N deposition effects on forest soil C cycling

Ivan Janssens

Thanks to:

Wouter Dieleman, Sebastiaan Luyssaert & Sara Vicca

Bev Law, Josep Peñuelas, Sune Linder, + several colleagues + everybody who sweats in the field

Take home messages:

1. N deposition often slows down soil C cycling.

2. The main reason is probably a nutrient-induced C-allocation shift
   not between roots and shoots,
between biomass production and the non-biomass components of NPP

Introduction (1)

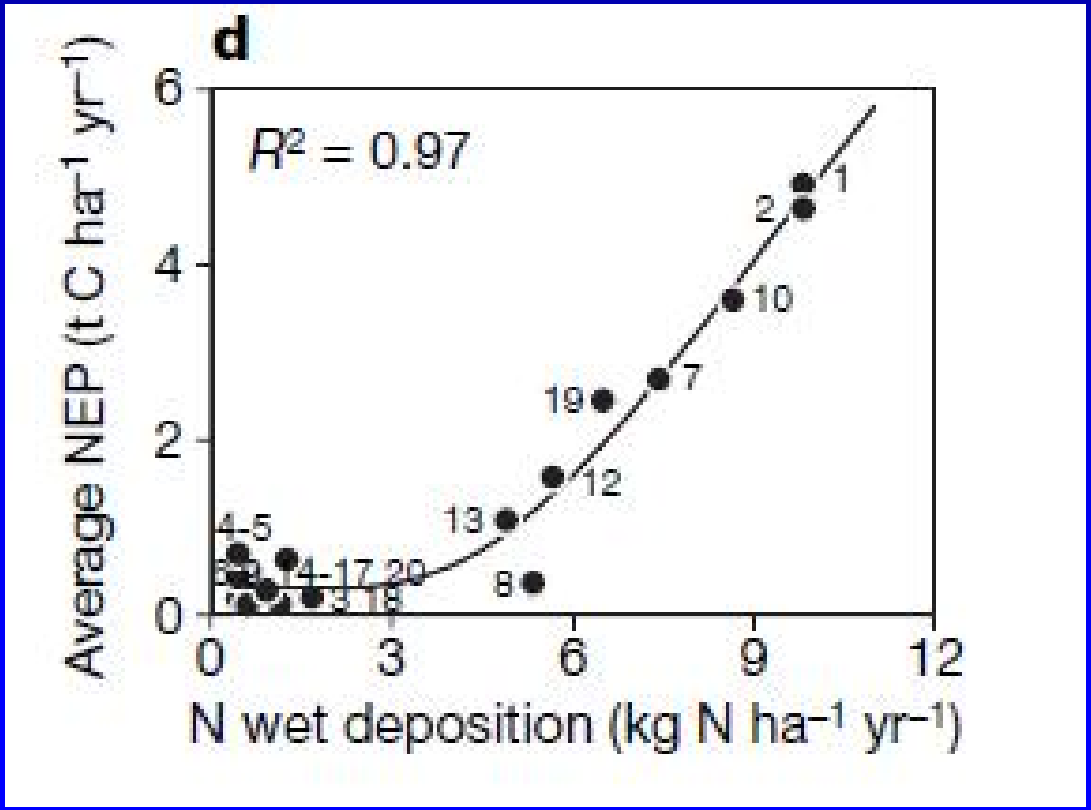
In ’98, Waring et al. suggested that NPP/GPP ratio is constant in forests (0.47).

If so: C allocation to biomass production would be constant

Unfortunately: very large variation in ratio of biomass production / GPP (Litton et al. 2007; DeLucia et al., 2007).

Introduction (2)

- 2007: N deposition is the main determinant of forest NEP (Magnani et al., Nature 2007 and subsequent discussion)



Magnani result was very novel and surprising, but plausibel :

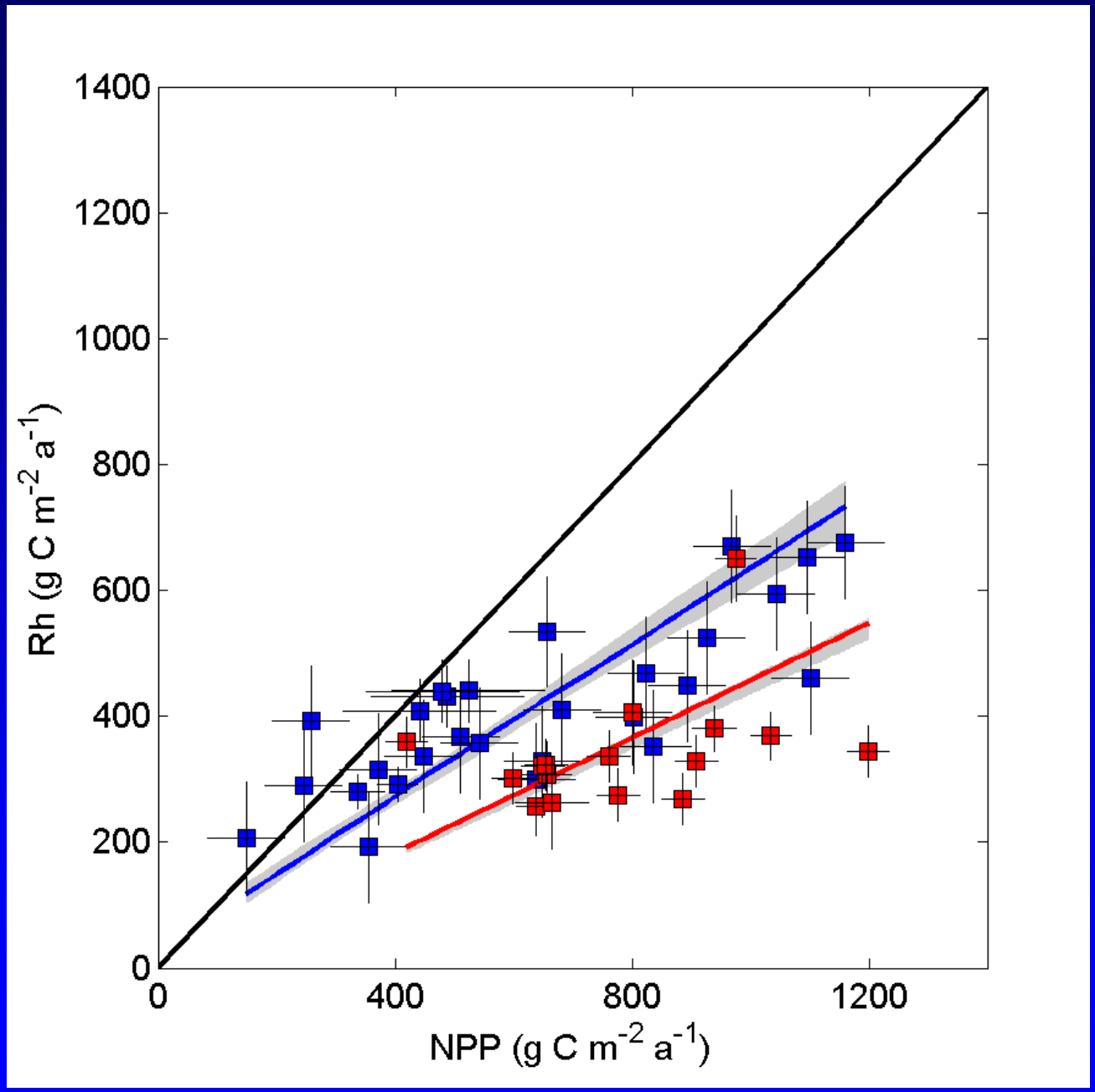
- Stimulation of CO2 sink >> Stimulation of wood production; implying a large soil C sink

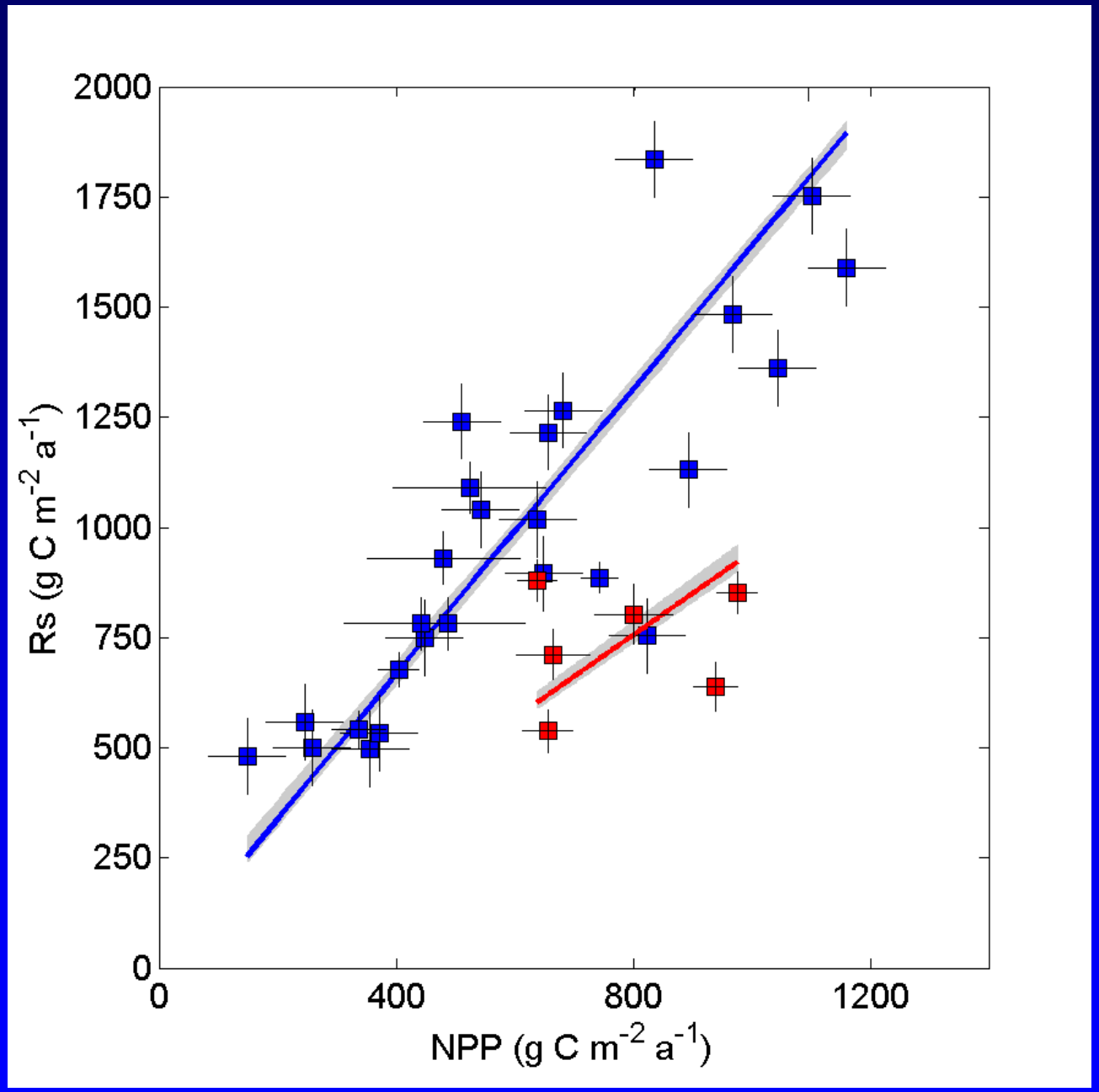
- N-rich litter decomposes faster in short term, but N addition reduces decomposition of recalcitrant plant litter (Fog, 1988; Berg B., several papers)

Federico's finding was relevant

We had just compiled a global forest C flux database (Luyssaert et al., 2007)

Could we detect a similar N deposition response in our database ?


