N14C: a plant-soil nitrogen and carbon cycling model to simulate long-term ecosystem enrichment by atmospheric N deposition

Ed Tipping	CEH Lancaster
EC Rowe	CEH Bangor
CD Evans	CEH Bangor
RTE Mills	CEH Bangor + Bangor University
BA Emmett	CEH Bangor
JS Chaplow	CEH Lancaster
JR Hall	CEH Bangor

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

NATURAL ENVIRONMENT RESEARCH COUNCIL

Background

N enrichment

Agriculture

Fossil fuel burning

N deposition

To natural & semi-natural ecosystems

Effects

Acidification

Eutrophication

Carbon sequestration

Loss of biodiversity

N_2O emissions

Concepts & processes

N limitation

N saturation

Interactions of N with C

Broad scale

AIMS OF THE N14C MODEL

- Simulate pools and fluxes of C and N in natural / semi-natural terrestrial ecosystems over long time periods

- Parameterise with basic plot-scale data available for a range of sites representing different plant types, and with different N deposition rates

- Apply at national scale to account for contemporary survey data, and forecast responses to N dep change, climate change

- Adjust for individual sites with more data

DRIVERS

MAT

MAP

N deposition, inc. history

^{14}C in atmosphere, inc. history

Vegetation type

SITE OBSERVATIONS

Soil C pool

Soil N pool

Soil CN ratio

N_{inorg} leaching flux

DOC leaching flux

DON leaching flux

INFORMED GUESSES

Pristine N fixation

NPP

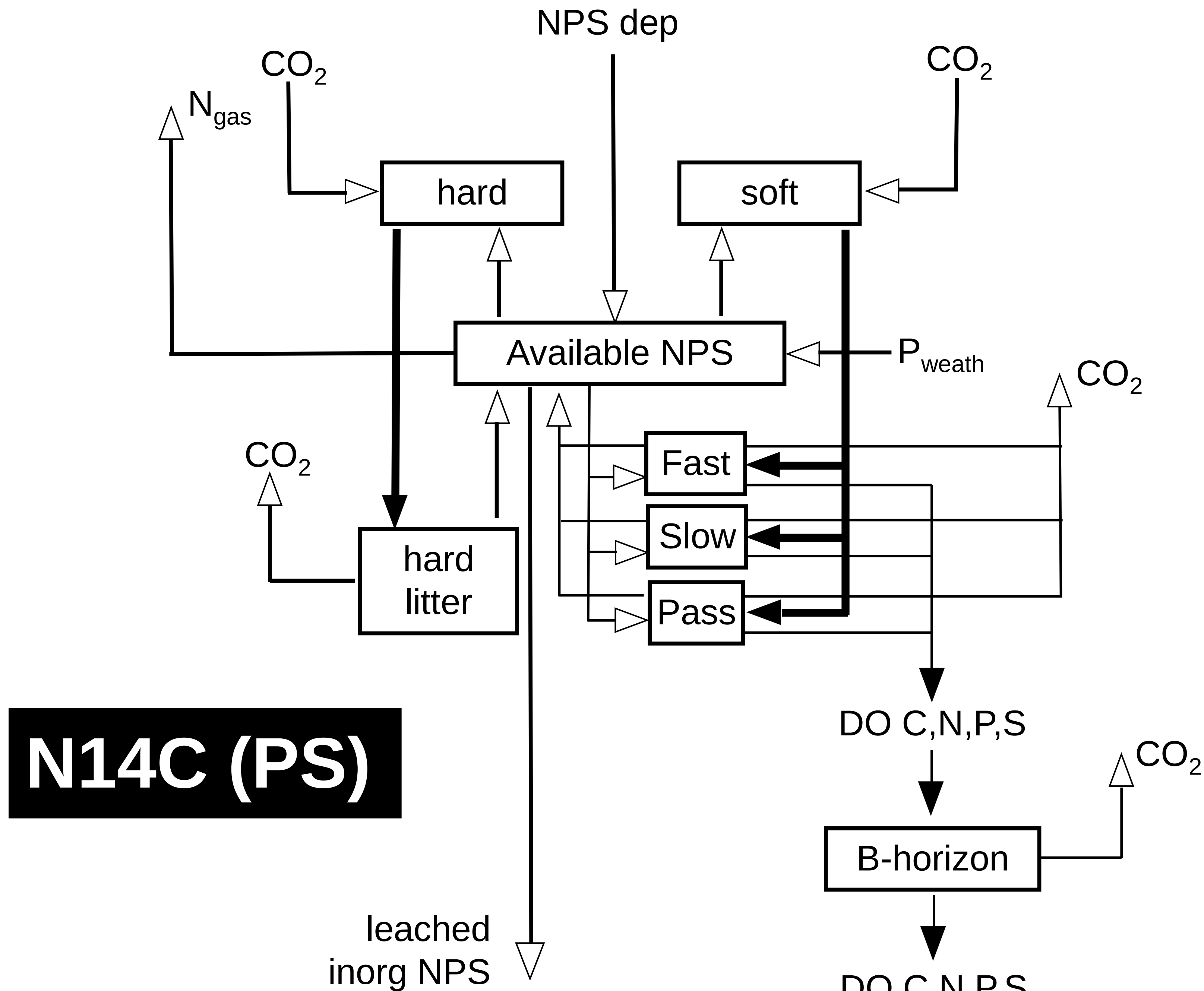
No / little land use change

GENERIC OBSERVATIONS

^{14}C of bulk soil

denitrification rates

Parameterisation of N14C for 42 sites



NPS dep
CO_2
N_{gas}
hard
soft
CO_2
Available NPS
P_{weath}
CO_2
CO_2
Fast
Slow
Pass
hard
litter
N14C (PS)
DO C,N,P,S
CO_2
B-horizon
leached
inorg NPS
DO C,N,P,S

Features of N14C

- Long-term simulations, annual timestep
  13000 BP to present, N dep from 1800

- Plant functional types: broadleaf, conifer, herbs, shrubs
  "hard" and "soft" plant components (roughly wood, not-wood)

- Vegetation 1 : high CN
  Vegetation 2 : low CN

- SOM pools: fast, slow, passive / constrained by ^{14}C

- Seasonality: Dormant – Growth – Dormant

- Simulates NPP, plant and soil C and N
  DOC, DON, NO_3 leaching
  denitrification, $SO^{14}C$, $DO^{14}C$

- ***Underlying assumption: the vegetation determines the soil***

Values of optimised parameters

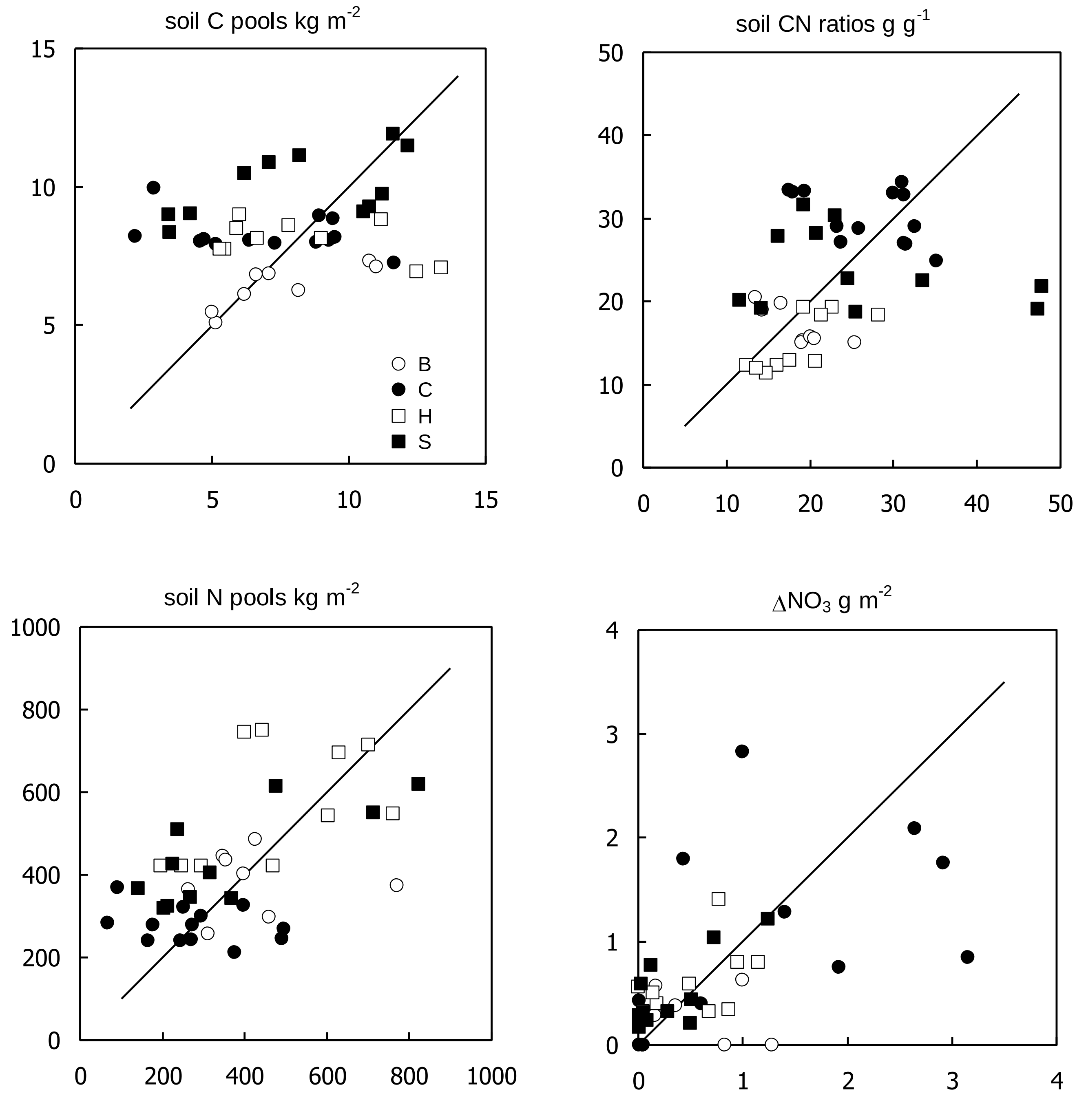
<table>
<tr><th></th><th>broadleaf</th><th>conifer</th><th>herbs</th><th>shrubs</th></tr>
<tr><td>f_{fast}</td><td colspan="2">0.434</td><td colspan="2">0.576</td></tr>
<tr><td>f_{slow}</td><td colspan="2">0.551</td><td colspan="2">0.399</td></tr>
<tr><td>$f_{passive}$</td><td colspan="2">0.015</td><td colspan="2">0.025</td></tr>
<tr><td>k_{immobN}</td><td>1.88×10^{-4}</td><td>7.78×10^{-5}</td><td>1.46×10^{-4}</td><td>7.62×10^{-5}</td></tr>
<tr><td>$f_{gr,1}$</td><td colspan="4">0.467</td></tr>
<tr><td>$f_{gr,2}$</td><td colspan="4">0.030</td></tr>
<tr><td>f_{DOC} f_{DON}</td><td colspan="4">0.0258</td></tr>
<tr><td>k_{denitr}</td><td colspan="4">0.0484</td></tr>
<tr><td>ΔN_{immob2}</td><td colspan="4">1.35</td></tr>
</table>

