Accounting for time

Long-term effects of N addition on forest biogeochemistry and C sequestration

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ICP FORESTS

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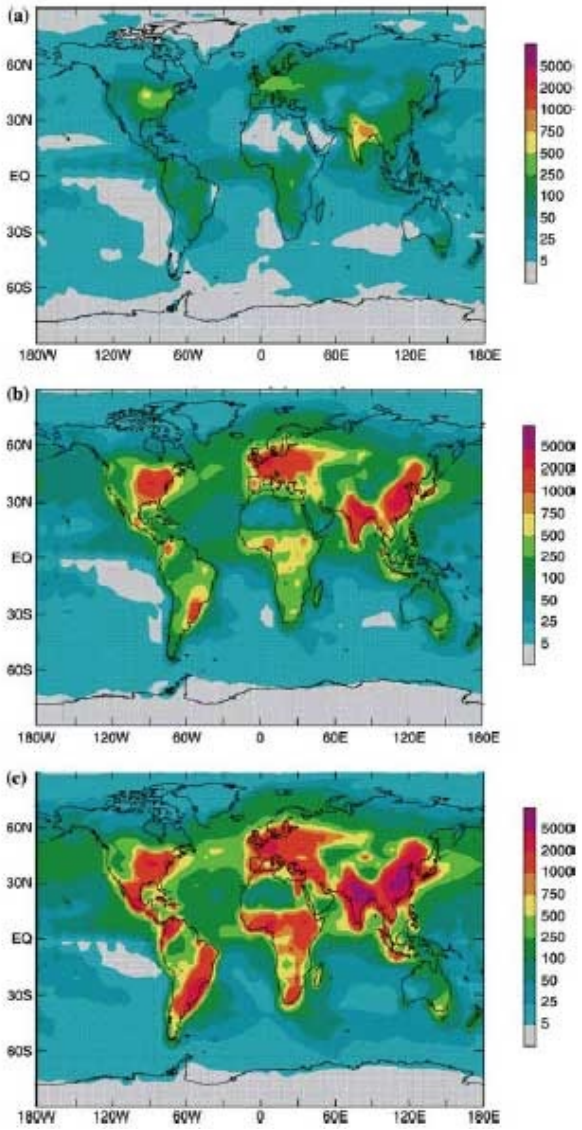
The problem

Atmospheric N deposition and forest ecosystems



N deposition
(mmol N m^{-2} yr^{-1})

1860

1990

2050

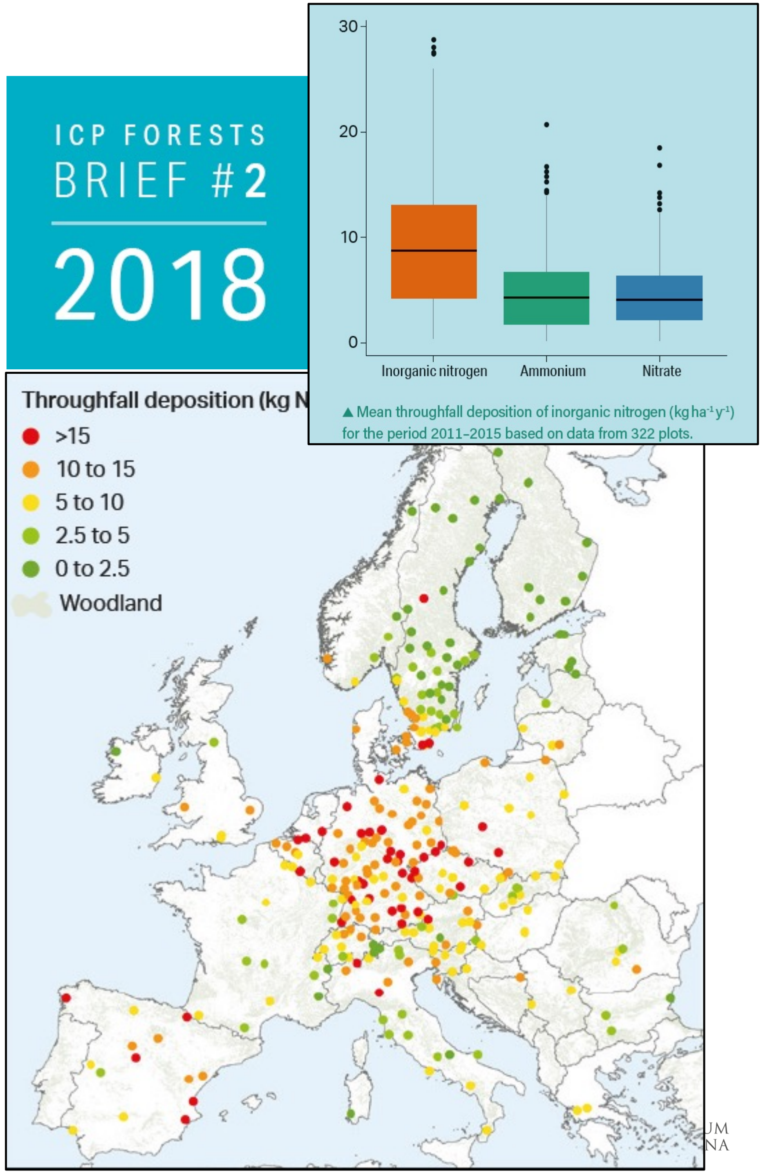
Galloway *et al.* (2004)

Transboundary air pollution and atmospheric N deposition: key macronutrient, yet potentially harmful to forests

Monitored since 1996 in ICP Forests Level 2 plots across Europe

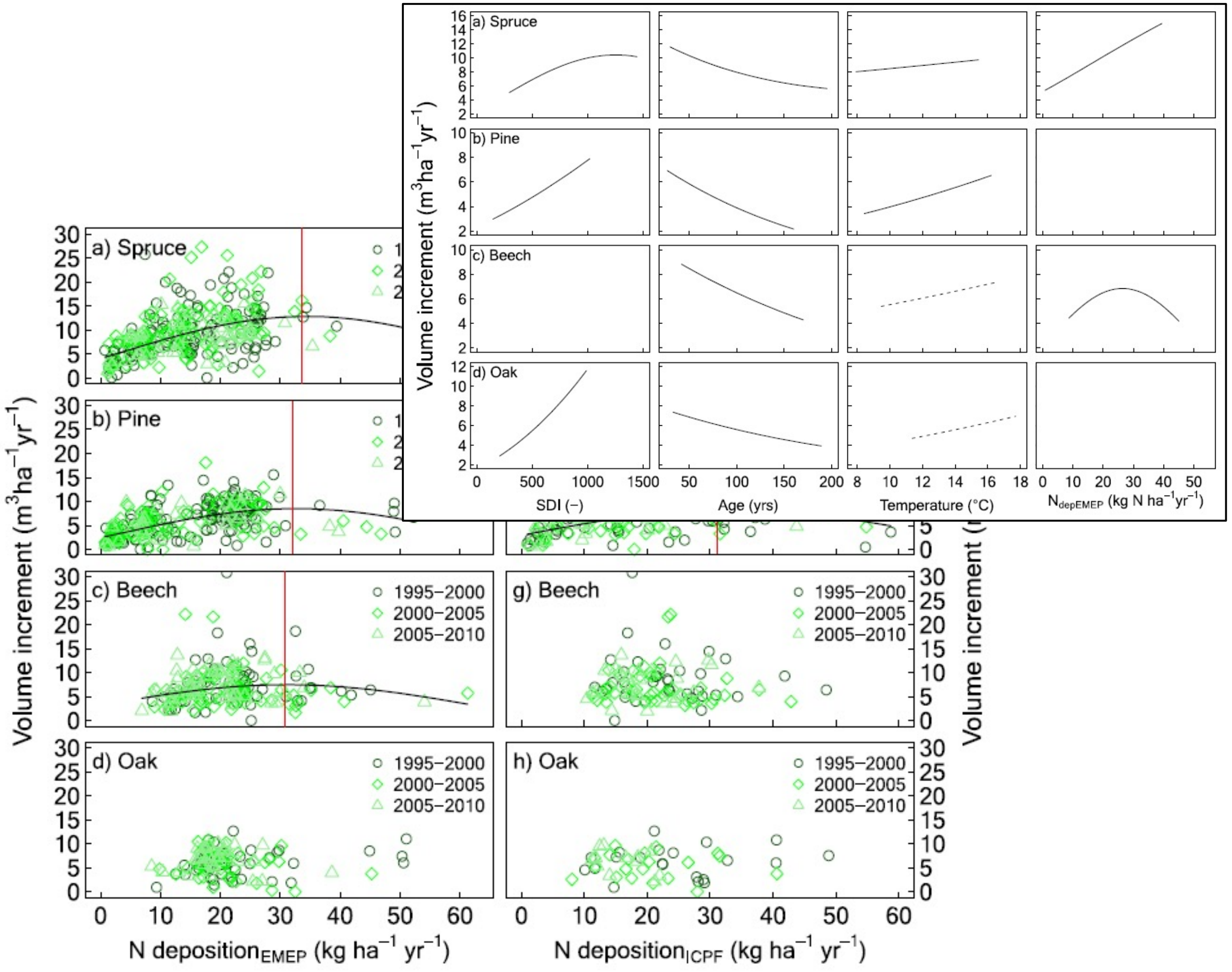
N deposition expected to increase globally, but to stabilize or decline in Europe

What are the (long-term) effects on forests?