1400
1200
1000
800
600
400
200
0
0
400
800
1200
Rh (g C m-2 a-1)
NPP (g C m-2 a-1)


2000
1750
1500
1250
1000
750
500
250
0
0
400
800
1200
Rs (g C m-2 a-1)
NPP (g C m-2 a-1)

Nitrogen-deposition enhances forest carbon sink through reduced respiration as well as increased productivity
(Luyssaert et al.)

1. 2007: Submitted to Nature ; sent out for review ; rejected but invited to resubmit a revised version; rejected

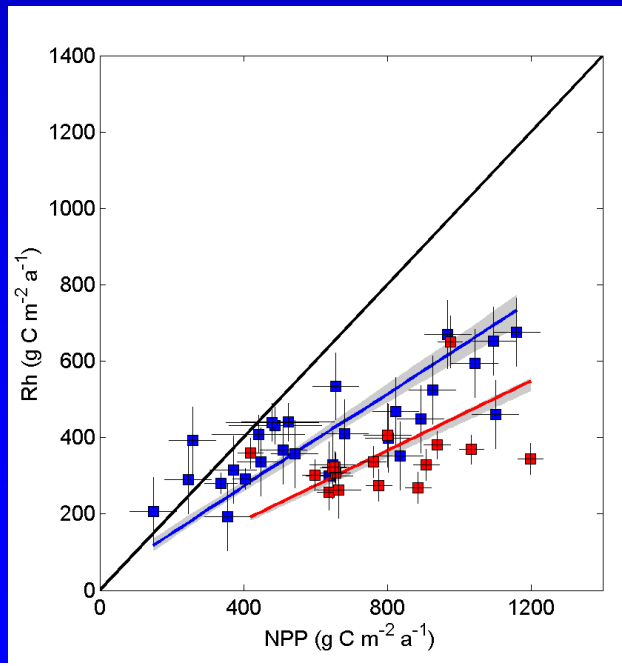
2. 2007 bis: Submitted to Science; sent out for review ; rejected but invited to resubmit a revised version; rejected

3. 2008: Submitted to Pnas ; sent out for review ; rejected

Among many nonsensical referee comments, was one interesting:

why would the red curve be shifted downward and not to the right ?

At that stage we gave up and buried the paper



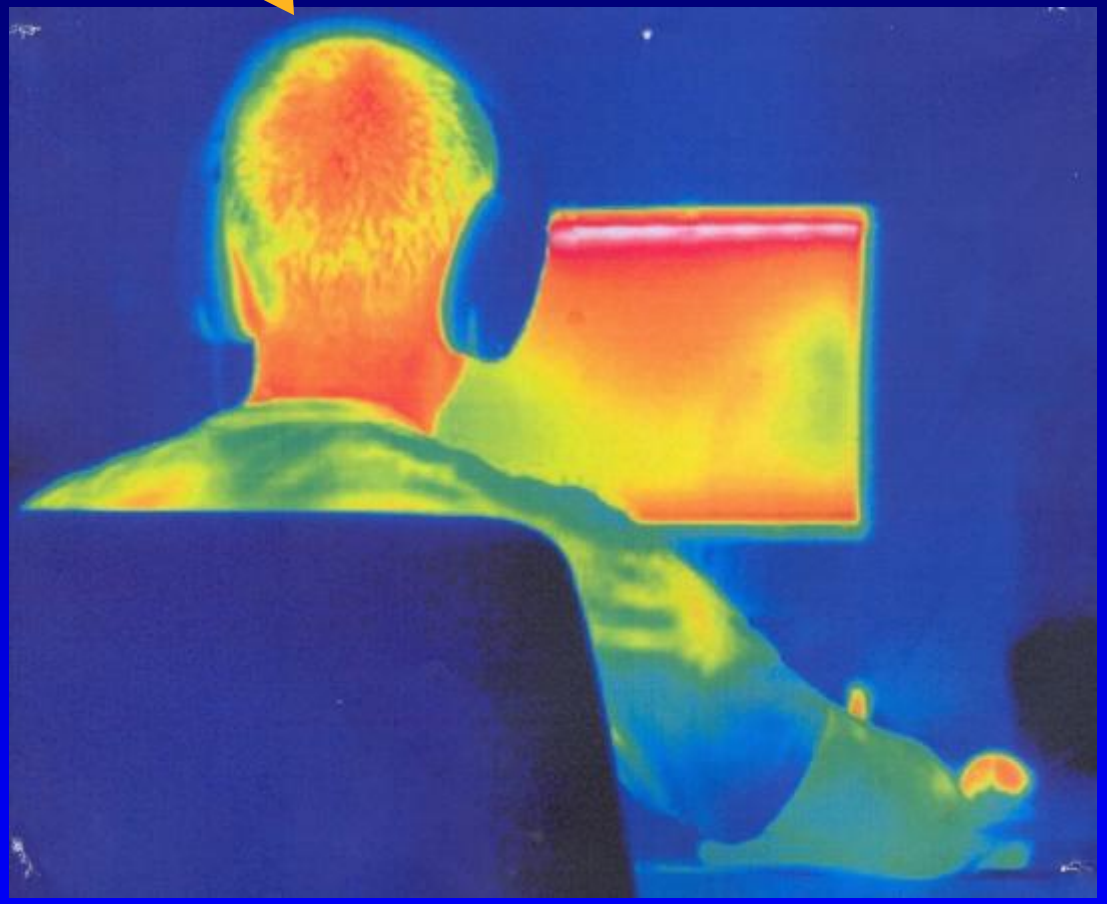
Early 2009, Sune Linder & colleagues organized a workshop on this topic.

Could we look at results from N-addition experiments (meta-analysis)?