Universal fit

Simulated

vs

Observed

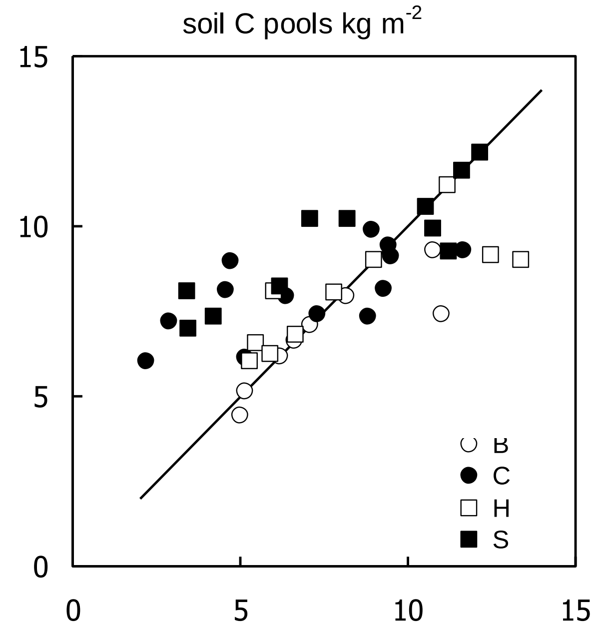


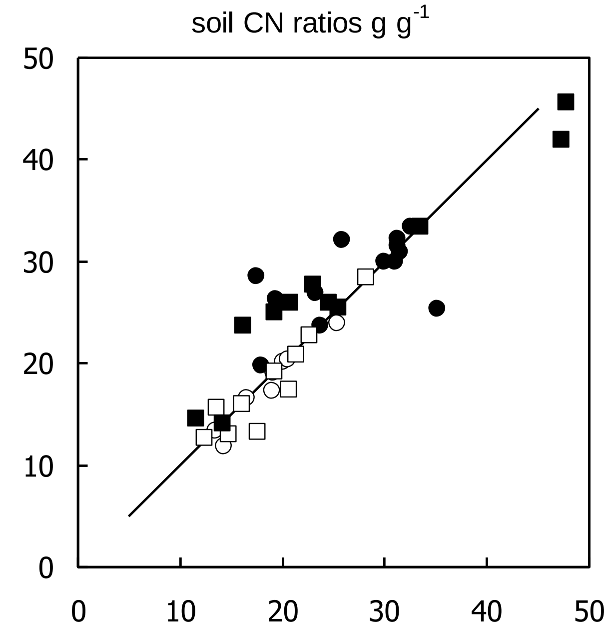
Site-specific fit

Simulated

vs

Observed





20%

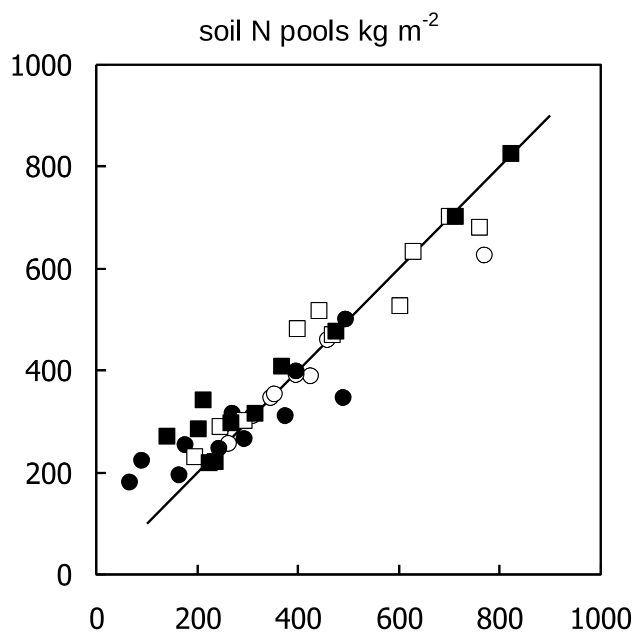
k_{immobN}

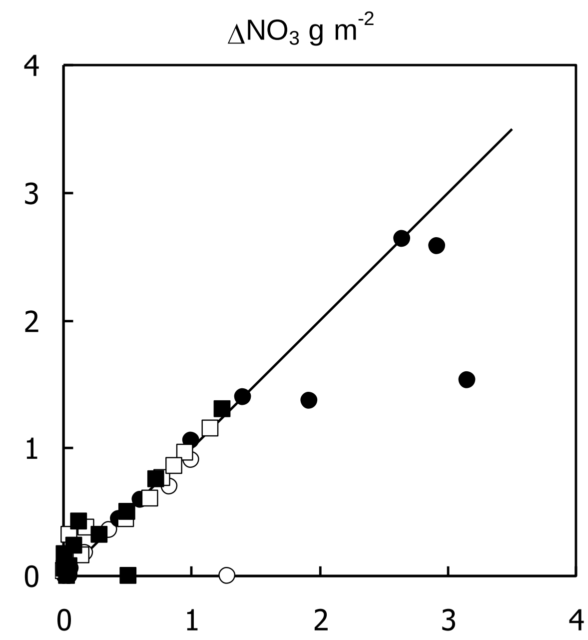
f_{gr}

k_{denitr}

ΔN_{immob2}

$\Delta N_{fix,pris}$

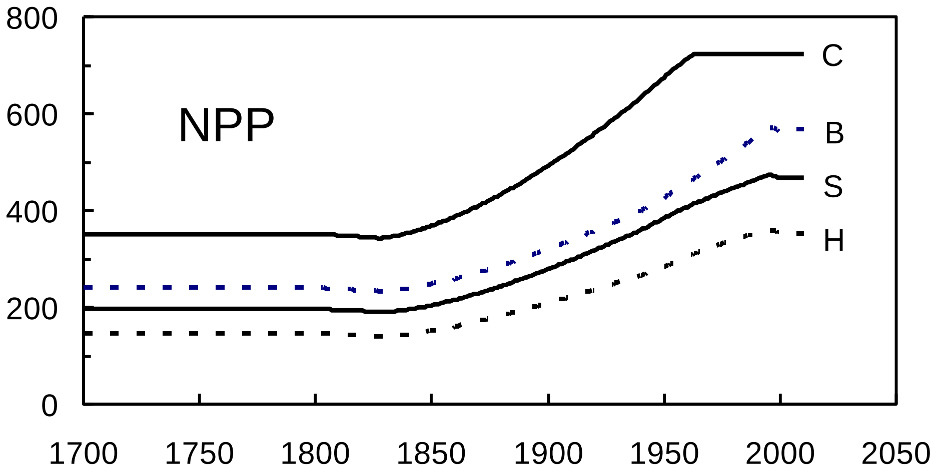




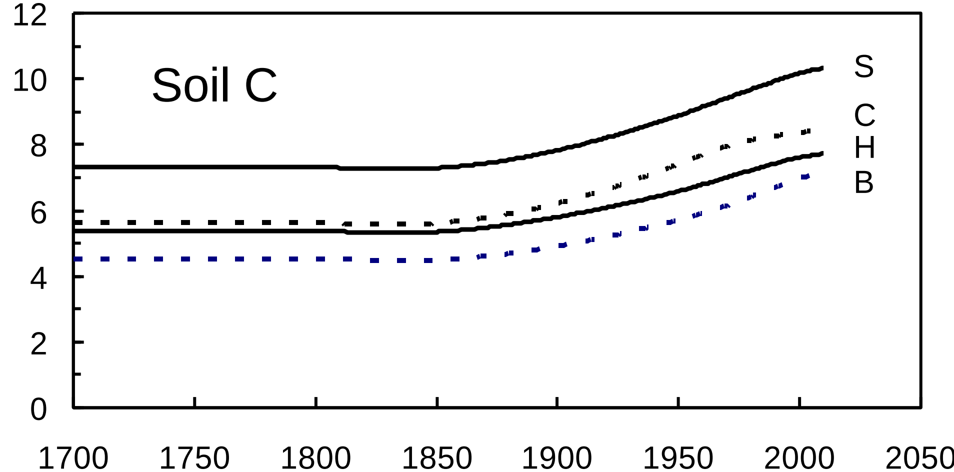
N14C simulations for Broadleaf, Conifer, Herbs, Shrubs

