Interactions between the N and C cycles in forests and how does the atmosphere chemistry impact forest ecosystems

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Hofstetten
C
N
Alptal

C

N

Alptal

An N-rich world...

Global conversions of N_2 to bioreactive N

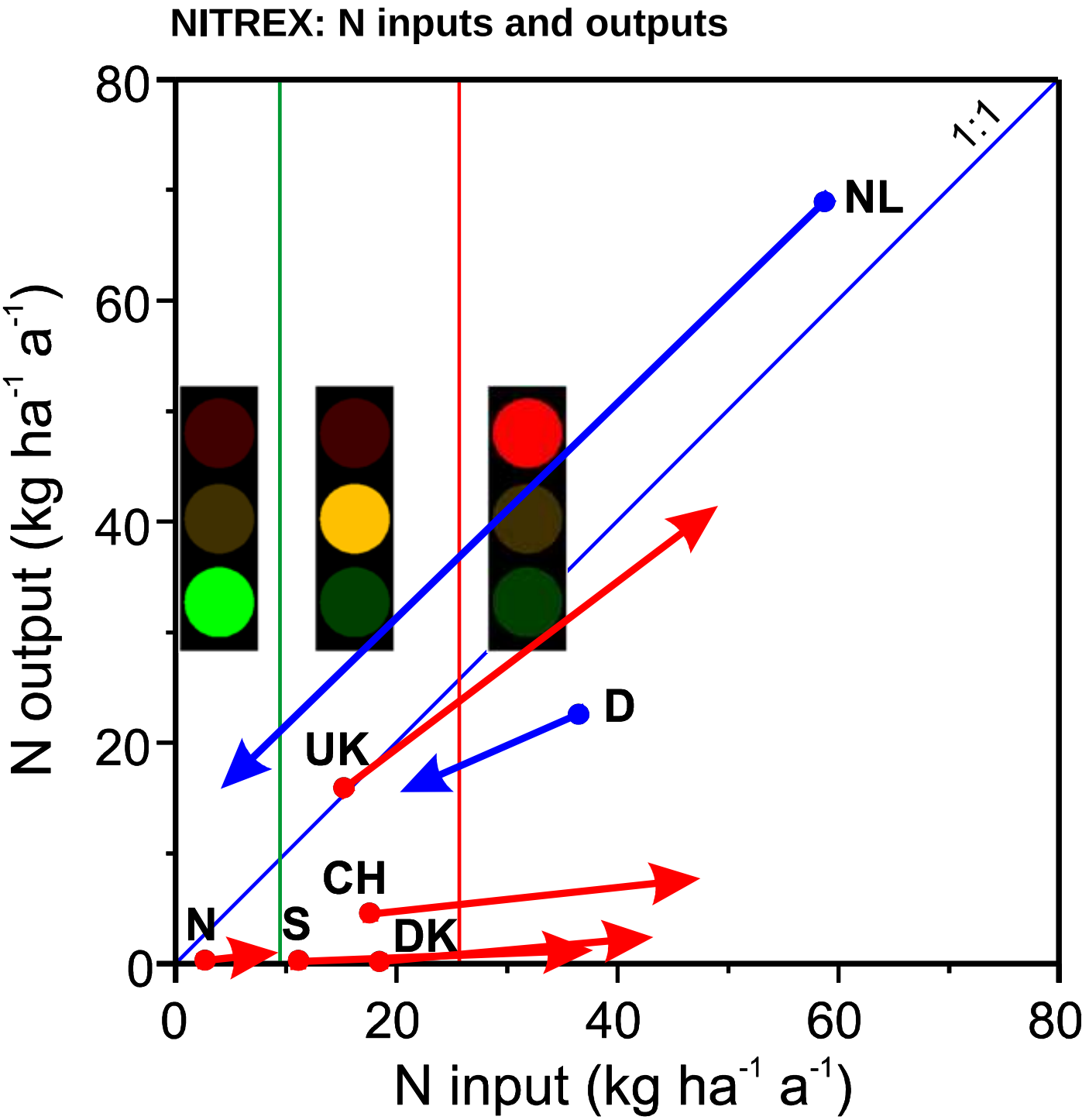
Natural : 113 Mt a^{-1}

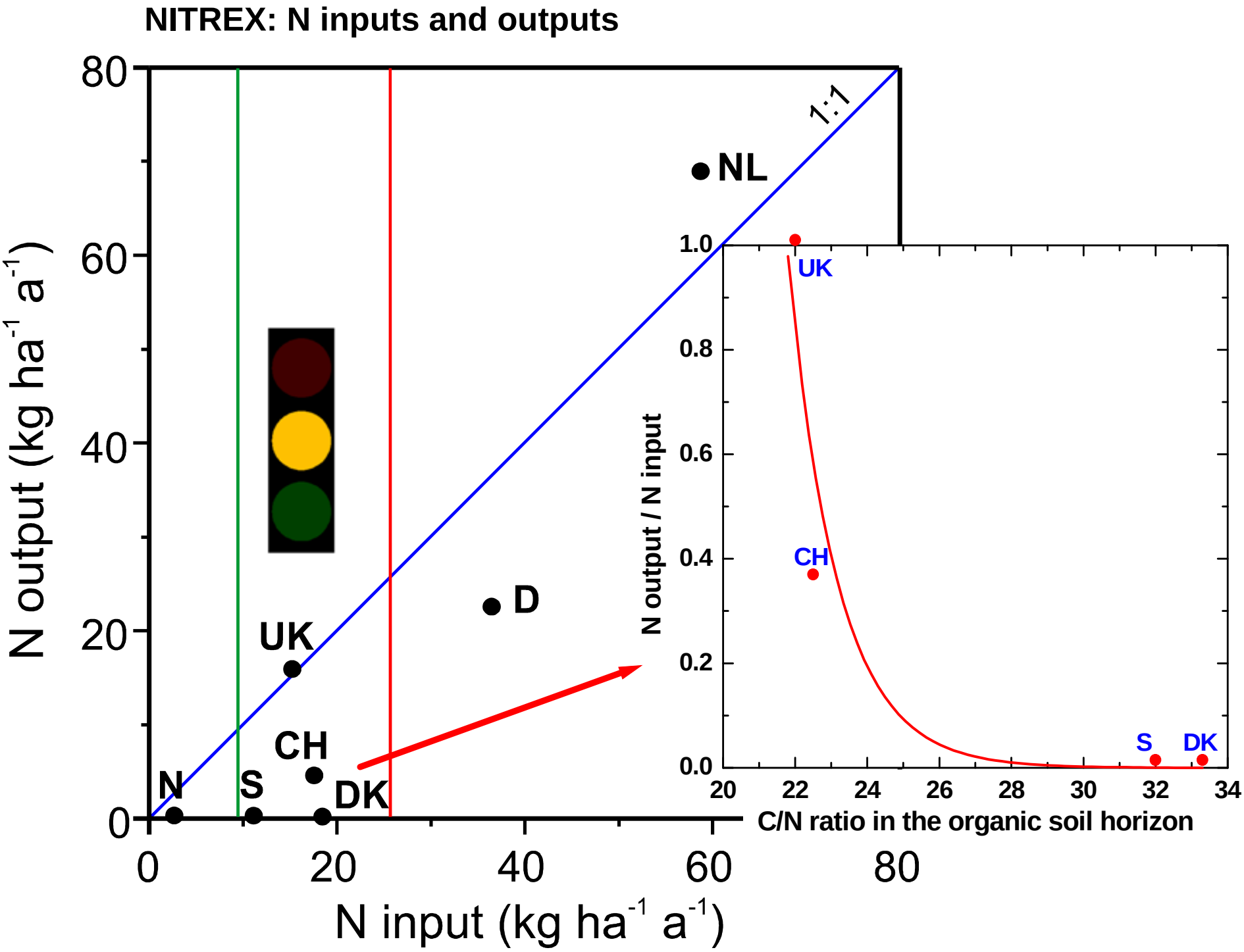
Antropogenic: 140 Mt a^{-1}

Vitousek et al. 1997 (Ecol. Appl.)

NITREX

Manipulation of N deposition


NITREX: N inputs and outputs
N output (kg ha-1 a-1)
N input (kg ha-1 a-1)
0
20
40
60
80
1:1
NL
D
UK
CH
DK
N
S


NITREX: N inputs and outputs
N output (kg ha-1 a-1)
N input (kg ha-1 a-1)
0
20
40
60
80
1:1
NL
D
UK
CH
S
DK
N
N output / N input
C/N ratio in the organic soil horizon
0.0
0.2
0.4
0.6
0.8
1.0
20
22
24
26
28
30
32
34

Alptal

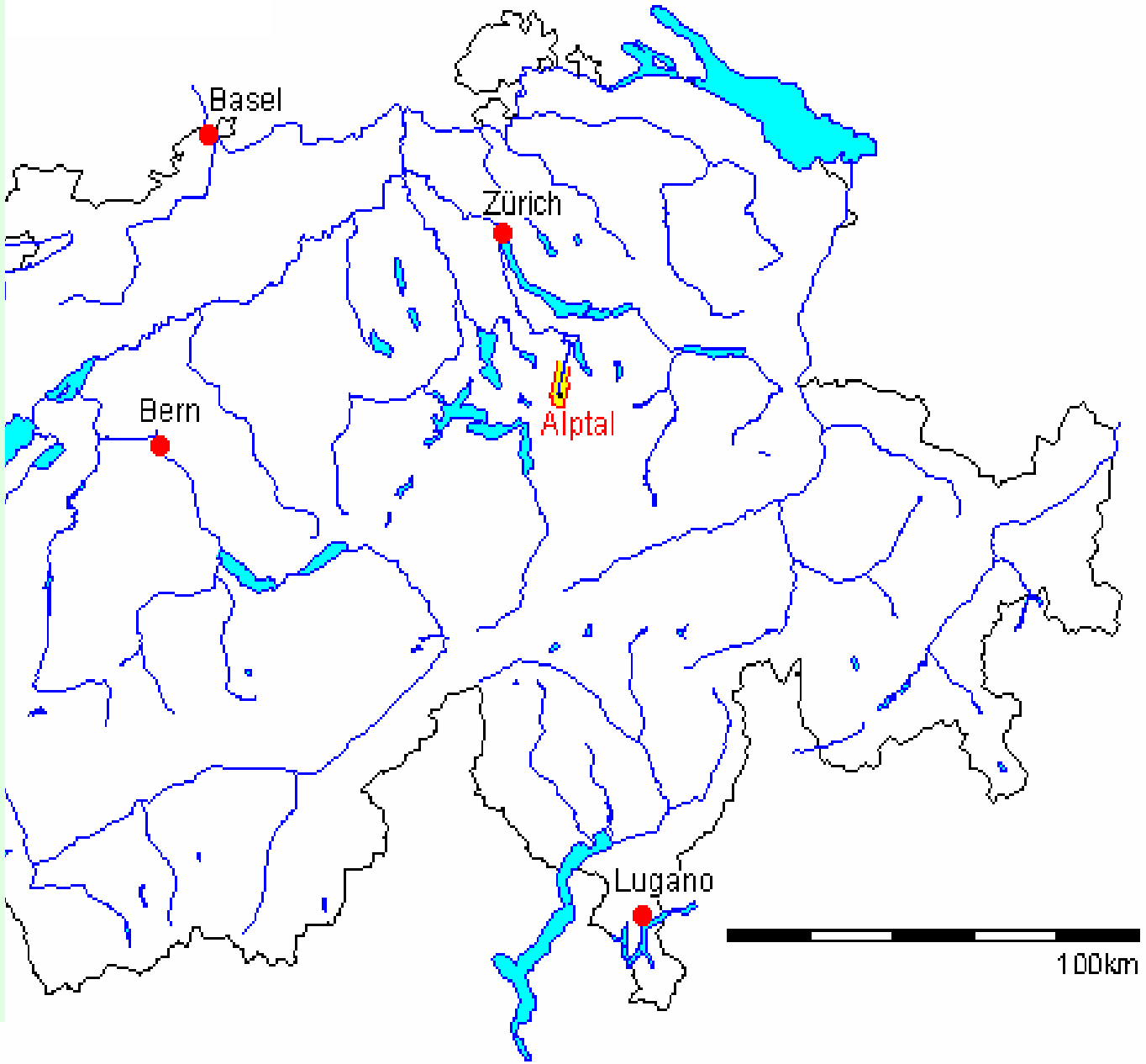
Altitude:
1200 m

Geology and soils:
Gleysol over Flysch

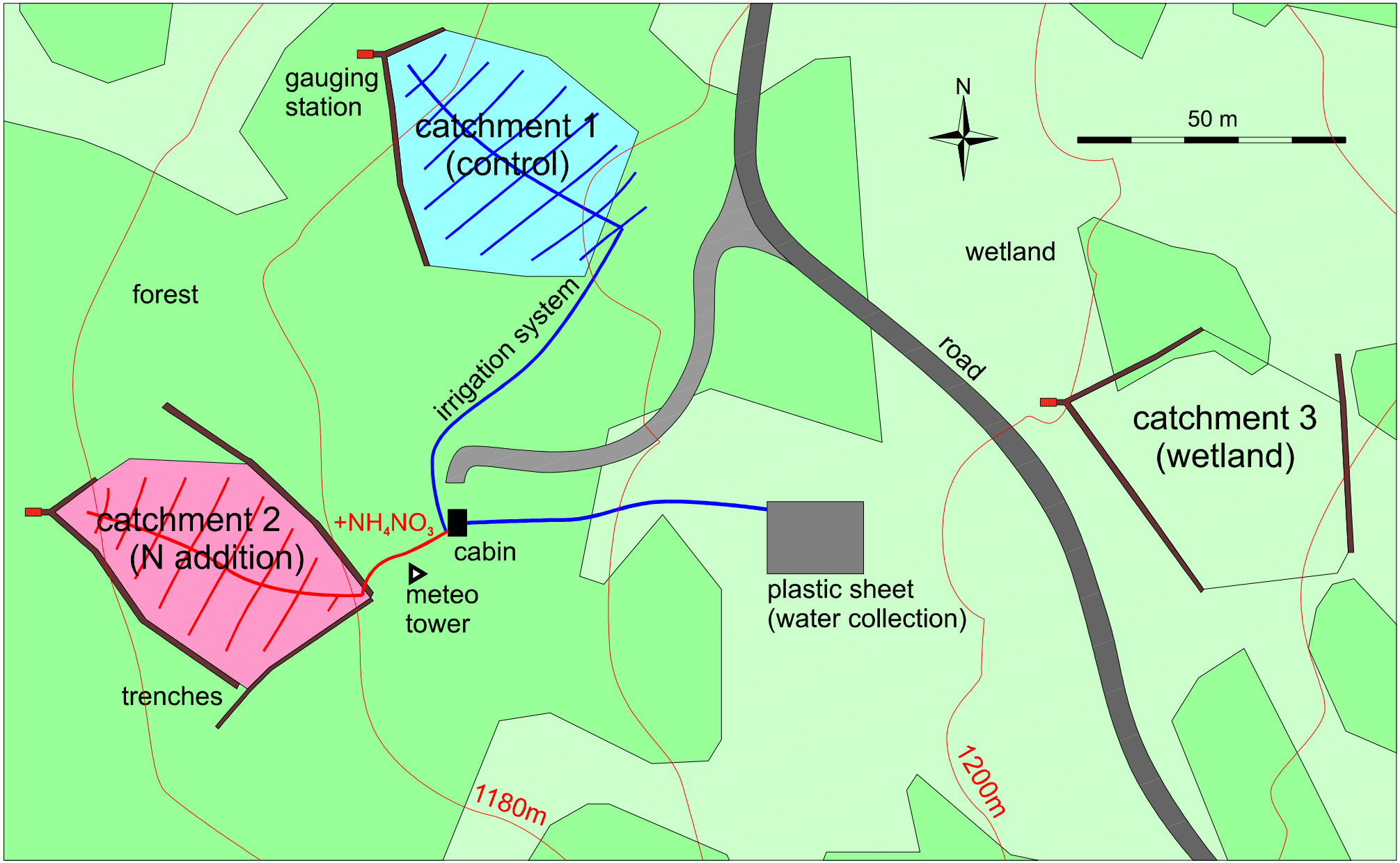
Vegetation:
mosaic of forest and wetland patches

Precipitation:
2300 mm/a
(30% as snow)

Bulk N deposition:
12 kg/ha/a
($NO_3^- \cong NH_4^+$)




LF
Aa
Gor
Gr


gauging station
catchment 1 (control)
N
50 m
wetland
forest
irrigation system
road
catchment 3 (wetland)
catchment 2 (N addition)
+NH4NO3
cabin
meteo tower
plastic sheet (water collection)
trenches
1180m
1200m