Wouter Dieleman

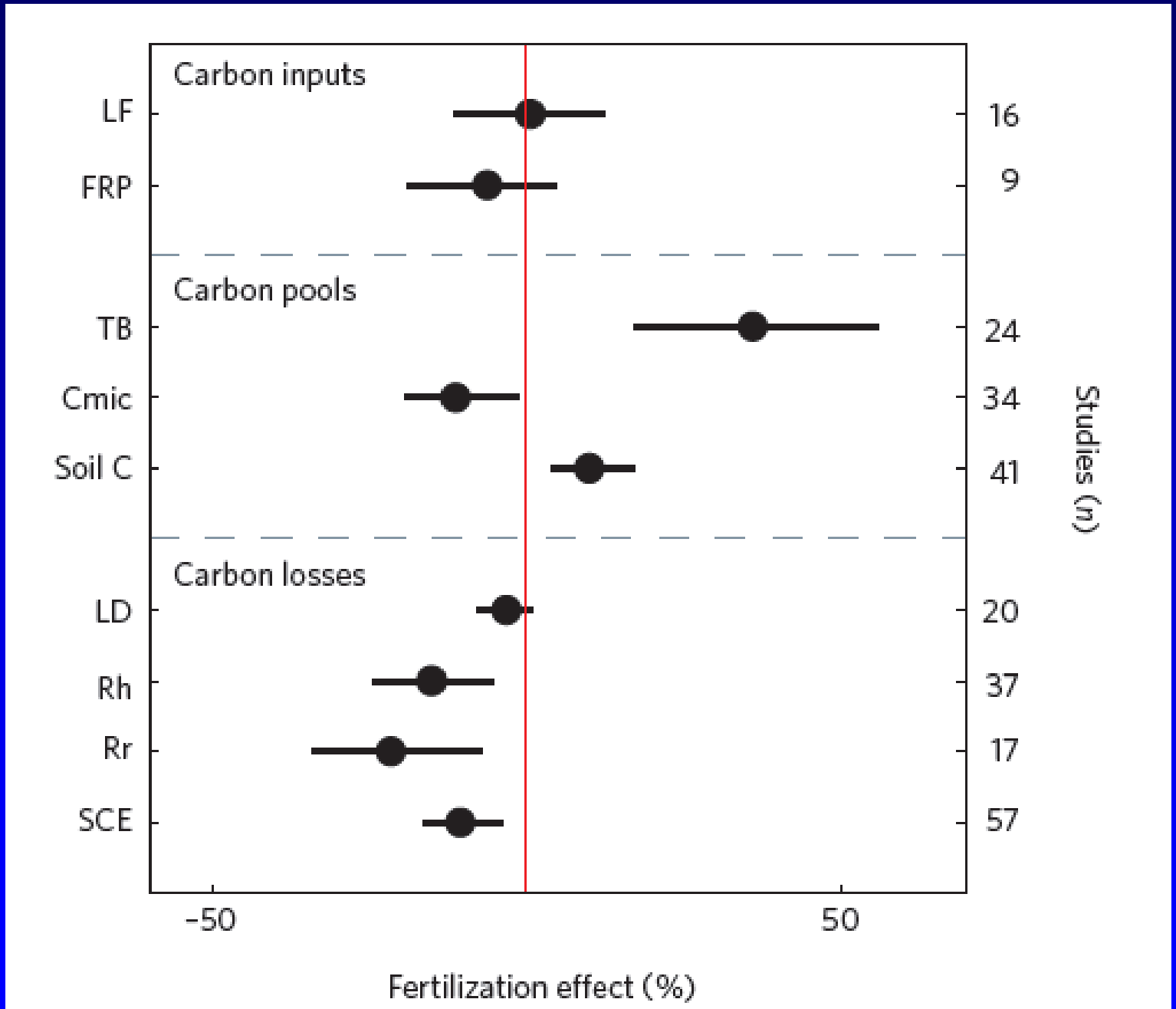
Substrate depleted

C-saturated

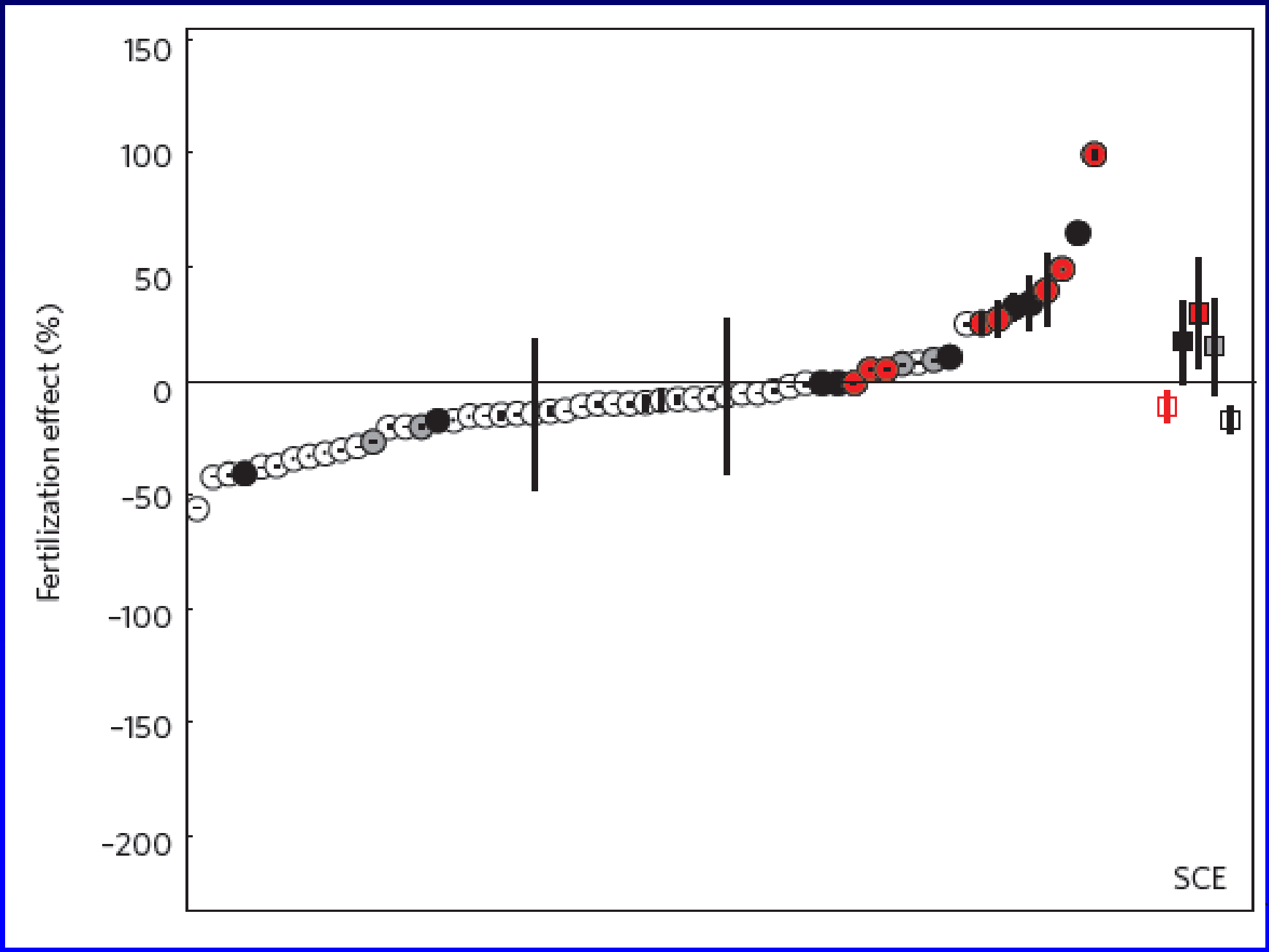


Meta-analysis of 57 fertilization experiments on trees/forests

RESULTS : Overall mean effects



How consistent is the decrease in SCE?

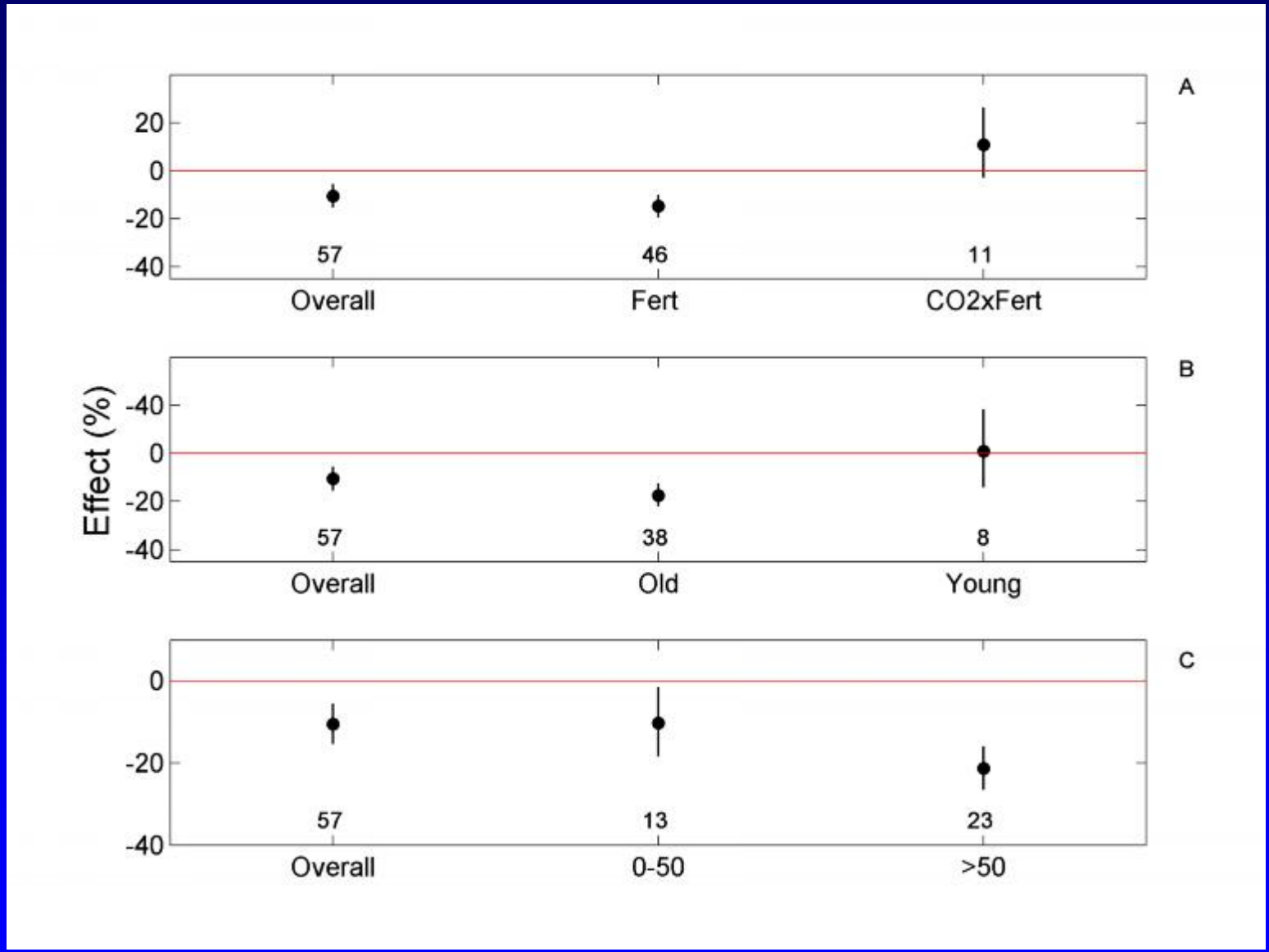


How consistent is this decrease of SCE?

P <0.001

P < 0.01 without CO_2

P = 0.01 without CO_2 and young trees



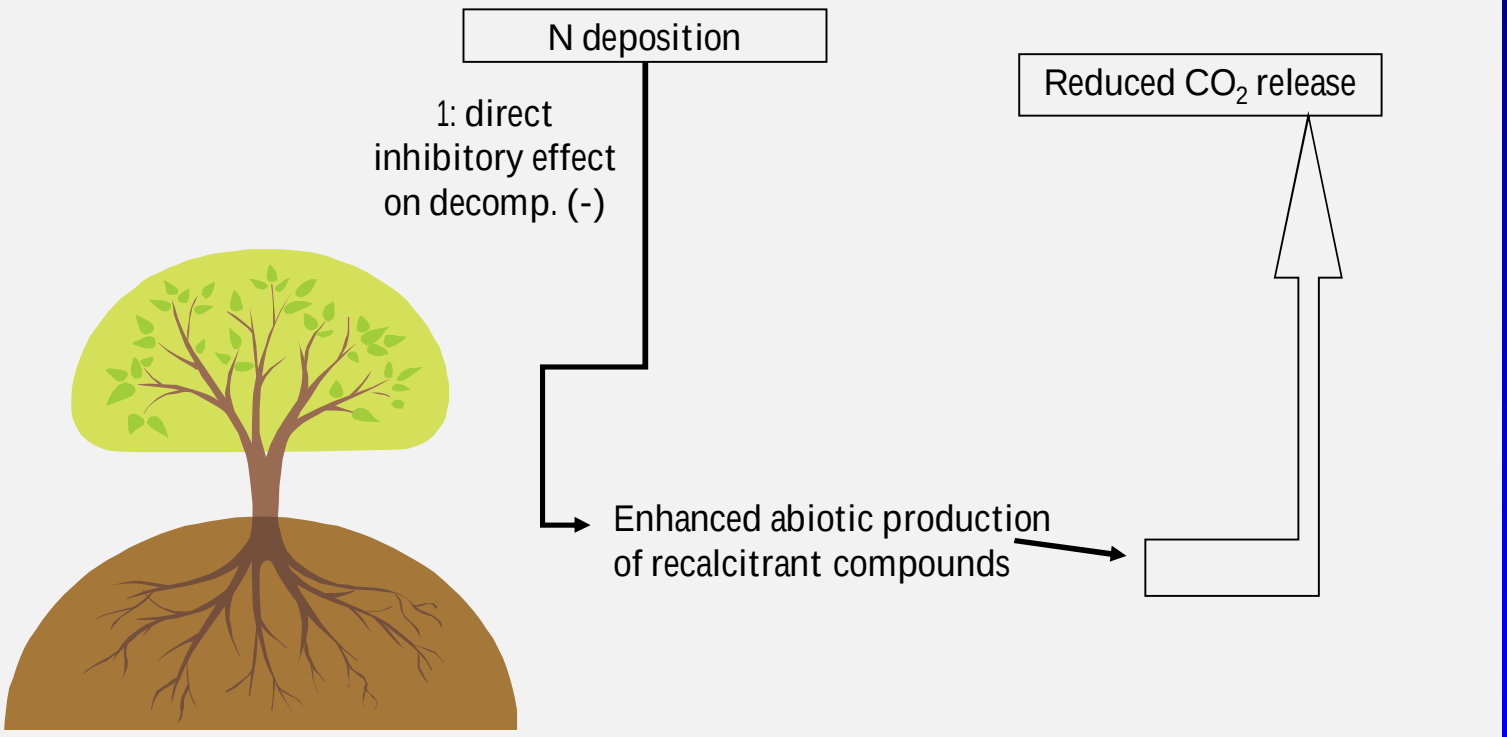
How consistent is the response:

always there except in young & CO2-fumigated forests

in young forests : faster canopy closure; LAI increases; GPP increases; excess C allocated to below-ground sinks