The problem

N effects on forest C: power and limitations of regional networks



Etzold *et al.* (2020) FEM

ICP Forests L2: invaluable dataset for the assessment of N deposition and its effects on forest C sequestration

Strong points: sample size, representative, standardized, long-term

Limitations: co-variation of N deposition and key environmental variables

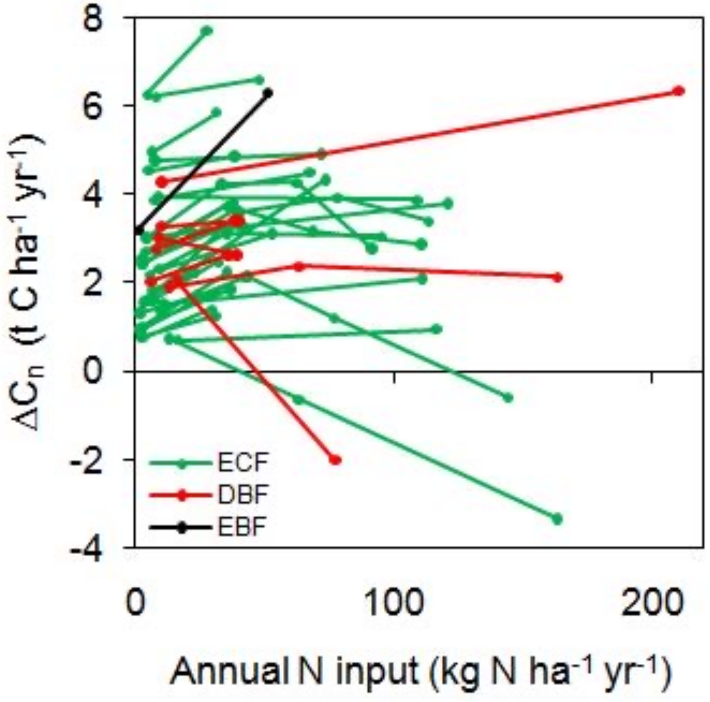
Solutions: statistical multivariate approach (e.g. Etzold et al. 2020), application of process-based models (e.g. Solberg et al. 2009). Uncertainties

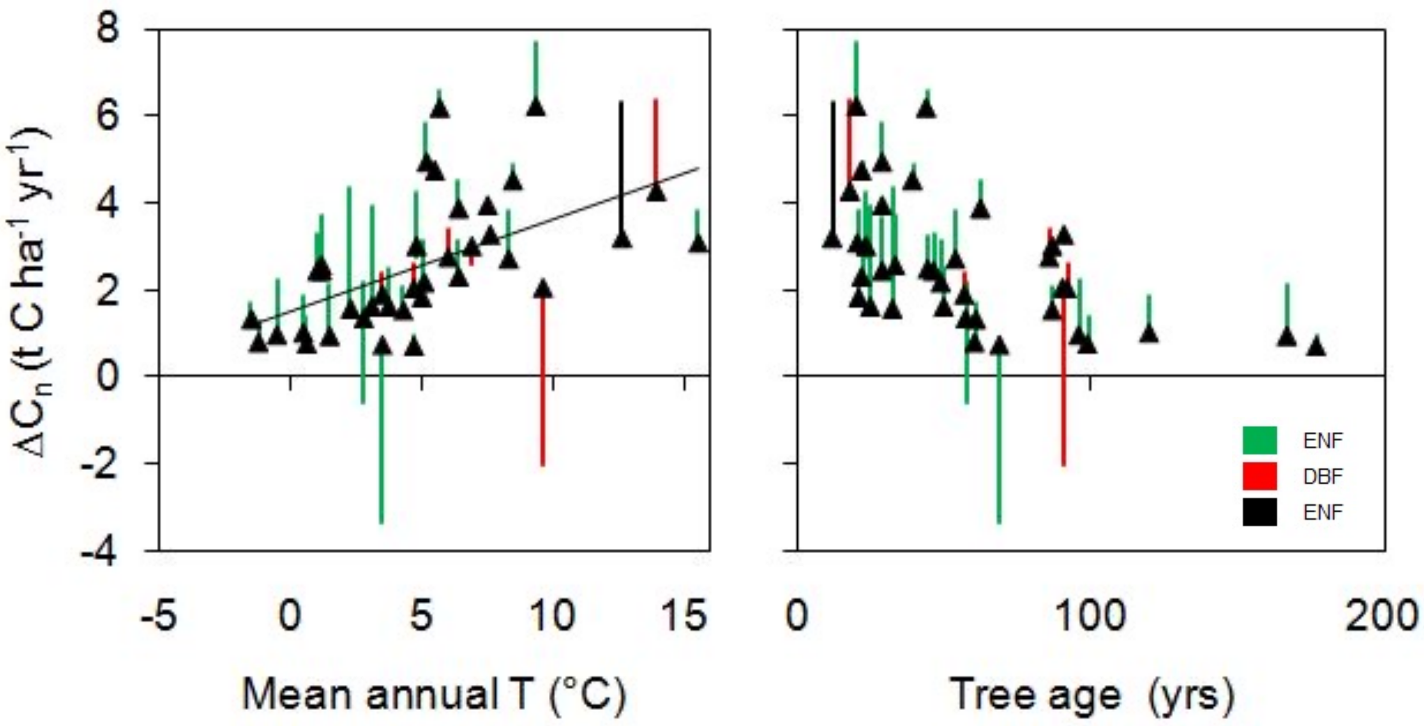
Proposal: combine with response *ceteris paribus* from long-term N fertilization studies

N effects *ceteris paribus*: fertilization experiments

Developing a dose-response curve for the effects of N inputs

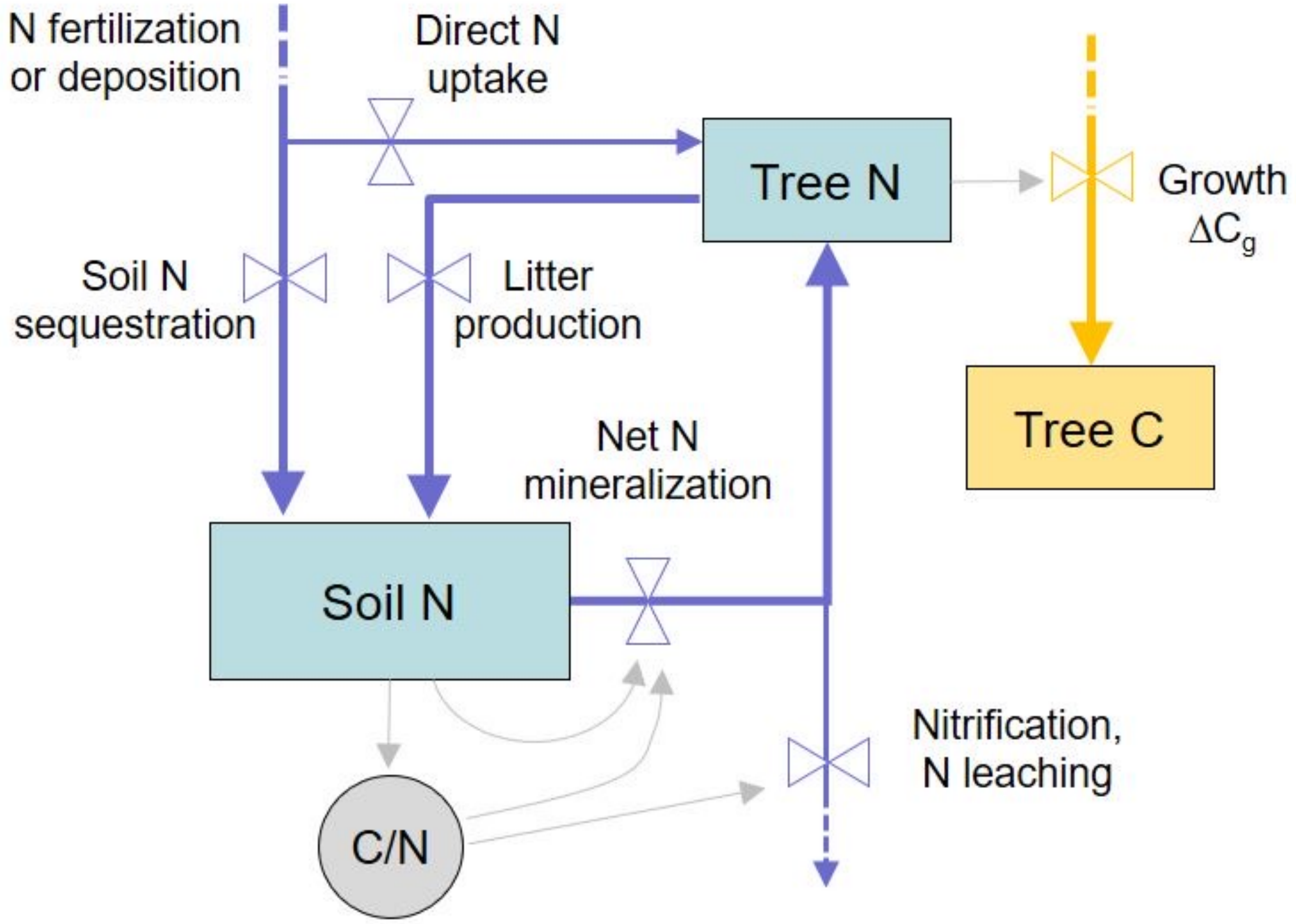
- Literature re-analysis: effects of long-term (> 4 years) ecosystem N fertilization on ecosystem C stocks (ΔC_n trees + soil); no other nutrients added
- 38 experiments (temperate and boreal forests), 13 include effects on soil net N mineralization
- long-term N deposition (1890 - present) derived from TM4 model