NITREX

IRISALP

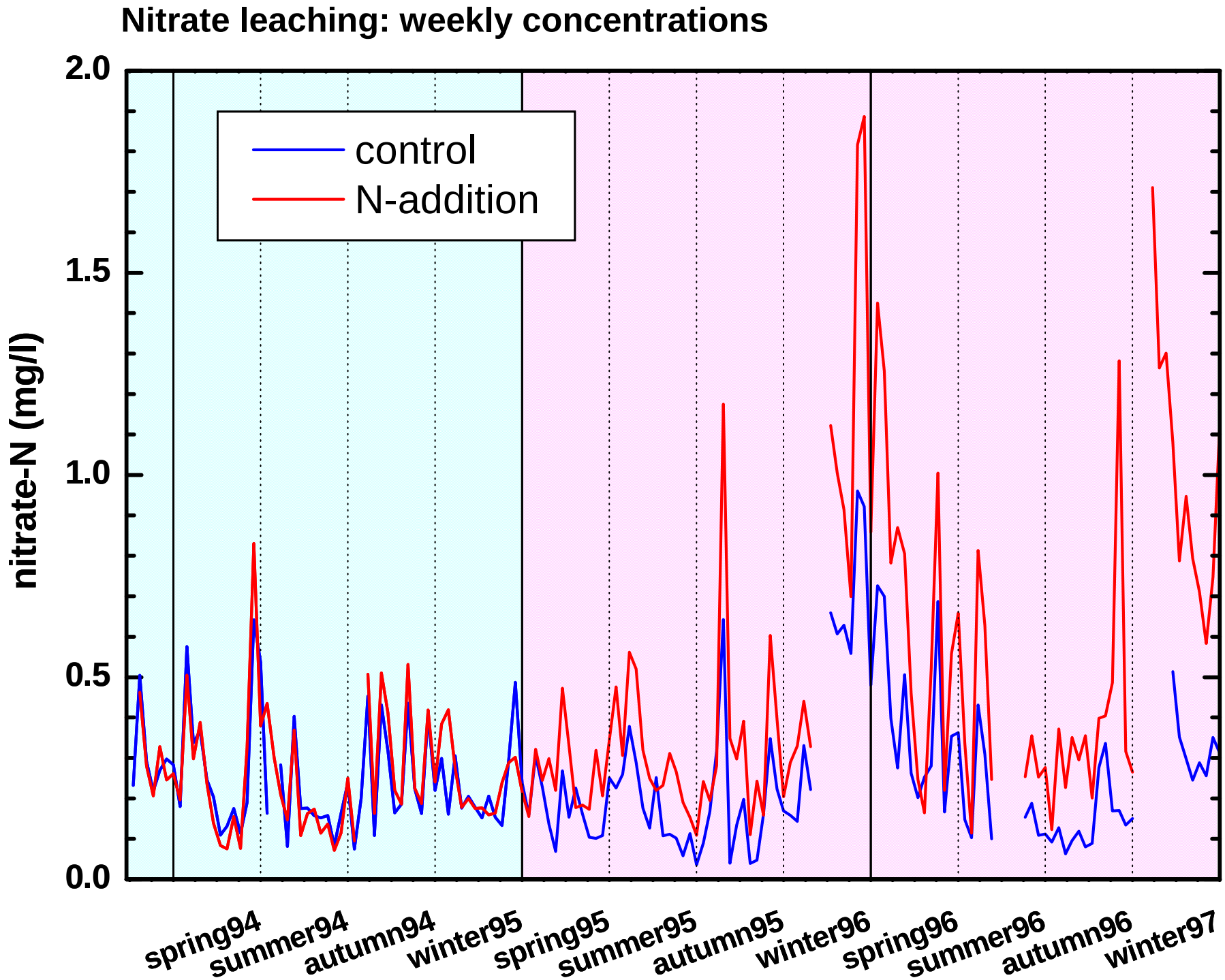
N

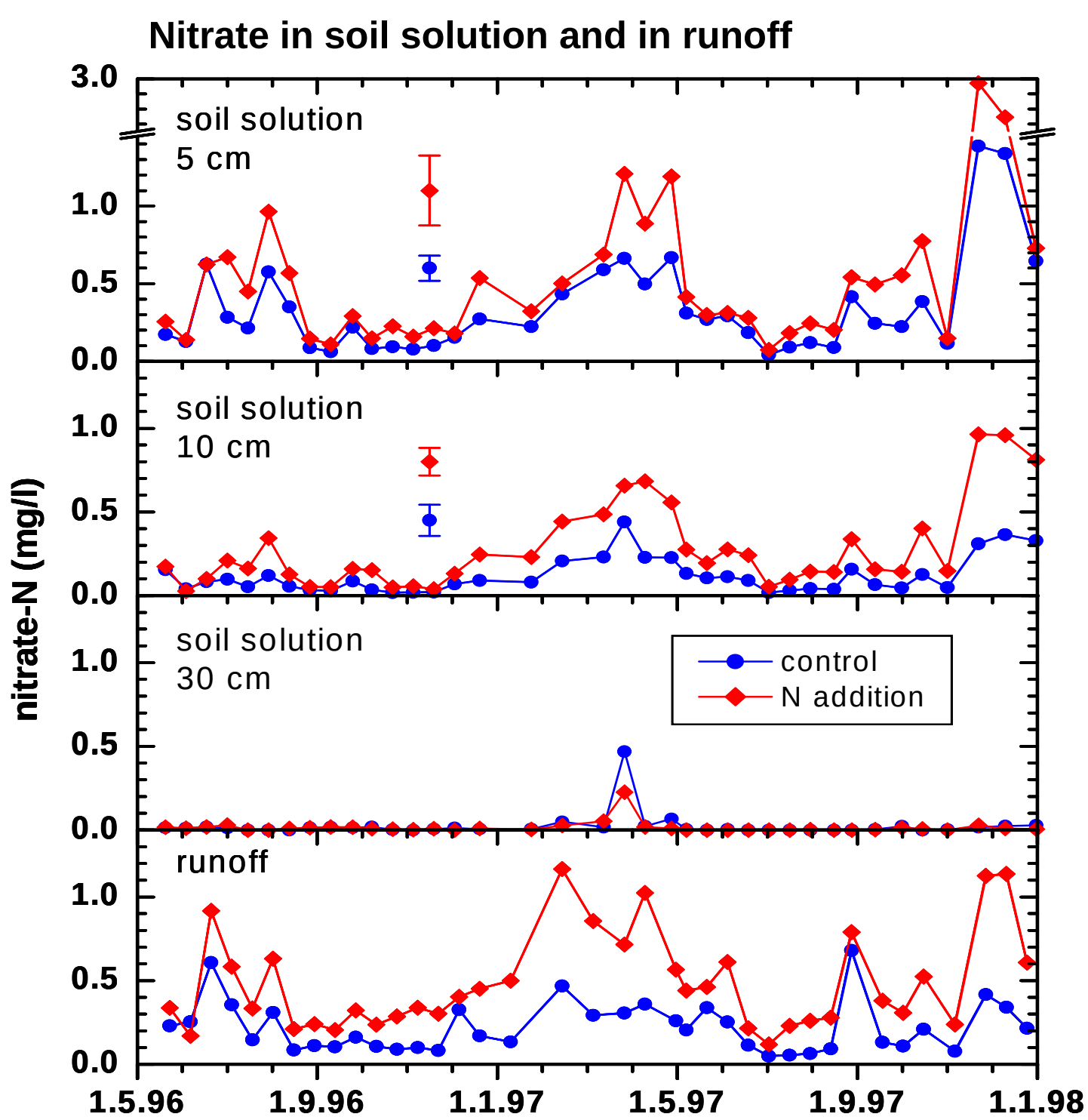
50 m

wetland

irrigation s

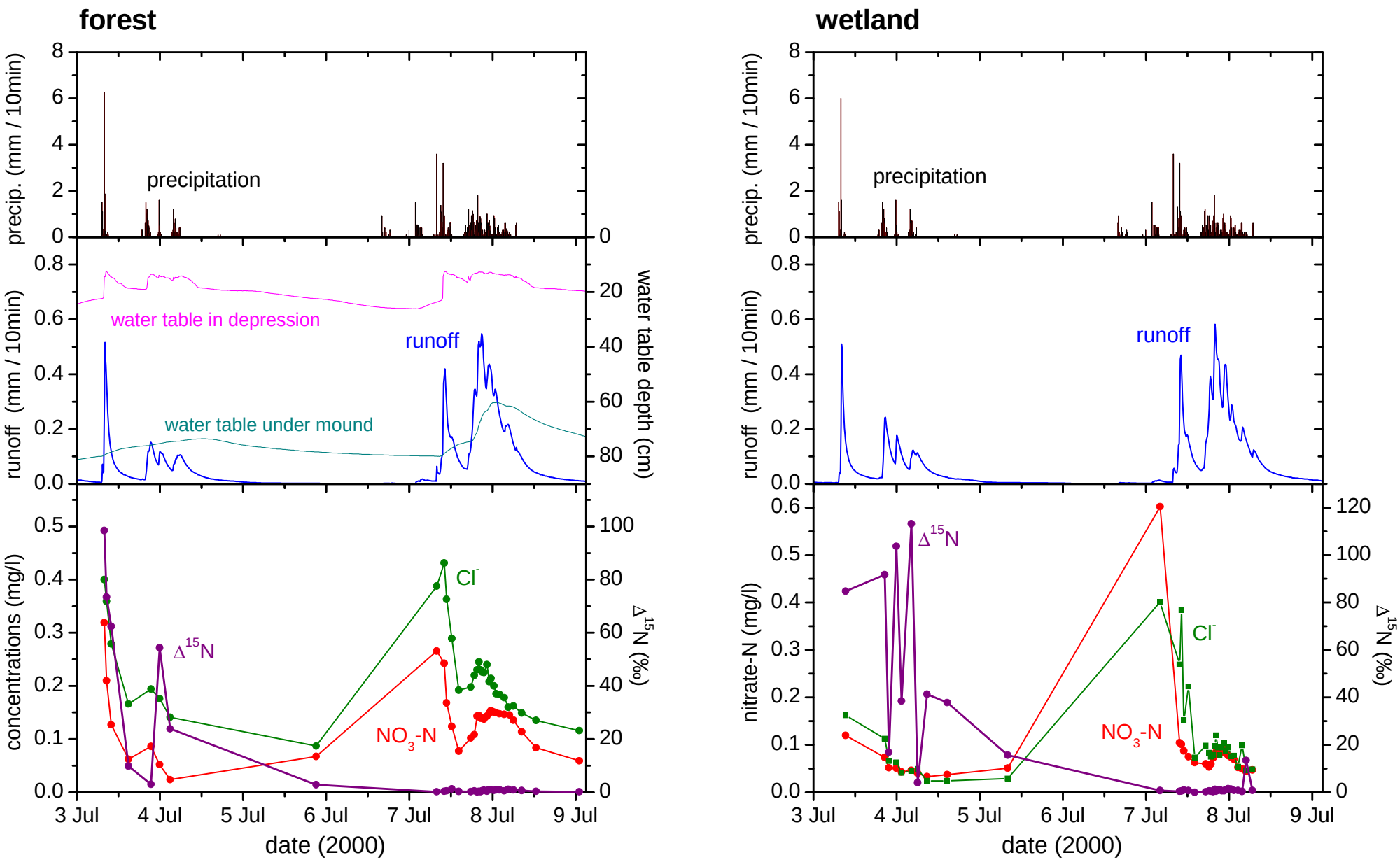
catchment 3
(wetland)


Nitrate leaching: weekly concentrations
control
N-addition
nitrate-N (mg/l)
2.0
1.5
1.0
0.5
0.0
spring94
summer94
autumn94
winter95
spring95
summer95
autumn95
winter96
spring96
summer96
autumn96
winter97


Nitrate in soil solution and in runoff
nitrate-N (mg/l)
soil solution
5 cm
soil solution
10 cm
soil solution
30 cm
runoff
control
N addition
3.0
1.0
0.5
0.0
1.5.96
1.9.96
1.1.97
1.5.97
1.9.97
1.1.98

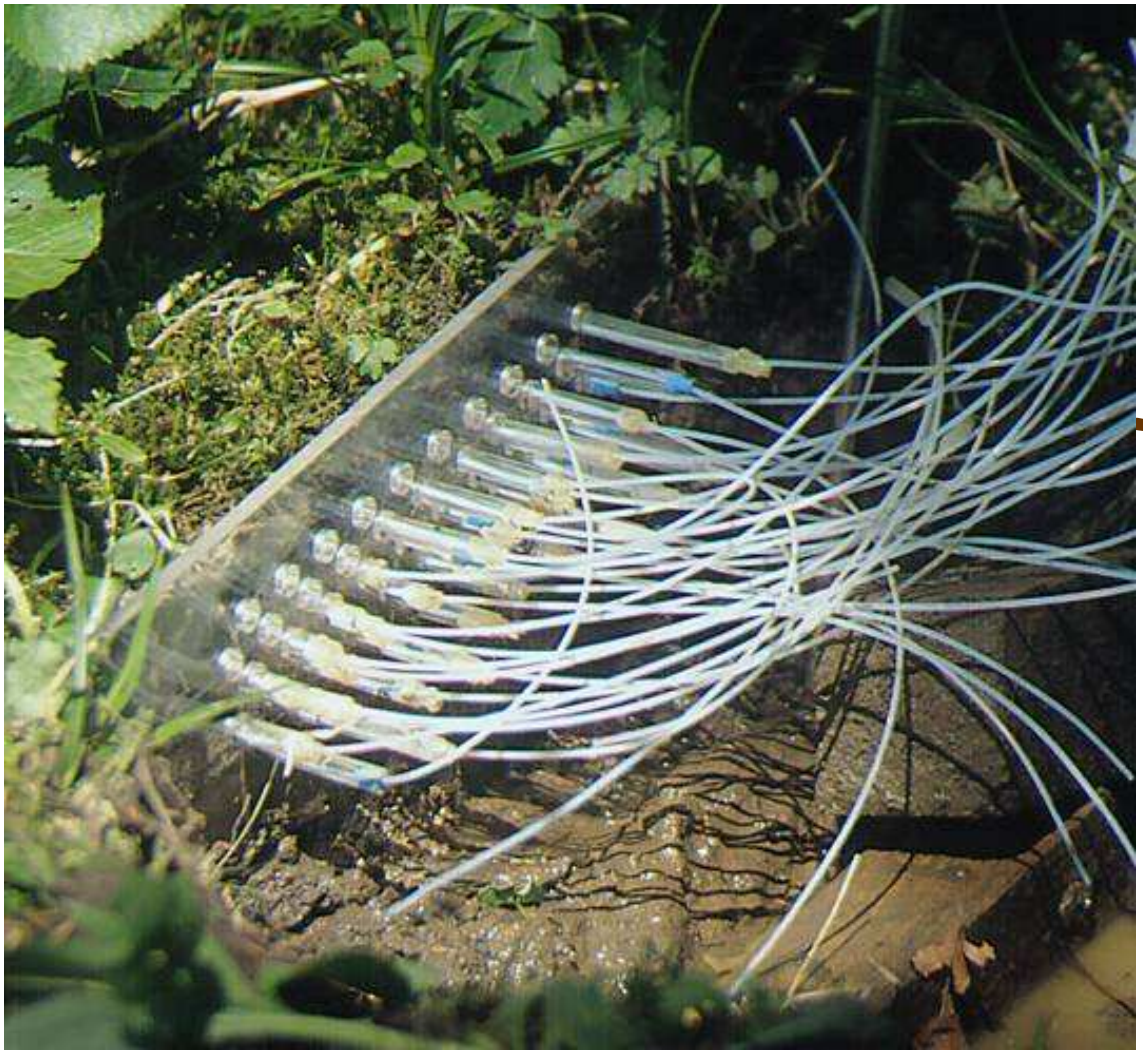

X?
Hagedorn *et al.* 2001
Water Air Soil Pollut.

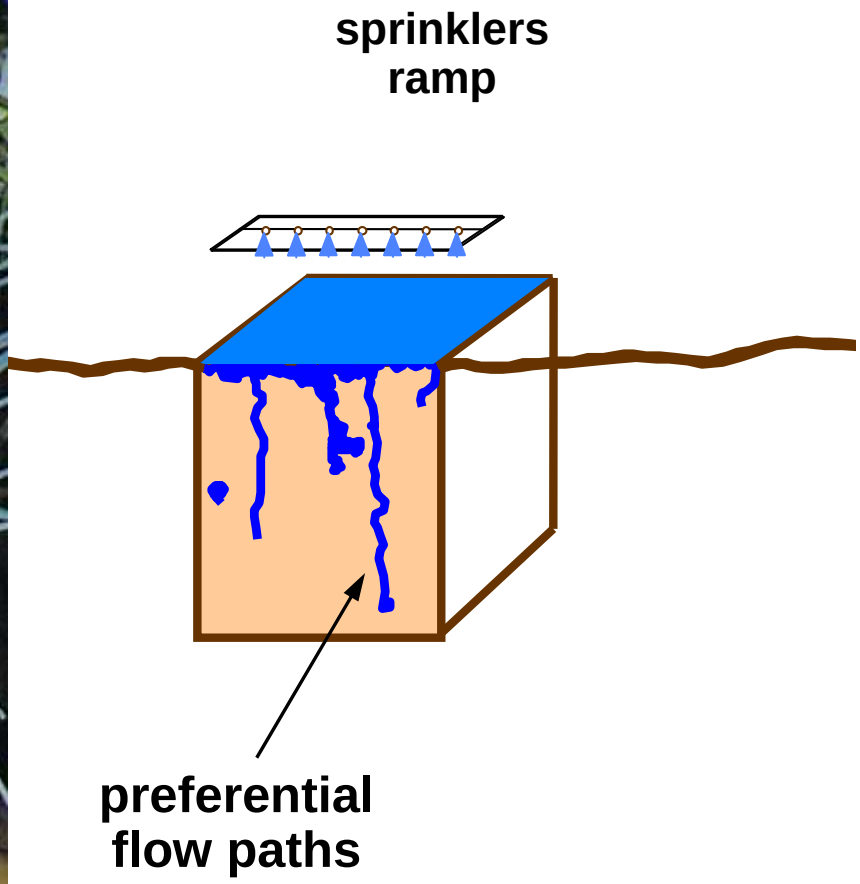
Nitrate leaching: first rain event after ^{15}N-labelling



Providoli *et al. 2005,* Biogeochemistry

Micro suction cups

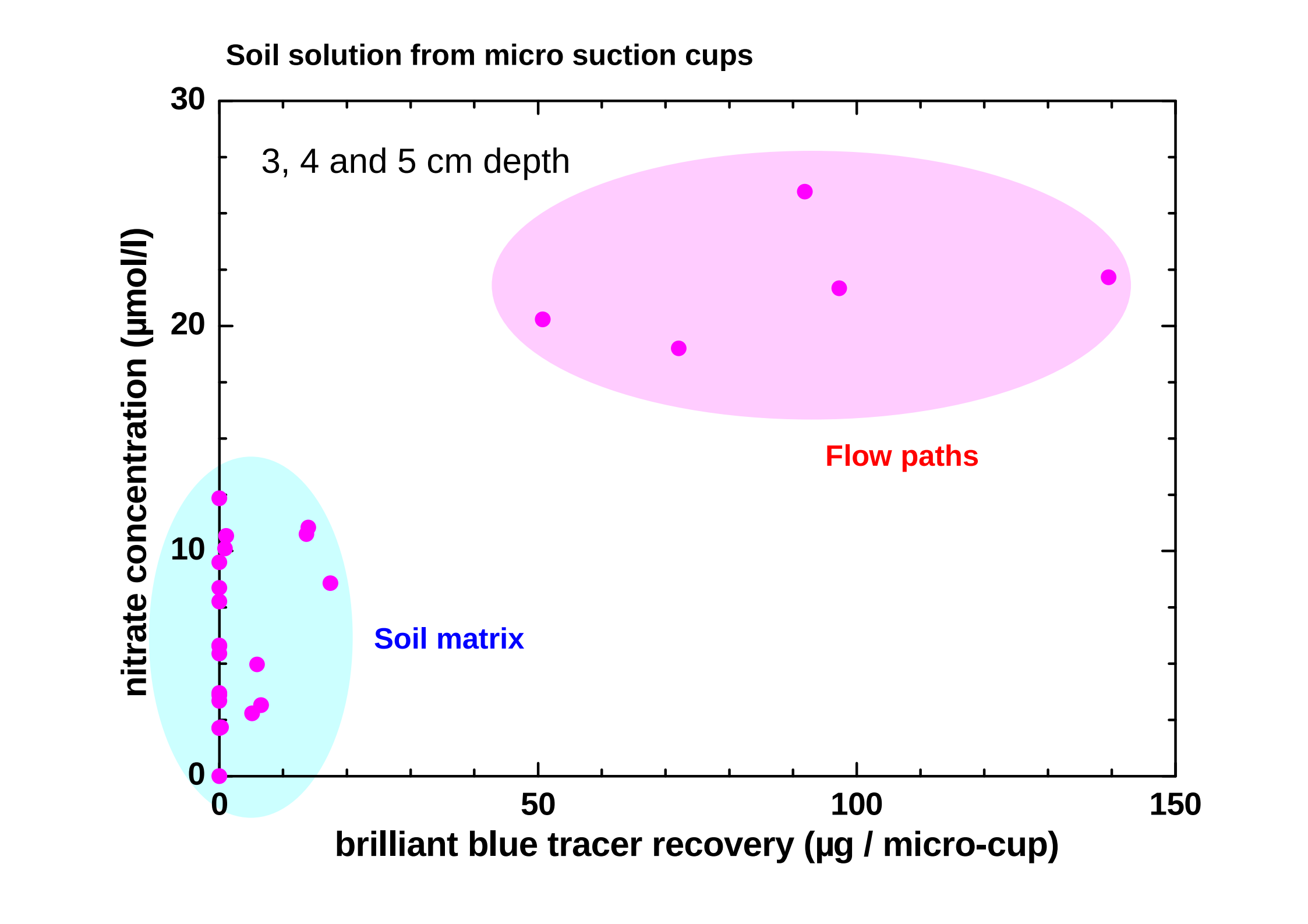




50 micro-cups

analysis: capillary electrophoresis

Hagedorn *et al.* 1999
Soil Sci. Soc. Am. J.