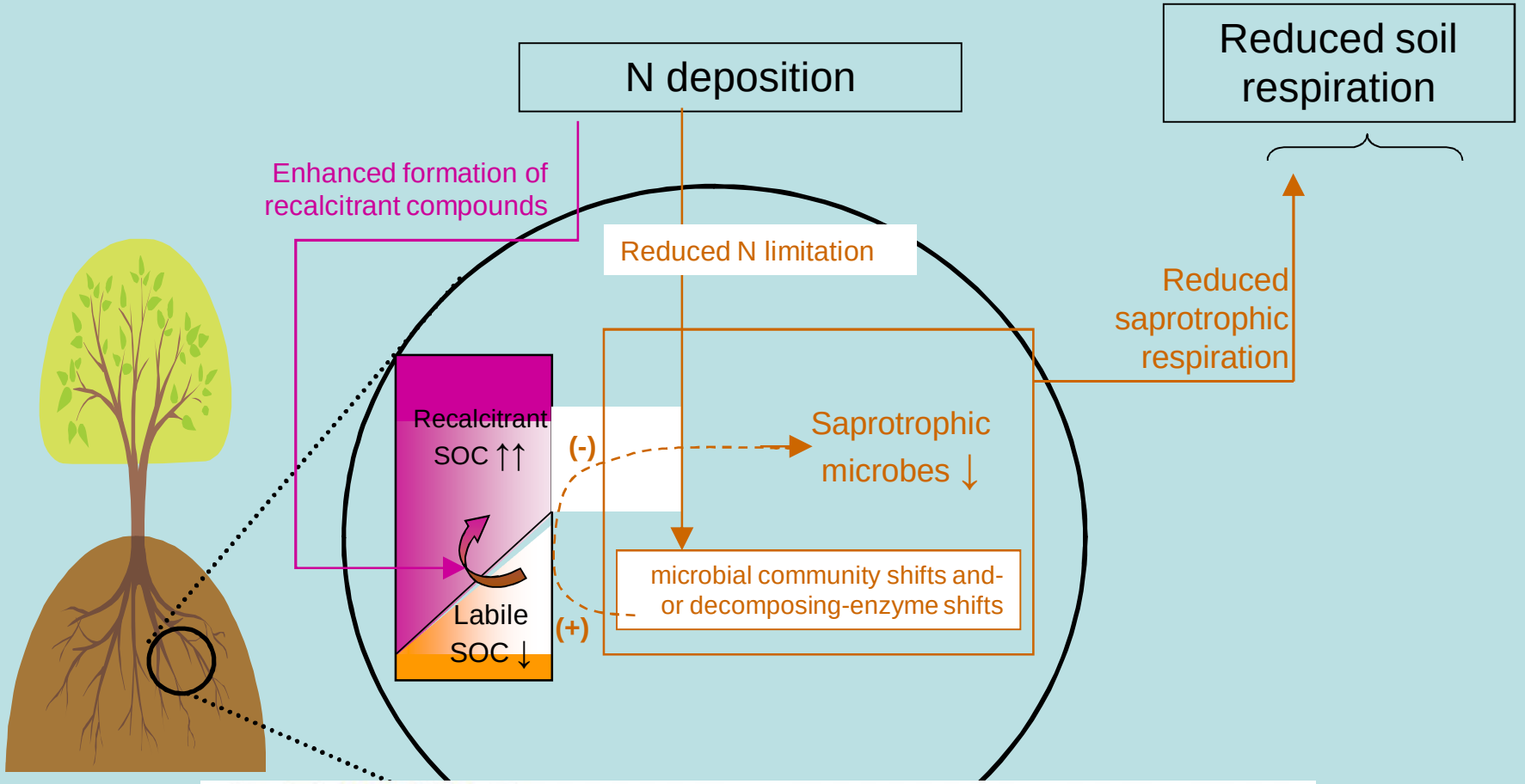
In FACE experiments : GPP increases; below-ground C allocation increases

UNDERLYING MECHANISMS? CONCEPTUAL SCHEME



THE EFFECT OF ADDED NITROGEN ON THE RATE OF DECOMPOSITION OF ORGANIC MATTER

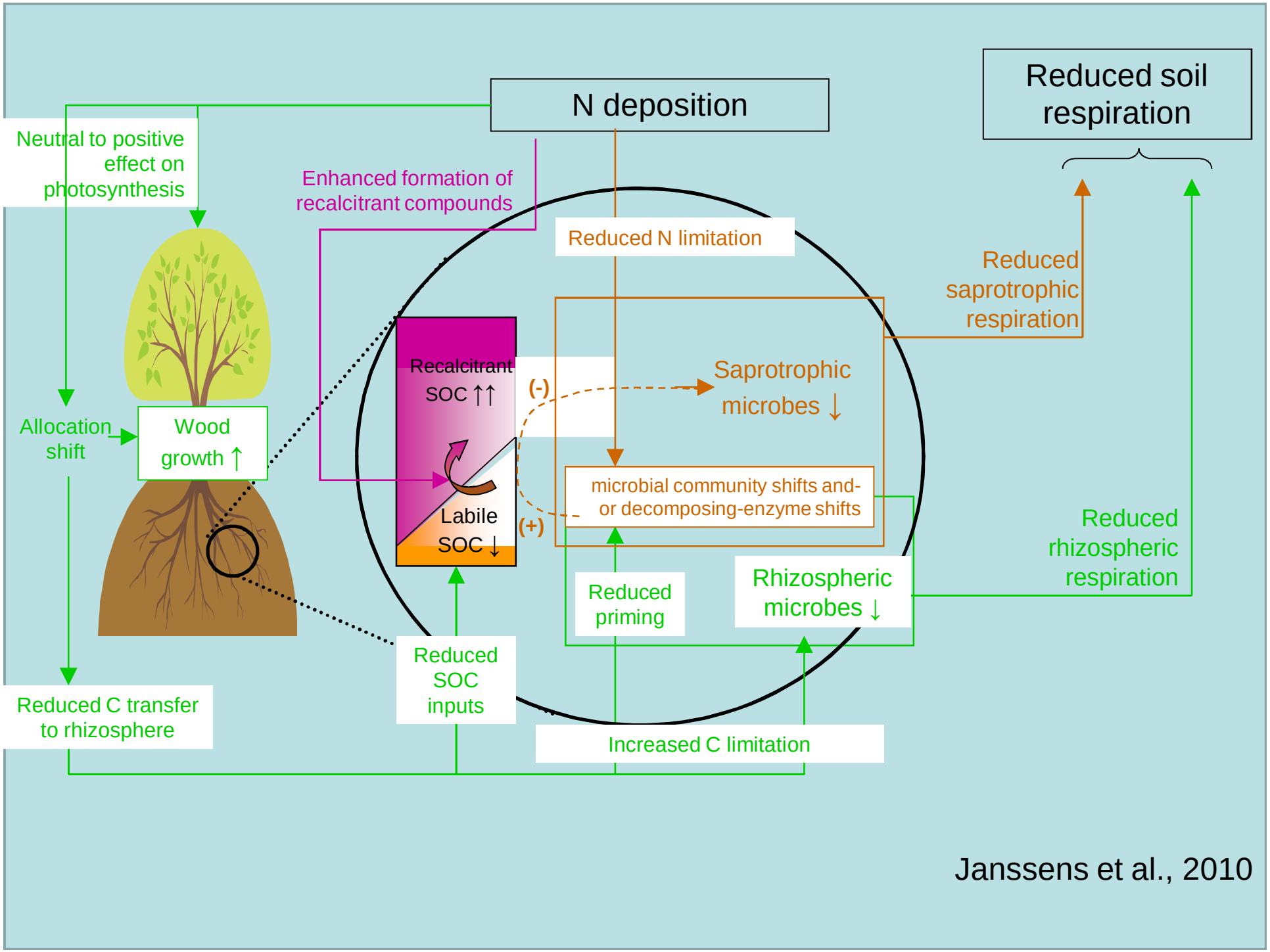
BY KÅRE FOG



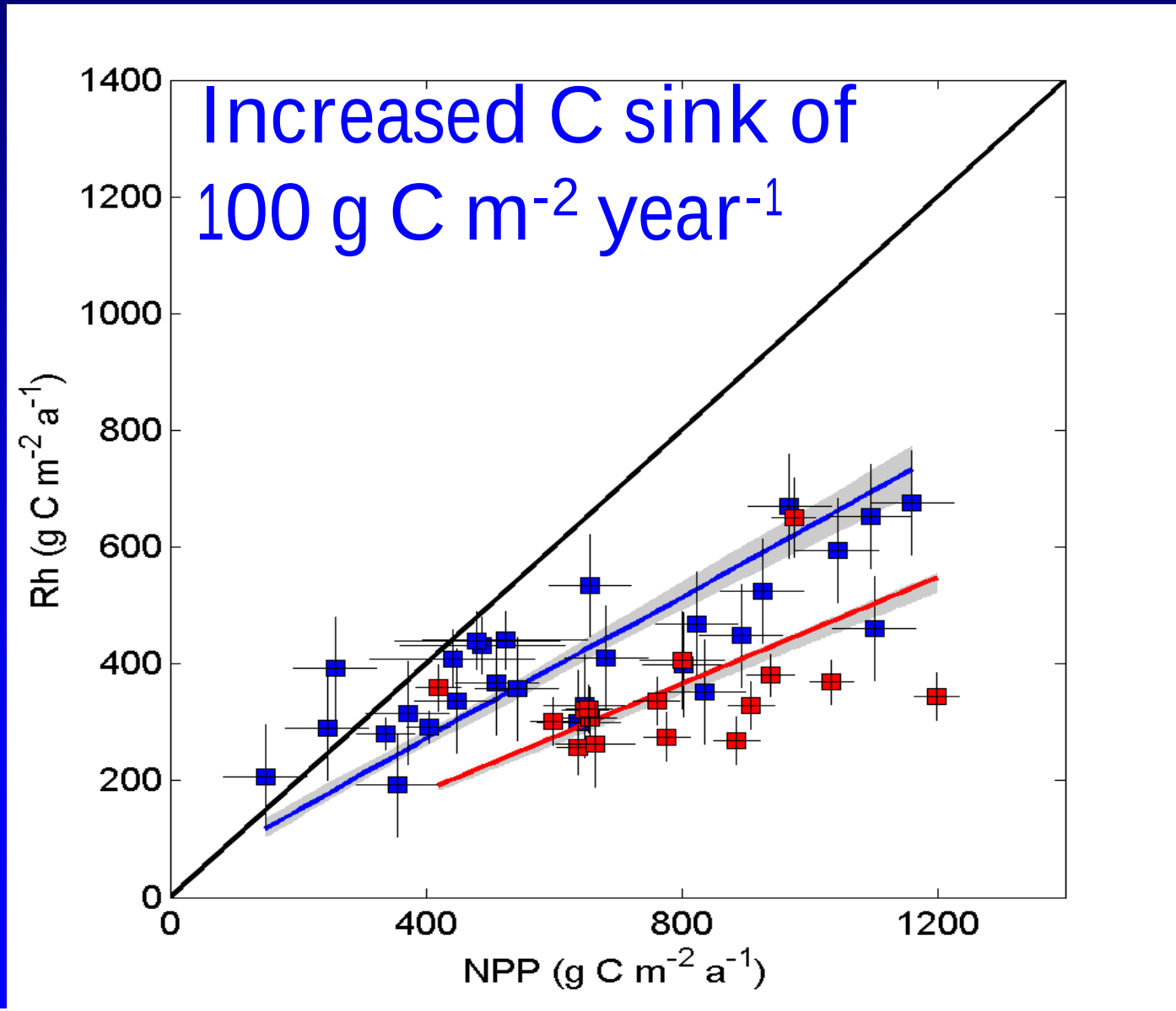
Oecologia (2001) 128:94–98
DOI 10.1007/s004420100646

Göran I. Ågren · Ernesto Bosatta · Alison H. Magill

Combining theory and experiment to understand effects of inorganic nitrogen on litter decomposition


N deposition
Reduced soil respiration
Neutral to positive effect on photosynthesis
Enhanced formation of recalcitrant compounds
Reduced N limitation
Reduced saprotrophic respiration
Recalcitrant SOC ↑↑
(-)
Saprotrophic microbes ↓
Allocation shift
Wood growth ↑
microbial community shifts and-or decomposing-enzyme shifts
Labile SOC ↓
(+)
Reduced rhizospheric respiration
Reduced priming
Rhizospheric microbes ↓
Reduced SOC inputs
Reduced C transfer to rhizosphere
Increased C limitation
Janssens et al., 2010