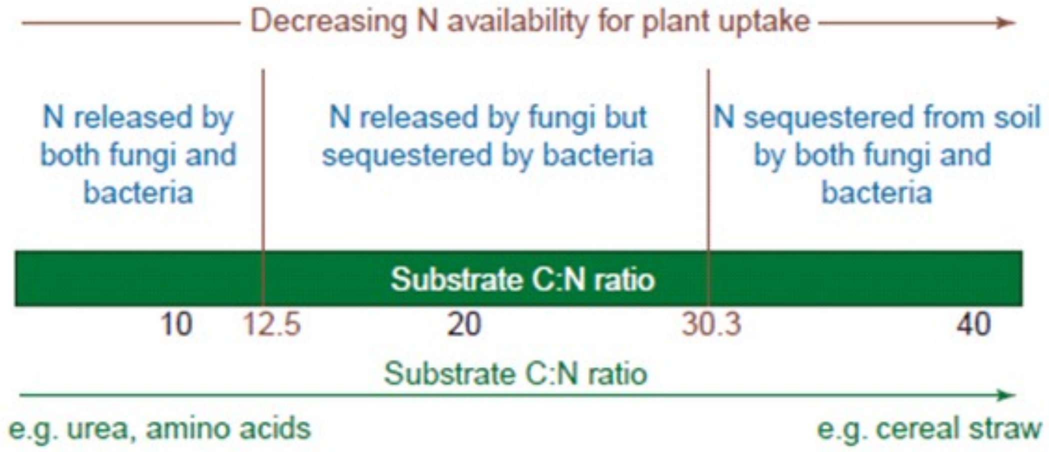


Effects of atmospheric N deposition

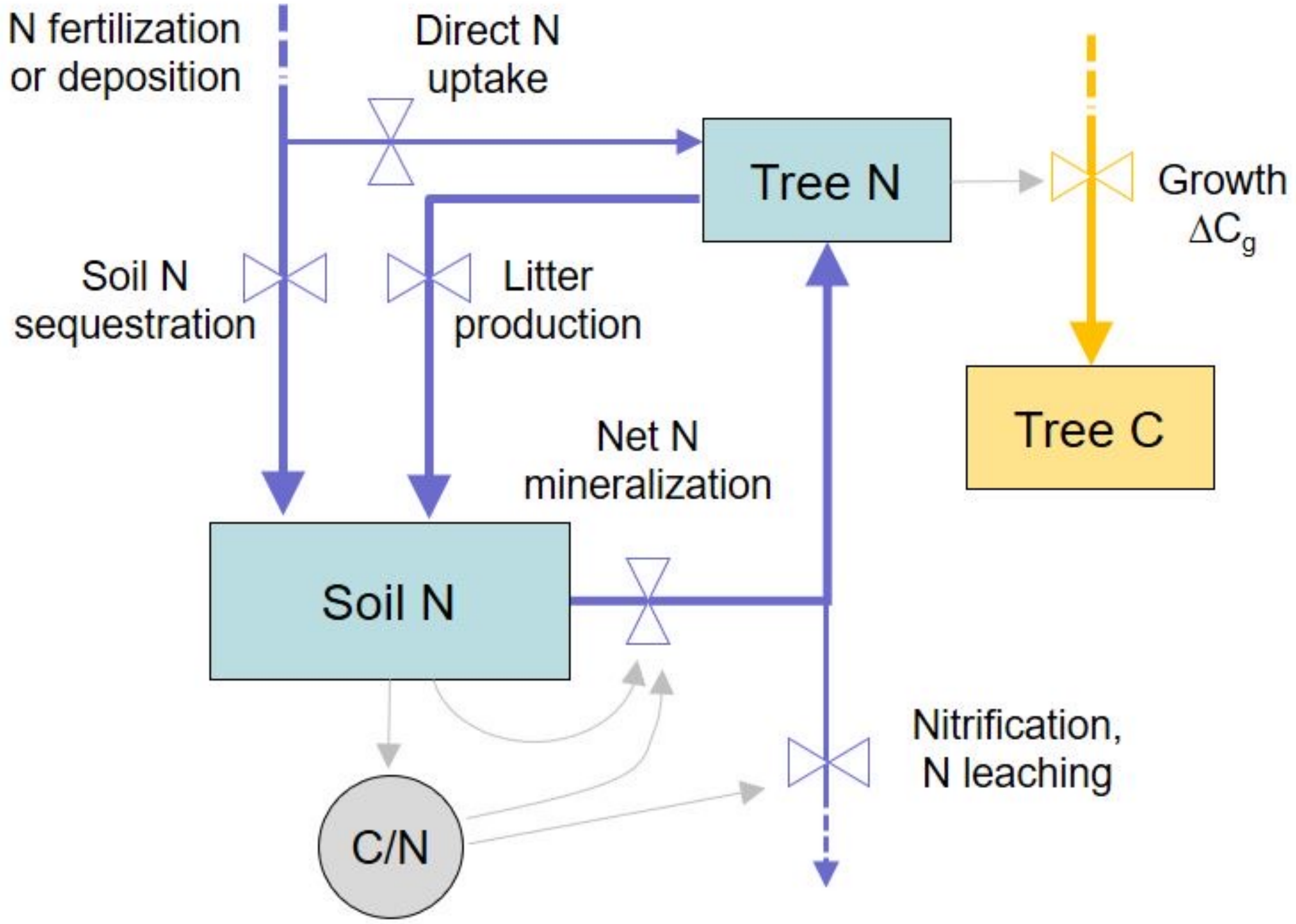
Let's place deposition in context: the overall ecosystem N cycle



- N input is largely absorbed by soil microorganisms, increasing soil N capital
- N deposition results in decline in soil C:N ratios (N stock increase > C stock)
- Soil C:N controls net N mineralization, due to fungal/bacterial stoichiometric requirements



Contribution of soil N spin-up to increased N availability



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Hypothesis 1: increase in soil N stock + C:N reduction lead over time to a progressive increase in net N mineralization, complementing direct N uptake

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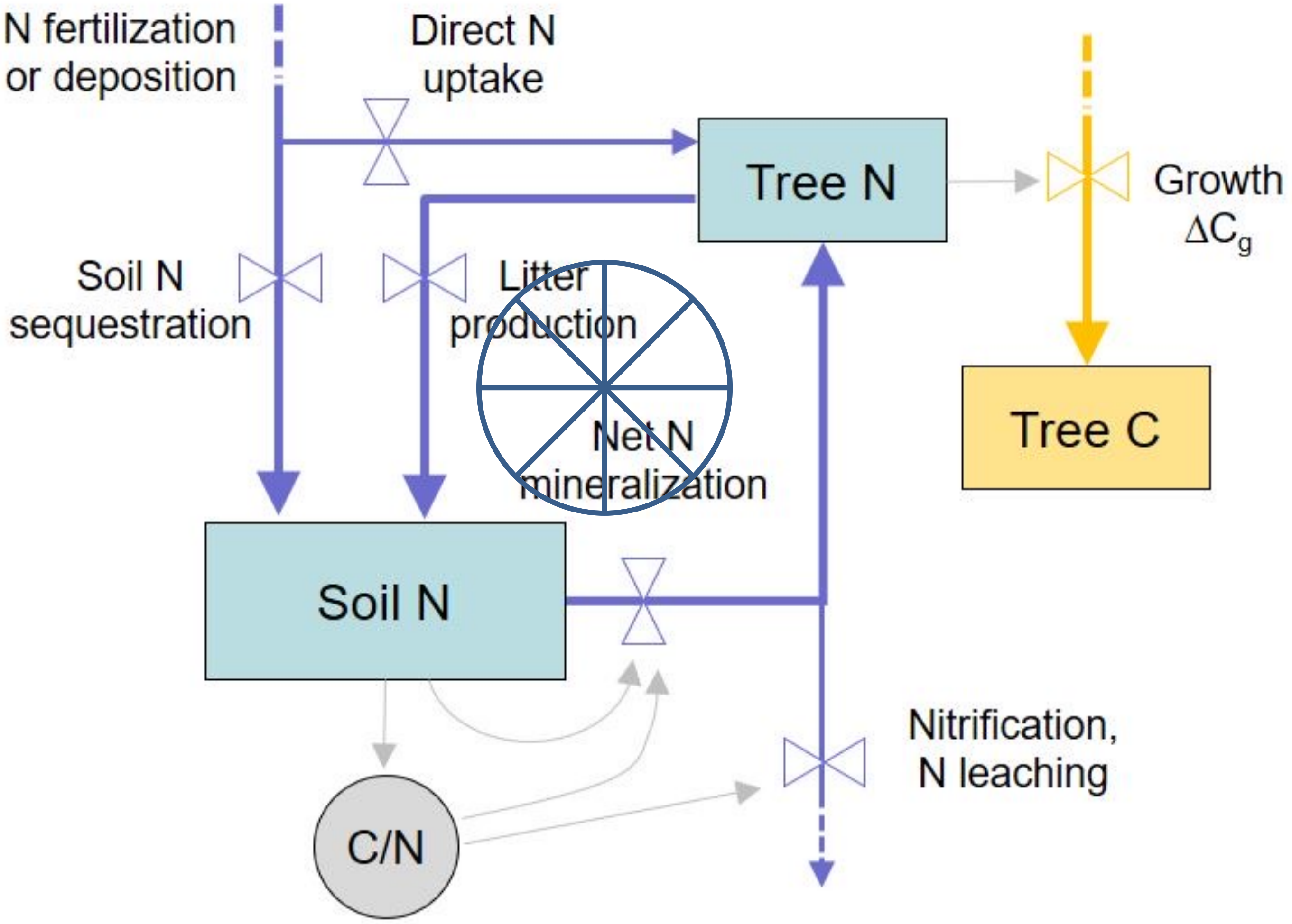