MAT = 8^{o}C , MAP = 1500 mm, Ndep(2000) = 2 g m^{-2}

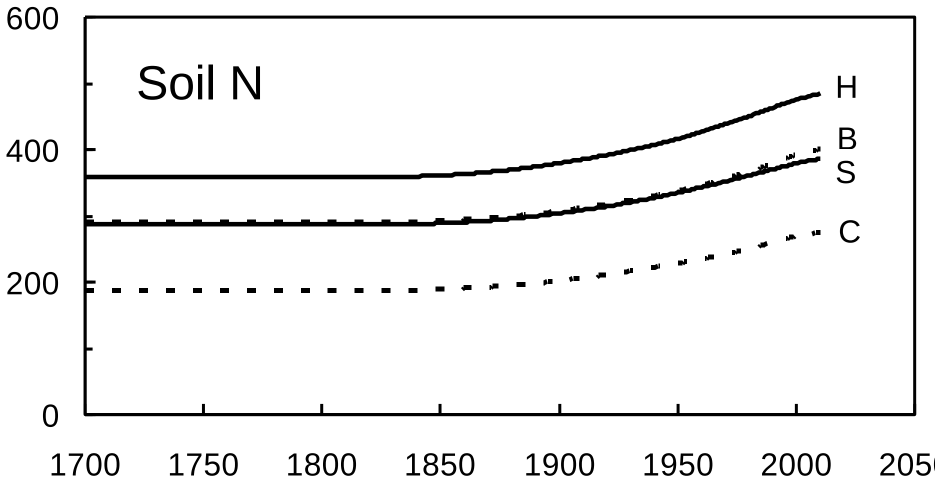
annual NPP gC m-2



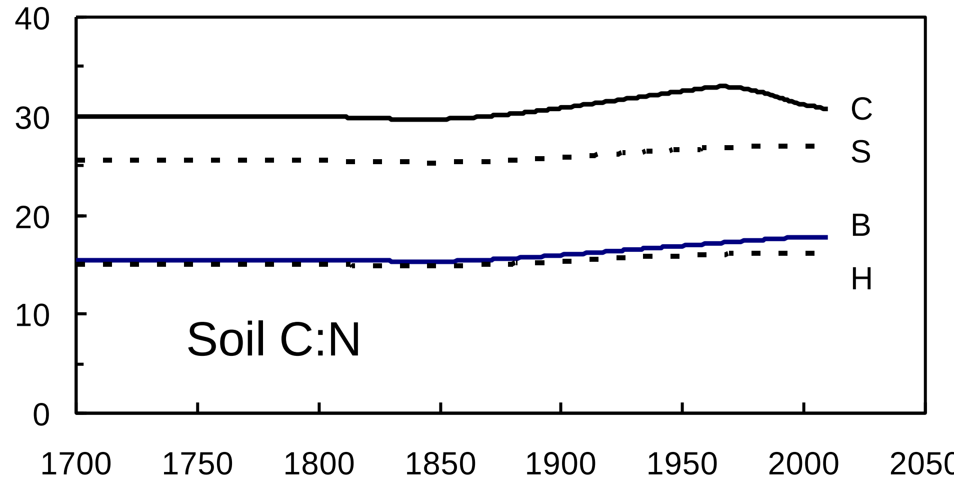
soil C kg m^{-2}



soil N g m-2

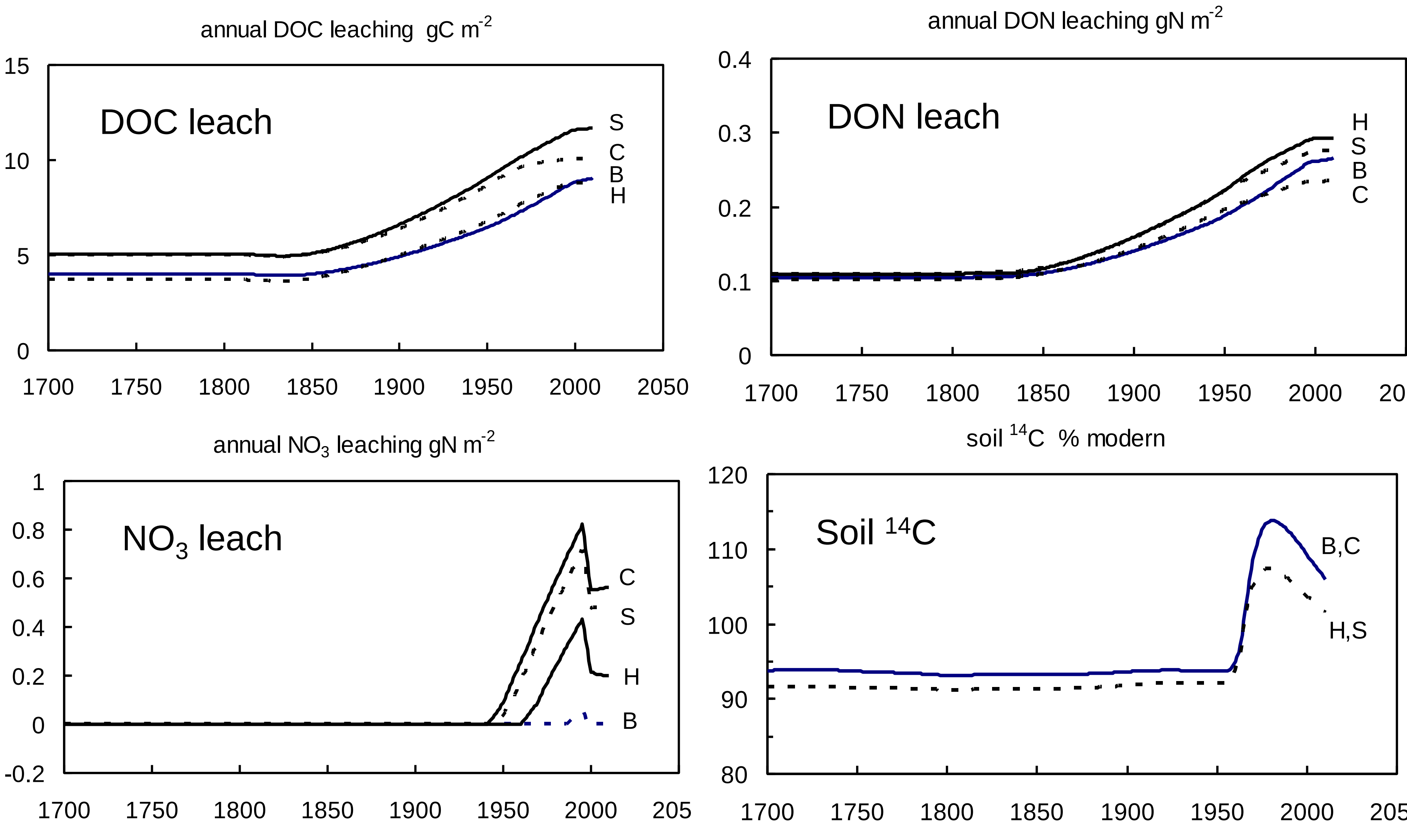


