ecological drivers (e.g. climate, soil, vegetation and anthropogenic activity).

- The second component, consisting of the nitrification, denitrification and fermentation submodels, predicts NO, N2O, N2, CH4 and NH3 fluxes based on the modelled soil environmental factors.

The DNDC Model



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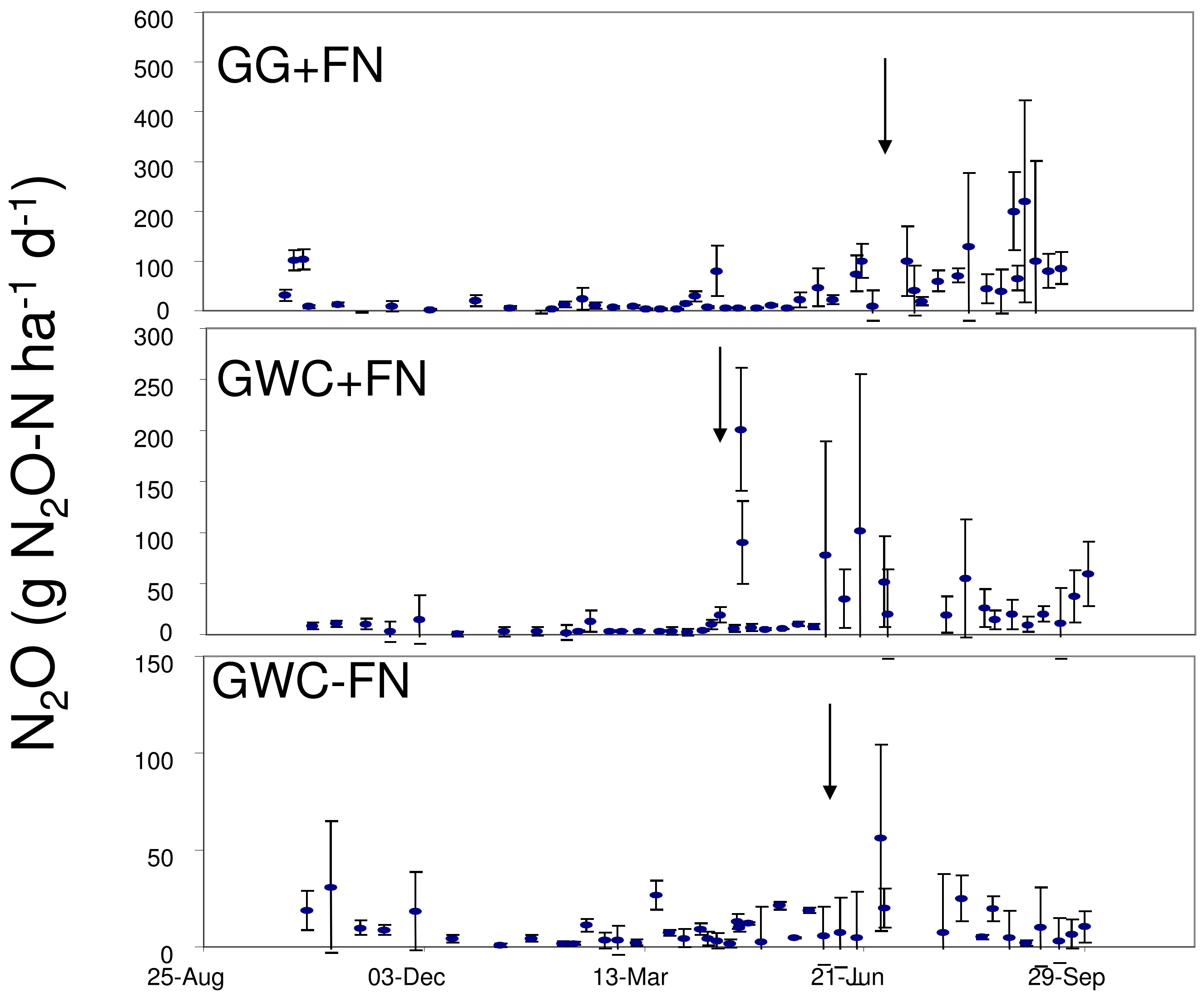
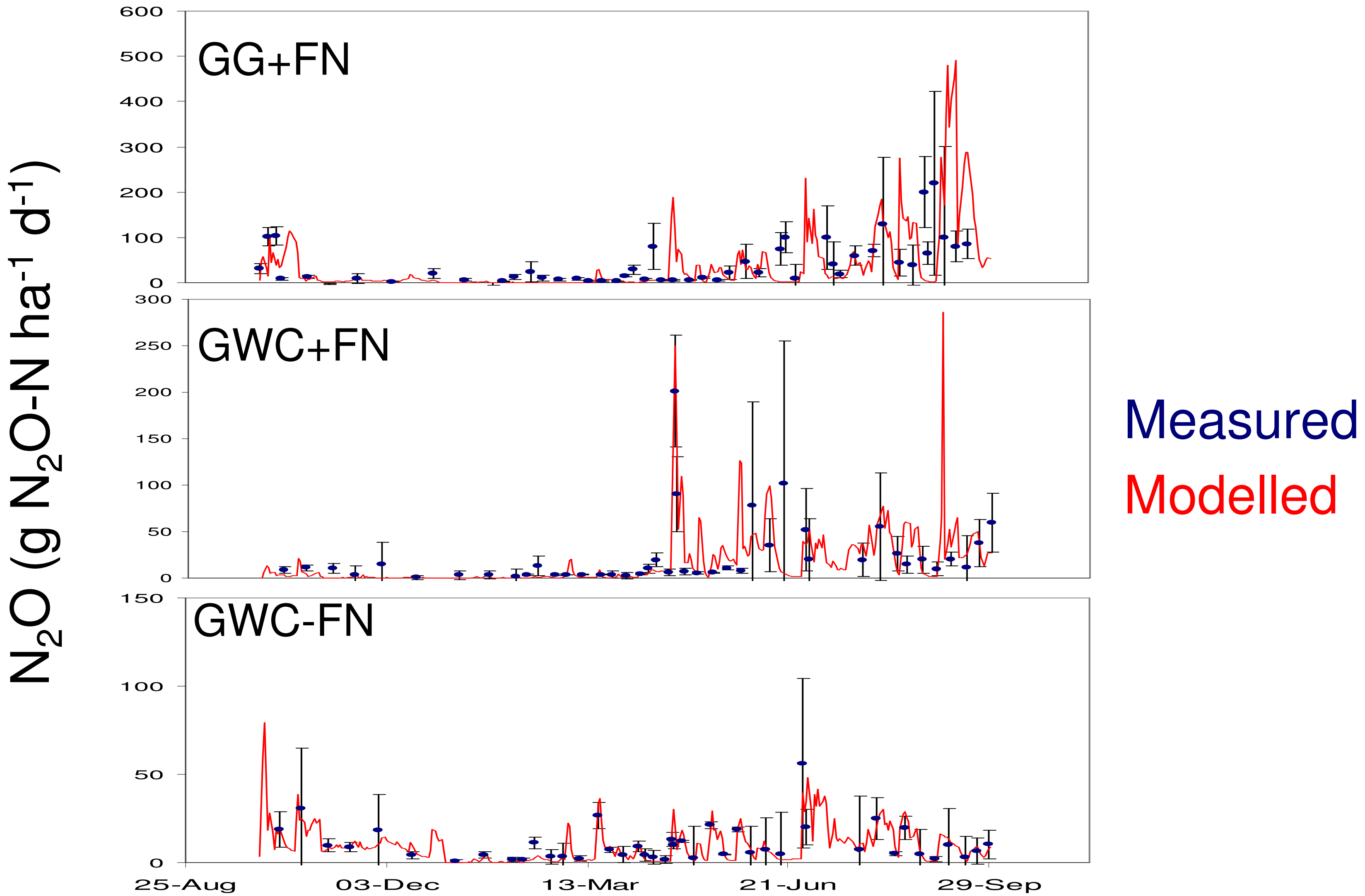