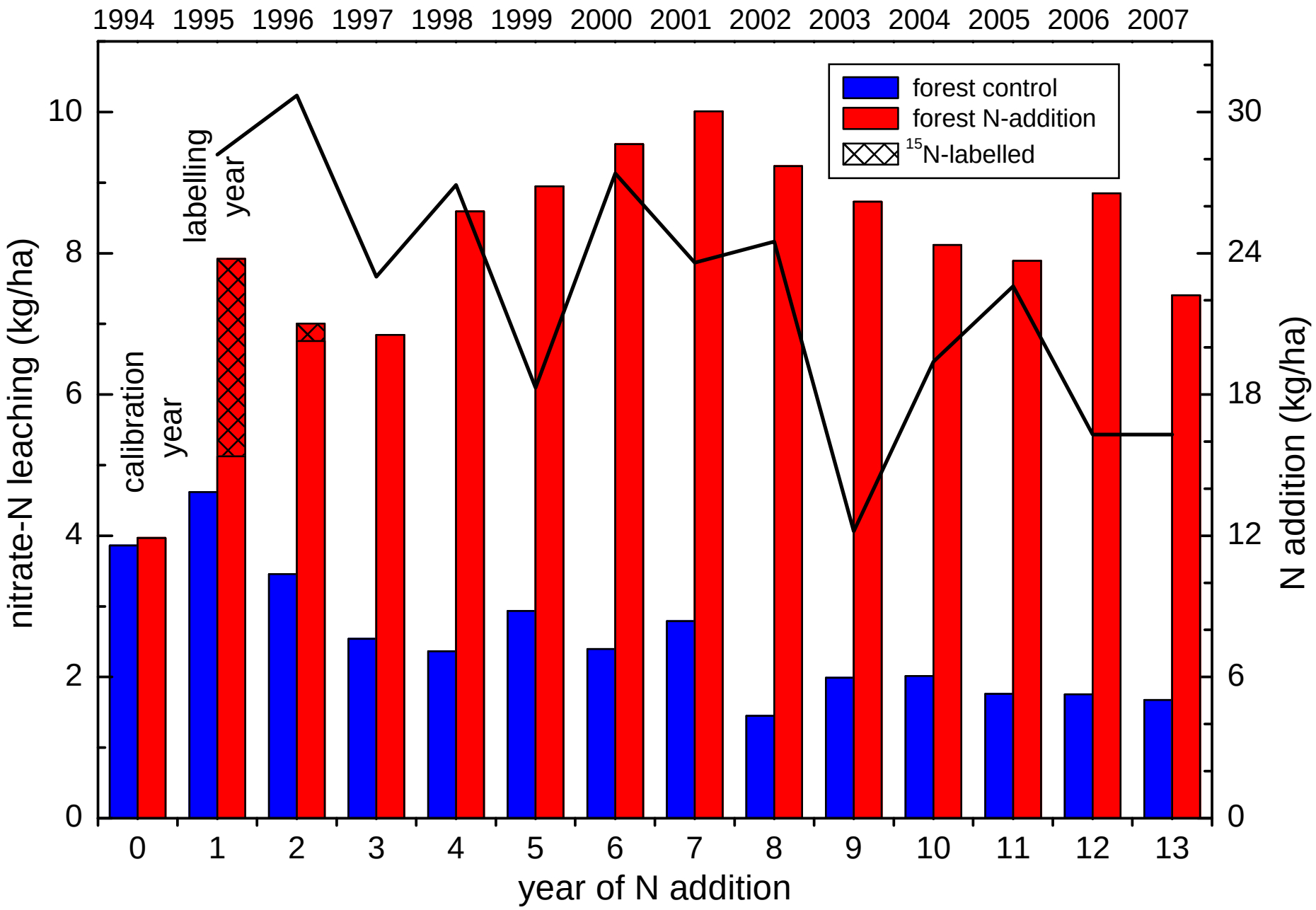

Soil solution from micro suction cups
3, 4 and 5 cm depth
Flow paths
Soil matrix
nitrate concentration (µmol/l)
brilliant blue tracer recovery (µg / micro-cup)
0
10
20
30
0
50
100
150

Short-term effects

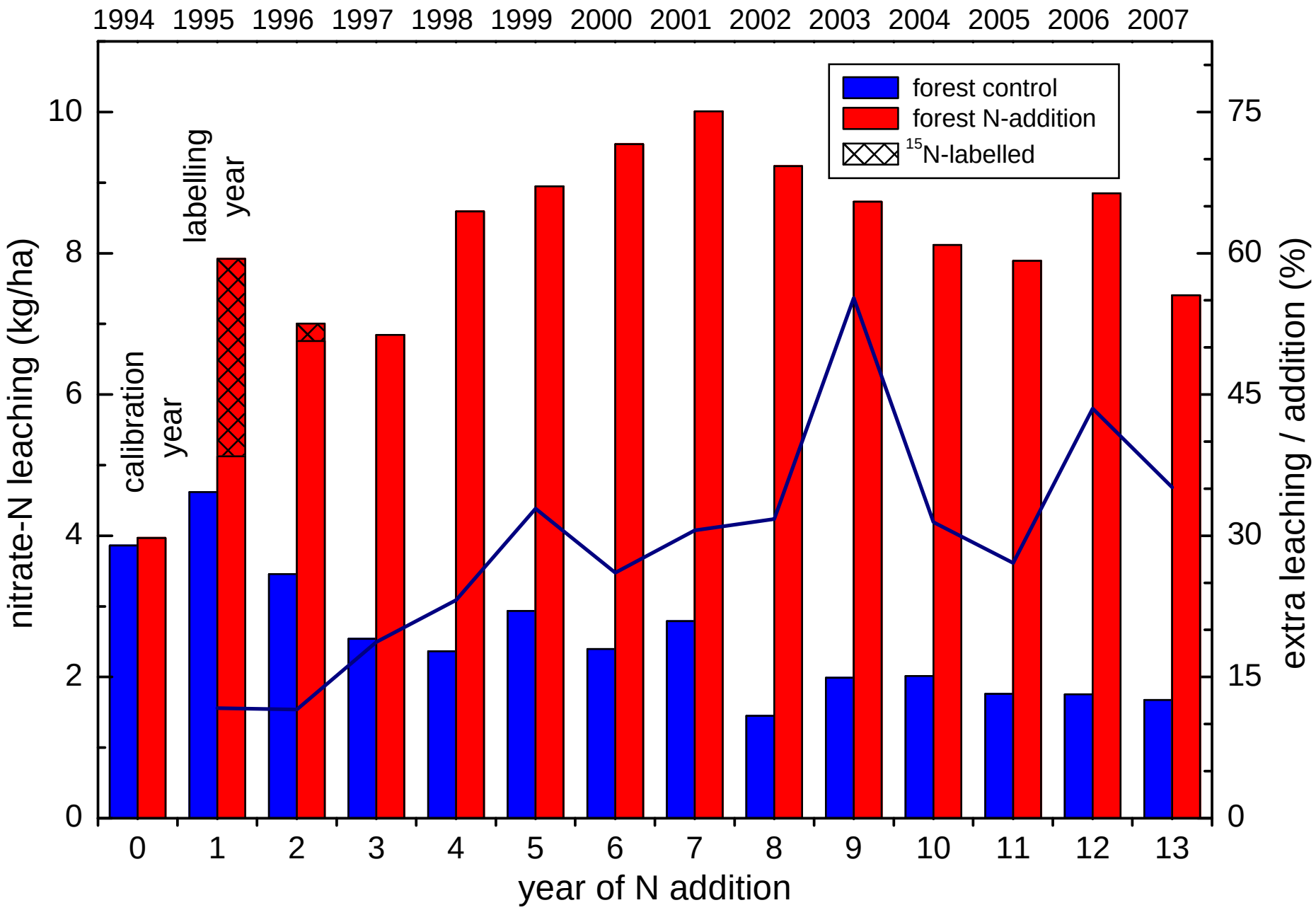
- preferential flow $\Rightarrow$ fast NO_3^- leaching
- short term NO_3^- storage / flushing
- preferential N transformations along flow paths