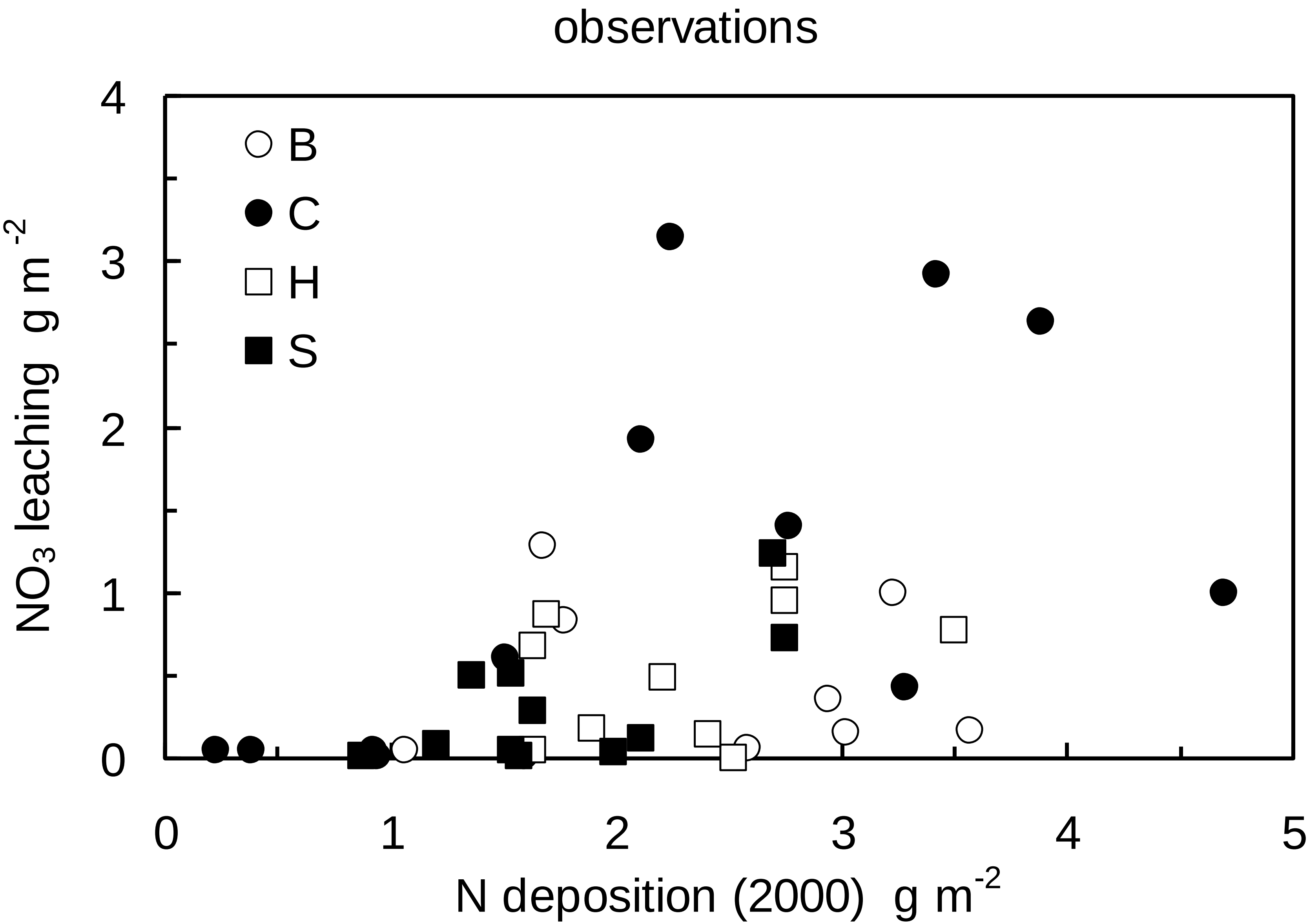
soil C:N g g^{-1}

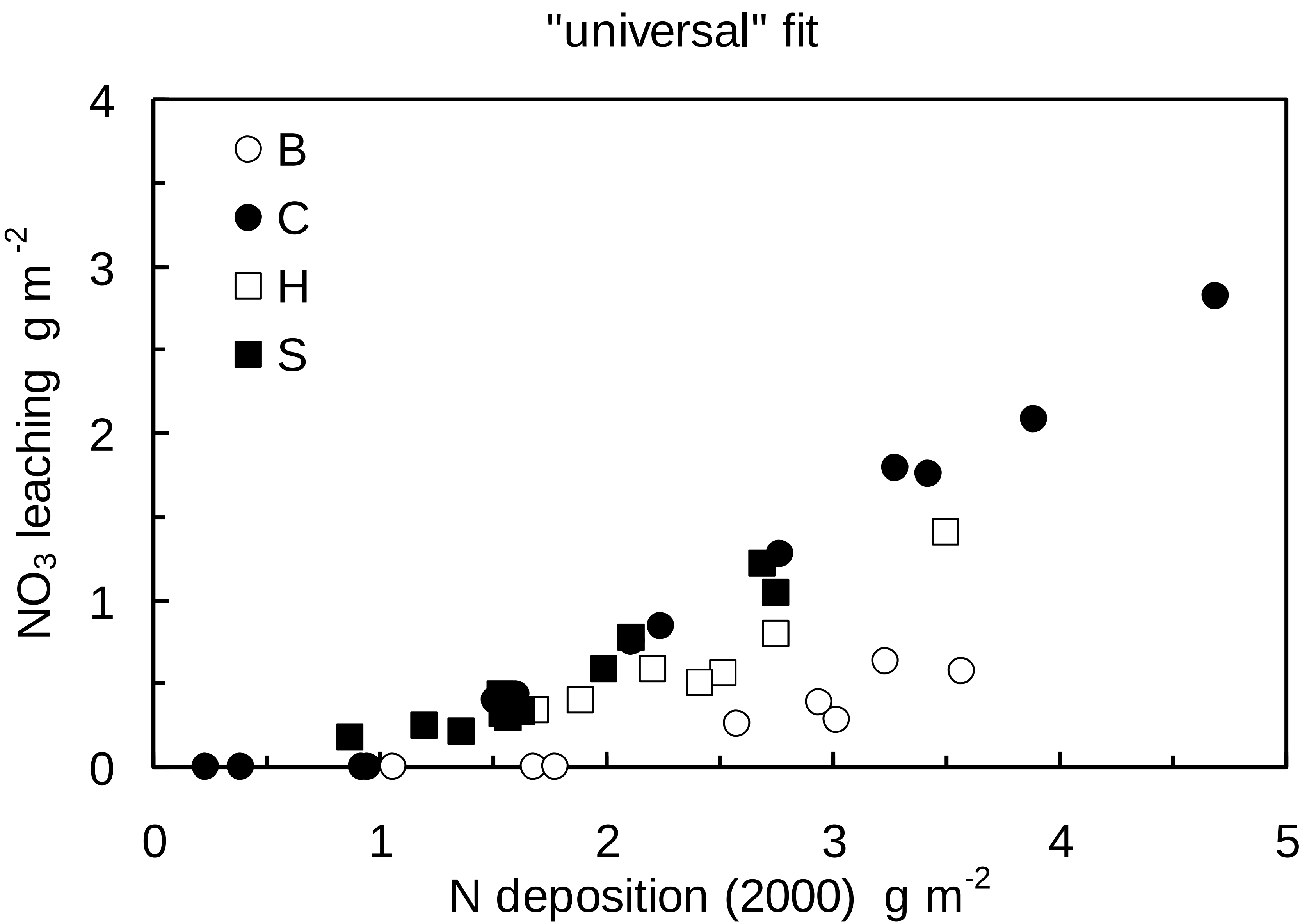


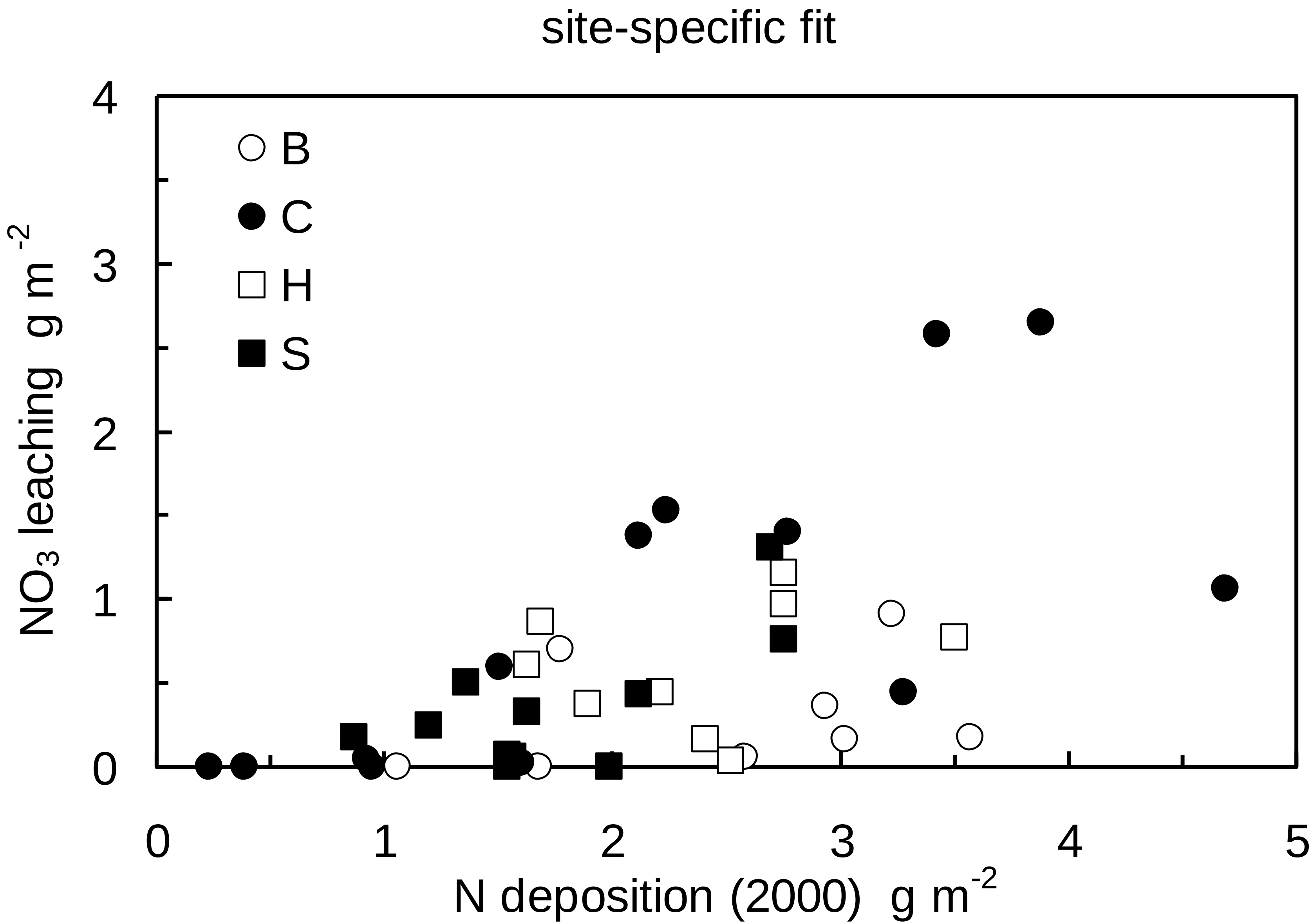
N14C simulations for Broadleaf, Conifer, Herbs, Shrubs