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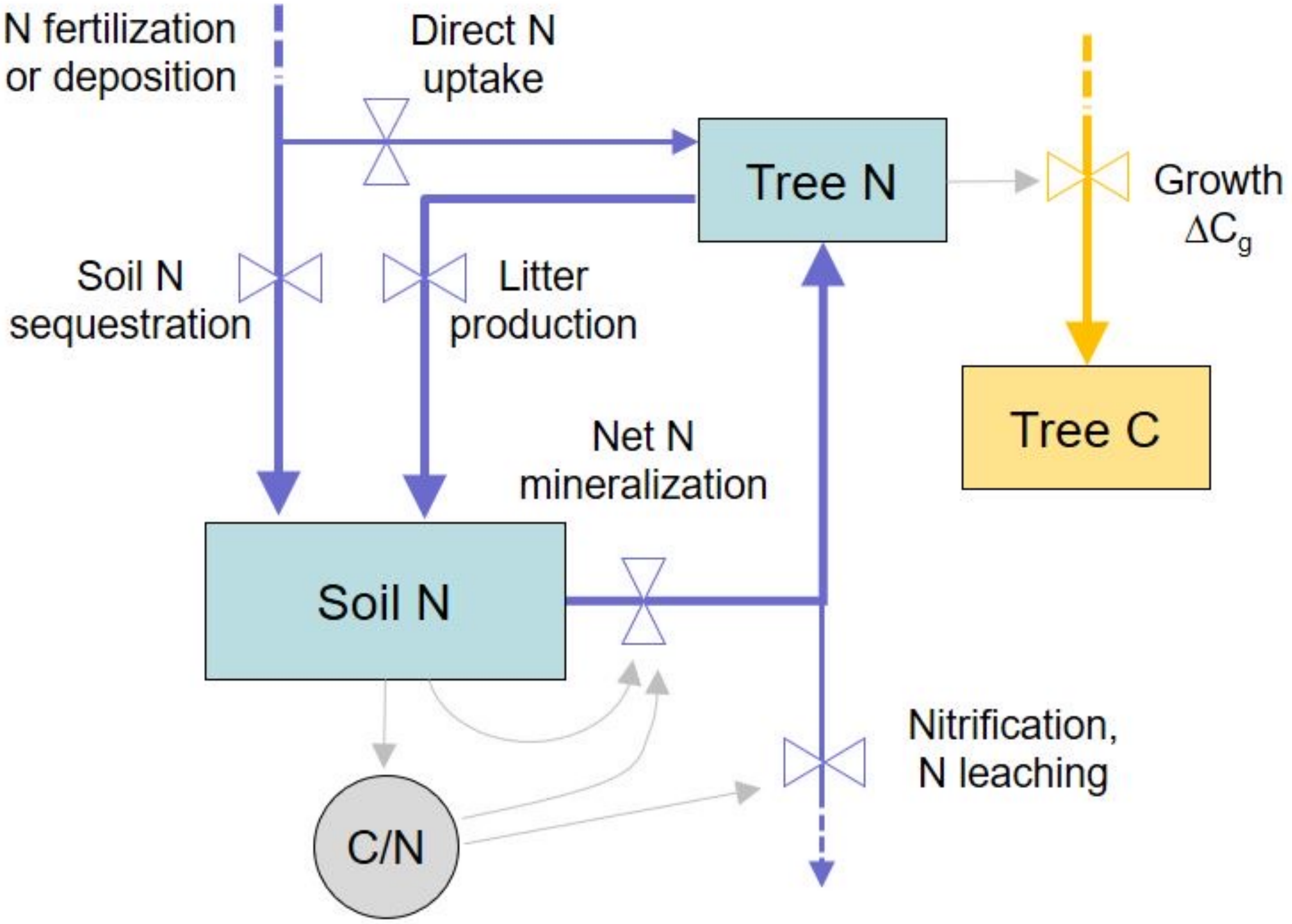
Combined effects of additional N on C sequestration



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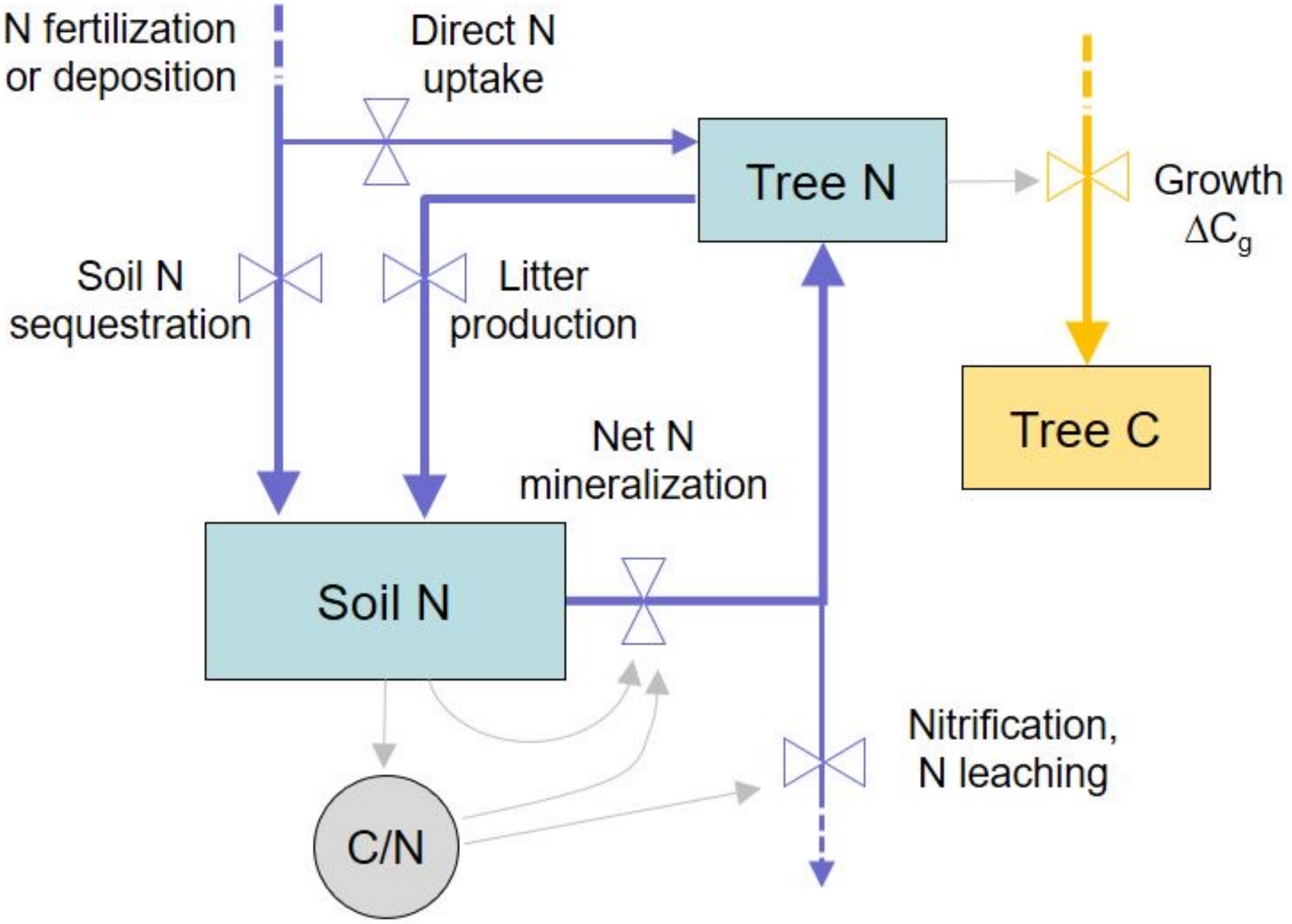
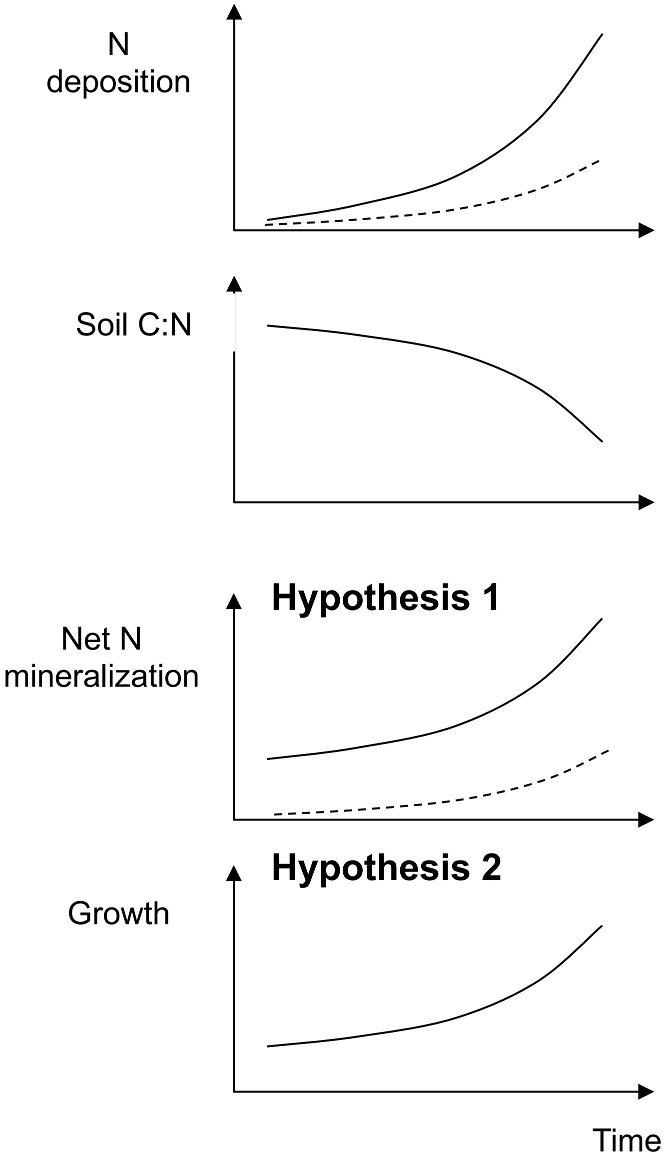
Hypothesis 1: increase in soil N stock + C:N reduction lead over time to a progressive increase in net N mineralization, complementing direct N uptake