- complex, very dynamic system

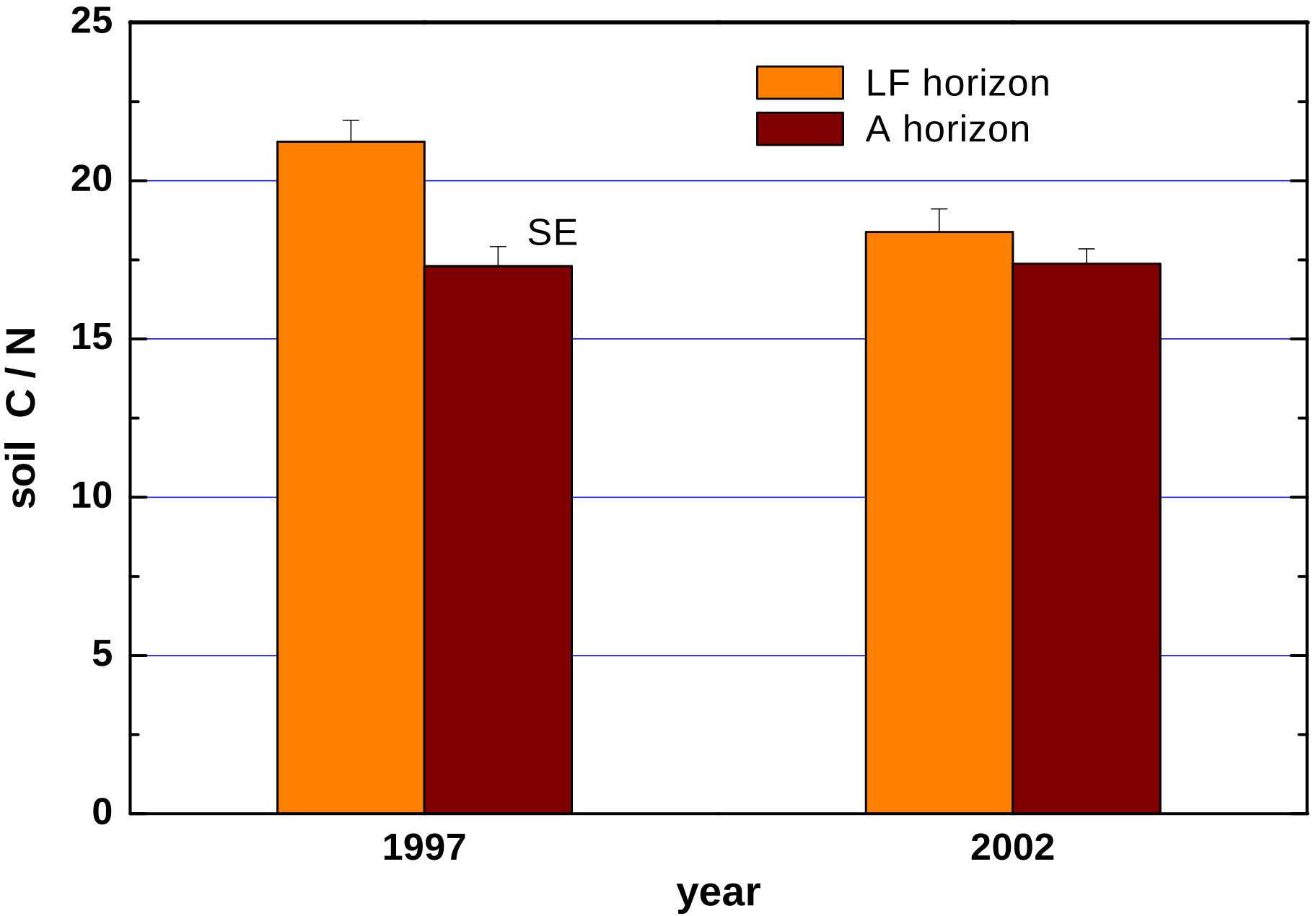
Nitrate leaching: long-term effects



Nitrate leaching: long-term effects

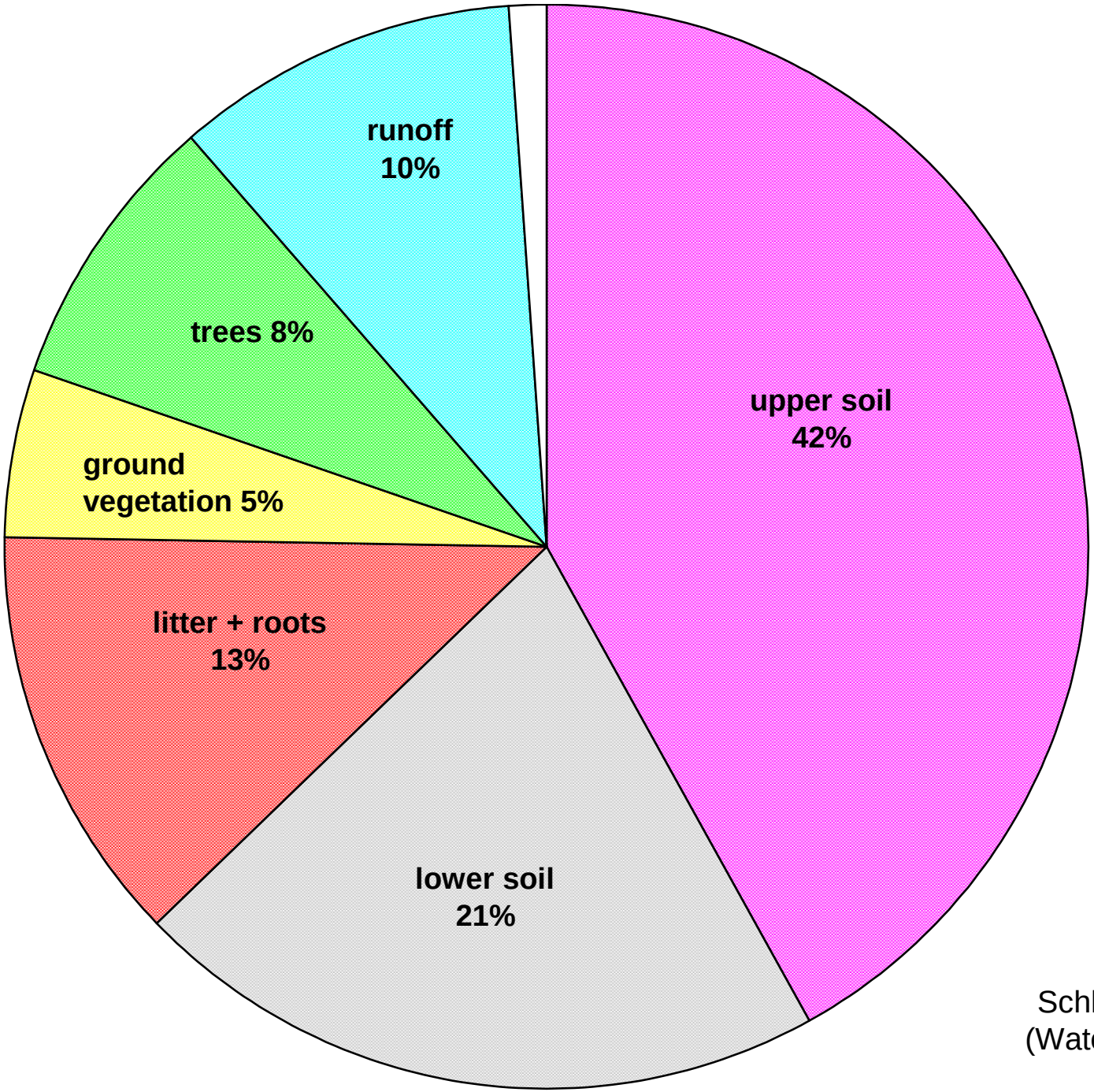


N addition: accumulation in the soil



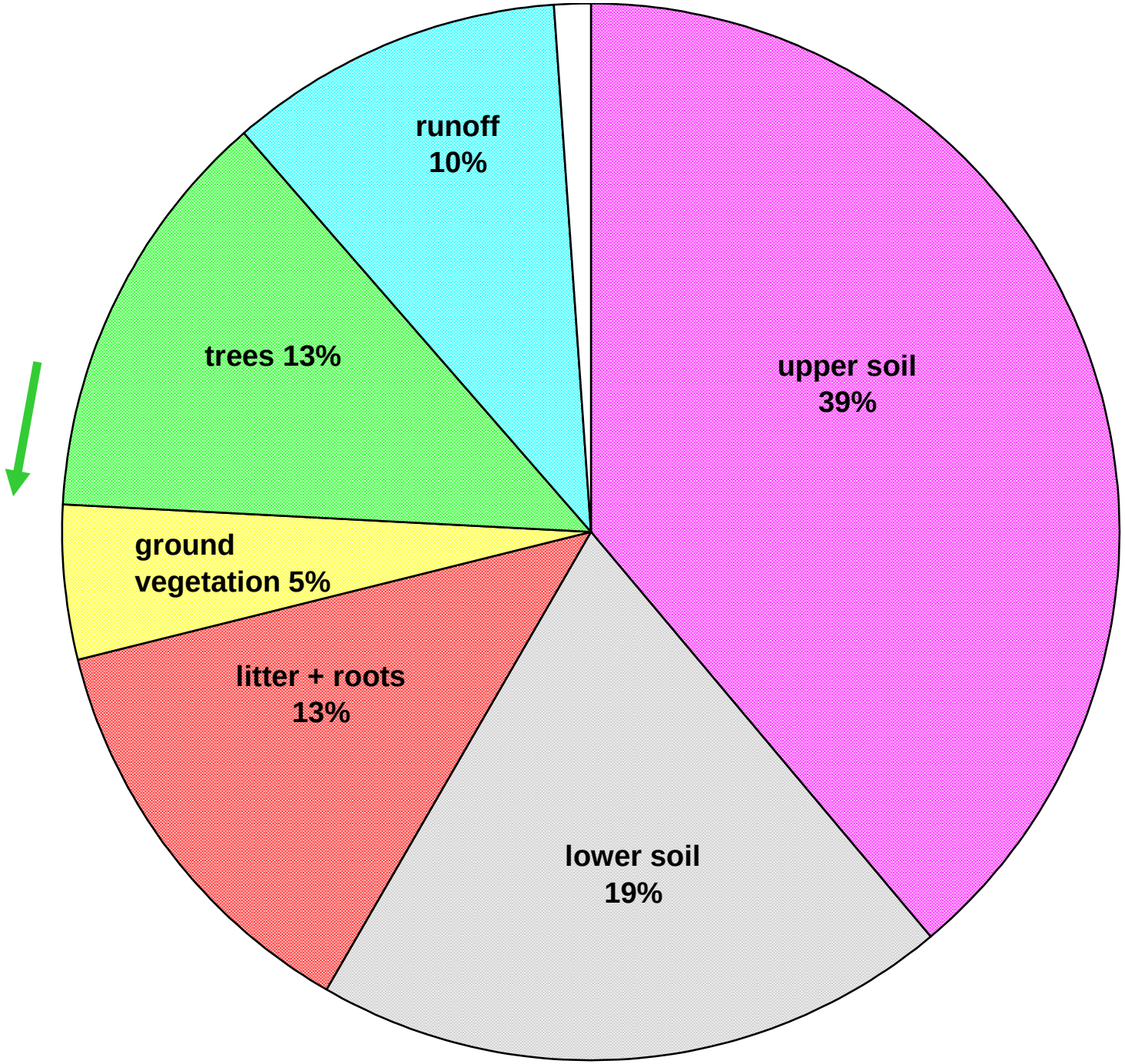
Schleppi *et al.* 2004 Water Air Soil Pollut. Focus

Partitioning of ^{15}N after 1 year

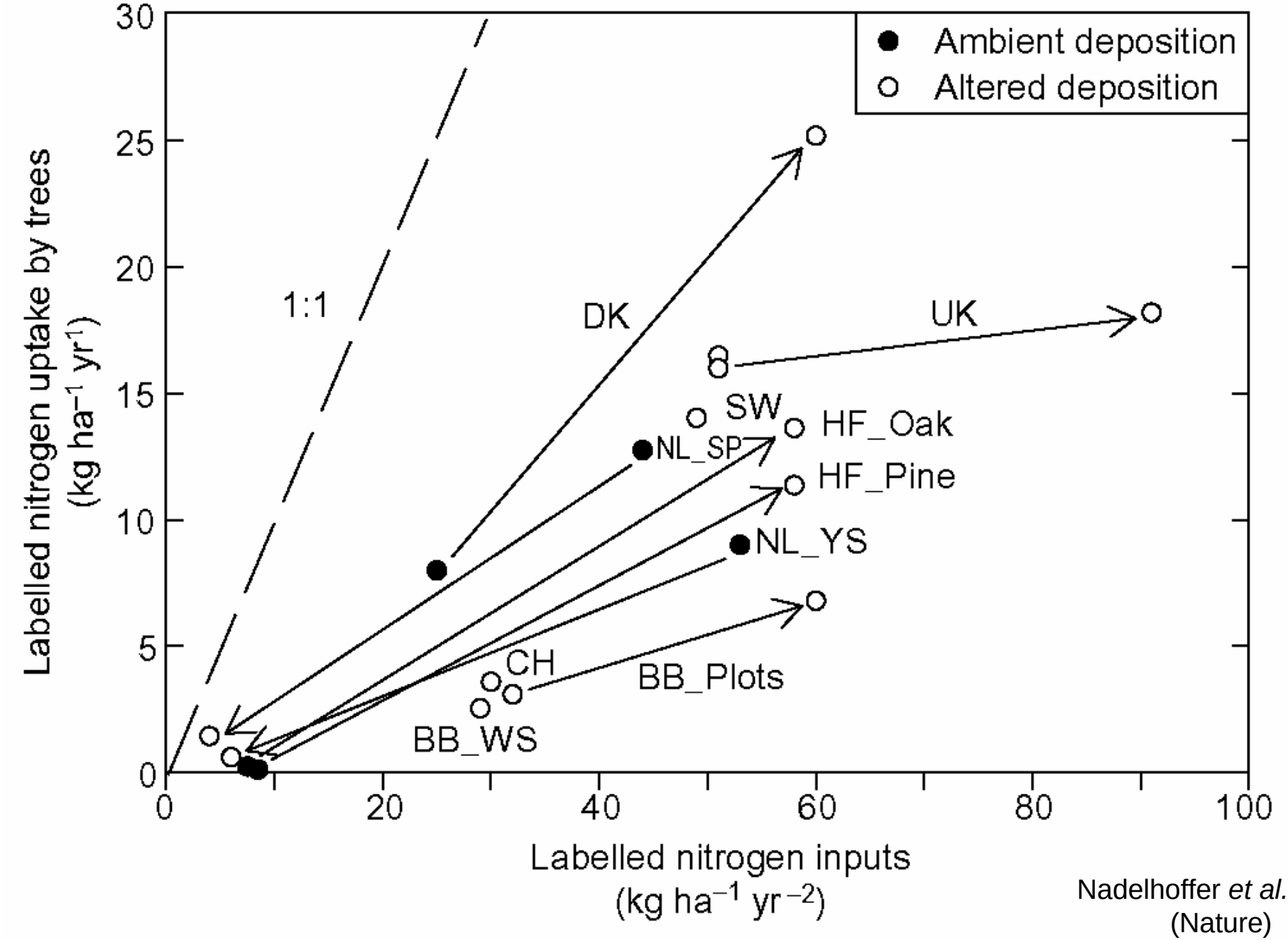


Schleppi *et al.*, 1999
(Water Air Soil Pollut.)