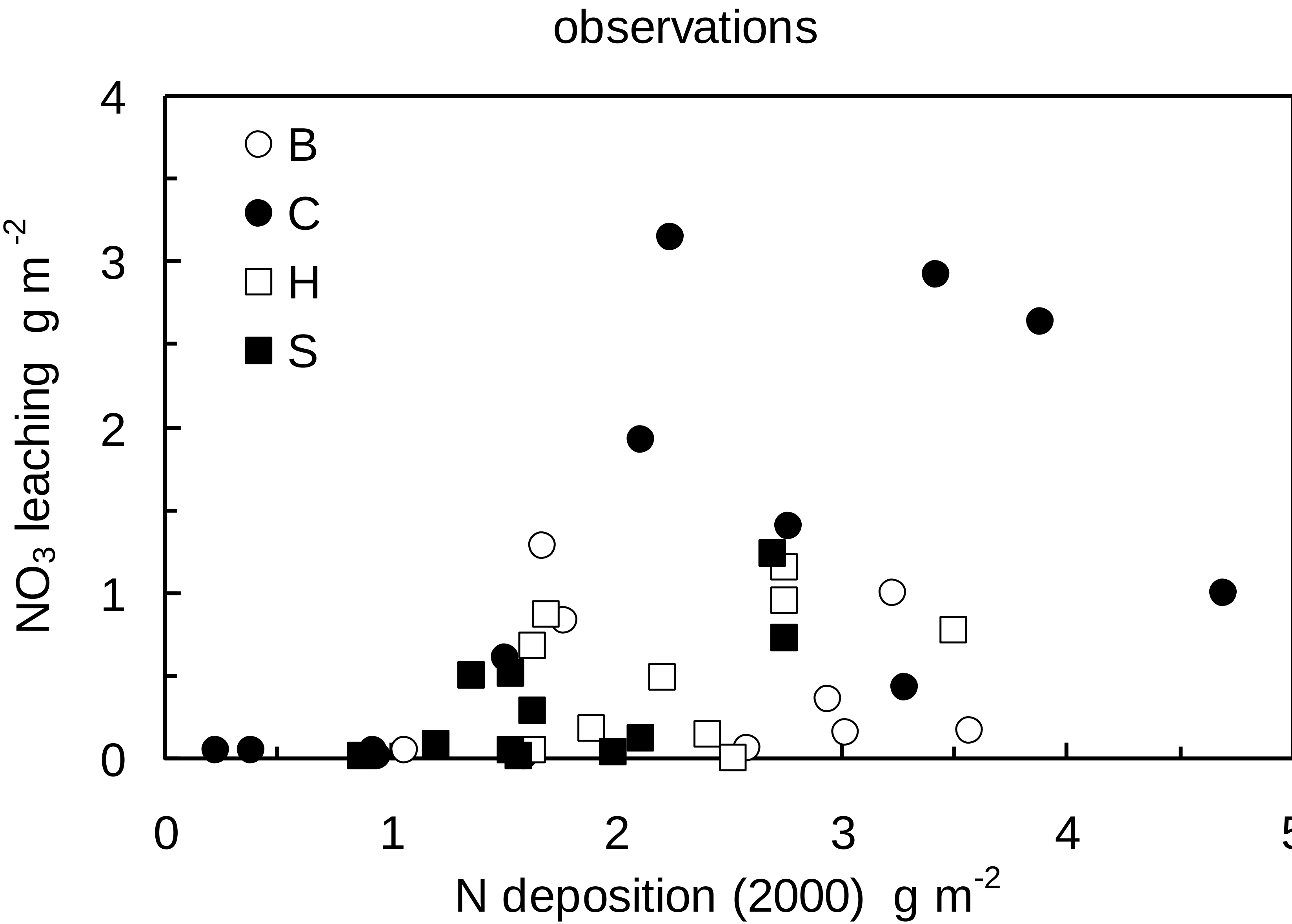
MAT = 8^{o}C , MAP = 1500 mm, Ndep(2000) = 2 g m^{-2}



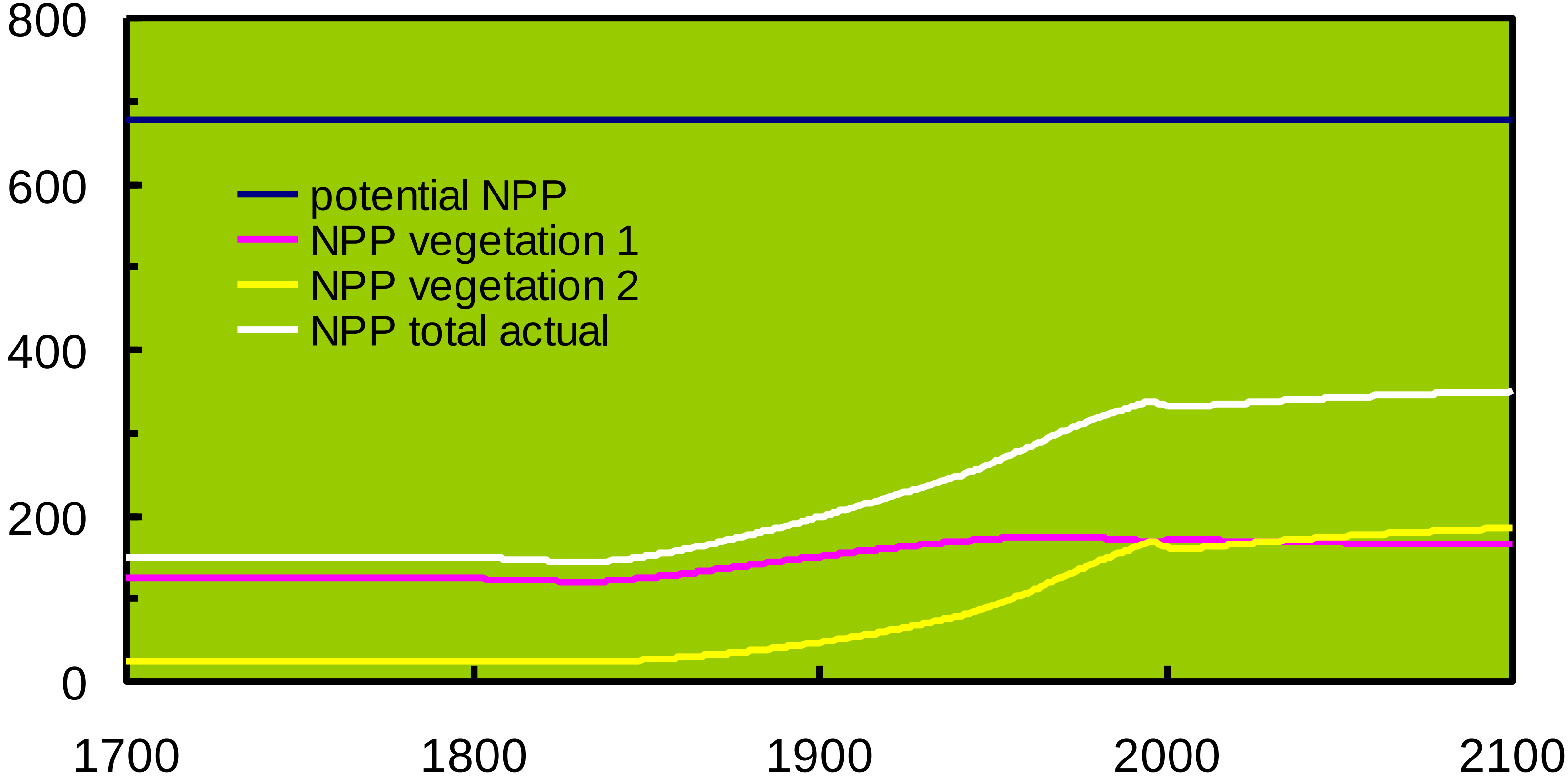

observations
B
C
H
S
NO_3 leaching g m^{-2}
0
1
2
3
4
0
1
2
3
4
5
N deposition (2000) g m^{-2}