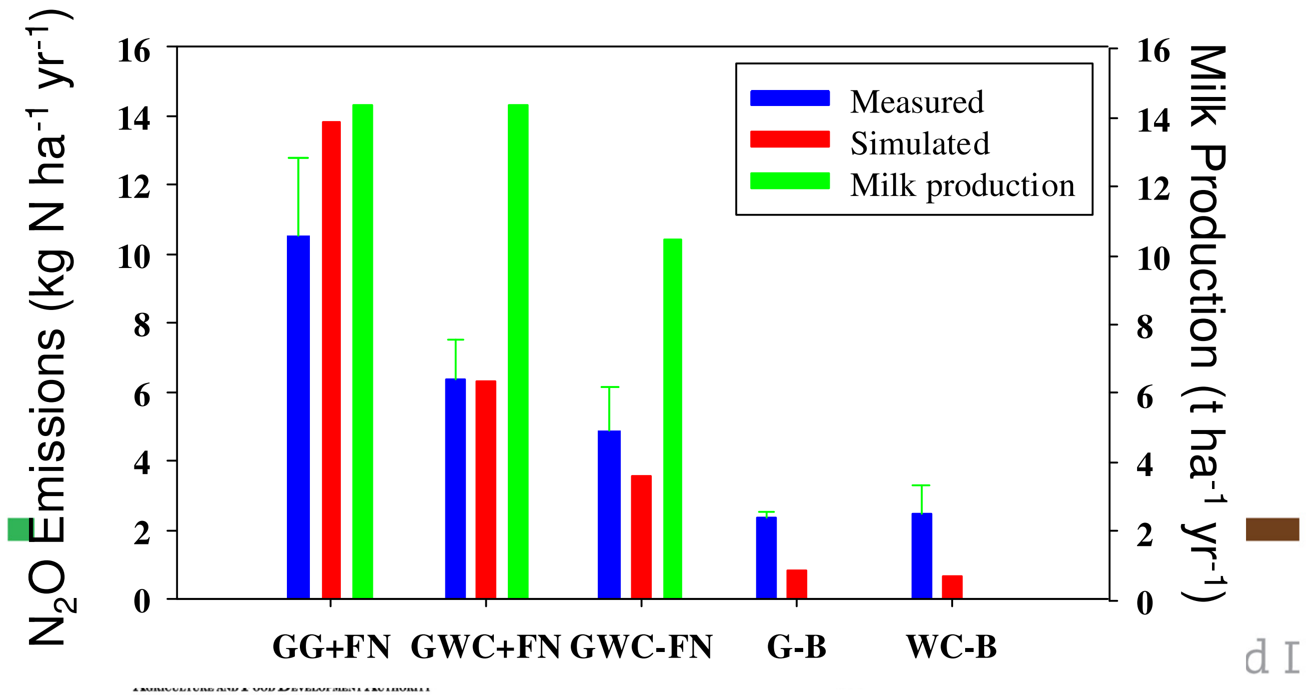
Temporal Emissions Profile – Grazed plots