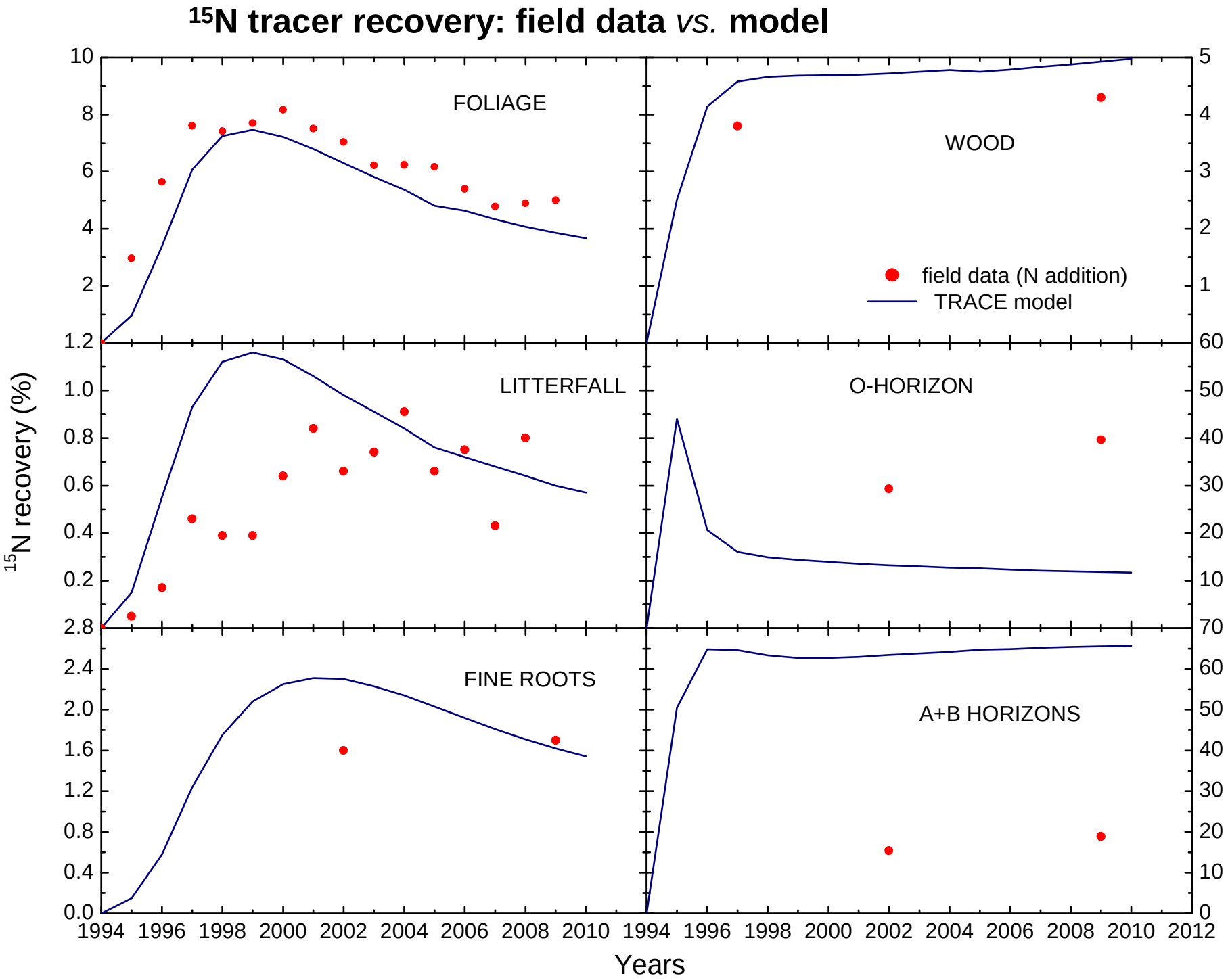
Partitioning of ^{15}N after 7 years

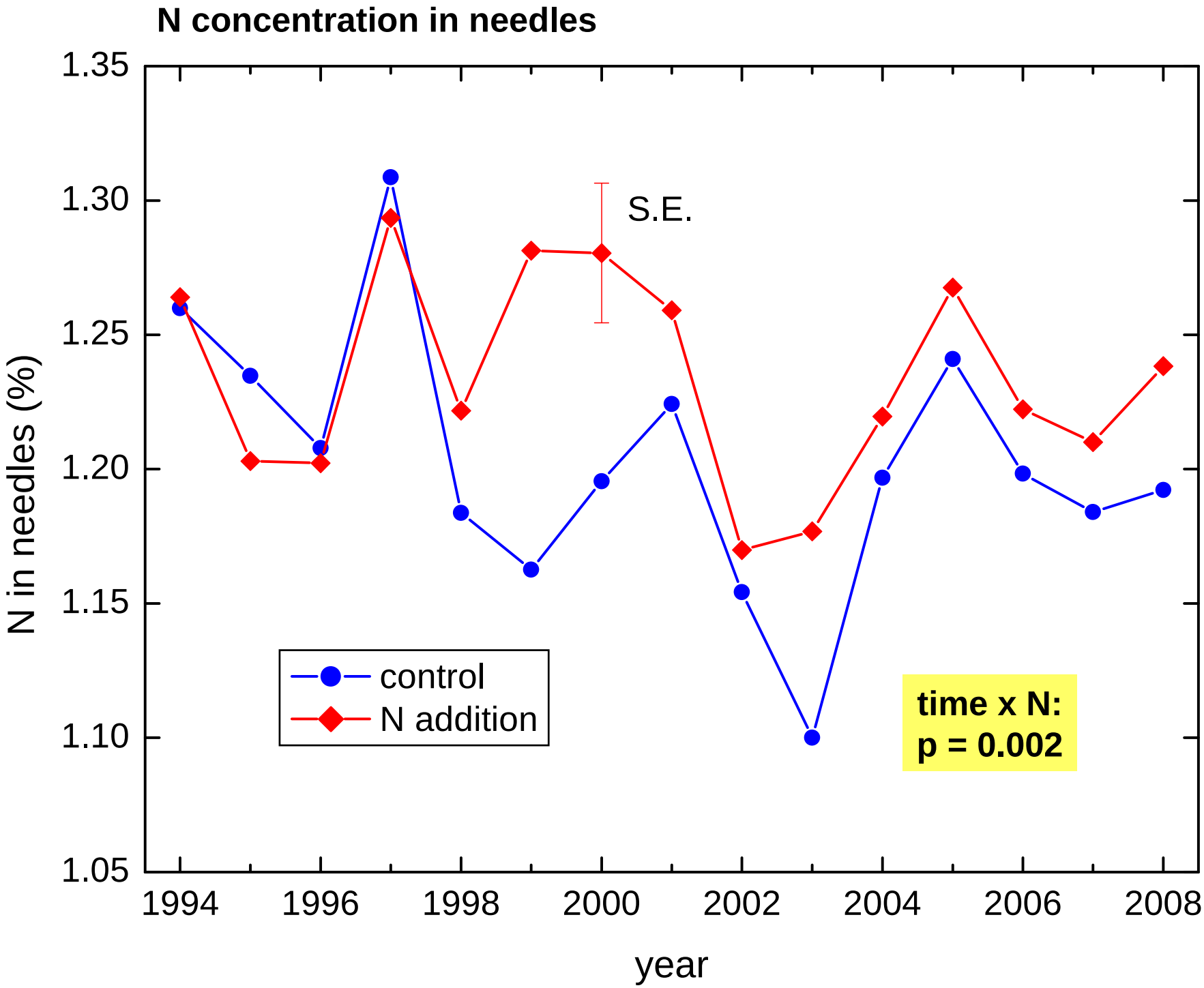


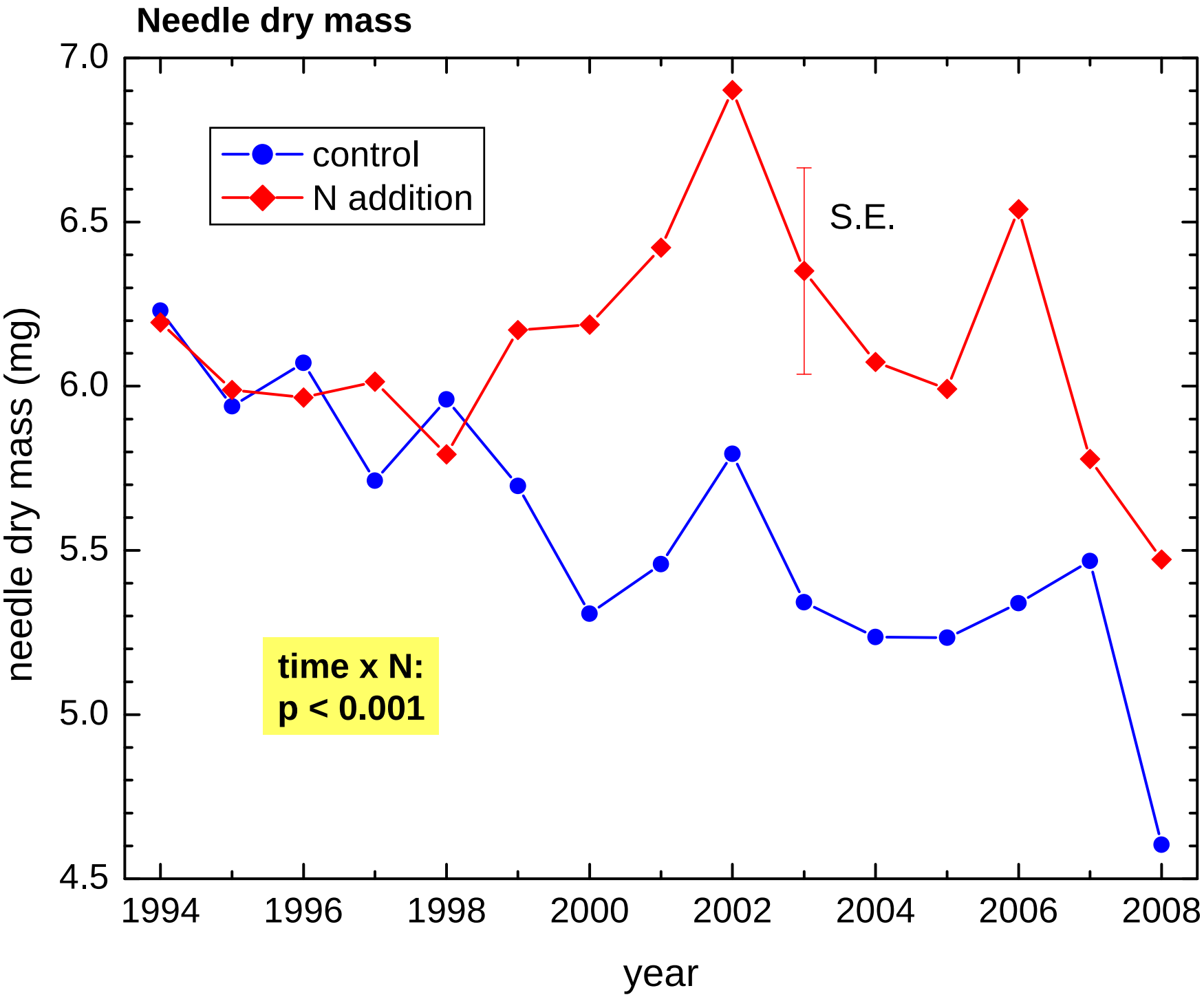
Tree uptake of ^{15}N

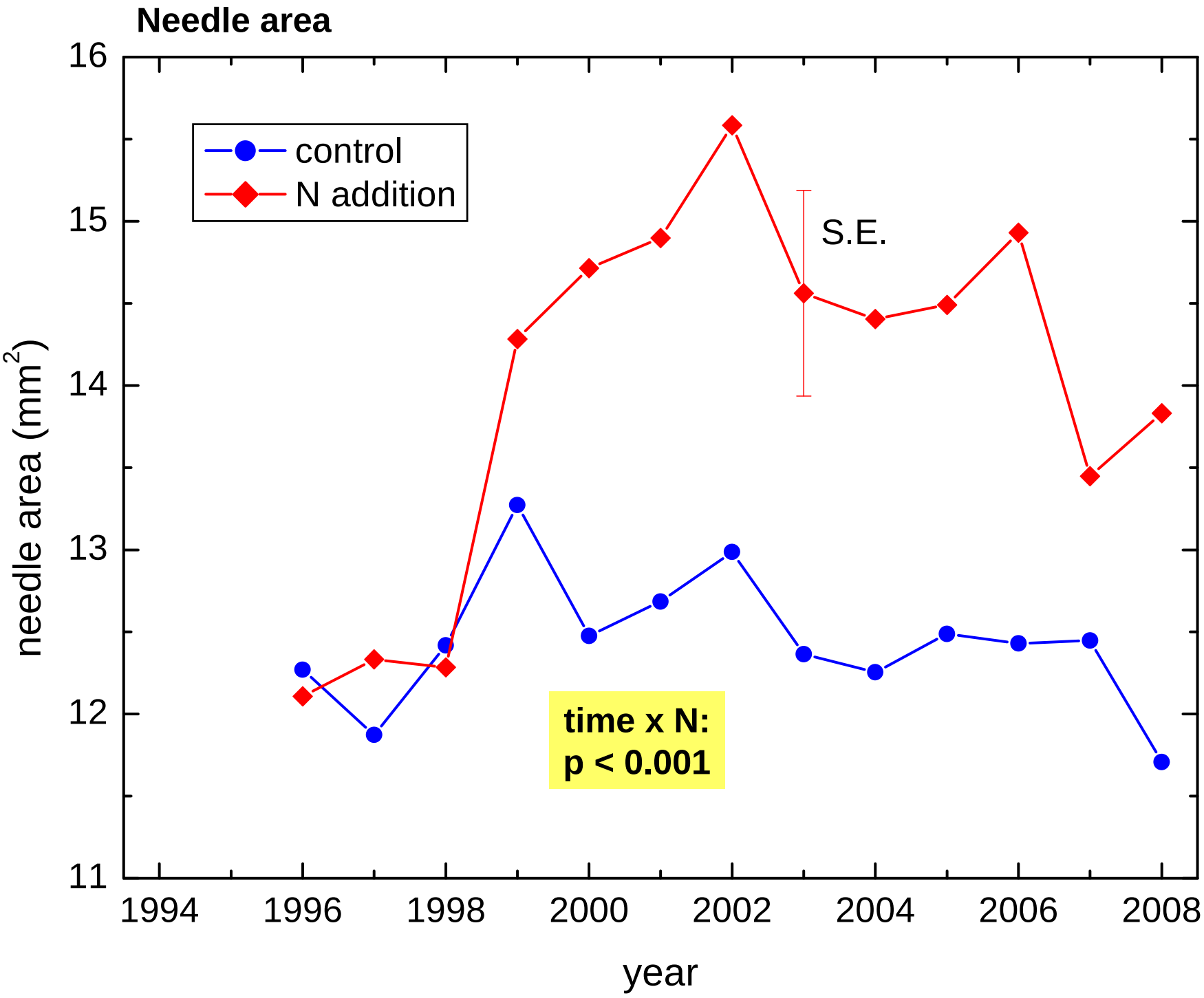


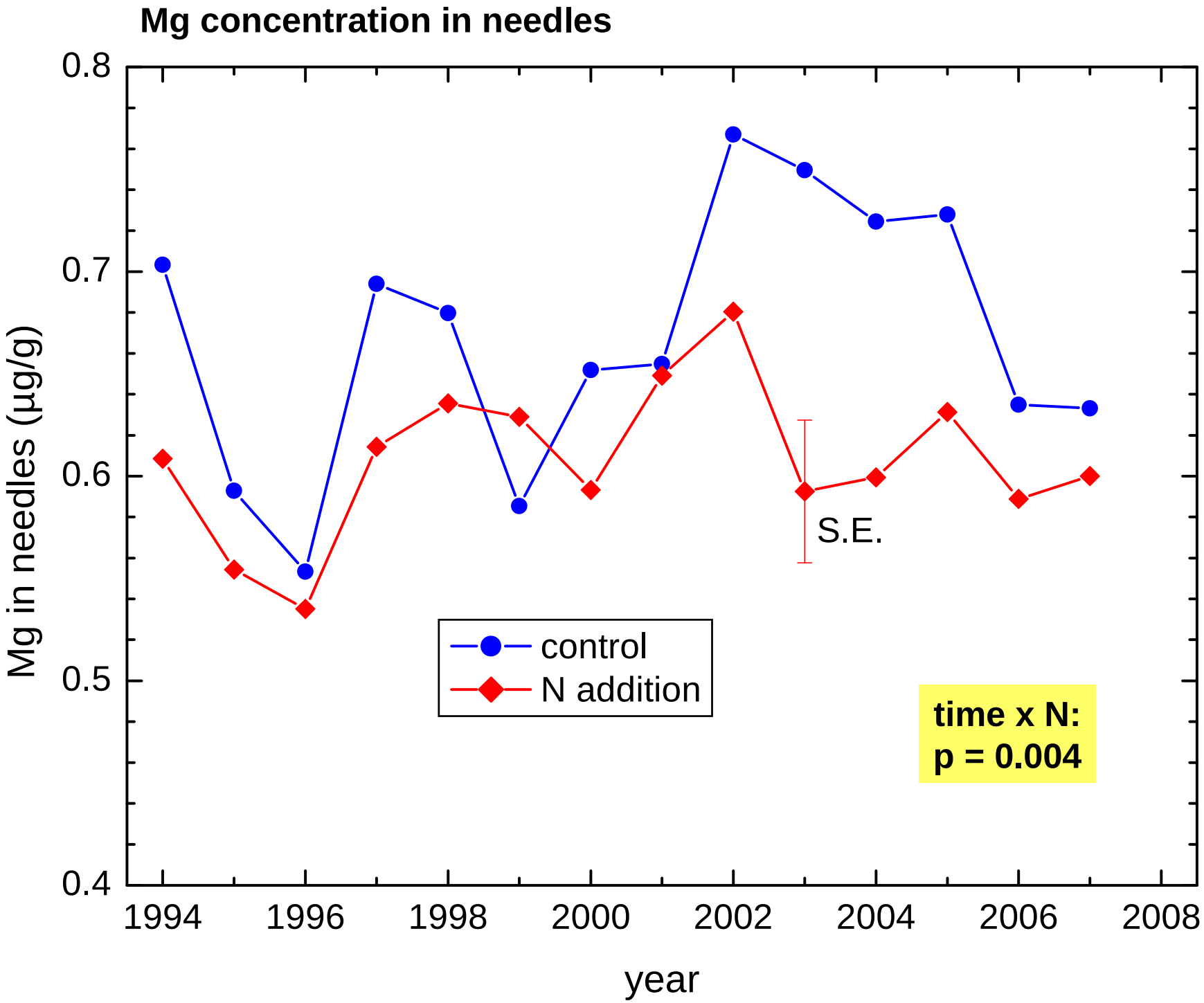
Nadelhoffer *et al.*, 1999 (Nature)

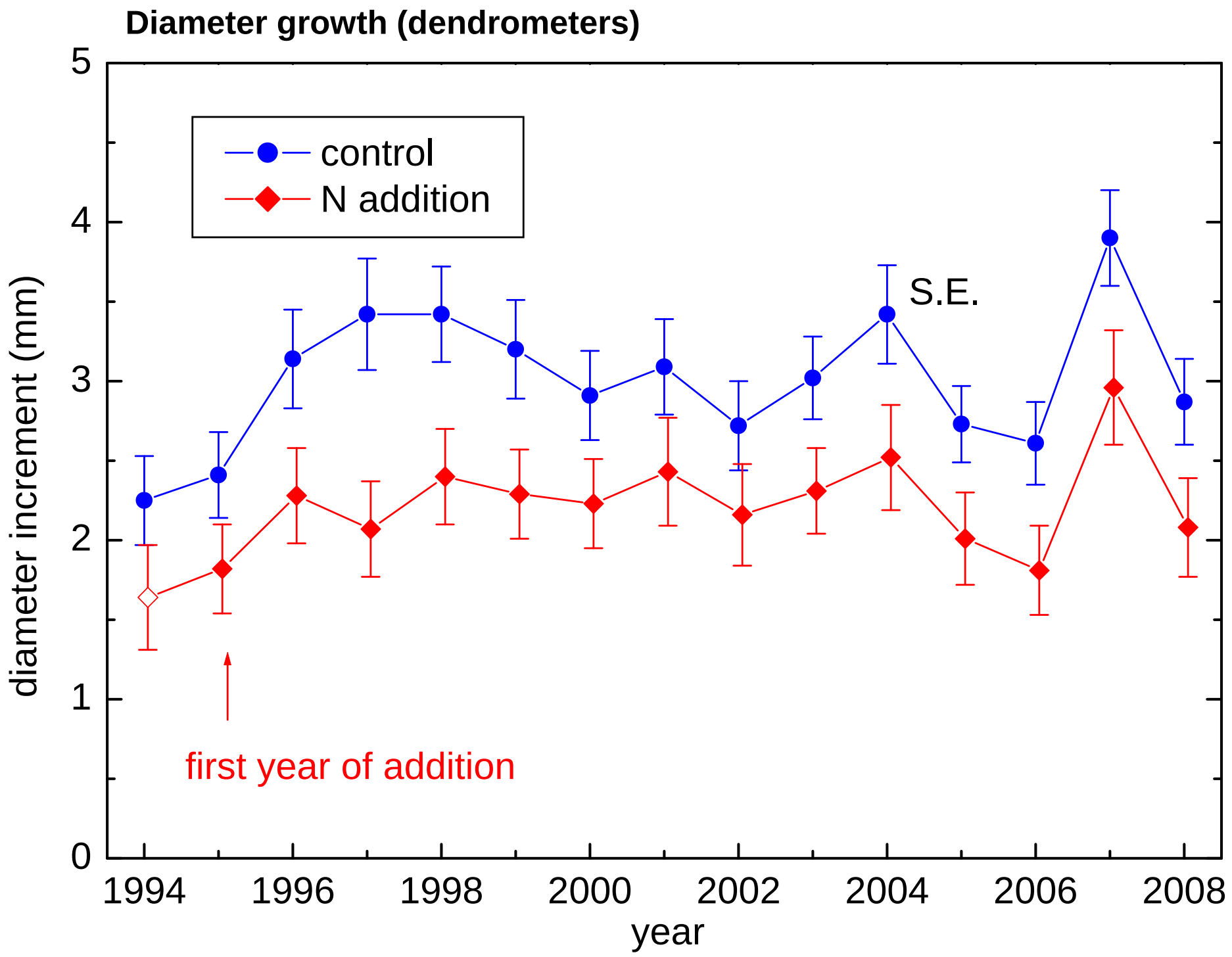

15N tracer recovery: field data vs. model
FOLIAGE
WOOD
LITTERFALL
O-HORIZON
FINE ROOTS
A+B HORIZONS
field data (N addition)
TRACE model
15N recovery (%)
Years

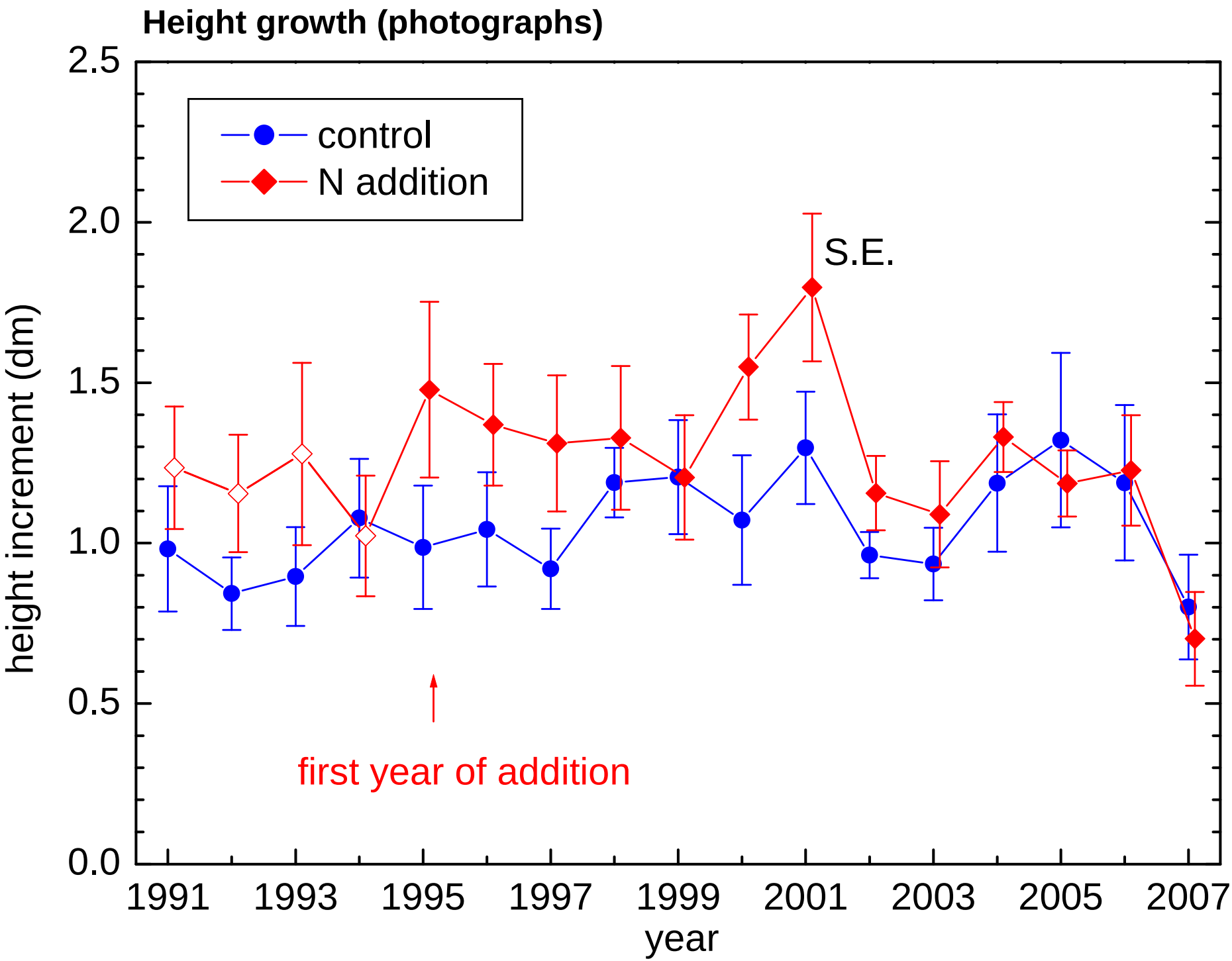

N concentration in needles
1.35
1.30
1.25
1.20
1.15
1.10
1.05
N in needles (%)
S.E.
control
N addition
time x N:
p = 0.002
1994
1996
1998
2000
2002
2004
2006
2008
year

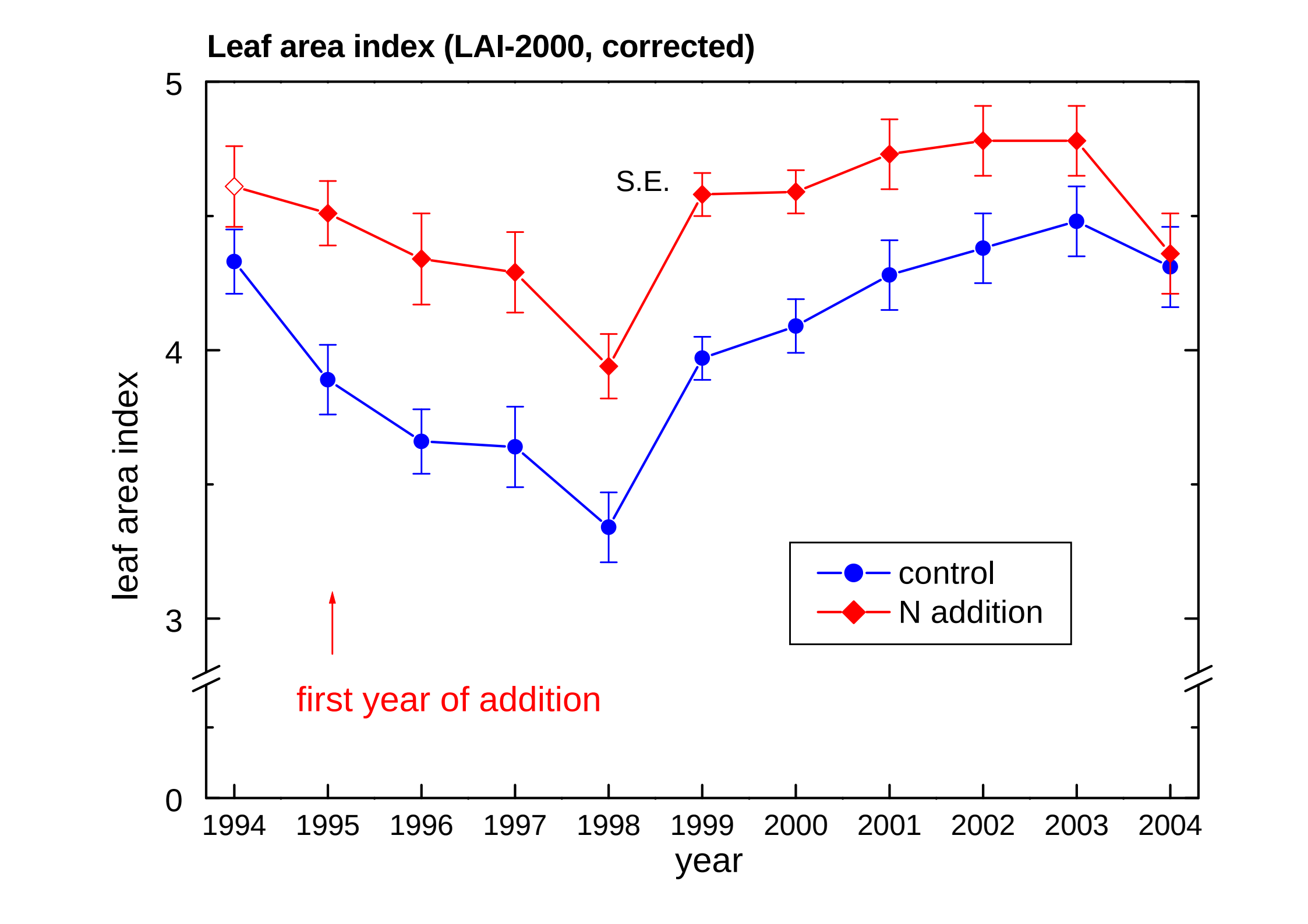

Needle dry mass
7.0
6.5
6.0
5.5
5.0
4.5
needle dry mass (mg)
1994
1996
1998
2000
2002
2004
2006
2008
year
control
N addition
S.E.
time x N:
p < 0.001