"universal" fit
B
C
H
S
NO3 leaching g m-2
N deposition (2000) g m-2
0
1
2
3
4
5


site-specific fit
B
C
H
S
0
1
2
3
4
0
1
2
3
4
5
NO3 leaching g m-2
N deposition (2000) g m-2


observations
B
C
H
S
4
3
2
1
0
0
1
2
3
4
5
NO3 leaching g m-2
N deposition (2000) g m-2

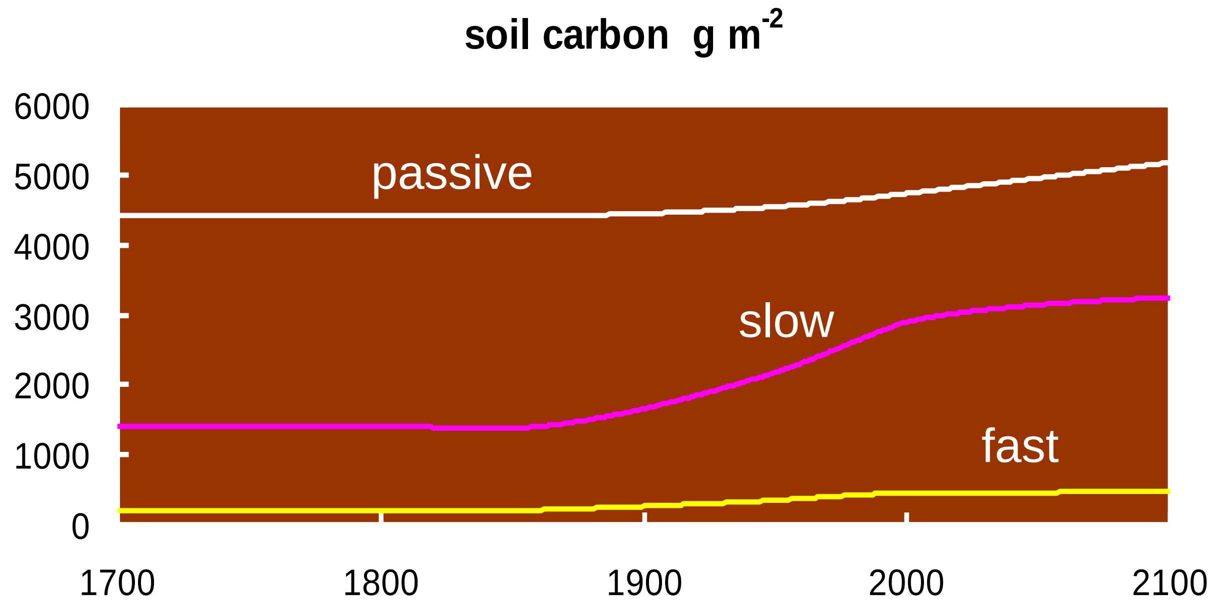
Annual NPP / upland grassland / N_{dep}(2000) = 2.25 gN m^{-2} a^{-1}

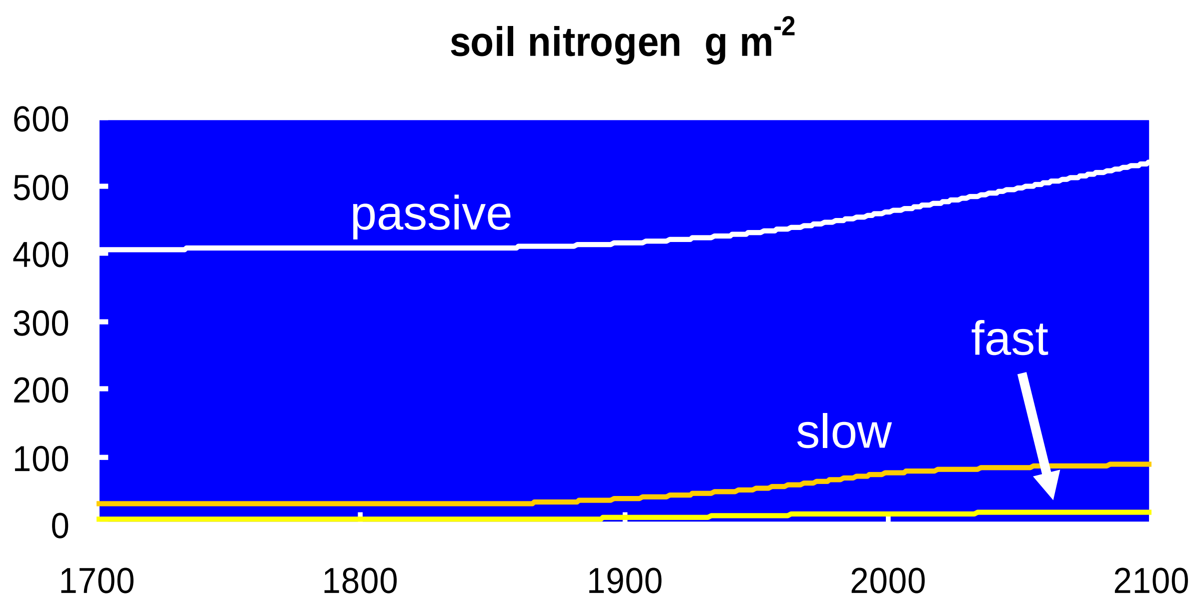


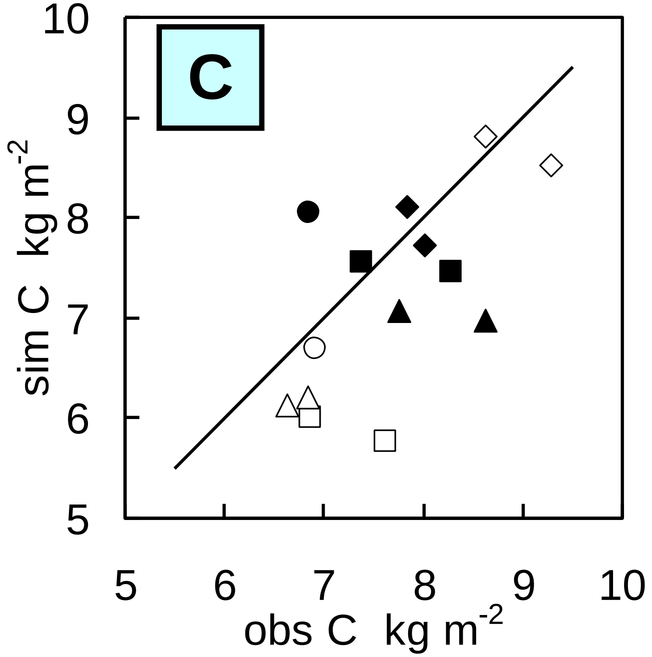
Upland grassland

Ndep(2000) = 2.25 gN m^{-2} a^{-1}

simulated soil C and N pools



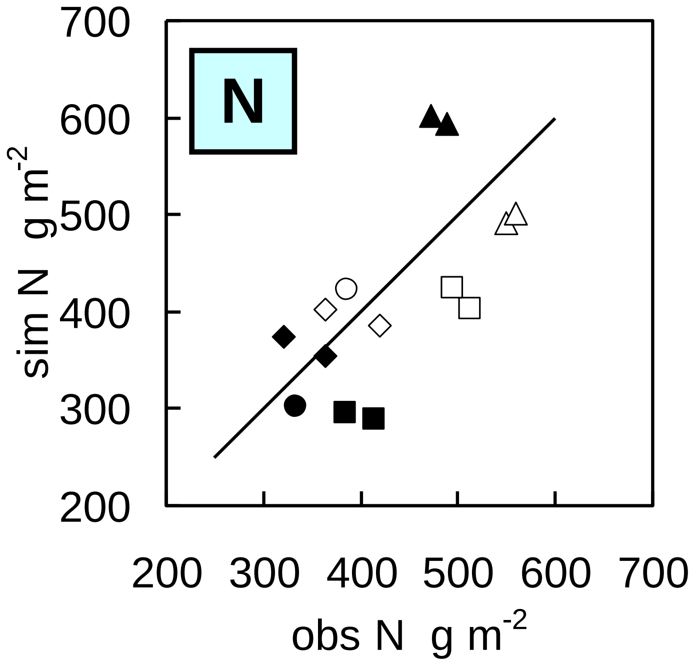


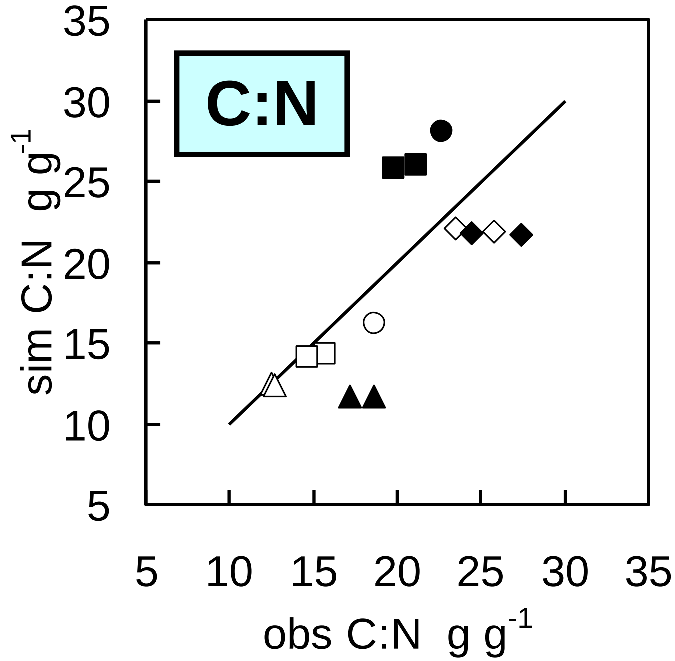


- ○ NI-CA broadleaf (5)
- ● NI-CA conifer (6)
- □ CS broadleaf (91)
- ■ CS conifer (124)
- △ CS neutral grassland (231)
- ▲ CS acid grassland (96)
- ◇ CS heath (105)
- ◆ CS bog (159)