Mechanism = unknown, but magnitude of reduction = large



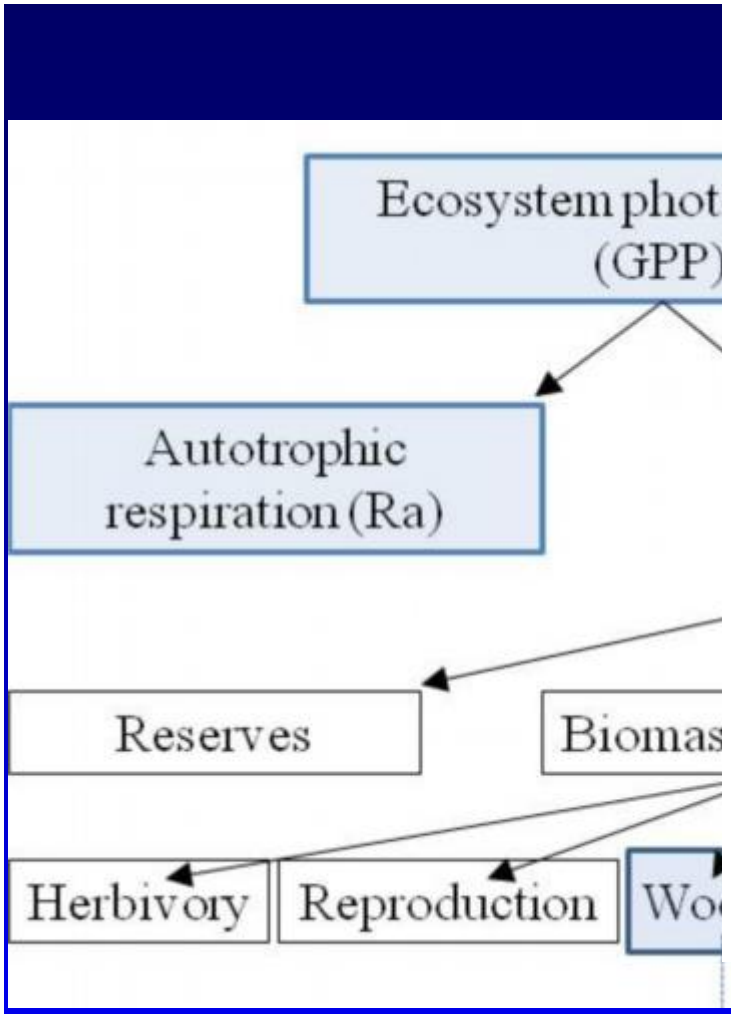
IMPLICATIONS

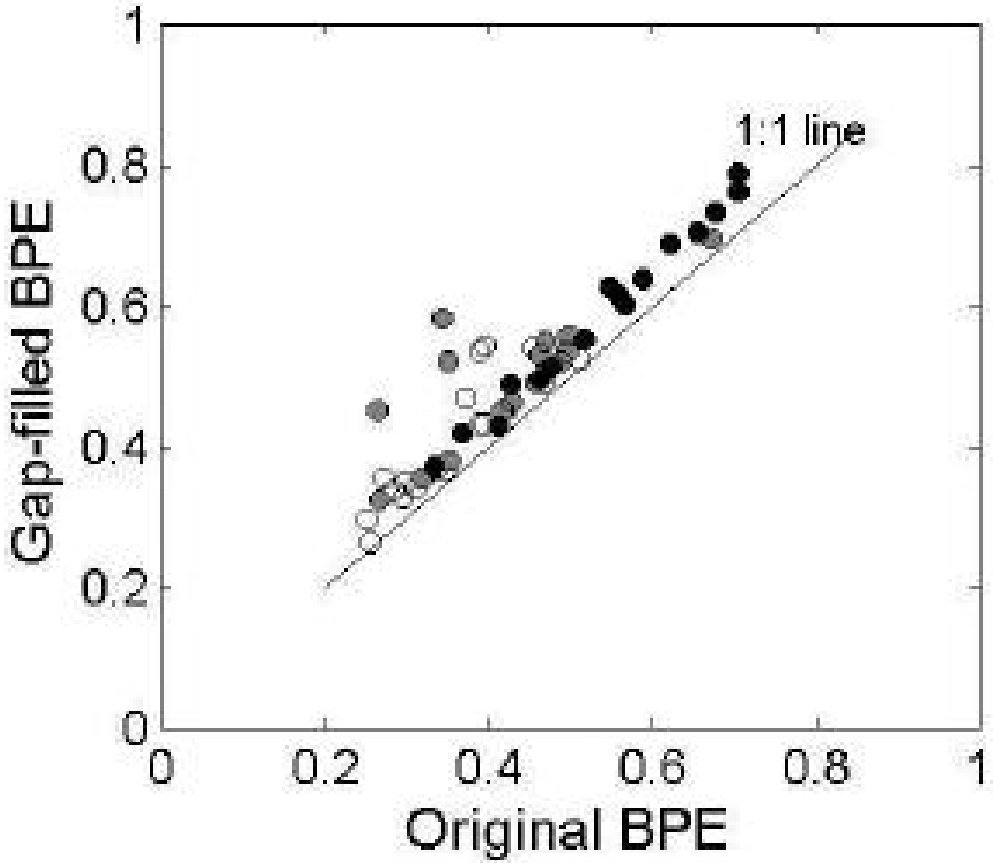
If direct inhibition = main mechanism: soil C sink = 100 g

BUT: if all of the reduction is due to shifted allocation and reduced C inputs, soil C sink = 0 !!

Could we detect allocation shifts in our global forest C database ?

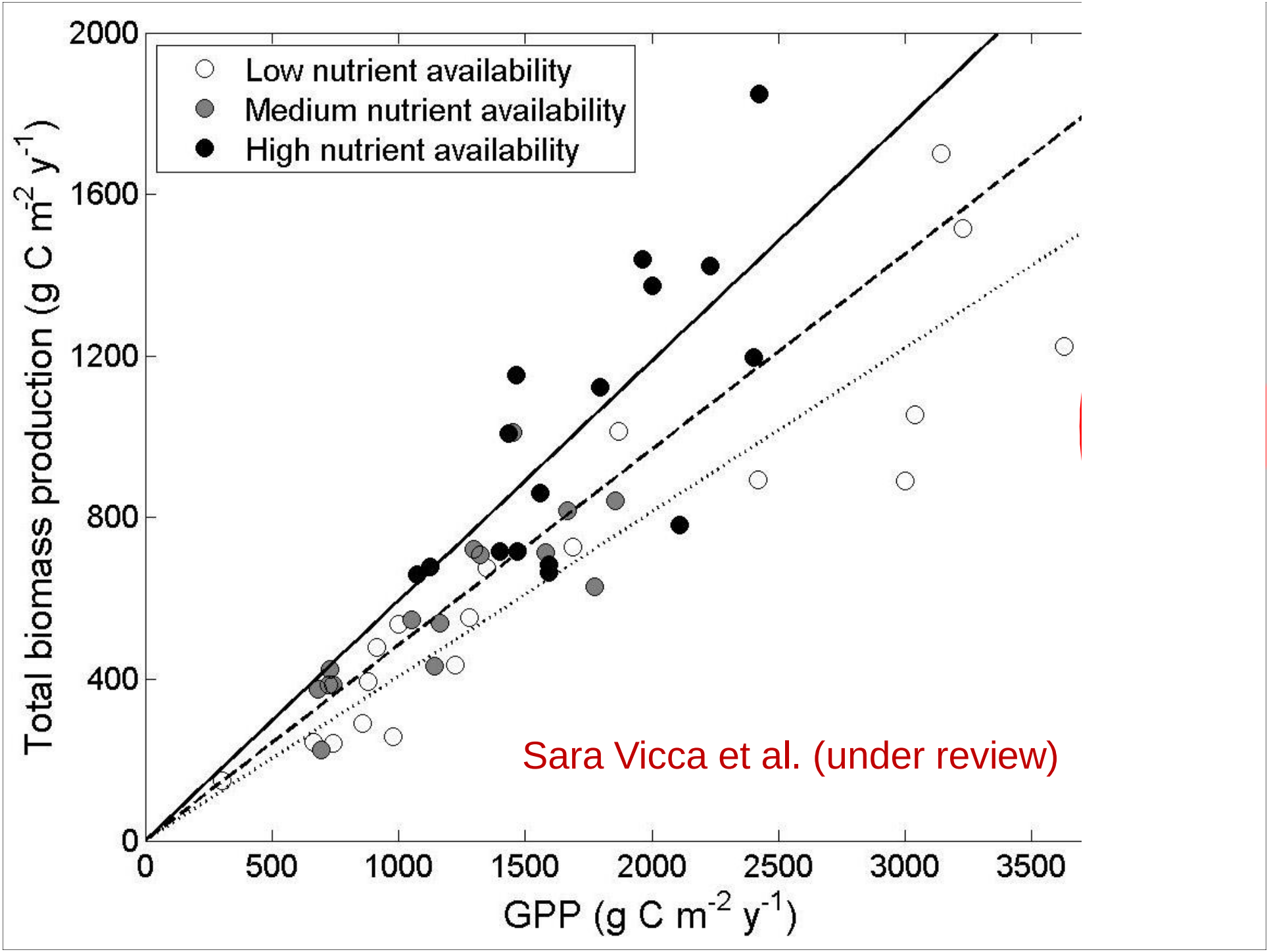
YES !