Needle area
16
15
14
13
12
11
1994
1996
1998
2000
2002
2004
2006
2008
year
needle area (mm2)
control
N addition
S.E.
time x N:
p < 0.001


Mg concentration in needles
0.8
0.7
0.6
0.5
0.4
Mg in needles (µg/g)
1994
1996
1998
2000
2002
2004
2006
2008
year
S.E.
control
N addition
time x N:
p = 0.004


Diameter growth (dendrometers)
control
N addition
S.E.
first year of addition
diameter increment (mm)
year
0
1
2
3
4
5
1994
1996
1998
2000
2002
2004
2006
2008


Height growth (photographs)
control
N addition
S.E.
first year of addition
height increment (dm)
year
0.0
0.5
1.0
1.5
2.0
2.5
1991
1993
1995
1997
1999
2001
2003
2005
2007


Leaf area index (LAI-2000, corrected)
leaf area index
5
4
3
0
S.E.
control
N addition
first year of addition
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
year

Long-term effects

- progressive N saturation
- effect cascade air / soil + water / plants
- effects on vegetation: very slow (except mosses)
- decreased retention as effect of C/N ↘
- N deposition cannot account for much C sequestration

Ongoing project: tree girdling...

... and felling: effects on nitrate leaching and on greehouse gases


Hofstetten
C
N

Hofstetten

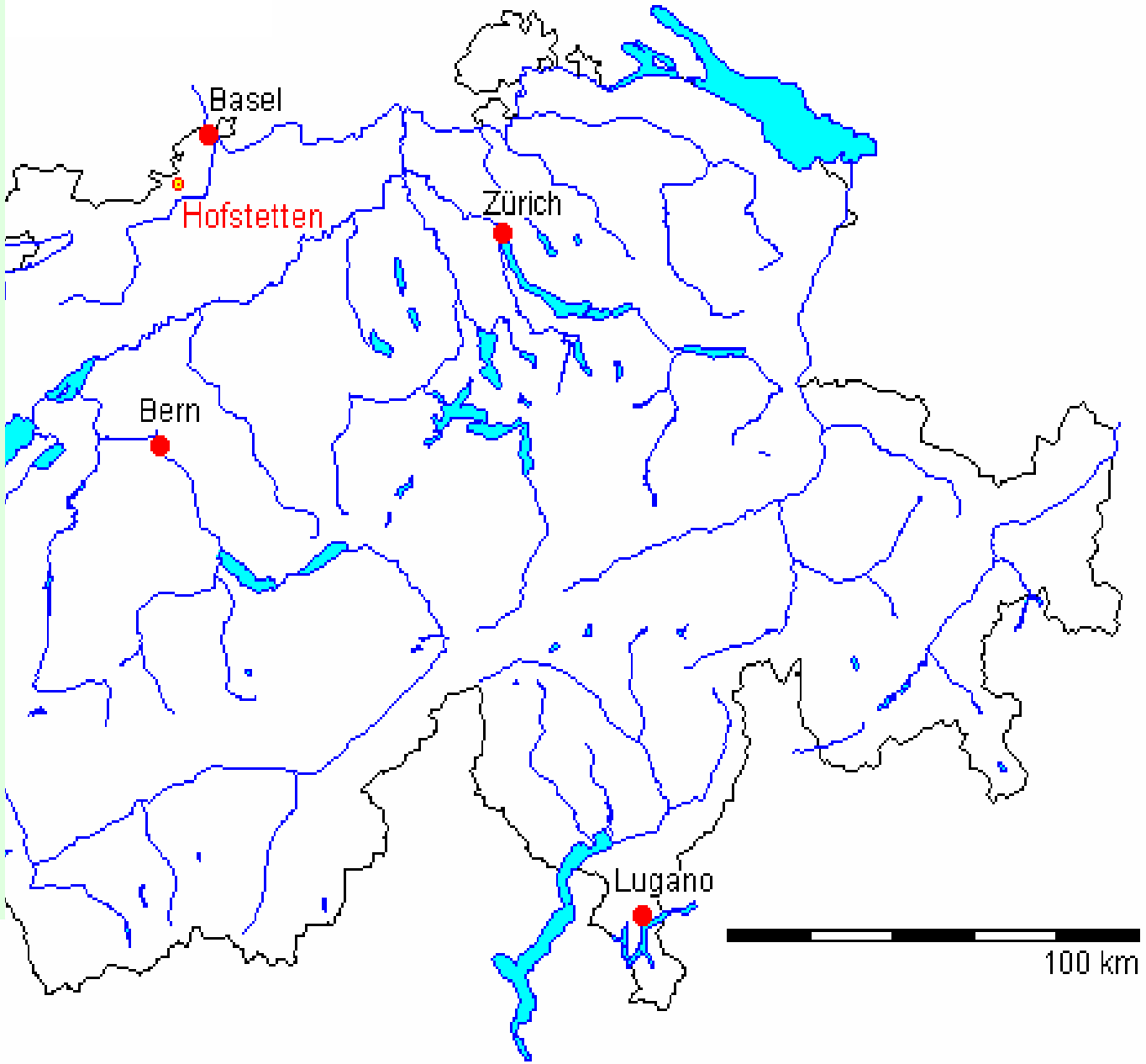
Altitude:
540 m

Geology:
Jura limestone

Vegetation:
mixed forest, 80-120 year old

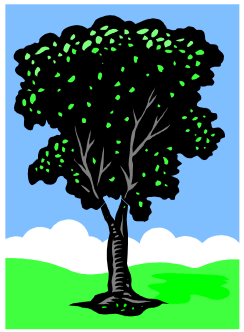
Precipitation:
1000 mm/a

Bulk N deposition:
≅ 20 kg/ha/a



Hypotheses

+ CO_2



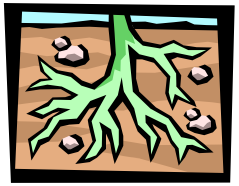
- photosynthesis ↑
- growth ↑

•down-regulation

•C/N ratio ↑

- litterfall ↑
- C/N ratio ↑
- N demand for decomposition ↑

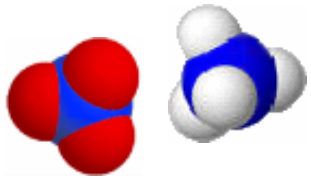
- C root exudation ↑
- N demand for microbial activity ↑



•N uptake ↓

•N availability ↑

N availability ↓ (NO_3^-, NH_4^+)

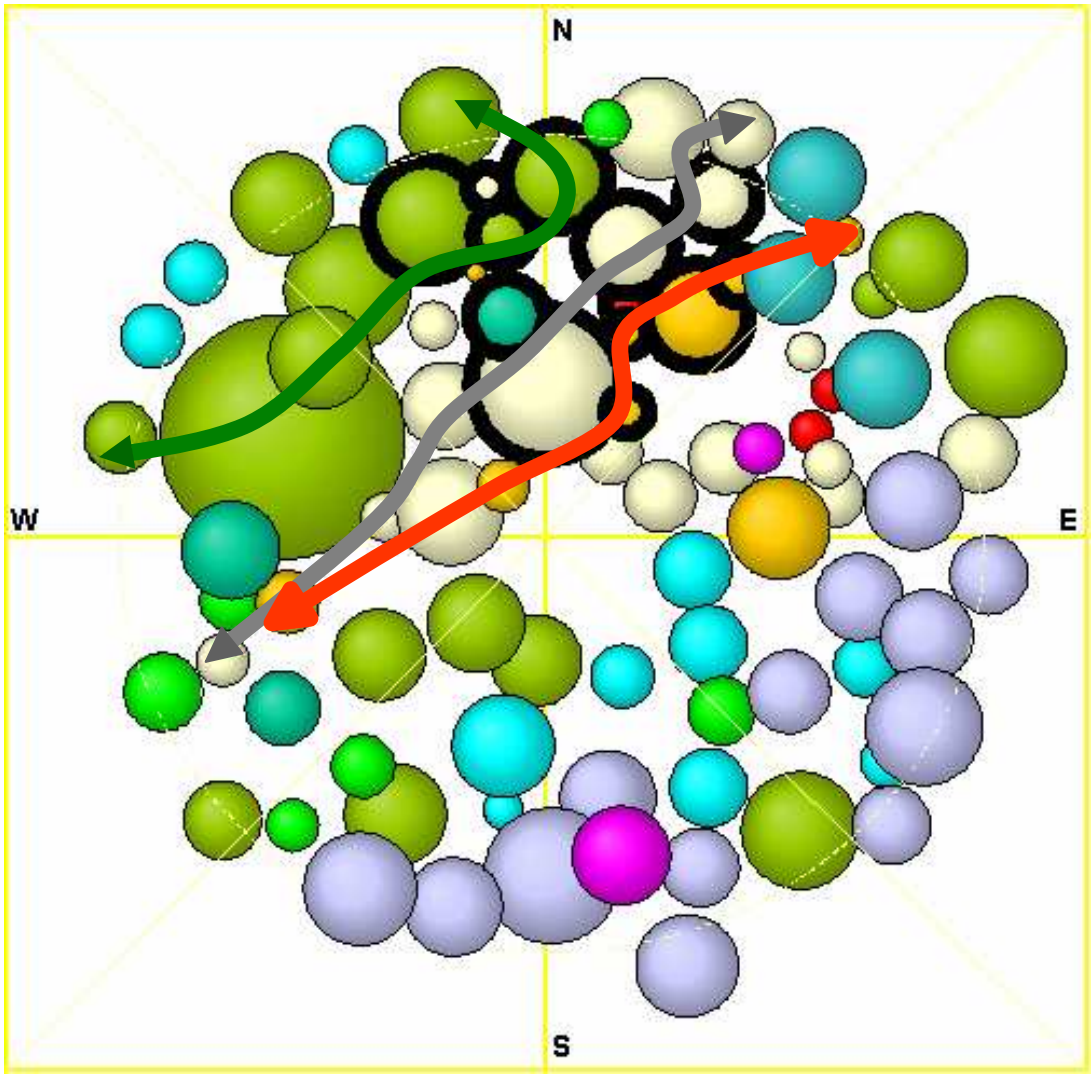


Transects for soil solution sampling

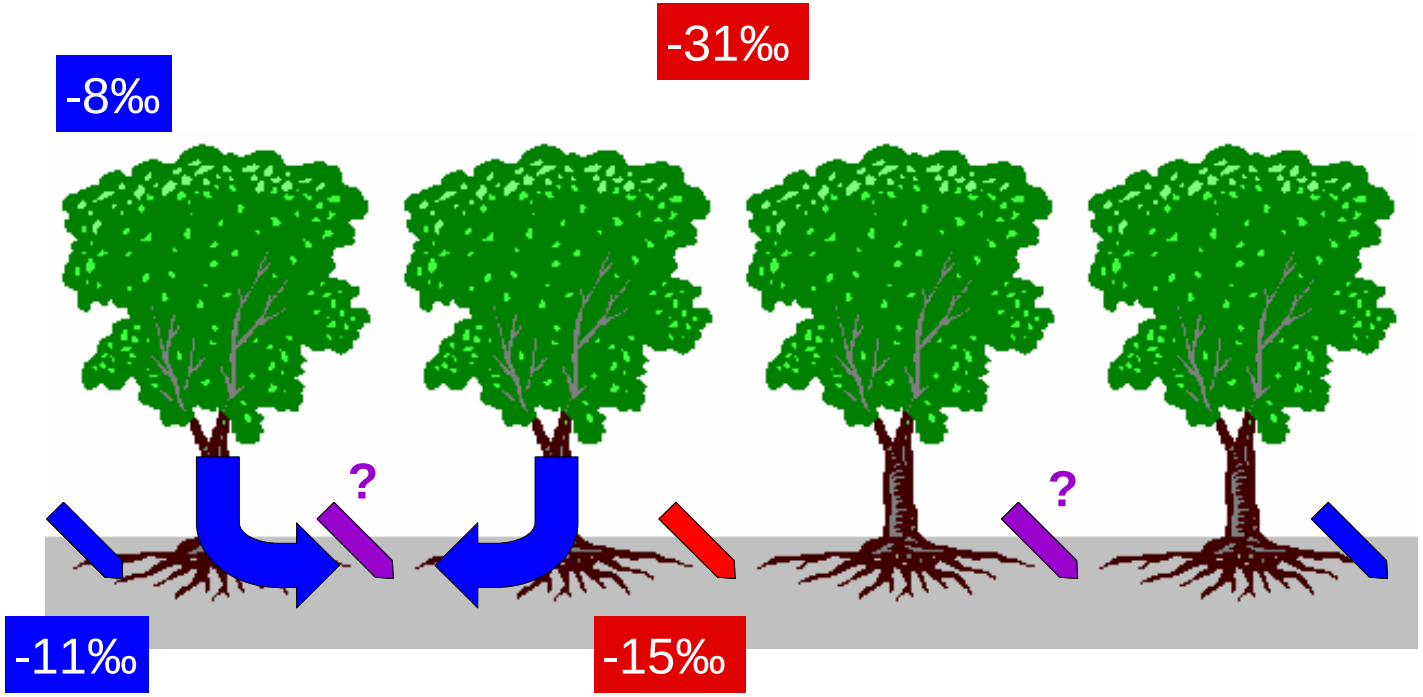
(suction cups and resin bags)

Trees

- 360 µl/l CO_2
- 560 µl/l CO_2
- *Acer campestre*
- *Fagus sylvatica*
- *Quercus* sp.
- *Picea abies*
- *Pinus sylvestris*
- *Carpinus betulus*
- *Prunus avium*
- *Larix decidua*
- *Tilia platyphyllos*
- *Abies alba*

