Articulation and consistency of the processes driving soil organic matter dynamics at different scales

Laurent Saint-André, Delphine Derrien, Bernhard Zeller

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Laurent SAINT-ANDRE, Delphine DERRIEN, Bernd ZELLER

With special thank to Rémi d'Annunzio, Pierre-Joseph

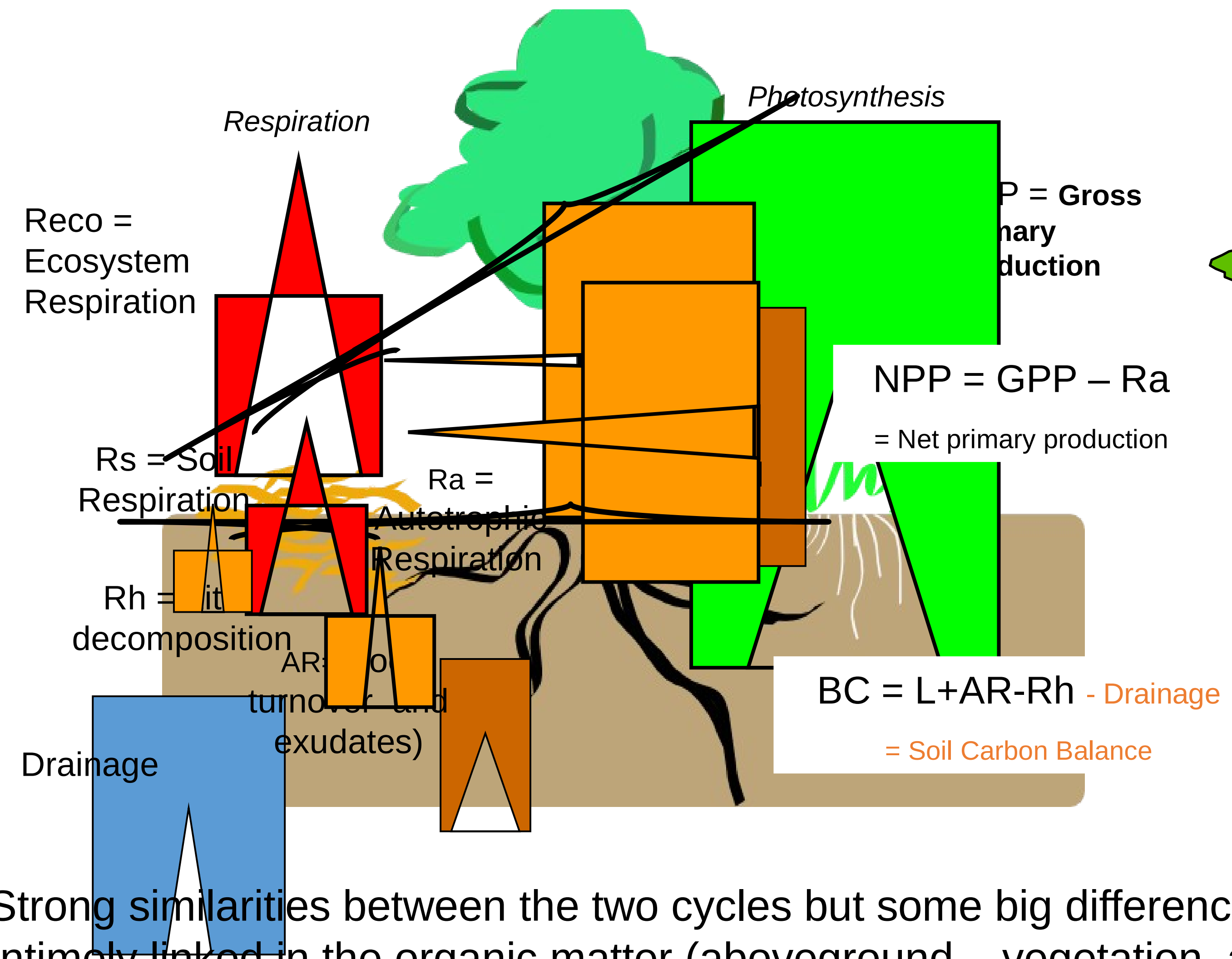
Carbon and Nitrogen cycle in a Forest Ecosystem ?