Independent data

Predicted vs observed soil C & N





MAT

MAP

N_{dep} 2000

Veg type

Preliminary predictions / outputs

- Most of the studied conifer sites are N-saturated

  - other sites are still N-limited

- NO_3 leaching responds quickly to changes in N deposition

  Soil N cycling responds more slowly

- C sequestration (vegetation + soil) due to N deposition

trees	~ 20-40 g g^{-1}
herbs & shrubs	~ 10-15 g g^{-1}

- Increased temperature tends to reduce NO_3 leaching

  - via faster soil cycling, increased NPP

Conclusions

- Can approximately account for C and N cycling as
  f(vegetation type, MAT, MAP, Ndep)

- N14C is a useful tool to understand interactions

- Testing so far is promising, but need more

- Additional factors : *P, acidity,* O_3*, trace elements, soil moisture, erosion, grazing, fire, disease, history…*

- N14C simulates changes in productivity
  – *potential link to plant biodiversity*

Funded by Defra and NERC

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

NATURAL ENVIRONMENT RESEARCH COUNCIL

NERC Macronutrient Cycles Programme

Consortium Grant

LTLS
Analysis and simulation of the Long-Term / Large-Scale interactions of C, N and P in UK land, freshwater and atmosphere

E Tipping *CEH*

JF Boyle *U Liverpool*

J Quinton *Lancaster U*

ME Stuart *BGS*

AP Whitmore *Roth Res*

RC Helliwell *JHI**

NL Rose *UCL*

S Ullah *U Keele*

CL Bryant *NERC RCF*

* Funded by the Scottish Government

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

NATURAL ENVIRONMENT RESEARCH COUNCIL

LTLS questions

- Over the last 200 years, what have been the temp... responses of soil C, N and P pools in different UK cat... ...ient enrichment?
- What have been th... ...nd P transfers from land to th... ...estuaries?
- How ... ...water biodiversity responded to increa... ...stem productivity engendered by nutrient enrich... ...t at different locations?

…or, how did we get to where we are today?

<u>Answered by:</u>

integrated modelling analysis,

aimed at accounting for observable present element pools and fluxes in different UK catchments in terms of their nutrient enrichment histories

LTLS scope & approach

Long-term processes	1800-present
	20,000 BP – 1800

All UK catchments to the tidal limit
+ water directly entering estuaries & sea

Existing data

New gap-filling data

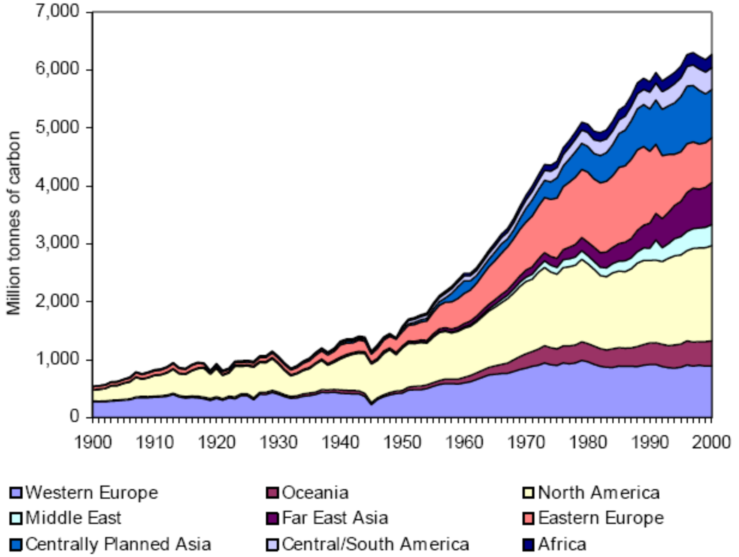
Integrated modelling

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

NATURAL ENVIRONMENT RESEARCH COUNCIL

LTLS focus period 1800-2000

Chart 5A.1 Global emissions from fossil fuel combustion from 1990 to 2000



Source: Marland, G., T.A. Boden, and R. J. Andres, Global, Regional, and National CO_2 Emissions

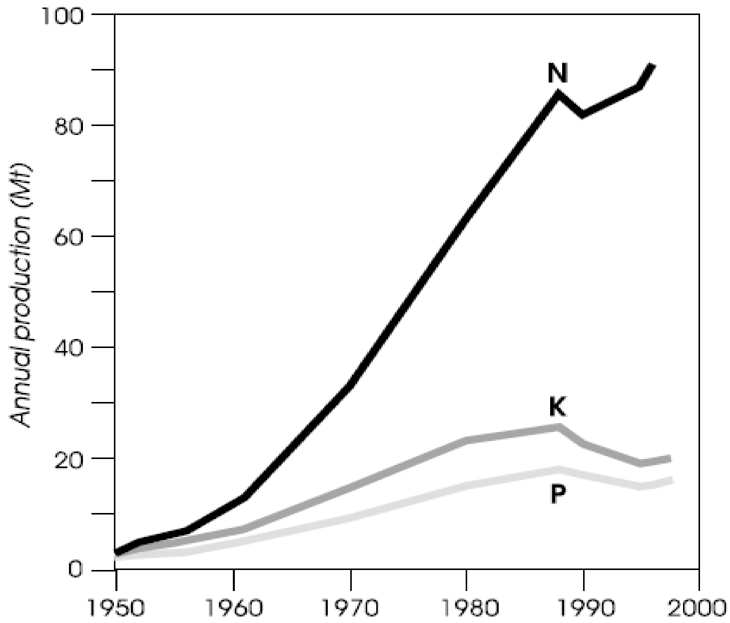


Figure 3. Global Production of Inorganic Fertilizers, 1950-2000.

"…human beings are now carrying out a large scale geophysical experiment…"

Revelle & Suess, 1956

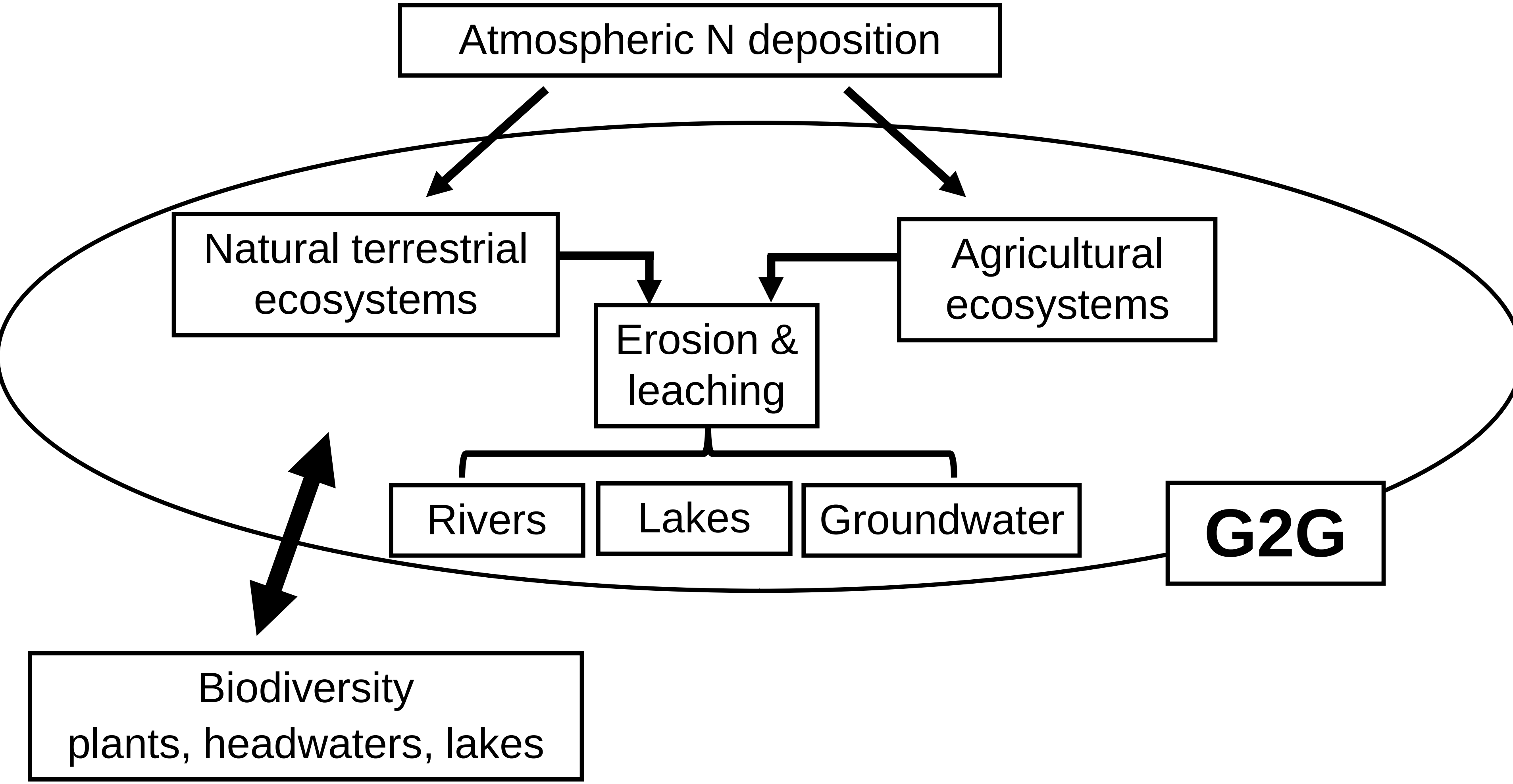
"…the UK's long-term, spatially-distributed, biogeochemical experiment in nutrient enrichment…"