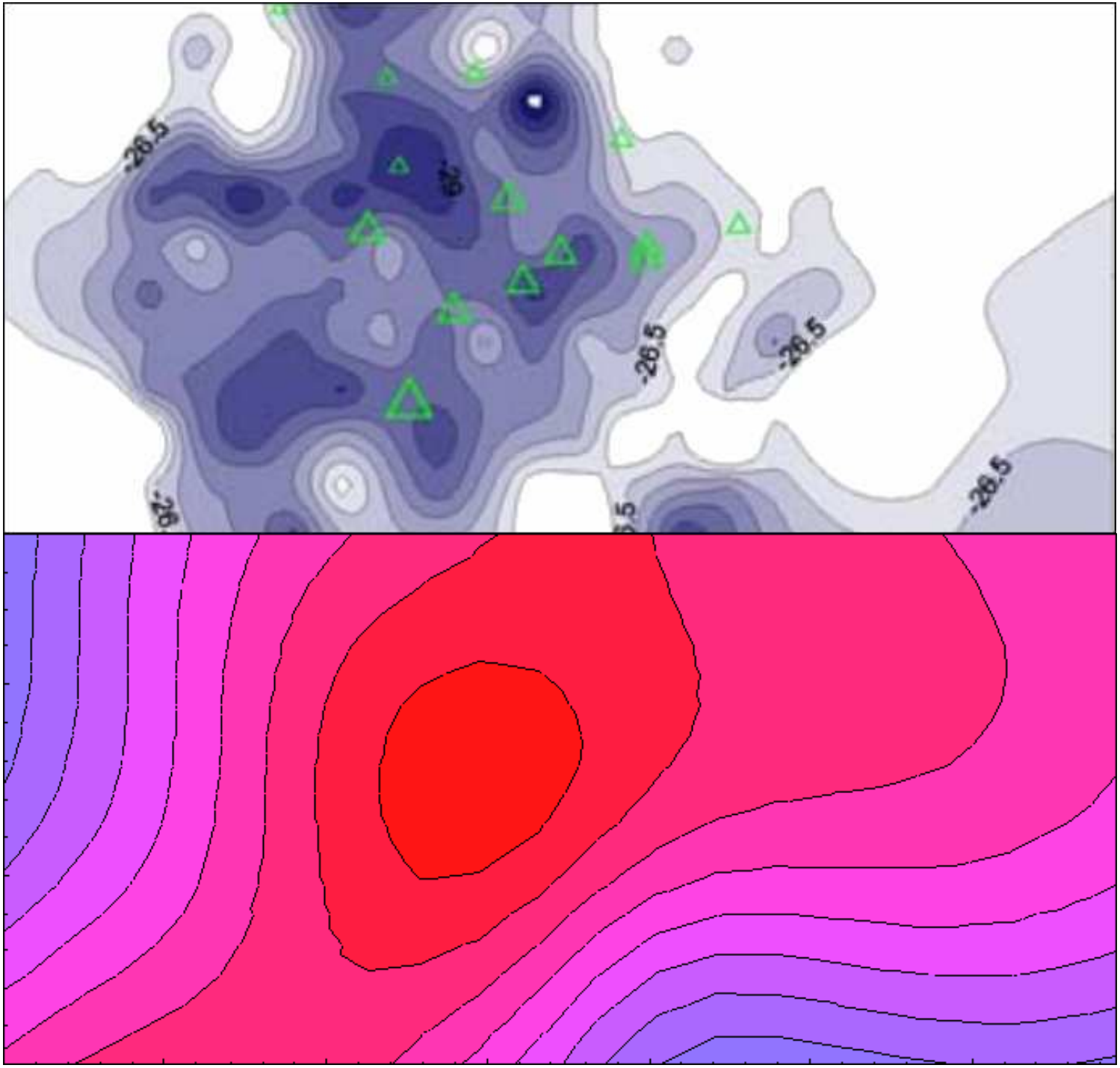


Statistical approach



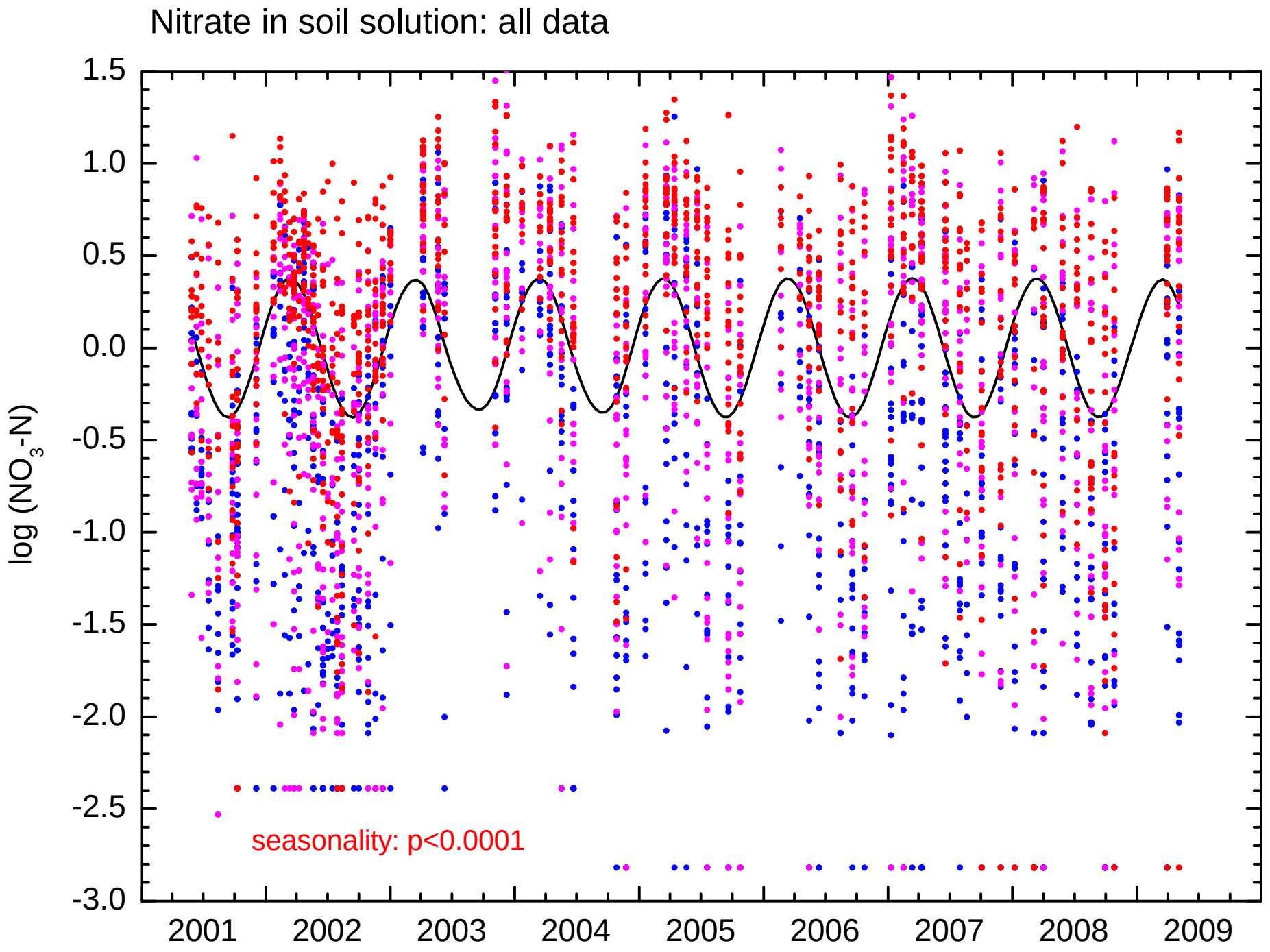
- Response variables: soil solution chemistry
- Experimental factor: CO_2 ambient *vs.* elevated
- Problem: unknown gradient along transect
- Indicator: $\delta^{13}C$ of inorganic C in soil solution
- Statistics: dose → response relationship
- Graphs: ambient *vs.* intermediate *vs.* elevated

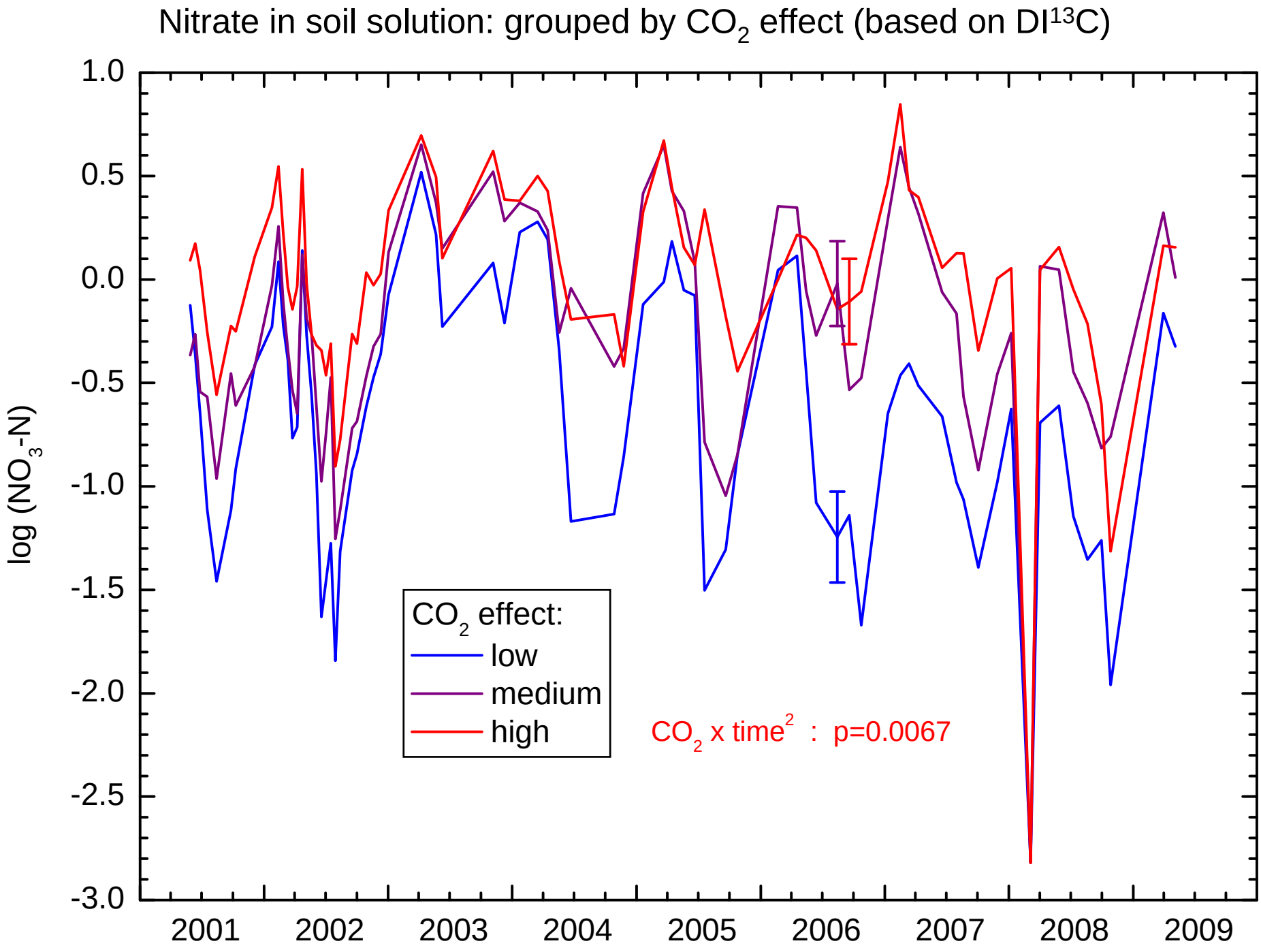
Relative CO_2 effect (based on ^{13}C)



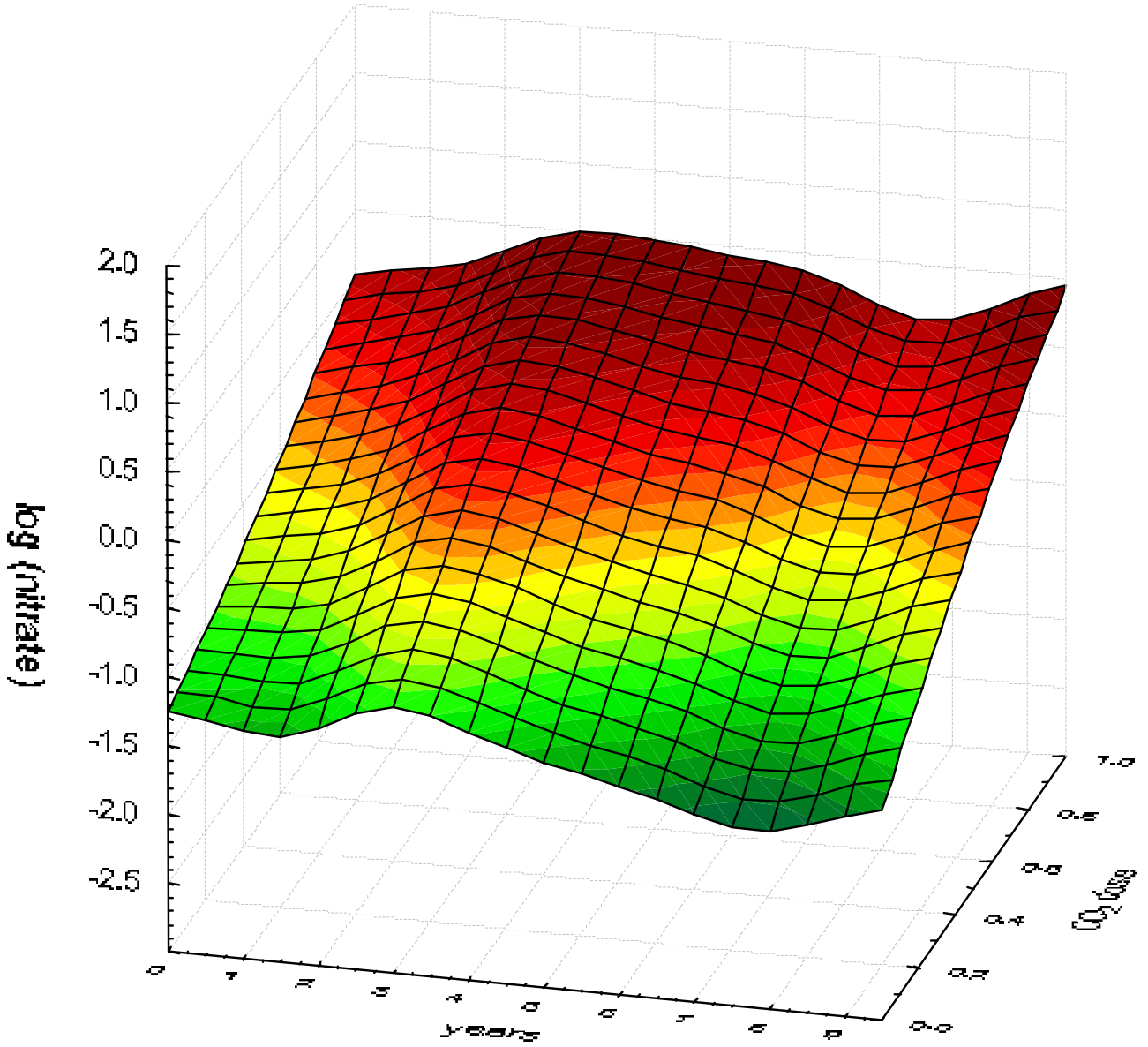
in soil CO_2
(Steinmann *et al.*, Oecologia, 2004)

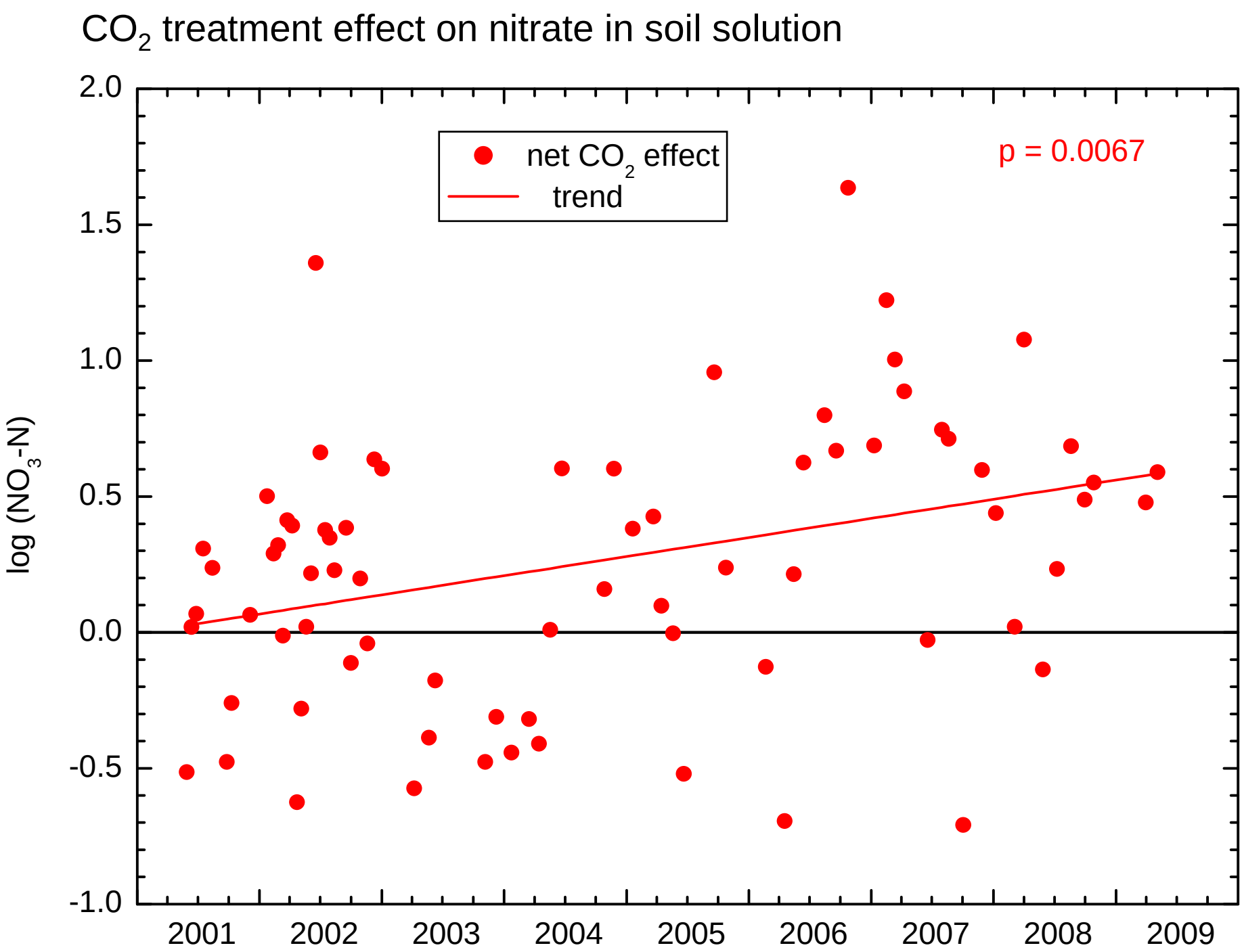
in soil DIC

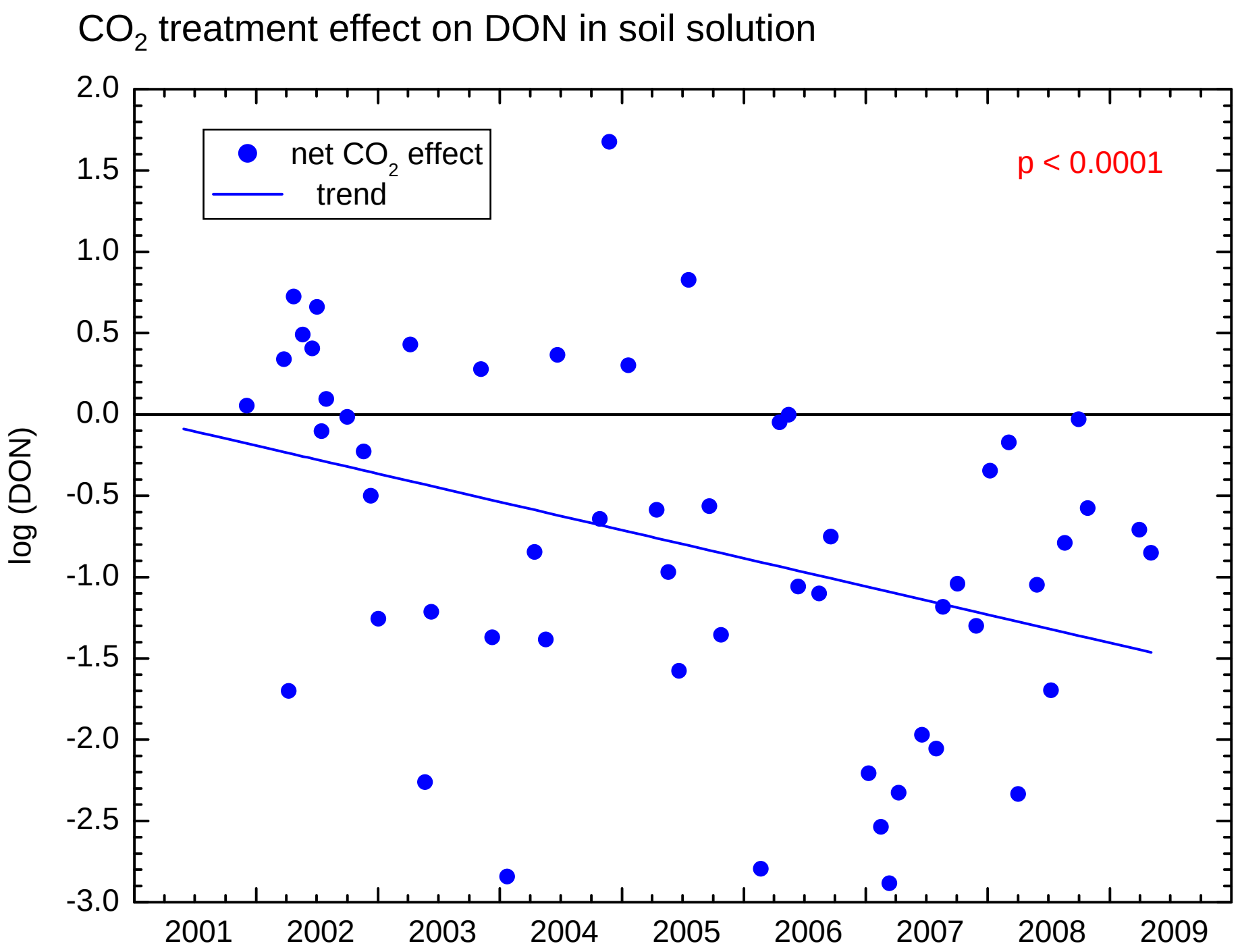

Nitrate in soil solution: all data
log (NO3-N)
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
2001
2002
2003
2004
2005
2006
2007
2008
2009
seasonality: p<0.0001