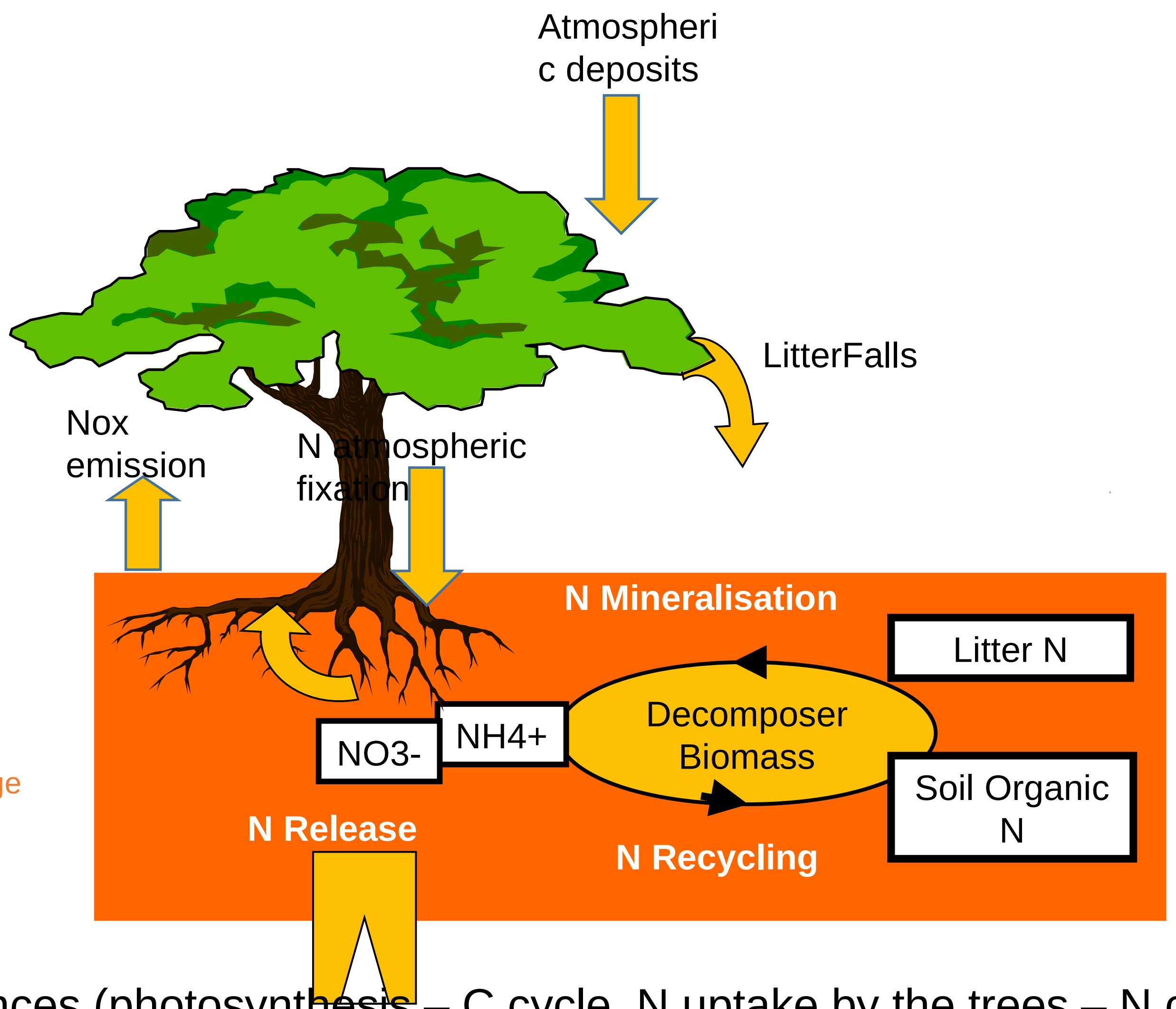
CARBON

NITROGEN

Net Ecosystem Exchange : NEE = GPP – Reco

Carbon Uptake or Release

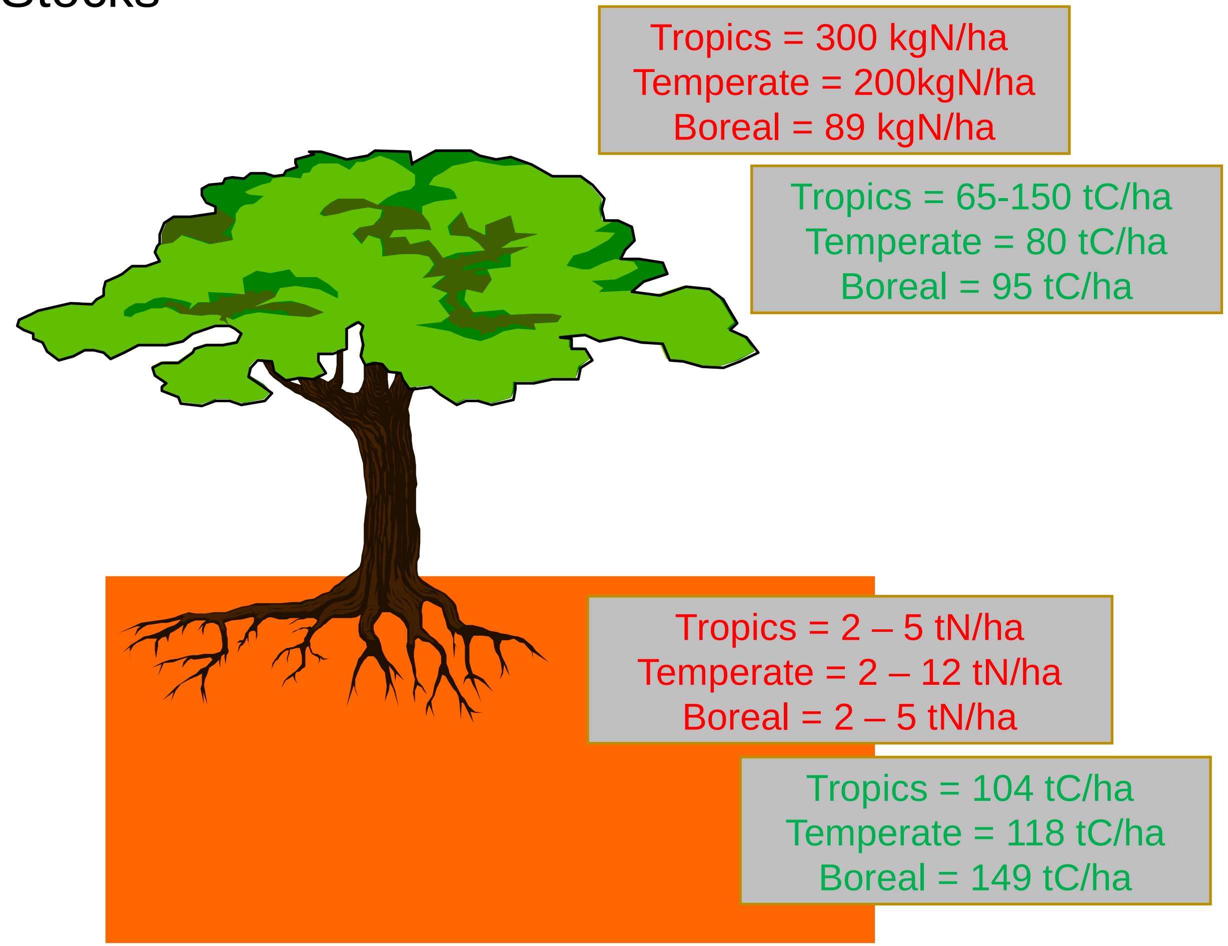




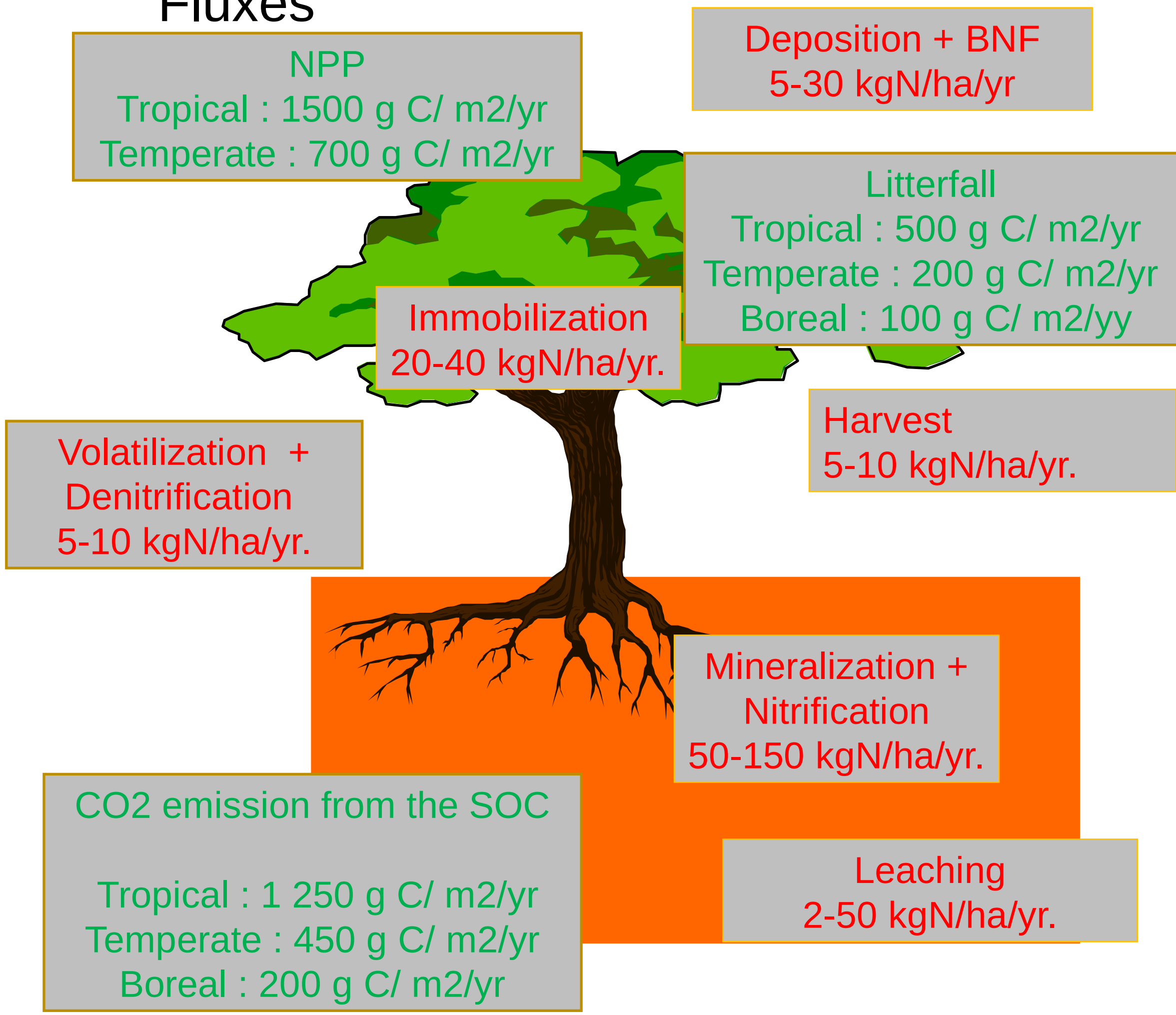
Strong similarities between the two cycles but some big differences (photosynthesis – C cycle, N uptake by the trees – N c
ntimely linked in the organic matter (aboveground – vegetation, and belowgroound – the soil organic matter)

Soil Organic Matter…….. Does it matter ?