Hypothesis 2: together with direct N uptake, the increase in net N mineralization results in an increase in forest growth and C sequestration

Effects of atmospheric N deposition

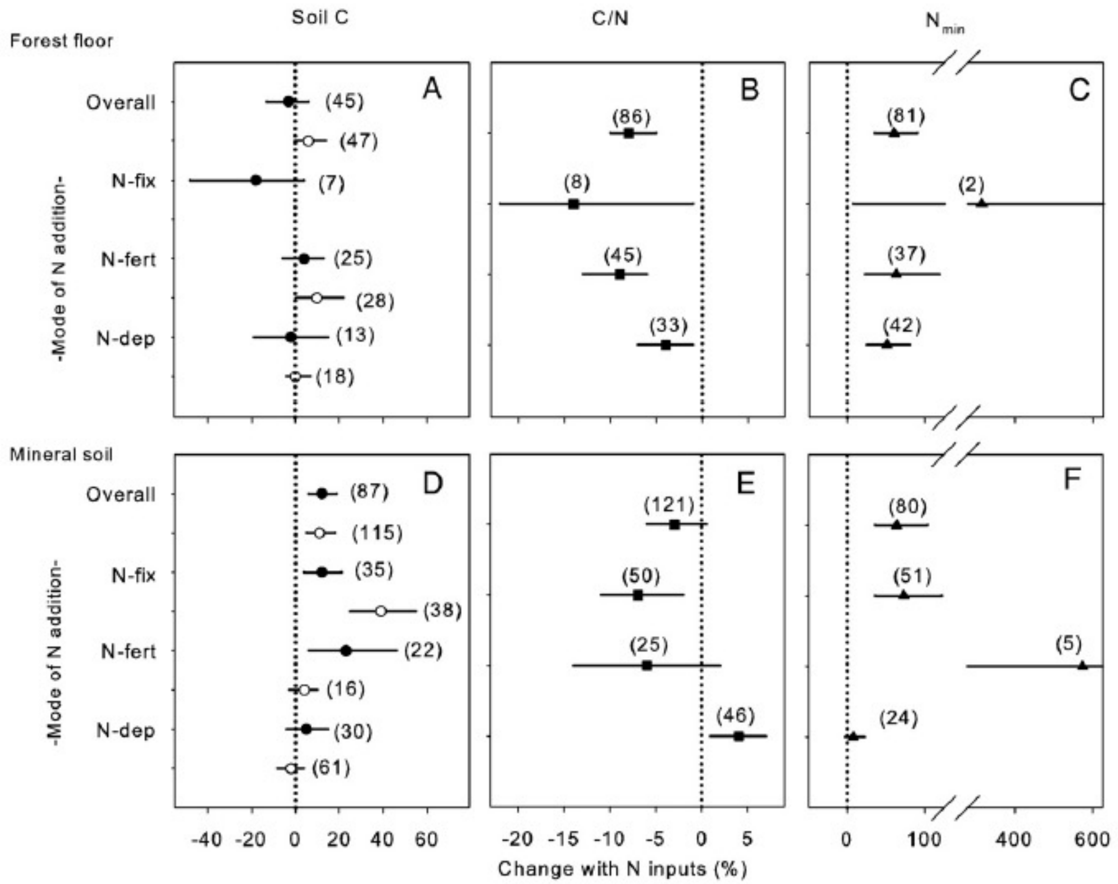
Combined effects of additional N on C sequestration





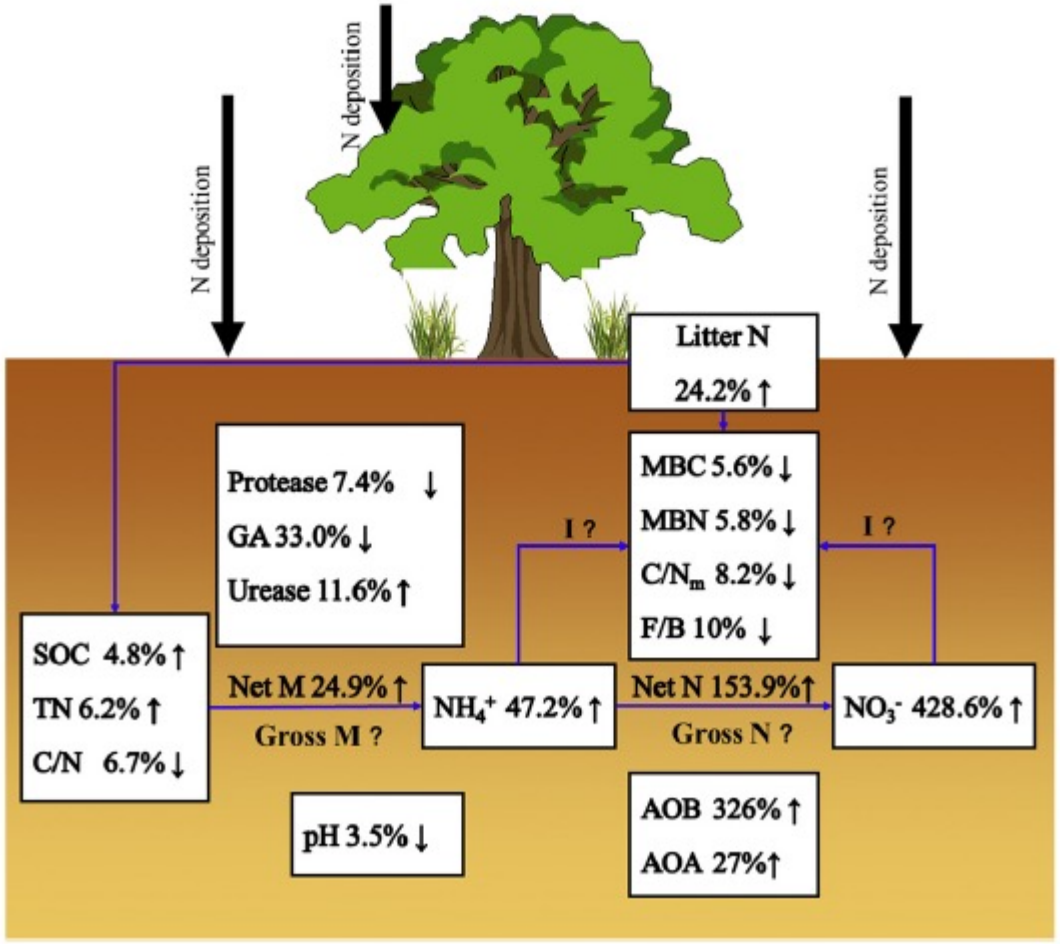
Hypothesis 1: effects of N addition on soil N cycling