Nitrate in soil solution: grouped by CO2 effect (based on DI13C)
log (NO3-N)
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
2001
2002
2003
2004
2005
2006
2007
2008
2009
CO2 effect:
low
medium
high
CO2 x time2 : p=0.0067

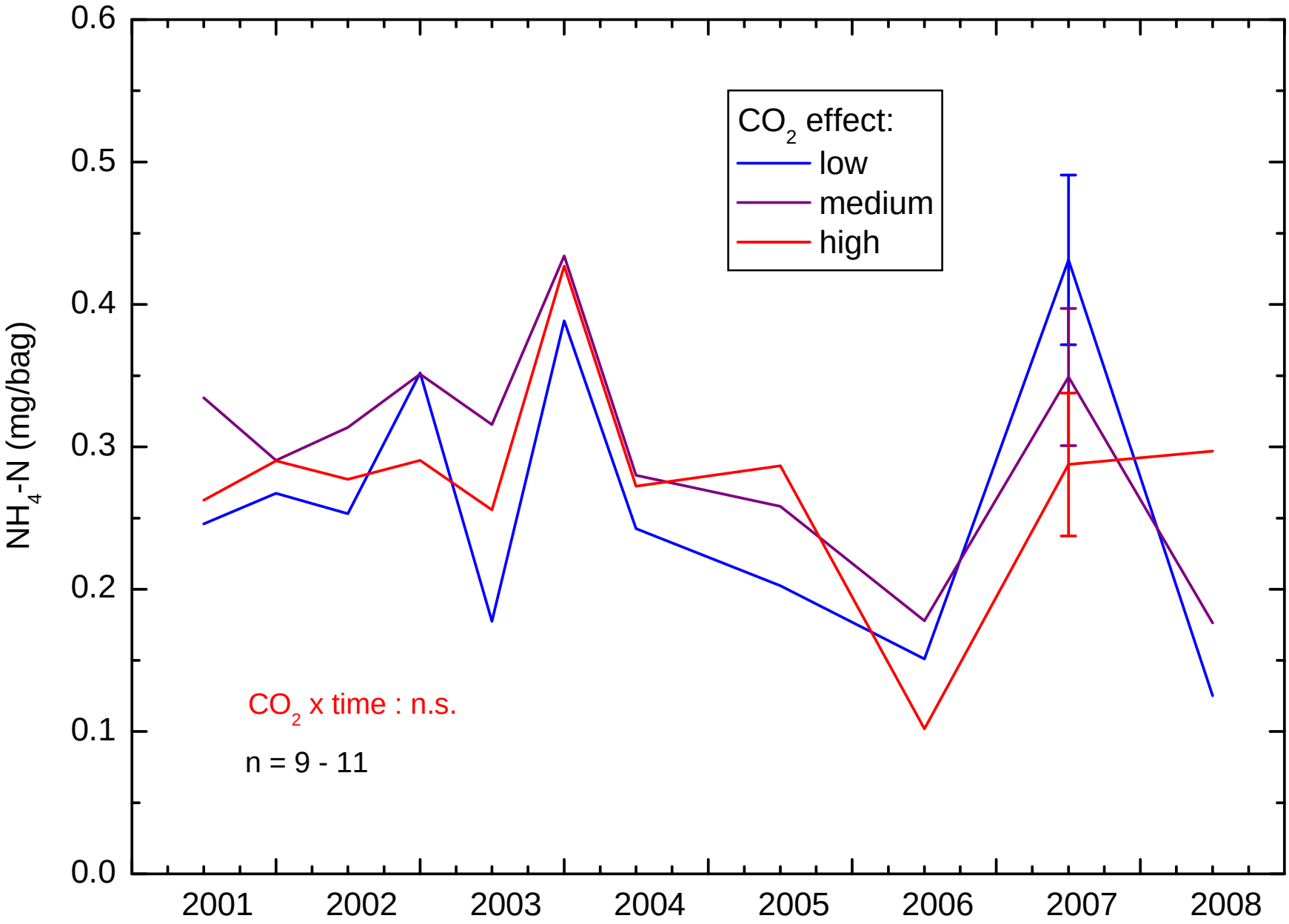
Nitrate in soil solution (distance-weighted least squares)



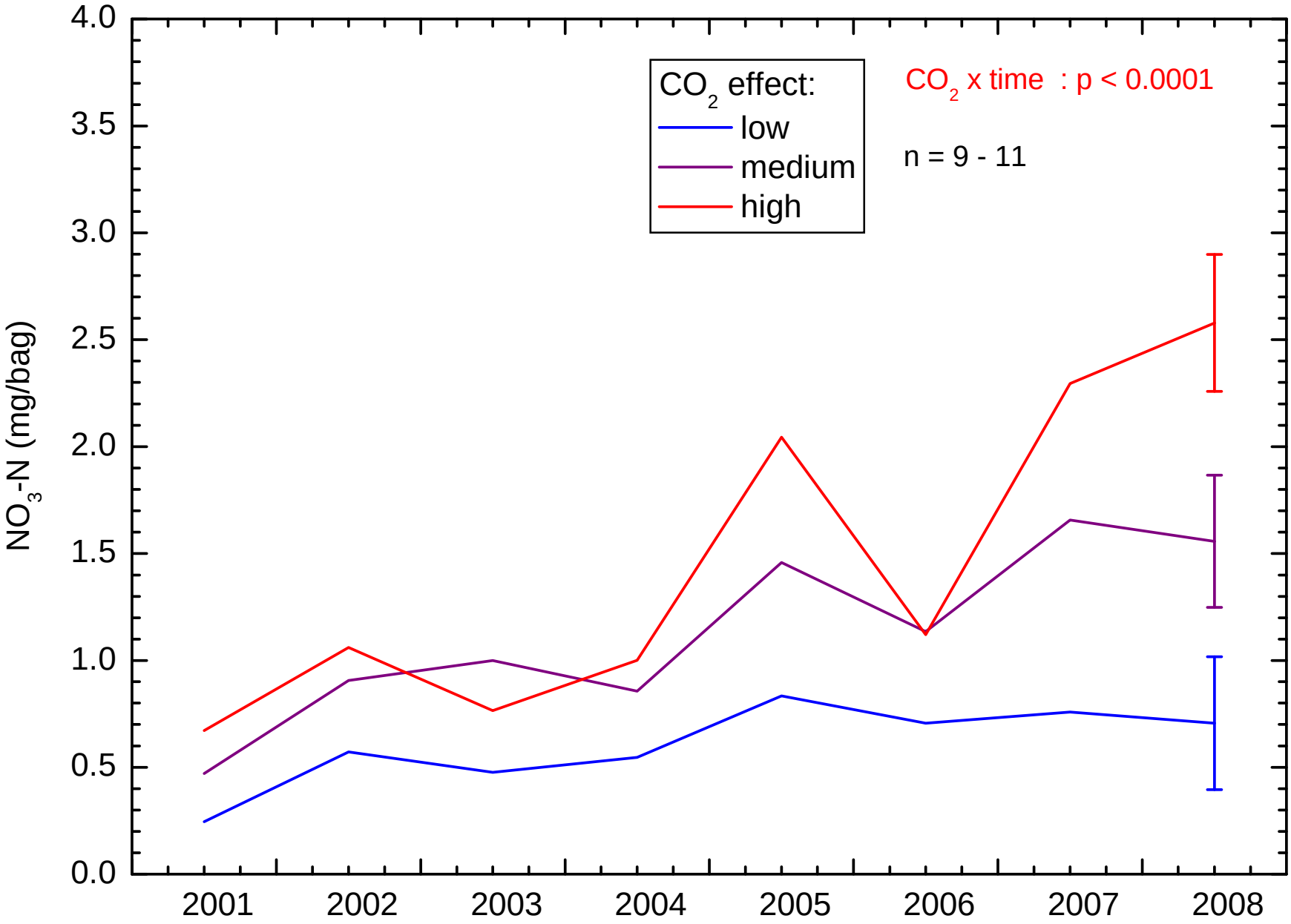

CO_2 treatment effect on nitrate in soil solution
net CO_2 effect
trend
p = 0.0067
log (NO_3-N)
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
2001
2002
2003
2004
2005
2006
2007
2008
2009

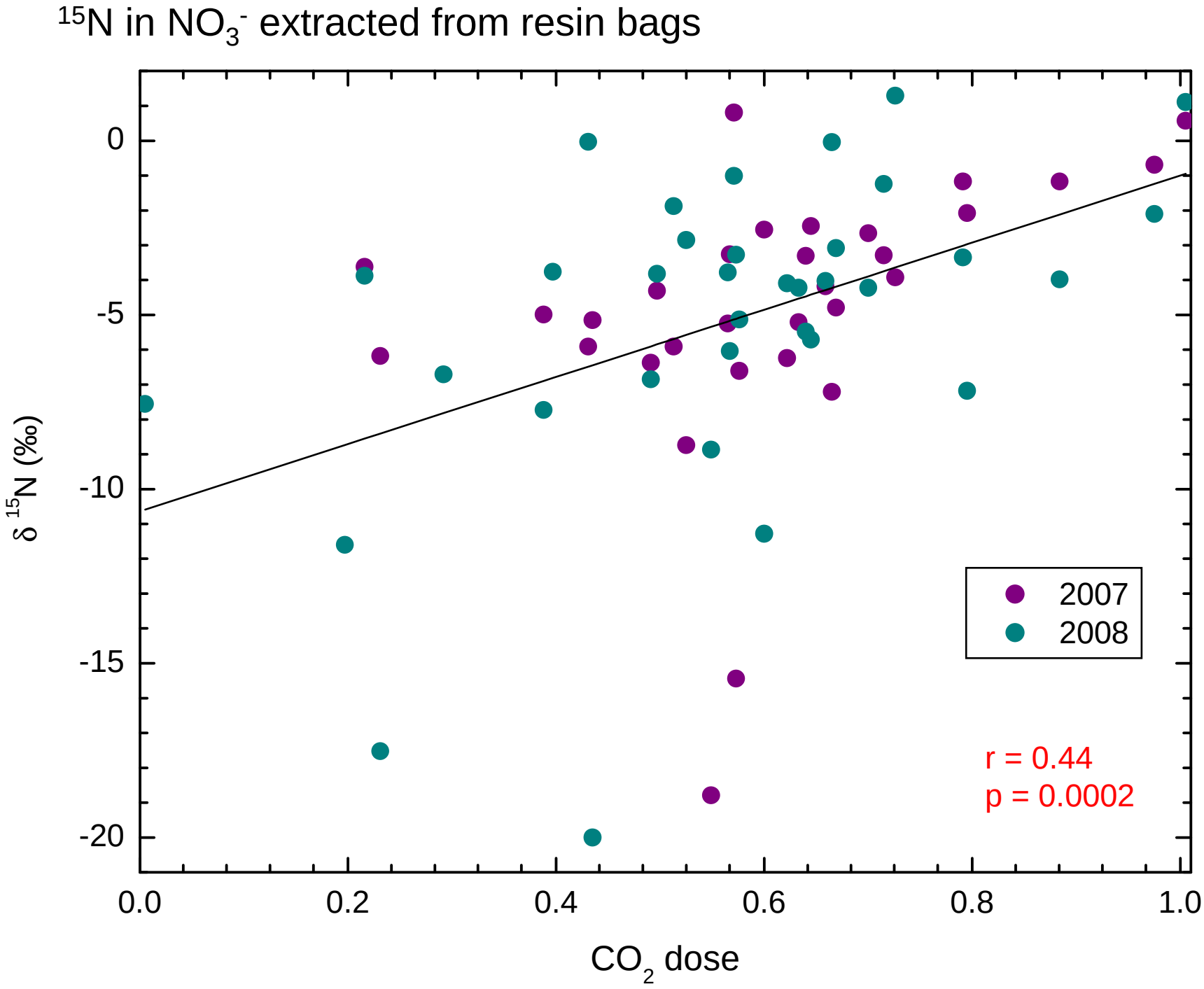

CO2 treatment effect on DON in soil solution
net CO2 effect
trend
p < 0.0001
log (DON)
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
2001
2002
2003
2004
2005
2006
2007
2008
2009

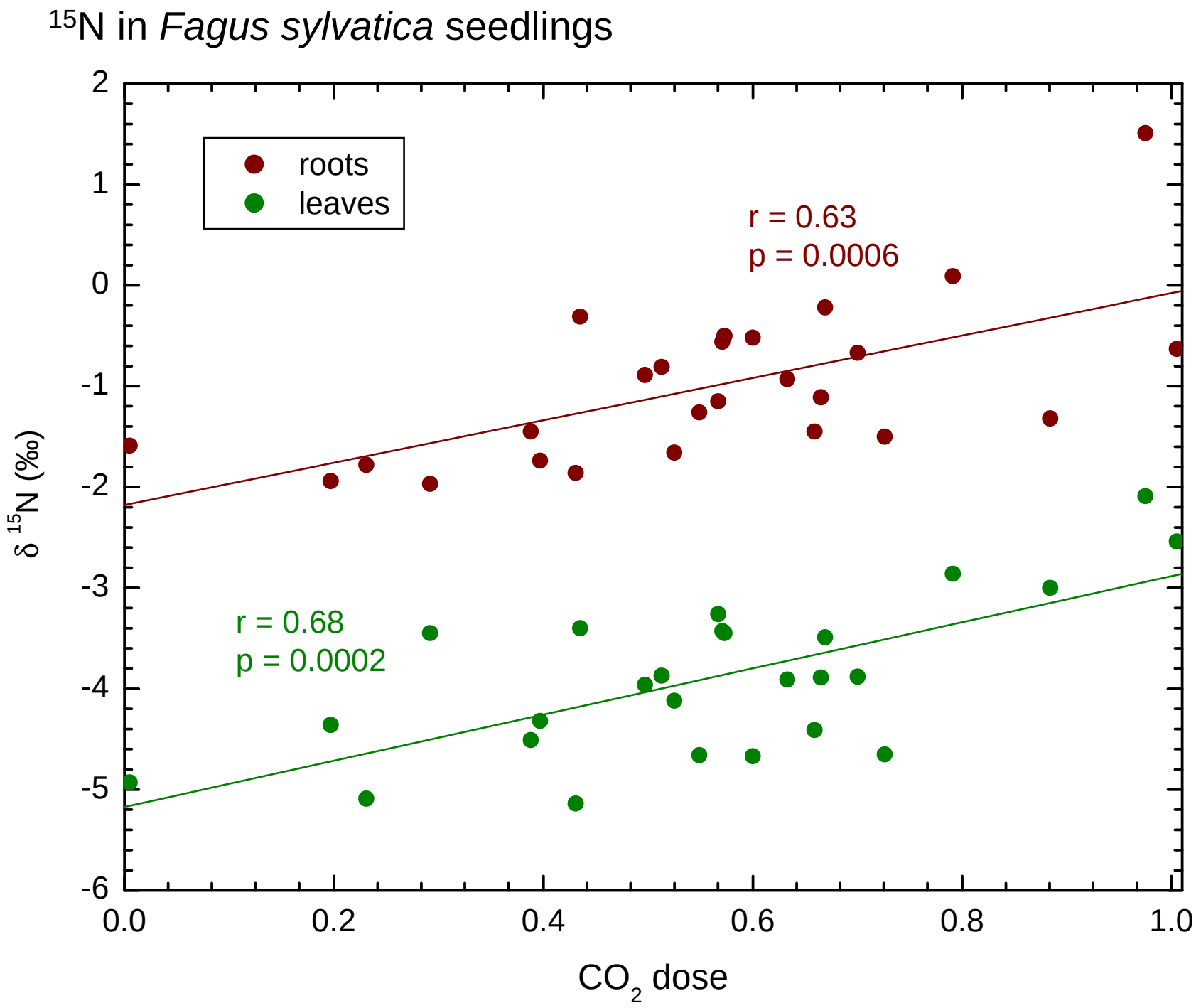
Ammonium in ion-exchange resin bags



Nitrate in ion-exchange resin bags




^{15}N in NO_3^- extracted from resin bags
0
-5
-10
-15
-20
0.0
0.2
0.4
0.6
0.8
1.0
$\delta\ ^{15}N$ (‰)
CO_2 dose
2007
2008
r = 0.44
p = 0.0002


^{15}N in *Fagus sylvatica* seedlings
roots
leaves
r = 0.63
p = 0.0006
r = 0.68
p = 0.0002
δ ^{15}N (‰)
CO_2 dose
2
1
0
-1
-2
-3
-4
-5
-6
0.0
0.2
0.4
0.6
0.8
1.0

Conclusions

- large variability of soil solution
- CO_2 => more nitrate in the soil
- ... but less DON
- more ^{15}N in soil nitrate and in plants
- most likely explanation: more mineralisation + nitrification
- no progressive N limitation (PNL) under adult trees


THE END