Stocks



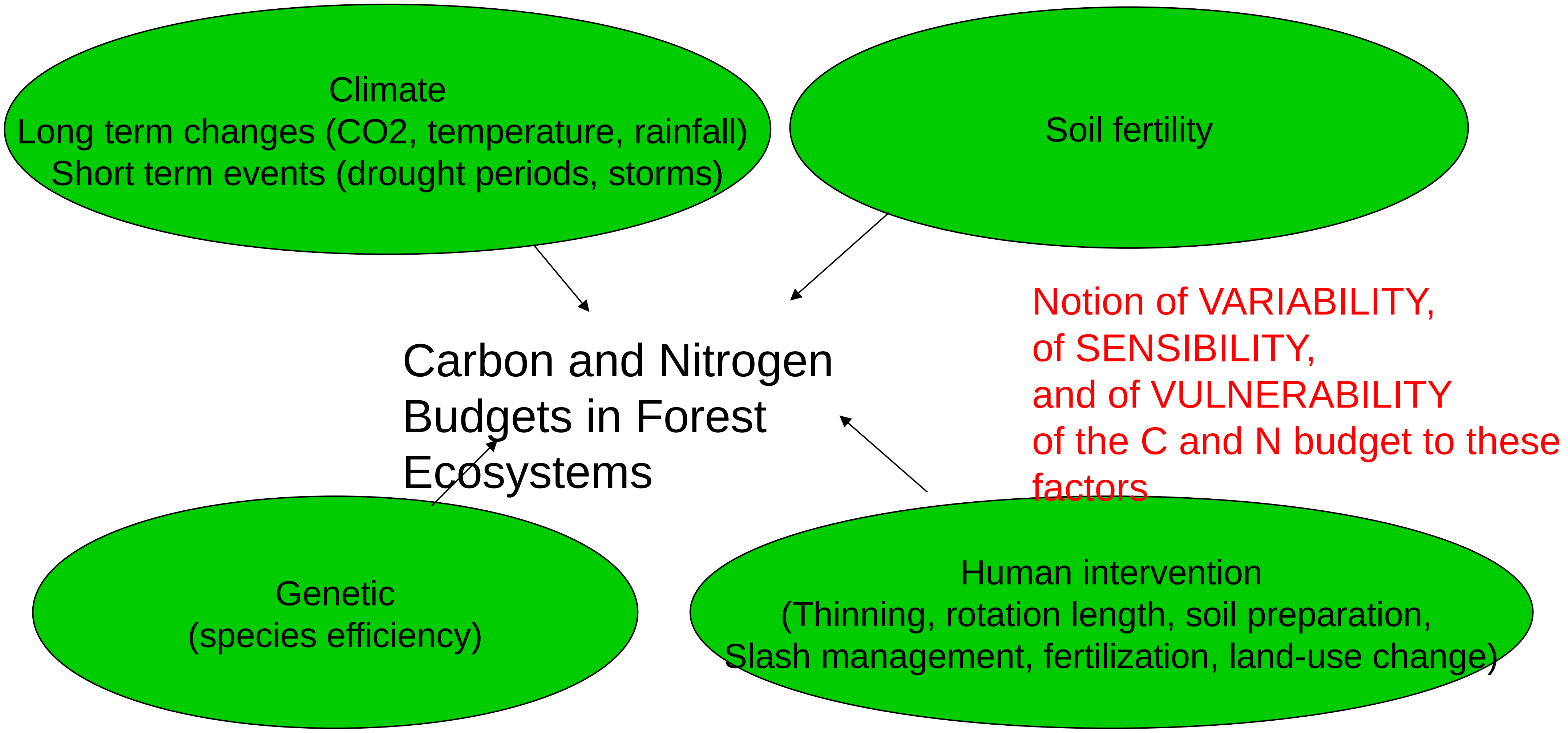
Fluxes



r Nitrogen : highest stocks and fluxes take place in the soil
r Carbon : highest stocks in the soil (in average), and of the same magnitude of NPP (third flux after GPP and Reco)

From Schlessinger 1997

Soil Organic Matter…….. Variable ? Sensible ? Vulnerable ?



Hypothesis 1

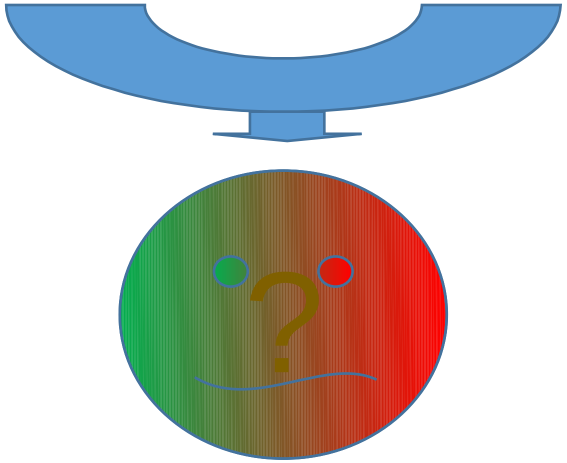
Increase of CO_2 and atmospheric deposits

- ⇒ Increased tree productivity
- ⇒ Increased litter inputs
- ⇒ Increased soil C and N stocks ?

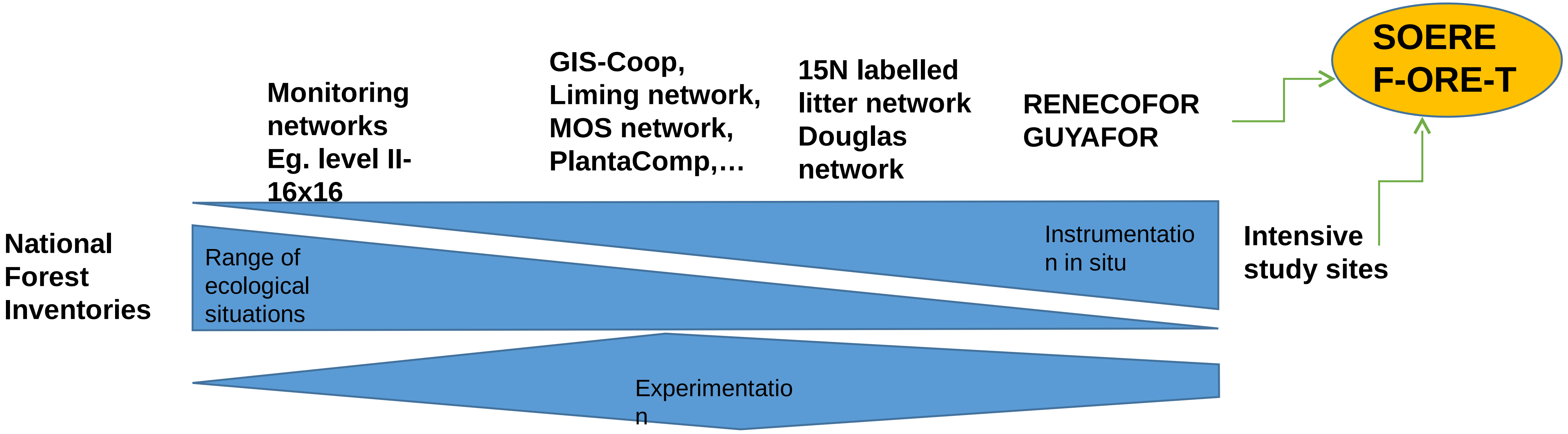
Hypothesis 2

Increase of temperature during winter

- ⇒ Increased micro-meso-macro fauna activities
- ⇒ Increased mineralization
- ⇒ Decreased soil C and N stocks ?