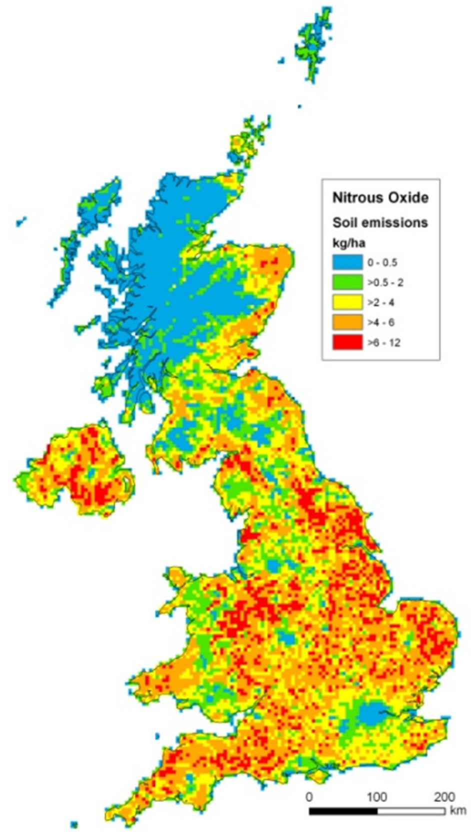


Modelling – assessment of options and regional variation

Good comparison between measurements and models in terms of cumulative emissions – temporal profiles are more problematic

Can be used to assess regional variation in emissions





Model Inputs

Climate

Mean daily temp
Min daily temp
Max daily temp
Precipitation
Windspeed
Wet deposited N
Atm ammonium conc
atm CO2 Conc
rate of CO2 increase

Fertilisation

Date of application
Application method (depth)
Application rate
N inhibitor applied

Date of application
Manure type
Application rate
C/N ratio

Soils

Land-Use
Texture
Bulk density
Ph
Clay content
WFPS
Wilting Point
Water layer retention depth
SOC
Depth of uniform SOC
Rate of SOC decrease with depth
Very Labile litter pool
Labile litter pool
Resistant litter pool
Active humus
Recalcitrant humus
Initial soil nitrate (0-5 cm)
Initial soil ammonium (0-5 cm)
Microbial activity
Slope

Grazing

No. of grazing periods
Start and end
Grazed hours per day
Intensity
No. silage cuttings
Silage yields

Outputs

Ecosystem N balance
N demand and uptake
N leached
N runoff
N volatilised
N_2O
NO
N_2
N uptake by vegetation
N stored
soil ammonium and nitrate
daily N assimilation and soil mineralization

Water balance
Transpiration
soil evaporation
Leaching
Runoff
water storage (end of run)
Potential Water demand and uptake by vegetation
Daily available water
Daily water table depth
DAILY WFPS (per each soil depth)

Ecosystem C balance
soil CO_2 respiration
DOC
Methane
C stored
actual yield
growth rate (daily only)

Grazing
Grazed C and N
Dung C and N urine N
Volatilisation from grazing

Summary

- Regardless of technique – important to dissaggreate between a) different N type and b) different soil type
- Development of higher tier emission factors is urgent in order for ‘flexibility’ in inventories - so mitigation options can be included
- High quality activity data (N excretion rates) is imperative
- Modelling (Tier 3) – allows for ‘option testing’ and climate-proofing of strategies

Acknowledgments

Department of Agriculture, Food and the Marine

An Roinn Talmhaíochta, Bia agus Mara

AGhgRI-I

Agricultural GreenHouse Gas Research Initiative for Ireland

Teagasc

Agriculture and Food Development Authority

The Irish Agriculture and Food Development Authority