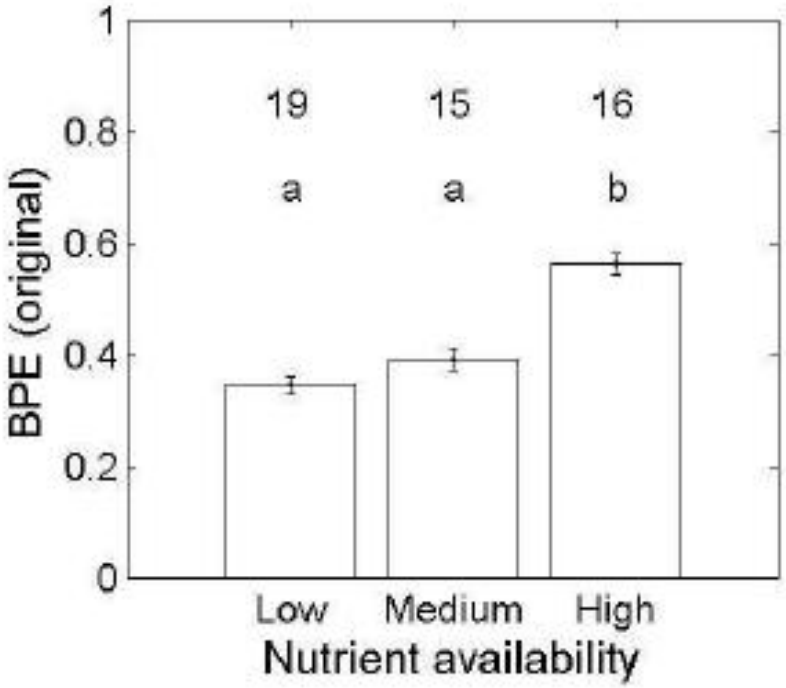


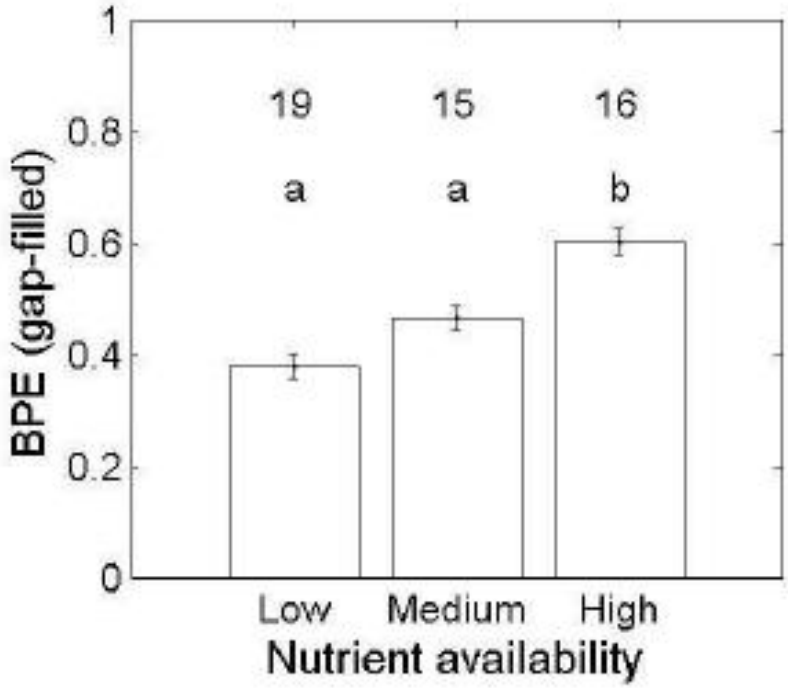


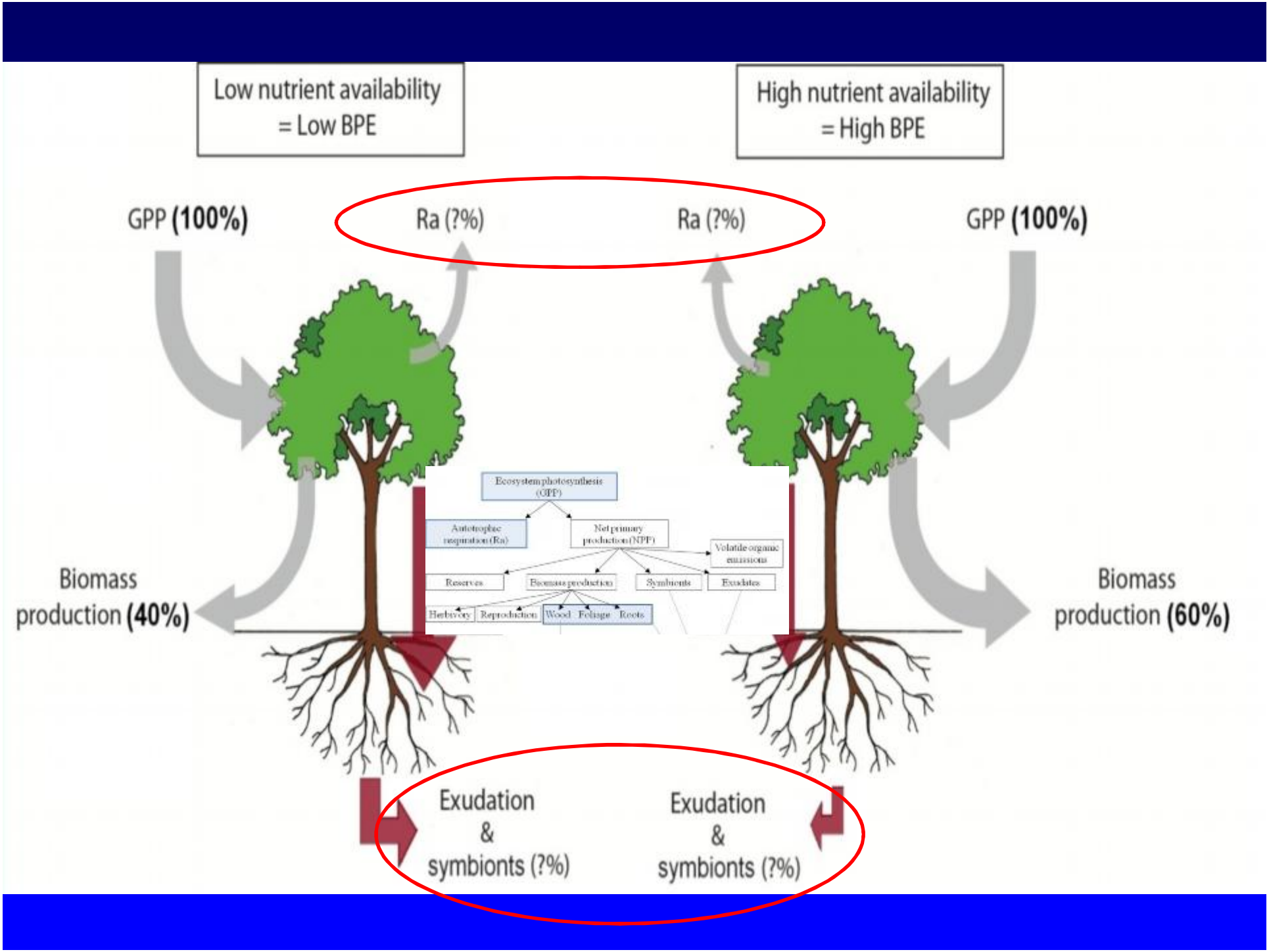
Original biomass production	Reproductive organ production	Understory production	Litterfall decomposition	Biomass losses to herbivores	Gapfilled biomass production

		Indicators									Extra support		
ID	Nutr. class	soil type	N soil	other nutr.	CEC/exch. bases	N min.	pH	water status	flora	atm. dep.	hist.	report	expert	certainty level
1	medium		x			x							x	4
2	low	x						x				x		3
3	medium	x								x				3
4	high		x									x	x	4
5	high		x									x	x	4
6	low			x	x									5


Low nutrient availability
Medium nutrient availability
High nutrient availability
Total biomass production (g C m-2 y-1)
GPP (g C m-2 y-1)
0
400
800
1200
1600
2000
0
500
1000
1500
2000
2500
3000
3500
Sara Vicca et al. (under review)


BPE (original)
1
0.8
0.6
0.4
0.2
0
19
15
16
a
a
b
Low
Medium
High
Nutrient availability


BPE (gap-filled)
1
0.8
0.6
0.4
0.2
0
19
15
16
a
a
b
Low
Medium
High
Nutrient availability


Low nutrient availability
= Low BPE
High nutrient availability
= High BPE
GPP (100%)
Ra (?%)
Ra (?%)
GPP (100%)
Biomass production (40%)
Biomass production (60%)
Ecosystem photosynthesis (GPP)
Autotrophic respiration (Ra)
Net primary production (NPP)
Volatile organic emissions
Reserves
Biomass production
Symbionts
Exudates
Herbivory
Reproduction
Wood
Foliage
Roots
Exudation & symbionts (?%)
Exudation & symbionts (?%)

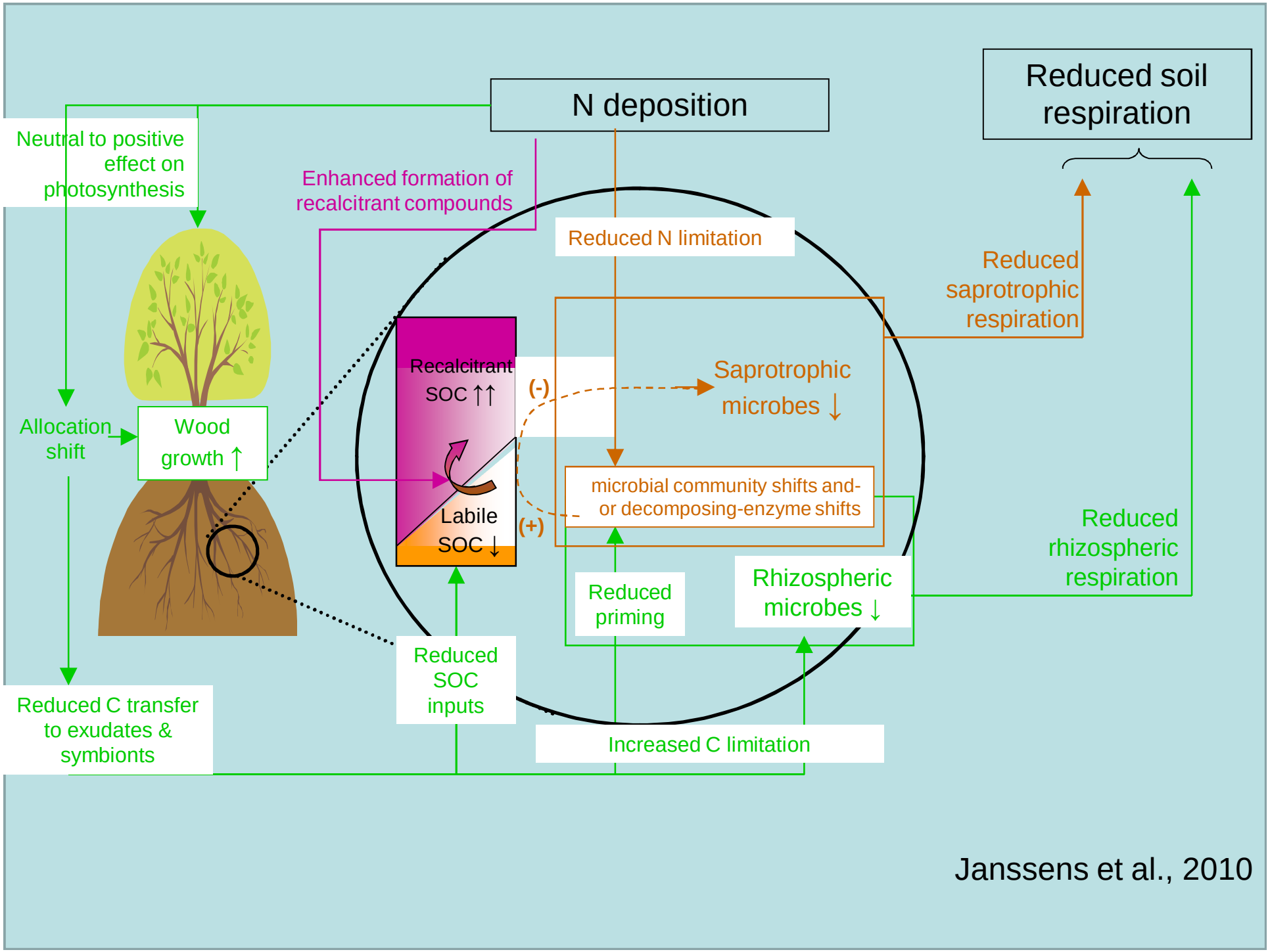
Could the unaccounted allocation to symbionts & exudation really amount to > 20% of GPP ??