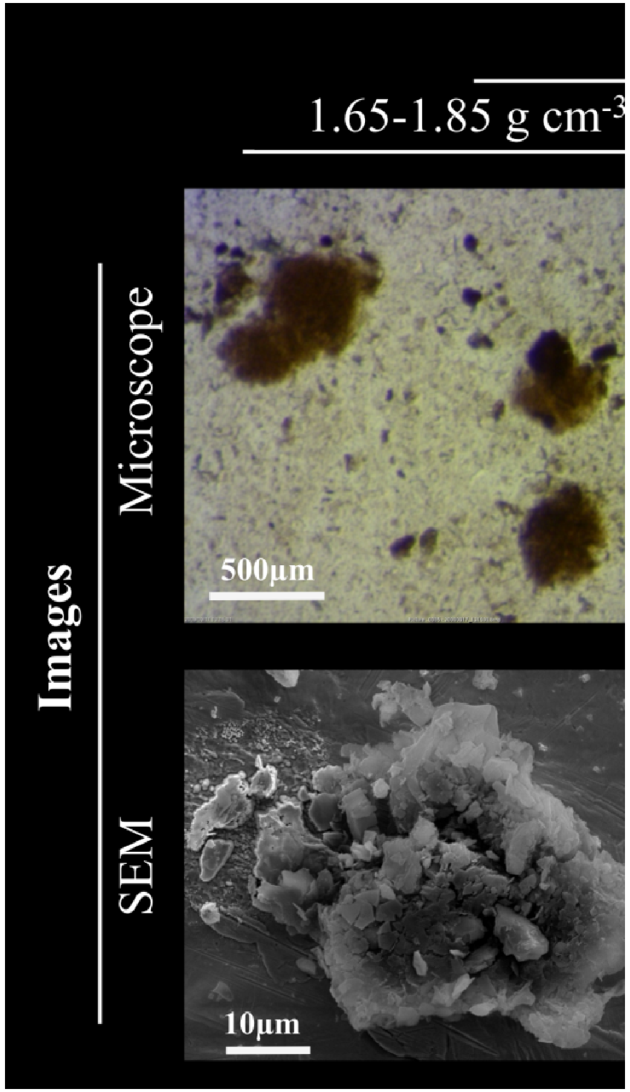
From processes to the budget……. A long way down our understanding of ecosystem functionning



Take advantage of the high (but structured) diversity
of monitoring and experimental networks in forest ecosystems

Let’s open the black box !!

Soil Organic Matter Processes…….. Organo-mineral interactions plays a role in C and N sequestration