LTLS proposal 2011

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

NATURAL ENVIRONMENT RESEARCH COUNCIL

LTLS joined-up models



Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

NATURAL ENVIRONMENT RESEARCH COUNCIL

LTLS outputs & benefits

Integrated model - spatially distributed, long-term description of UK macronutrient pools, fluxes and ***interactions***

- feasibility of joining up simple models
- large-scale / long-term implications for bioG and bioD

Platform – for incorporating more detailed / site-specific / short-term knowledge

Policy – national-scale description, multiple effects, scenario analysis

Capacity-building – upscaling, model linkage

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

NATURAL ENVIRONMENT RESEARCH COUNCIL

The end

Plant functional types

		broadleaf	conifer	herb	shrub
C:N hard		250	250	-	-
C:N soft low nutrient		50	65	40	50
C:N soft high nutrient		30	45	20	35
f_{hard}		0.35	0.45	0.00	0.00
f_{soft}		0.65	0.55	1.00	1.00
$f_{hard,litter}$		0.005	0.005	-	-
$f_{soft,litter}$		0.15	0.10	0.20	0.15
$f_{Nretained}$	low nutrient	0.24	0.16	0.33	0.25
	high nutrient	0.35	0.26	0.33	0.25

Summary of field sites

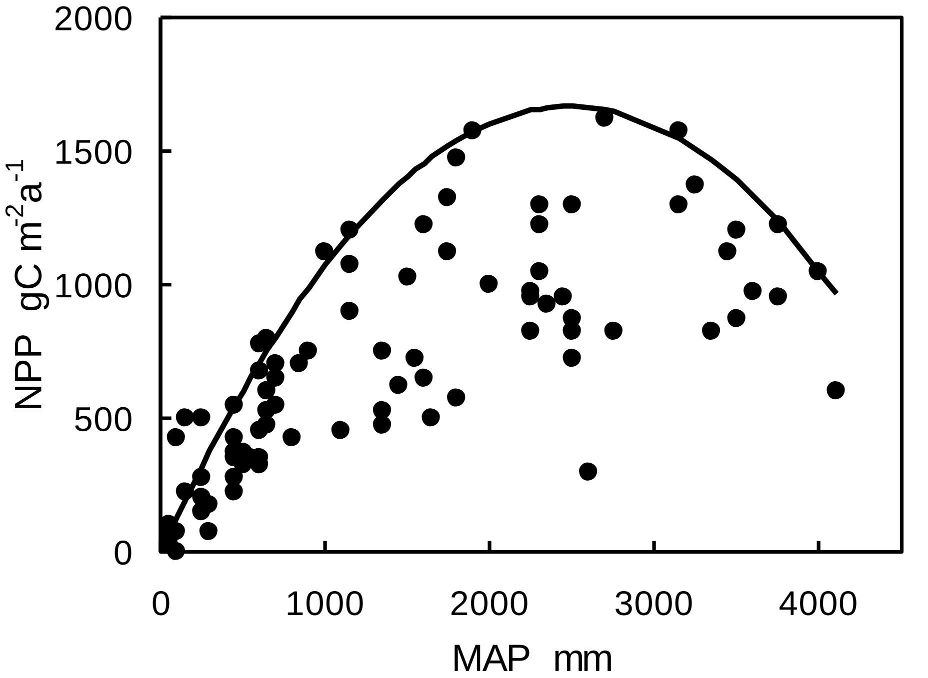
	units	Broadleaf	Conifer	Herbs	Shrubs
n		8	13	10	11
MAT	°C	8.2 - 11.0	2.1 - 9.6	5.3 - 8.5	4.7 - 10.1
MAP	mm a^{-1}	610 - 2230	580 - 1400	1230 - 3650	760 - 2300
N deposition	g m^{-2} a^{-1}	1.1 - 3.6	0.2 - 4.7	1.6 - 3.5	0.9 - 2.8
topsoil depth	cm	14 - 30	12 - 30	8 - 37	10 - 22
topsoil C pool	kg m^{-2}	5.0 - 11.0	2.2 - 11.7	5.3 - 13.4	3.4 - 12.2
topsoil N pool	g m^{-2}	260 - 770	70 - 500	200 - 760	140 - 820
topsoil C:N	g g^{-1}	13 - 25	17 - 35	12 - 28	12 - 48
N_{inorg} leaching	g m^{-2} a^{-1}	0.1 - 1.3	0.0 - 3.2	0.0 - 1.2	0.0 - 1.2
DOC leaching[a]	g m^{-2} a^{-1}	3.1 - 13.7	9.7	3.6 - 11.3	4.1 - 23.7
DON leaching[a]	g m^{-2} a^{-1}	-	0.06 - 0.28	0.14 - 0.46	0.11 - 0.60
NPP_{max}[b]	g m^{-2} a^{-1}	715-849	491-789	613-743	590-810
		2 DE 5 GB 1 NL	4 DE 1 DK 2 NL 1 NO 5 SE	6 GB 4 NO	1 DK 7 GB 1 NL 2 NO

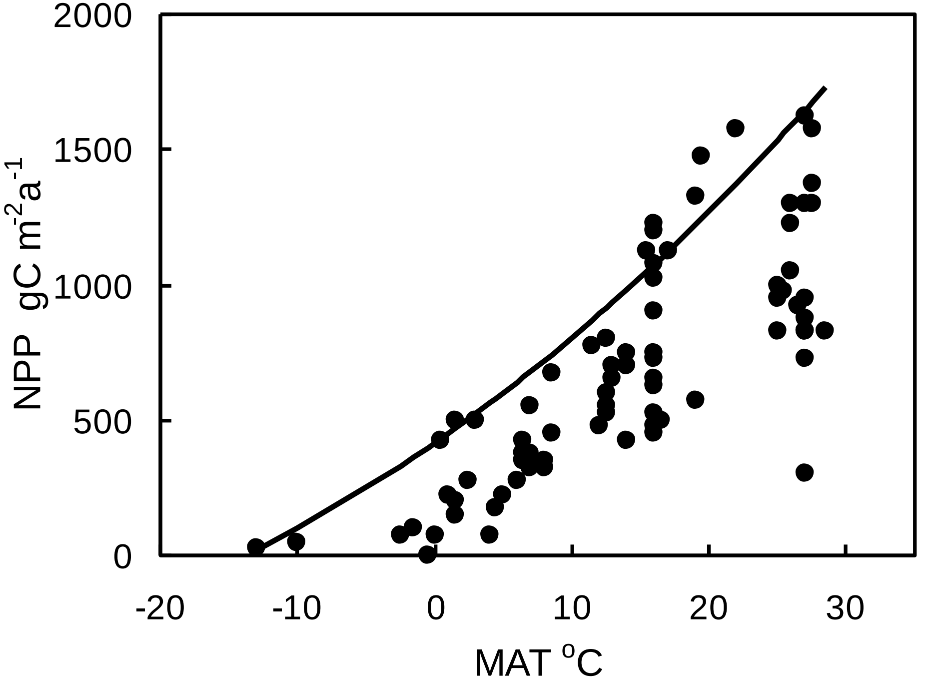
Net

Primary

Production

- maximum values estimated by quantile regression (90%)





N fixation

Pristine 0.3 gN m^{-2} a^{-1}

Based on sparse literature

Key to pre-industrial ecosystem N and C

Down-regulated by N deposition (DeLuca et al)

Preliminary estimates of C sequestration due to N_{dep}