- Litton et al. 2007: Total Below Ground Carbon Allocation = 10%-60% of GPP
- Phillips & Fahey 2007: fertilization reduces rhizosphere microbial activity by 40-50%
- Högberg M. et al. 2010: fertilization reduces C allocation to soil biota by 60%
- Hobbie E. et al. 2006: fertilization reduces root exudation and symbionts by up to 22% of GPP
- Treseder 2004: P fertilization reduces mycorrhizal abundance by 32%

If 20% more of GPP is transferred to non-biomass NPP components in low nutrient conditions, soil C cycling would be much higher

Thus, N addition in N (co-)limited systems may evoke a huge reduction in this C-flux

The large reduction in soil respiration under high N deposition is likely due to reduced C exudation & tranfers to symbionts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(+)
Reduced rhizospheric respiration
Reduced priming
Rhizospheric microbes ↓
Reduced SOC inputs
Reduced C transfer to exudates & symbionts
Increased C limitation
Janssens et al., 2010

Take home messages:

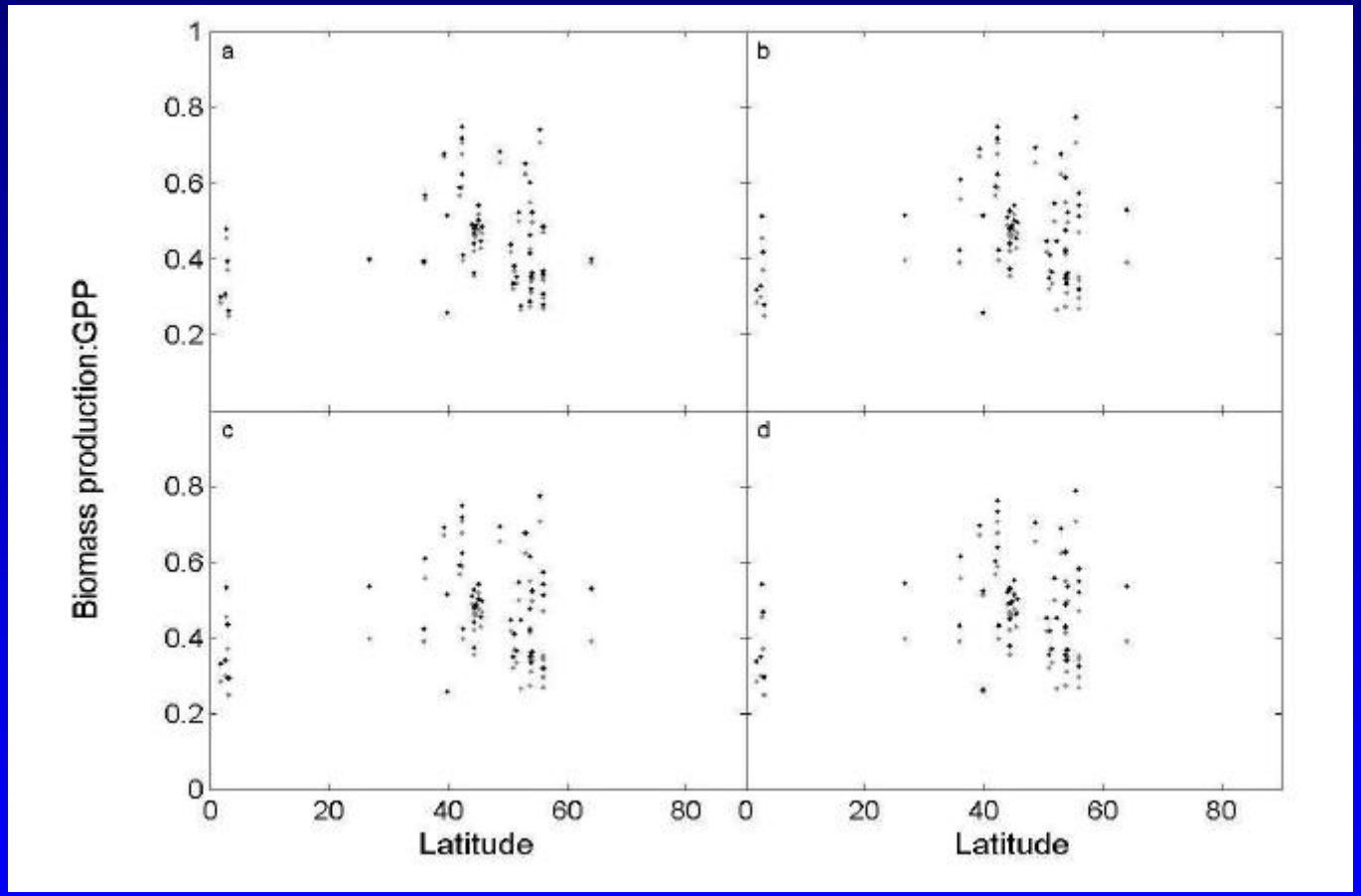
1. N deposition slows down soil C cycling. This change is HUGE !!! (hundred(s) of grams C m-2 yr-1)

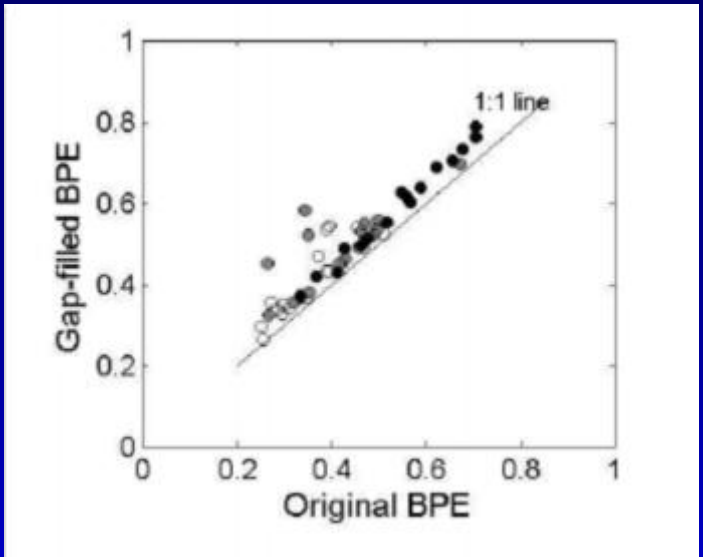
2. The main reason is a nutrient-induced C-allocation shift between the non-biomass components of NPP and biomass production (hundreds of grams C m-2 yr-1)

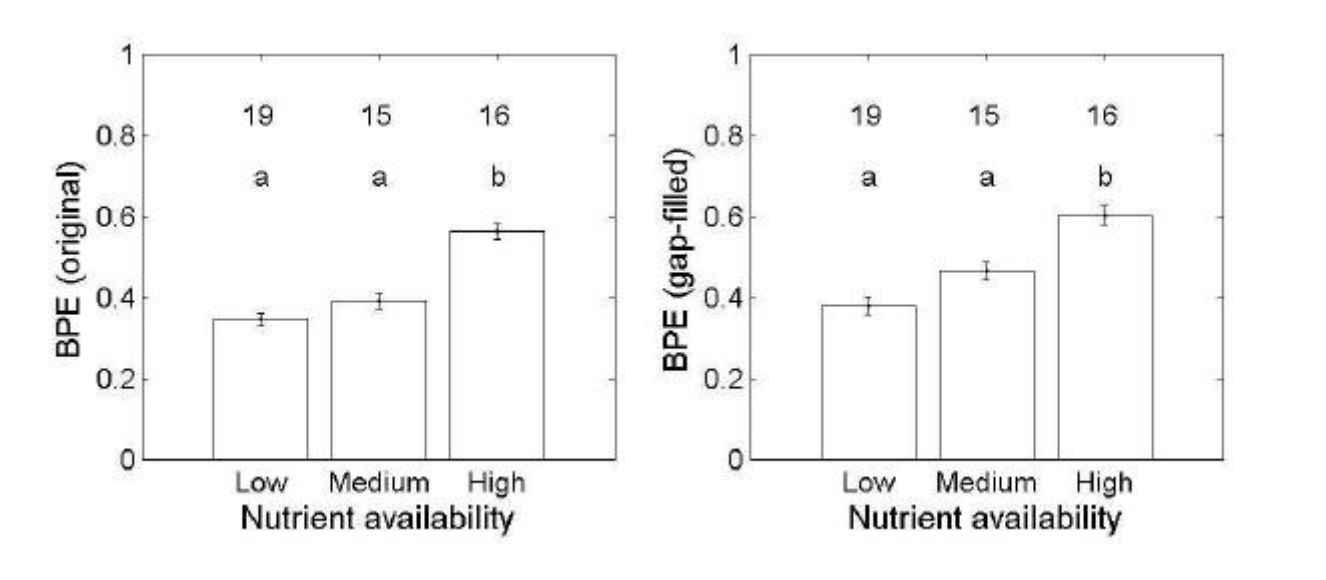
Thank you

		Indicators									Extra support		
ID	Nutr. class	soil type	N soil	other nutr.	CEC/exch. bases	N min.	pH	water status	flora	atm. dep.	hist.	report	expert	certainty level
1	medium		x			x							x	4
2	low	x						x				x		3
3	medium	x								x				3
4	high		x									x	x	4
5	high		x									x	x	4
6	low			x	x									5

ID	Original biomass production	Reproductive organ production	Understory production	Litterfall decomposition	Biomass losses to herbivores	Gapfilled biomass production
1	514.0	1.4	21.8	NA	10.2	547.4
2	842.5	35.5	NA	NA	15.3	893.3
3	656.0	36.2	NA	NA	15.5	707.8
4	668.0	34.3	NA	NA	14.9	717.2
5	805.0	38.6	NA	NA	16.3	859.9
6	1,036.4	45.0	76.1	46.6	18.5	1,222.7
7	638.8	24.6	3.3	NA	11.5	678.1
8	1,247.0	53.9	52.8	NA	21.3	1,375.0
9	389.0	10.6	130.0	NA	6.3	535.8


a
b
c
d
Biomass production:GPP
Latitude
Latitude
0
0.2
0.4
0.6
0.8
1
0
20
40
60
80


1:1 line
Gap-filled BPE
Original BPE
0
0.2
0.4
0.6
0.8
1


BPE (original)
19
15
16
a
a
b
Low
Medium
High
Nutrient availability
BPE (gap-filled)
19
15
16
a
a
b
Low
Medium
High
Nutrient availability

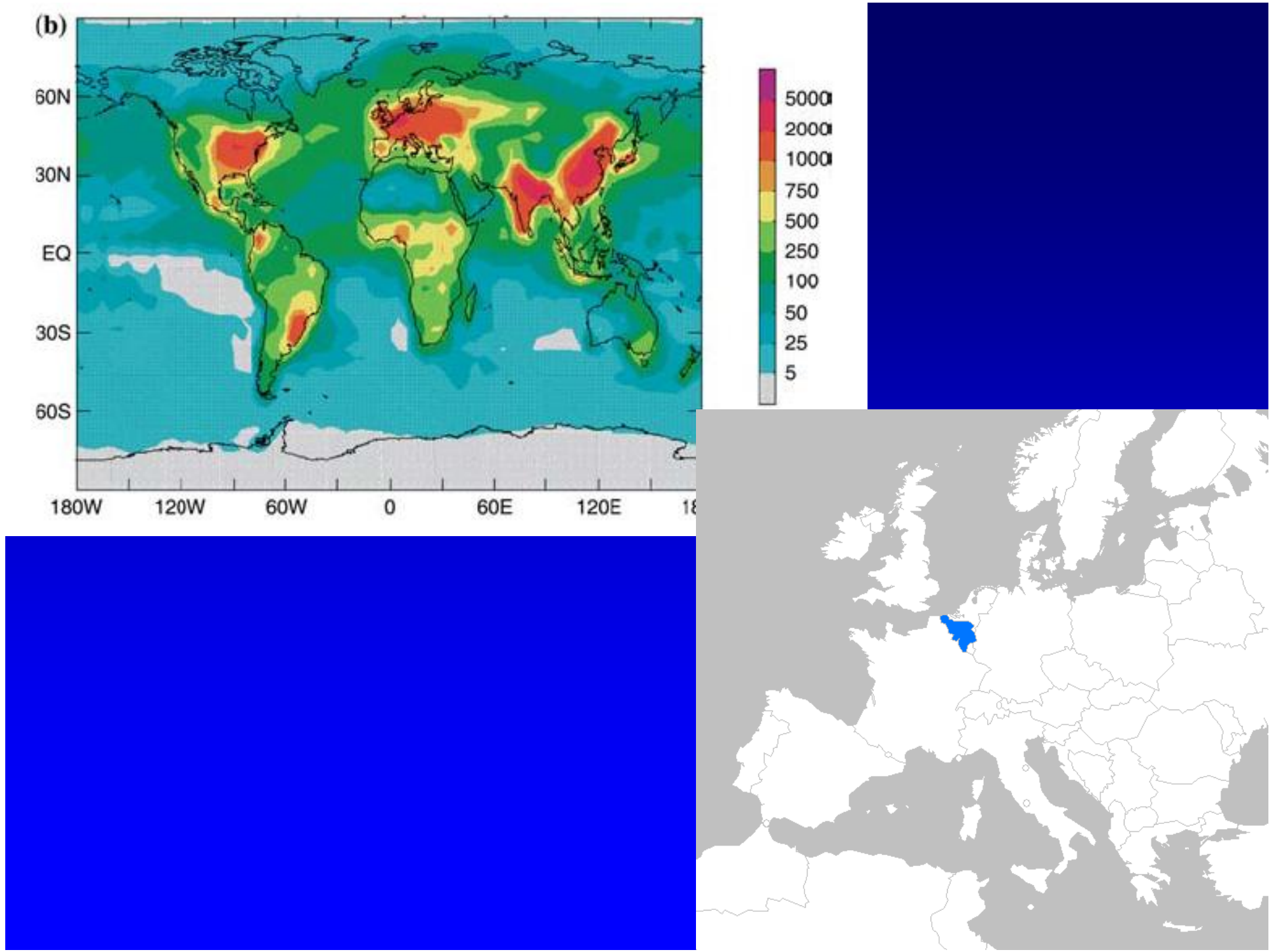
Effect of N deposition on decomposition of plant litter and soil organic matter in forest systems