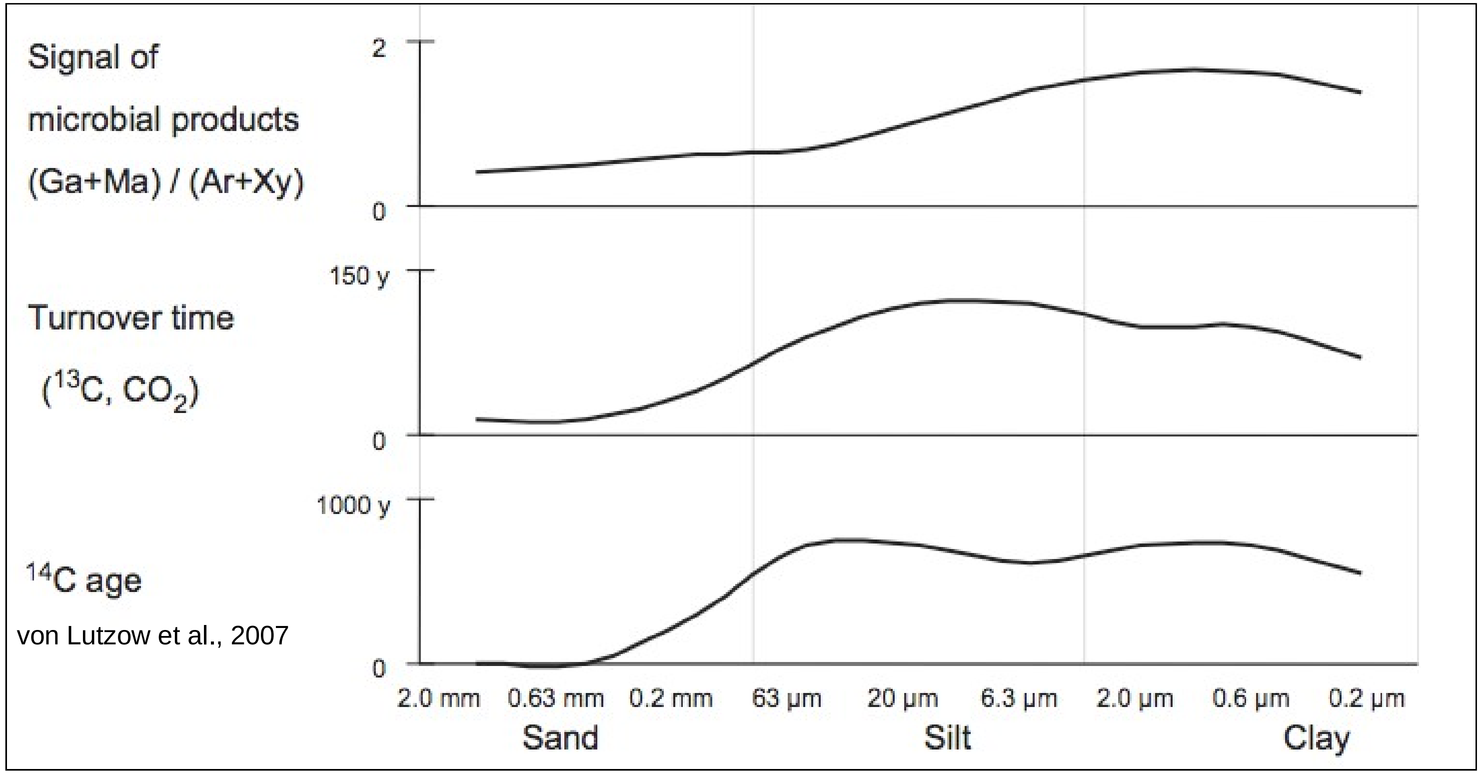
Micro aggreagtes
Clay minerals

Aggregated quartz and clay minerals

Isolated coarse minerals
Oxides and quartz

=>The processes involved need to be studied at the micron scale.

Hatton et al. RCM 2012



von Lutzow et al., 2007

When organo-mineral associations become finer, denser,

- they exhibit a stronger microbial signature
- their carbon is older

(see reviews from von Lutzow et al., 2007; Sollins et al., 2009)

Working hypothesis

Microbial transformation of litter residues would facilitate their preservation on the long term within organo-mineral associations

Research questions

What is the nature of OM stabilised (present to several years) on soil particle ?

→ Experiment 1: Fate of N using 15N labelled leaves (after an application 12 years ago)

What are the factors that control the spatial distribution of the microbial metabolites?

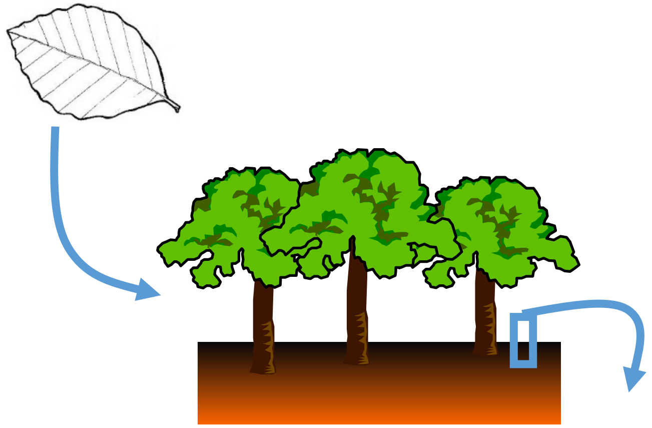
→ Experiment 2: Fate of C and N using 13C/15N labelled glycine (after short term soil incubation)

Experiment 1

1. Study site & soil sampling

   German Beech forest with moder humus-type.

   Acidic dystic Cambisol (Zeller et al., 2001).