Literature reviews of response to input rates



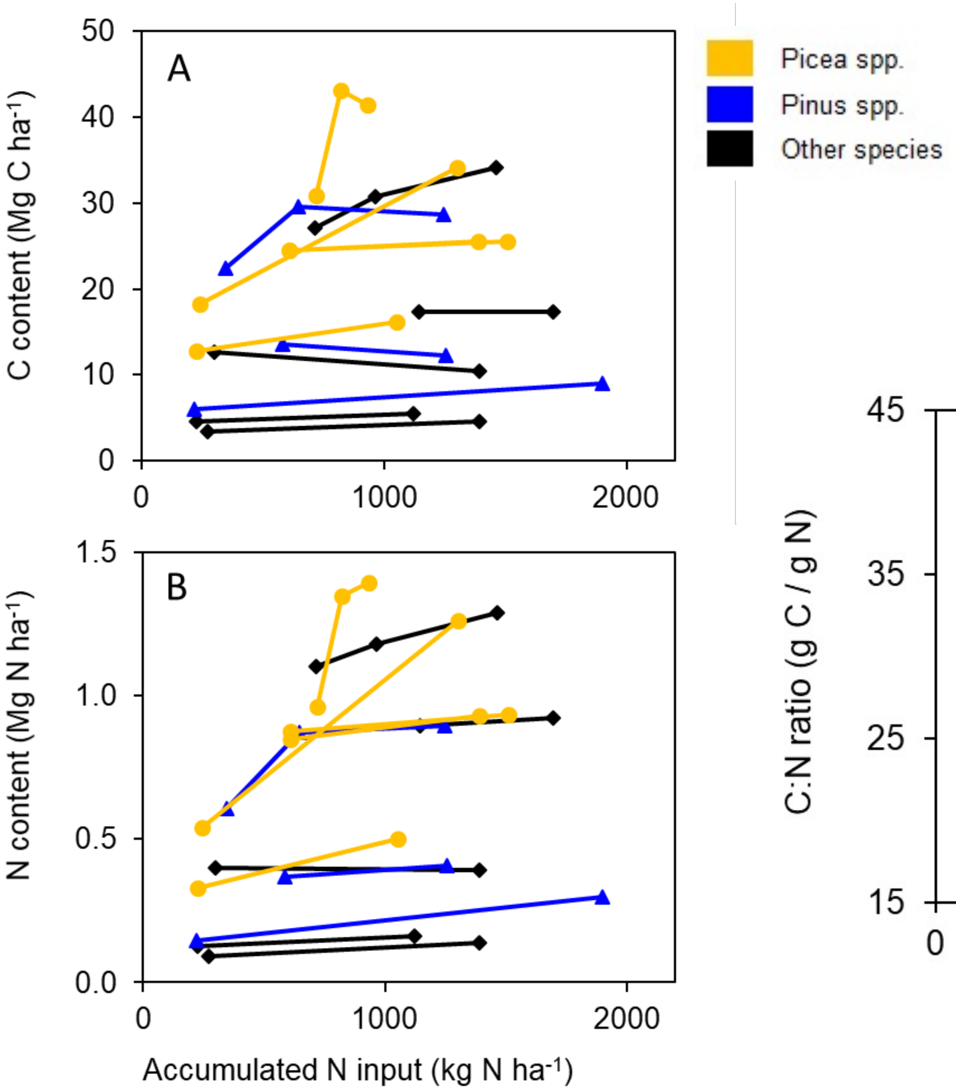
from Nave et al. (2009) Geoderma

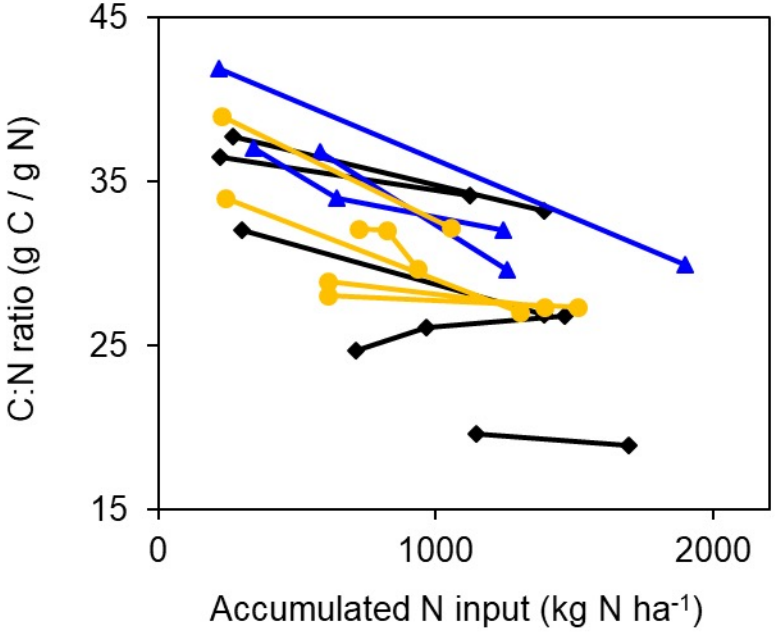
from Cheng et al. (2019) Envir Pollution



Hypothesis 1: effects of N addition on soil N cycling

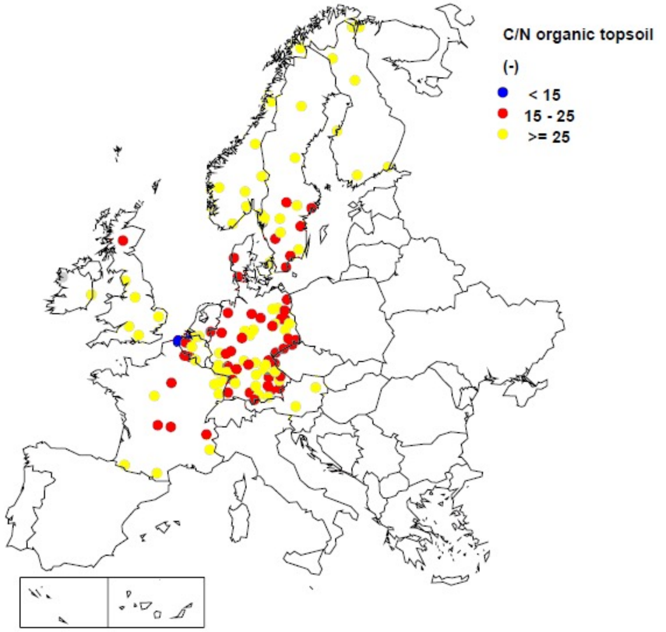
Long-term effects on soil stocks and C:N





Soil C accumulation, but greater increase in soil N stocks, hence decline in soil C:N

Rresults consistent with the C:N pattern observed in ICP Forests

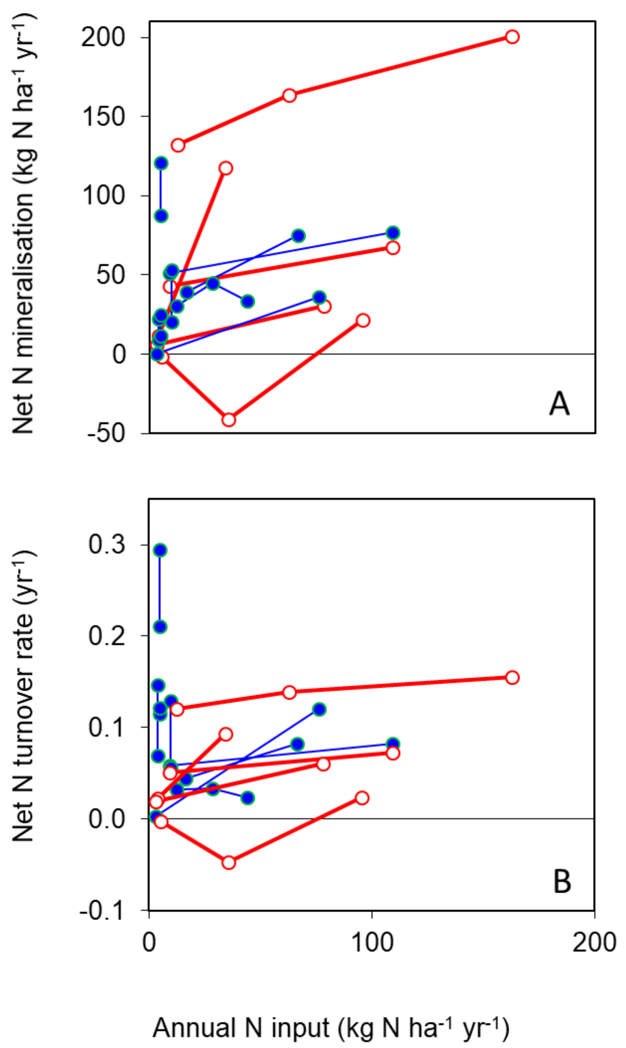


De Vries *et al.* GCB 2006

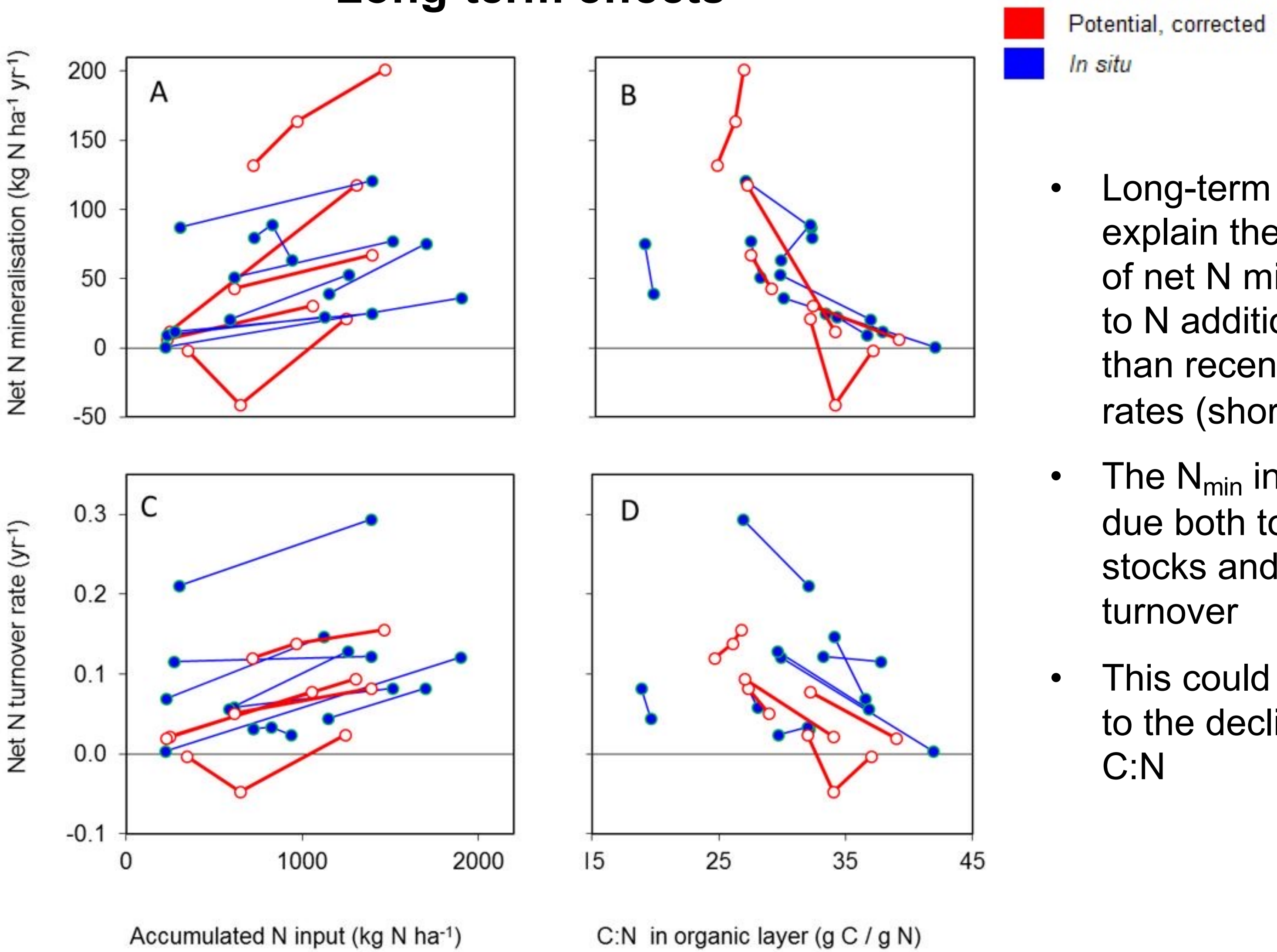
Hypothesis 1: effects of N addition on soil N cycling