Björn Berg and Egbert Matzner

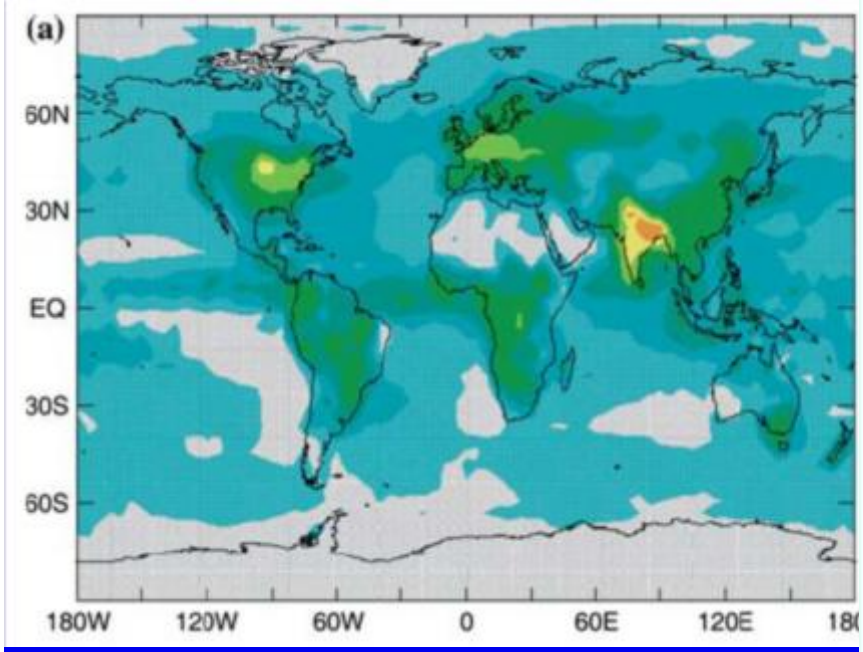
Oecologia (2001) 128:94–98
DOI 10.1007/s004420100646

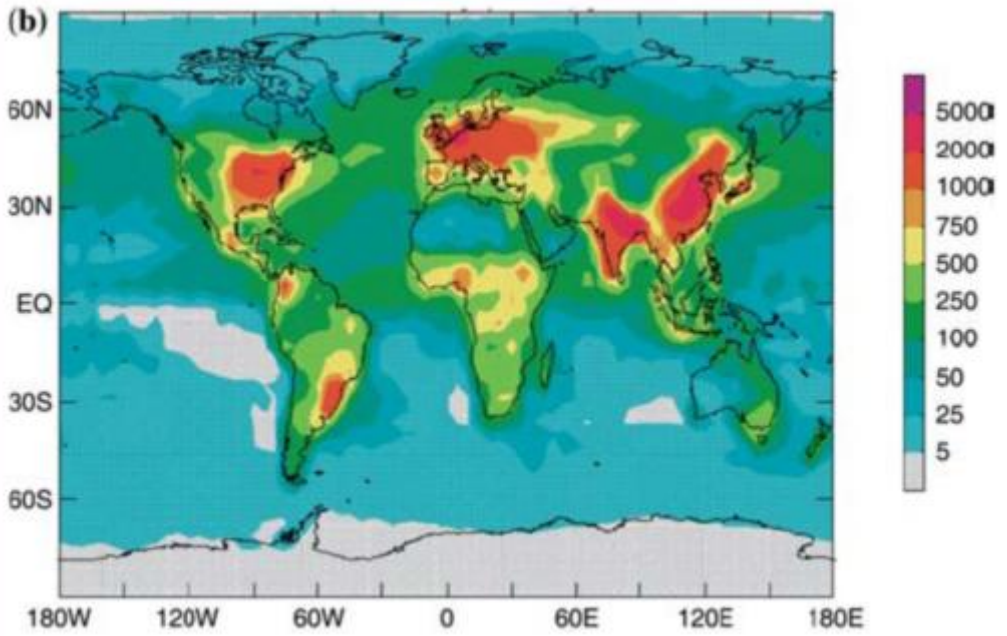
Göran I. Ågren · Ernesto Bosatta · Alison H. Magill

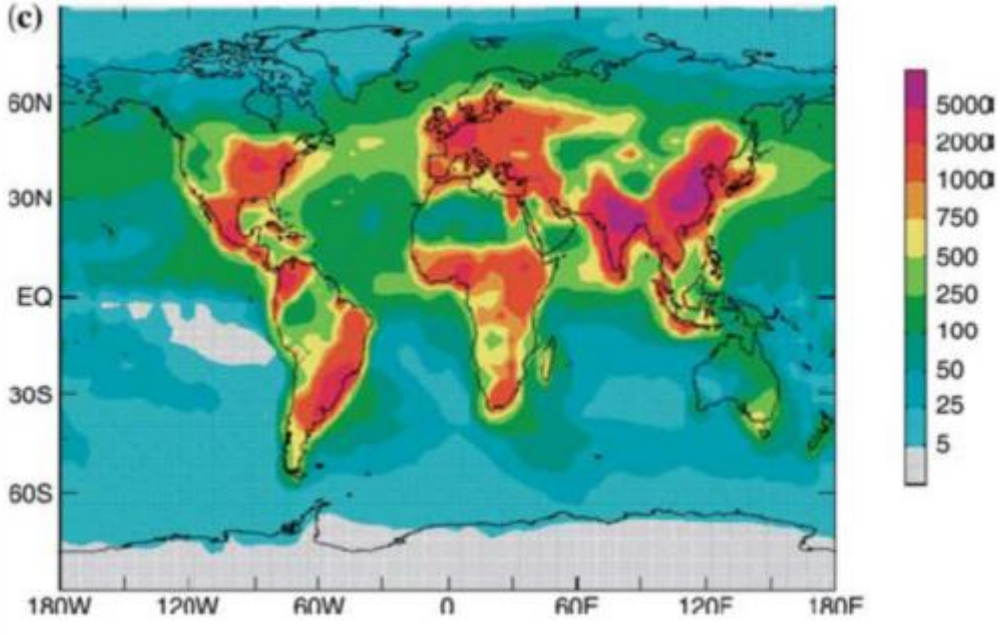
Combining theory and experiment to understand effects of inorganic nitrogen on litter decomposition


(b)
60N
30N
EQ
30S
60S
180W
120W
60W
0
60E
120E
5000
2000
1000
750
500
250
100
50
25
5

N deposition is predicted to increase further







Galloway et al., 2004

nature geoscience

FOCUS | REVIEW ARTICLE

PUBLISHED ONLINE: 25 APRIL 2010 | DOI: 10.1038/NGEO844

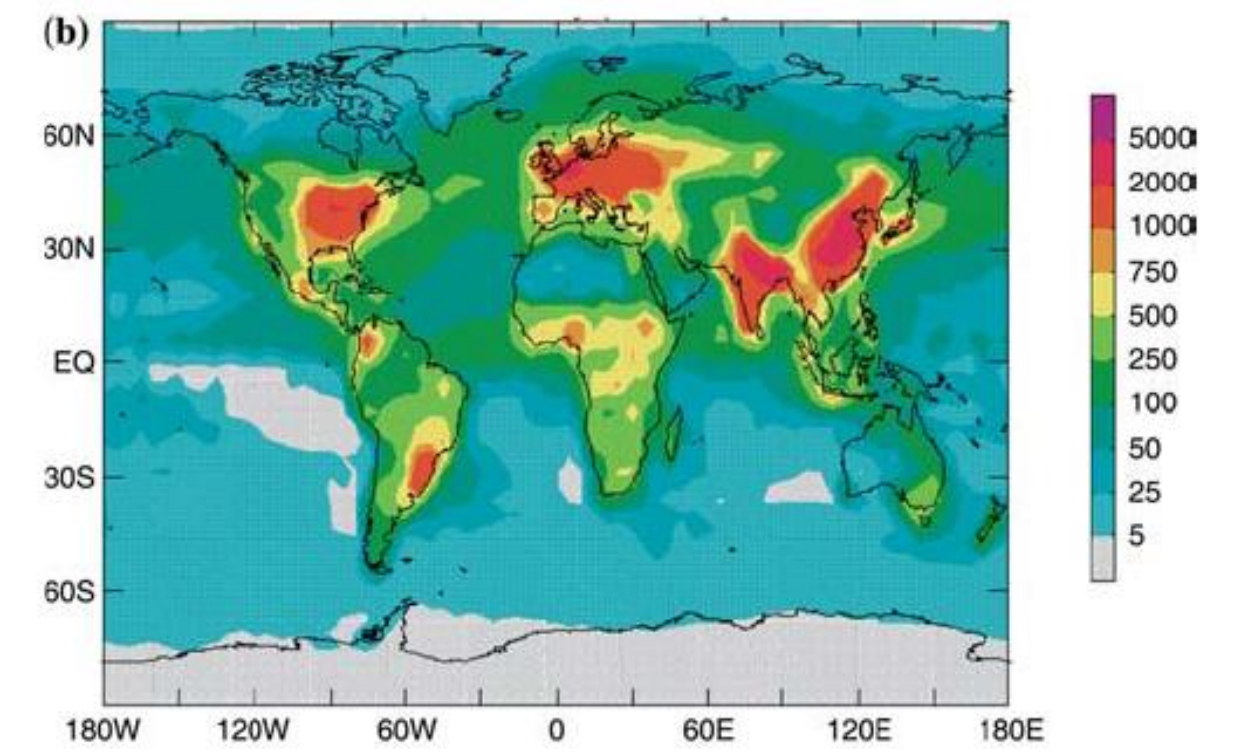
Reduction of forest soil respiration in response to nitrogen deposition

I. A. Janssens[1]*, W. Dieleman[1], S. Luyssaert[2], J-A. Subke[3], M. Reichstein[4], R. Ceulemans[1], P. Ciais[2], A. J. Dolman[5], J. Grace[6], G. Matteucci[7], D. Papale[8], S. L. Piao[9], E-D. Schulze[4], J. Tang[10] and B. E. Law[11]

N deposition retards below-ground C cycling in forests: evidence, underlying mechanisms and relevance

Introduction (2)

PhD on soil C in a highly eutrophied & acidified forest where SR < litter fall



Galloway et al., 2004