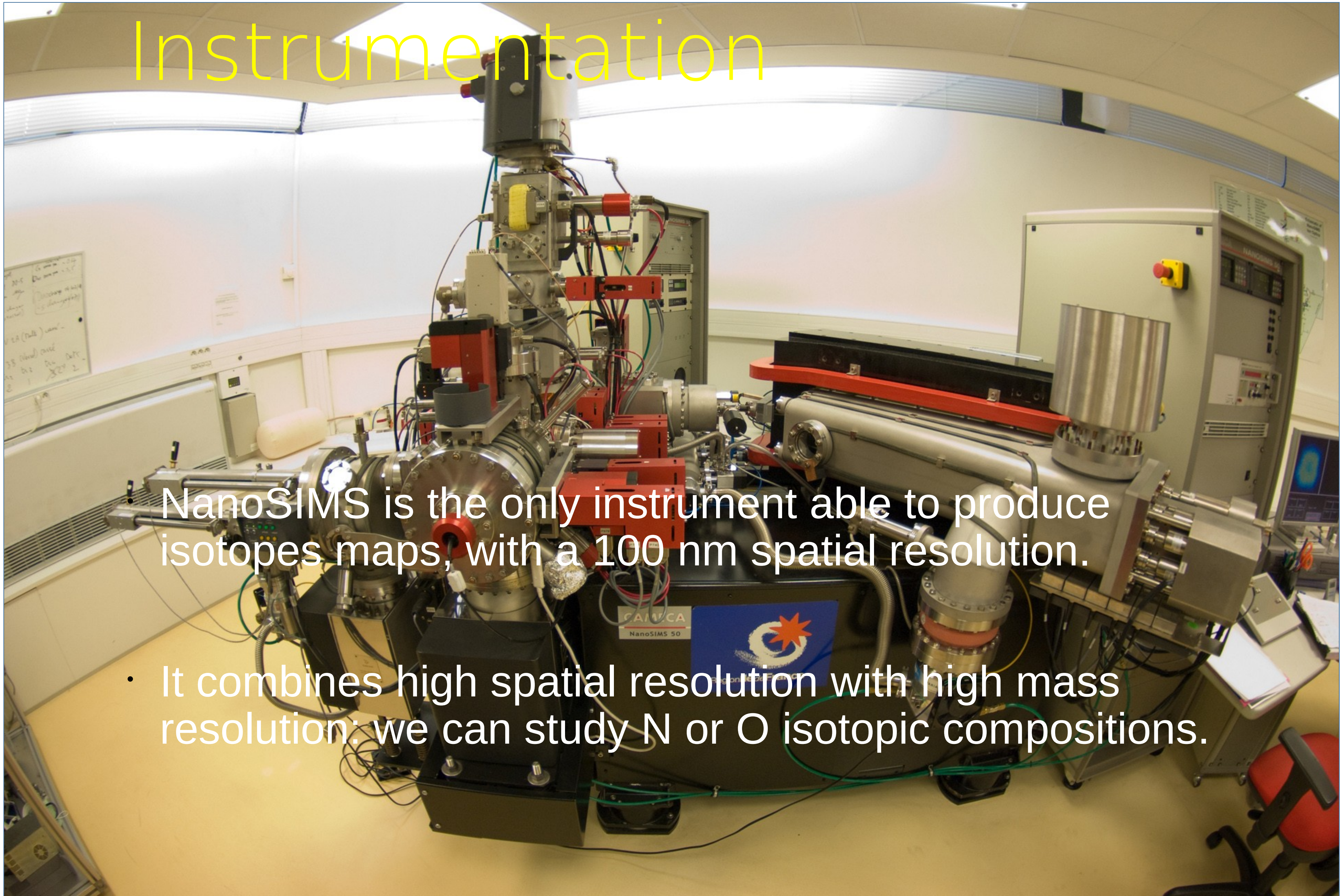


2. 15N labeling

- Beech leaves enriched in 15N (2.5 At% or δ15N=5700‰)

- Sampling after 12 years .
About 20% of the tracer is still in the top 2.5 cm soil layer