Short- vs long-term effects on net N mineralization, N turnover

Short-term



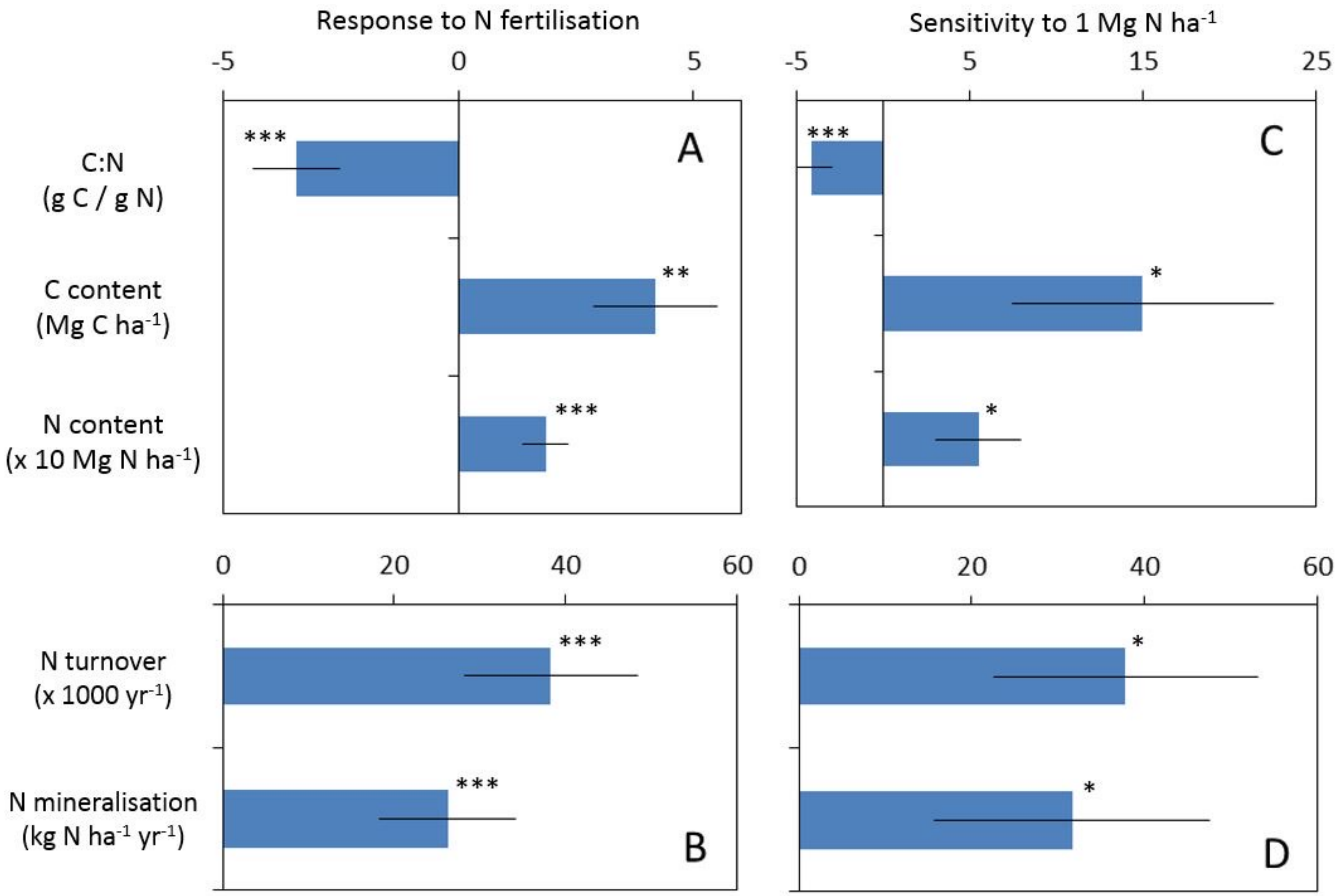
Long-term effects



- Long-term N effects explain the response of net N mineralization to N addition better than recent annual rates (short-term)
- The N_{min} increase is due both to greater N stocks and to faster turnover
- This could be related to the decline in soil C:N

Hypothesis 1: effects of N addition on soil N cycling

Long-term effects on net N mineralization and turnover: quantitative analysis



Corollary to Hypothesis 1

N fertilization vs N deposition: expected differences in (apparent) dC /dN

	N fertilization	N deposition
Time interval	20 years	110 years (1890-2000)
Annual N input (kg N ha^{-1} yr^{-1})	50	16 (in year 2000)
... available to plants (20%)		
Total N input (kg N ha^{-1})		
Increase net N mineralization (kg N ha^{-1} yr^{-1})		
Total additional N (kg N ha^{-1} yr^{-1})		
Tree C:N (g C g^{-1} N)		
ΔC_g (kg C ha^{-1} yr^{-1})		
Apparent dC / dN (g C g^{-1} N)		

Corollary to Hypothesis 1

N fertilization vs N deposition: expected differences in (apparent) dC /dN

	N fertilization	N deposition
Time interval	20 years	110 years (1890-2000)
Annual N input (kg N ha^{-1} yr^{-1})	50	16 (in year 2000)
... available to plants (20%)	10	
Total N input (kg N ha^{-1})	**1000**	
Increase net N mineralization (kg N ha^{-1} yr^{-1})	32	
Total additional N (kg N ha^{-1} yr^{-1})	42	
Tree C:N (g C g^{-1} N)		
ΔC_g (kg C ha^{-1} yr^{-1})		
Apparent dC / dN (g C g^{-1} N)		

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... available to plants (20%)	10	
Total N input (kg N ha^{-1})	**1000**	
Increase net N mineralization (kg N ha^{-1} yr^{-1})	32	
Total additional N (kg N ha^{-1} yr^{-1})	42	
Tree C:N (g C g^{-1} N)	70	
ΔC_g (kg C ha^{-1} yr^{-1})	2940	
Apparent dC / dN (g C g^{-1} N)	2940 / 50 = 58.8	

Corollary to Hypothesis 1

N fertilization vs N deposition: expected differences in (apparent) dC /dN

	N fertilization	N deposition
Time interval	20 years	110 years (1890-2000)
Annual N input (kg N ha^{-1} yr^{-1})	50	16 (in year 2000)
... available to plants (20%)	10	3.2
Total N input (kg N ha^{-1})	**1000**	**1000**
Increase net N mineralization (kg N ha^{-1} yr^{-1})	32	32
Total additional N (kg N ha^{-1} yr^{-1})	42	35.2
Tree C:N (g C g^{-1} N)	70	
ΔC_g (kg C ha^{-1} yr^{-1})	2940	
Apparent dC / dN (g C g^{-1} N)	2940 / 50 = 58.8	

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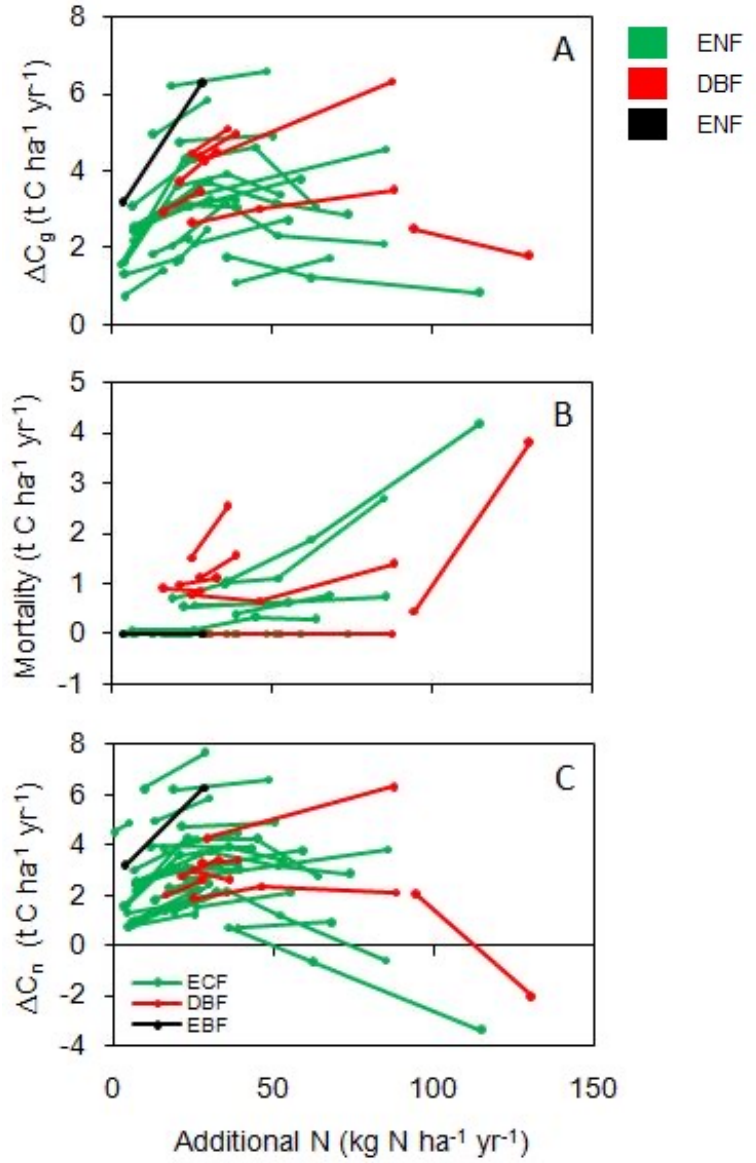
Total N input (kg N ha^{-1})	**1000**	**1000**
Increase net N mineralization (kg N ha^{-1} yr^{-1})	32	32
Total additional N (kg N ha^{-1} yr^{-1})	42	35.2
Tree C:N (g C g^{-1} N)	70	70
ΔC_g (kg C ha^{-1} yr^{-1})	2940	2464
Apparent dC / dN (g C g^{-1} N)	2940 / 50 = **58.8**	2464 / 16 = **154**

Hypothesis 2: overall effects of N input on C sequestration

Disentangling the effects on gross increments and mortality



Controlled N fertilization studies provide an understanding of N deposition effects, both on growth (ΔC_g) and on mortality, which together determine net C accumulation (ΔC_n).

- gross C accumulation is stimulated by increasing N availability up to a threshold, then declines (leaching, reduced CEC...)
- wide offset between ecosystems (effects of climate, age...)
- at high N deposition levels, an increase in mortality is often observed
- net C accumulation initially increases, then saturates. C losses can be induced by very high N inputs
- although most forests are still below saturation, N accumulation in the system is a matter of concern

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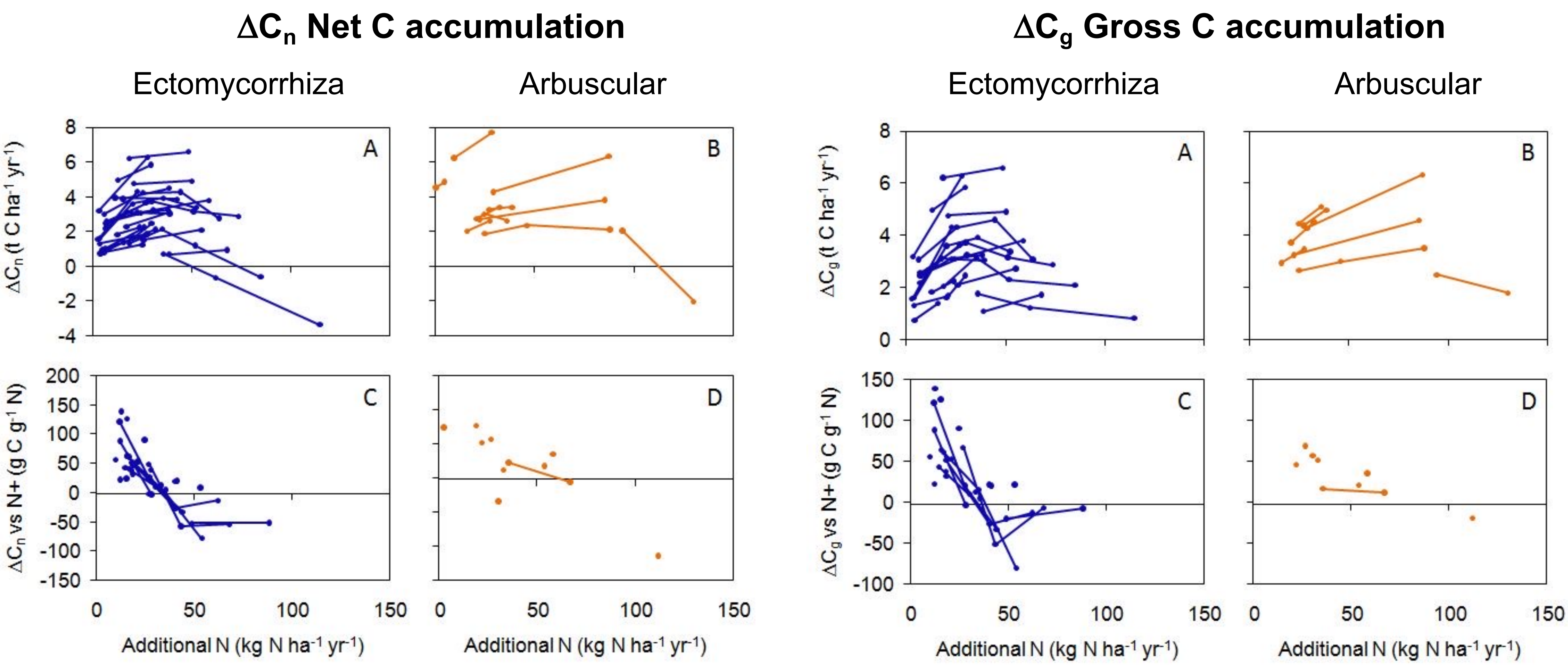
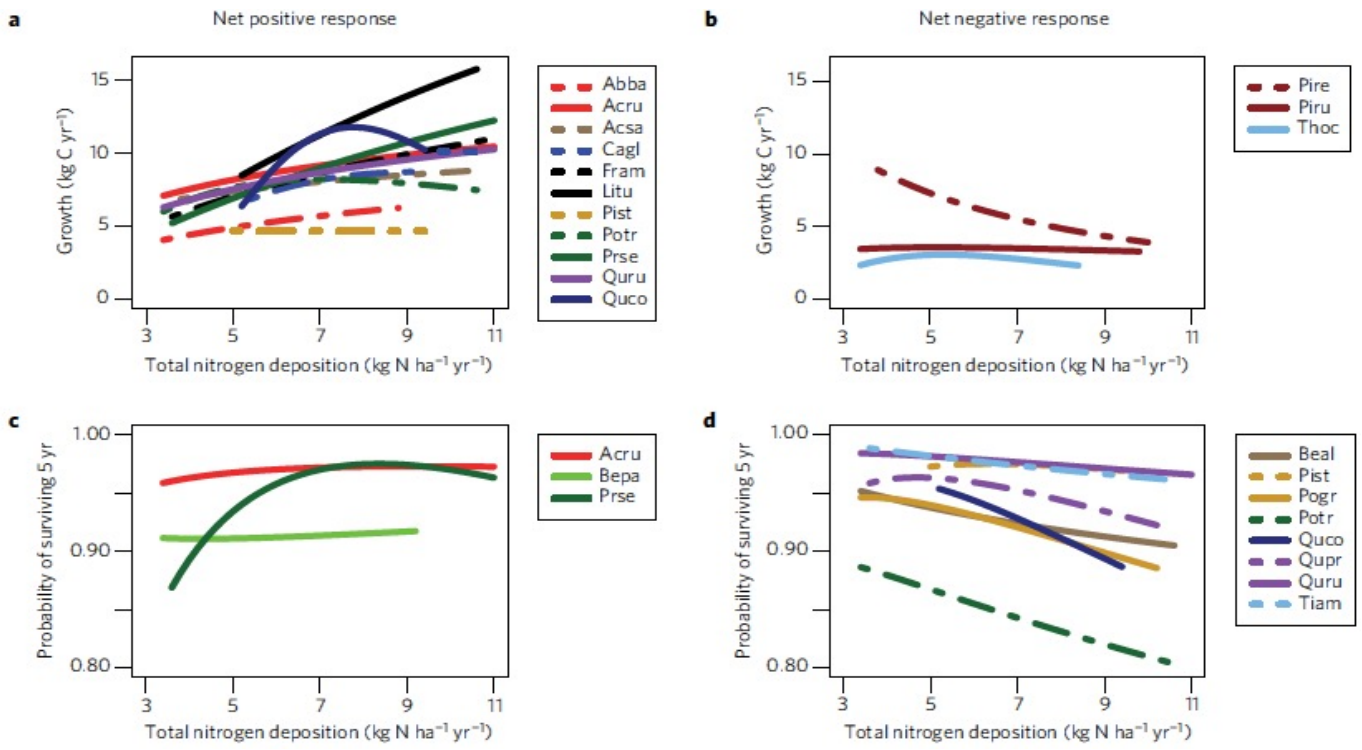
Hypothesis 2: overall effects of N input on C sequestration

C sensitivity to long-term N input: a role for mycorrhizal symbioses?



Hypothesis 2: overall effects of N input on C sequestration

C sensitivity to long-term N input: a role for mycorrhizal symbioses?



from Thomas et al (2010) Nature Geoscience

Results confirmed by forest inventories:

- positive effect of N deposition on gross increments for many (but not all) species, in particular those with arbuscular mycorrhizal symbionts
- in many species, however, the N input leads to a reduction in survival (increased mortality)

Conclusions and take-home message

- Forest C sequestration is modulated by age and climate, but also to large extent by N inputs
- Most N is captured by soil microbes, in the long run this results in (i) increase in N stocks, (ii) decline in soil C:N (reduced resorption, increased N turnover)
- For low-dose, long-term inputs (N deposition) the increase in net N mineralization can be more important than direct N input
- Additional N (short + long-term effects) stimulates gross increments, follows saturation and decline; tree mortality can also follow
- Arbuscular mycorrhiza (P nutrition) delay N saturation in some species
- Being the result of soil N build-up rather than annual doses, the dynamics can only be slowed by reductions in N deposition
- Needed: combine regional monitoring and long-term ecosystem manipulation

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