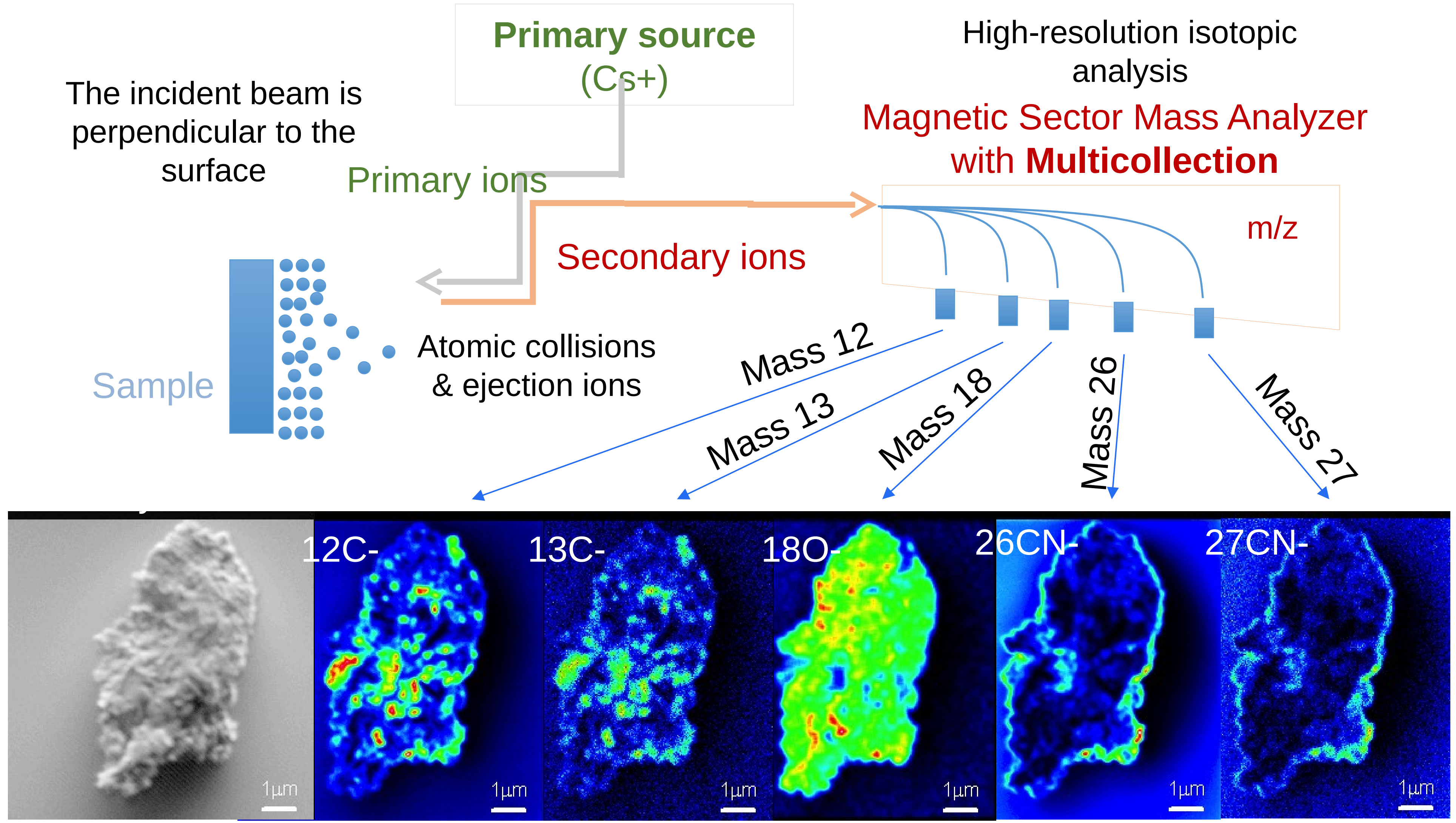
Instrumentation



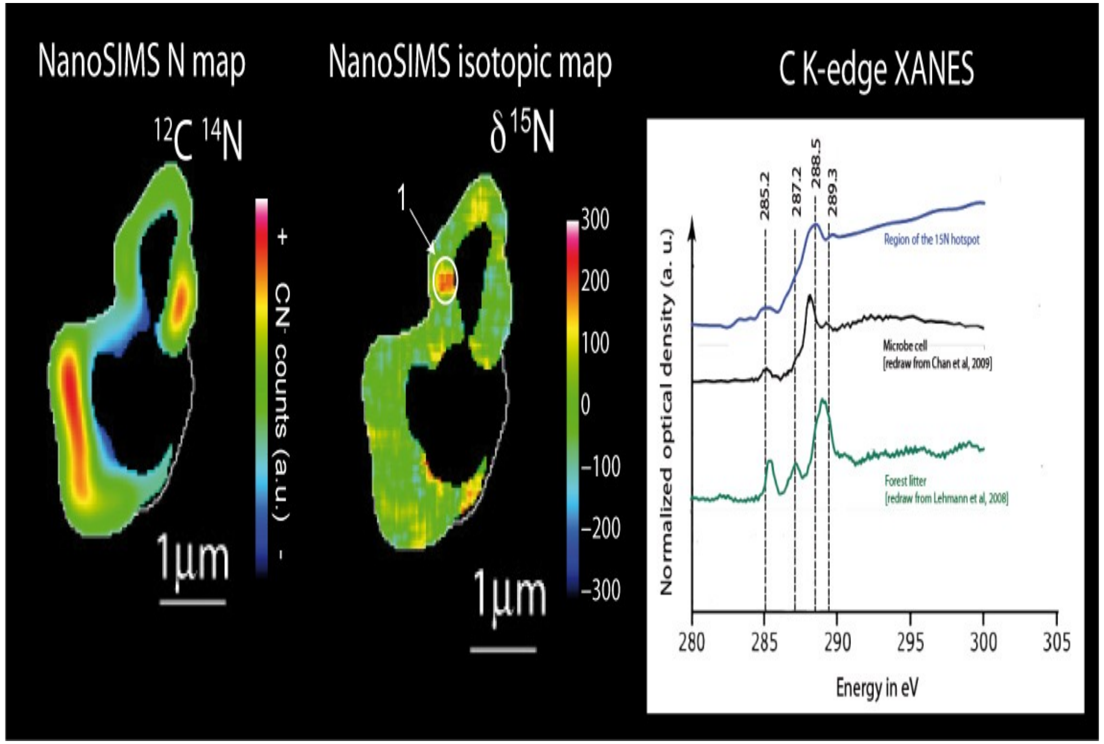
- NanoSIMS is the only instrument able to produce isotopes maps, with a 100 nm spatial resolution.
- It combines high spatial resolution with high mass resolution: we can study N or O isotopic compositions.

Coll. MHN, ……

NanoSIMS principles



An attempt to determine the nature of the OM bearing the label



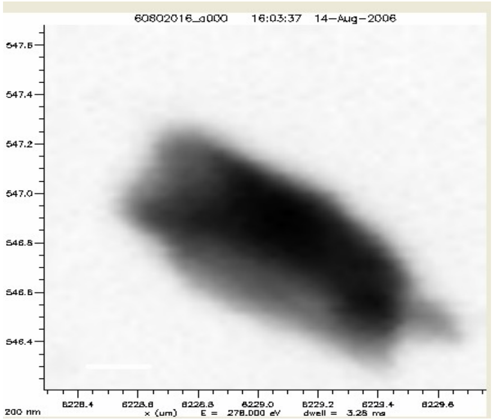
Combination of NanoSIMS with STXM-NEXAFS (molecular imaging).

STXM-NEXAFS principle

STXM is a transmission technique that maps C, N, and, through acquisition of NEXAFS spectra, can determine the type of C and N functional groups

Peak position	Functional group
285.2 eV	aromatic C
286.7 eV	phenolic or ketonic C
288.5 eV	aldehyde or carboxylic C
289.3 eV	O-alkyl C

Image 280 eV



Single Image @ 280 eV

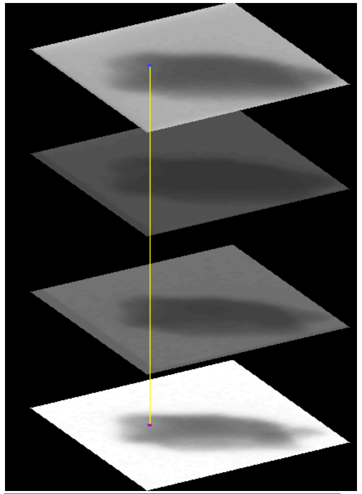
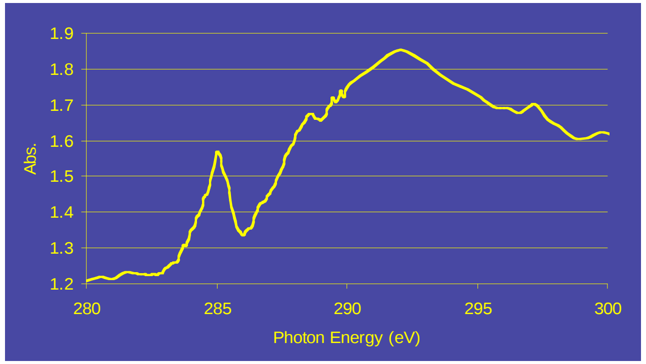


Image 300 eV



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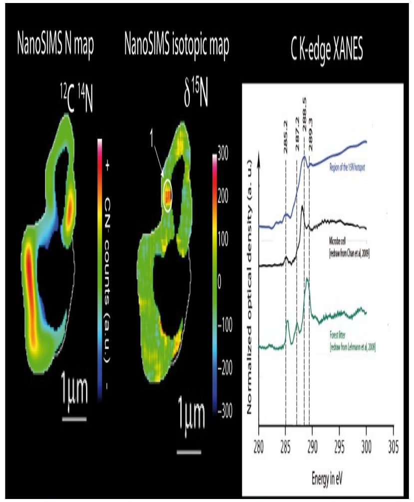

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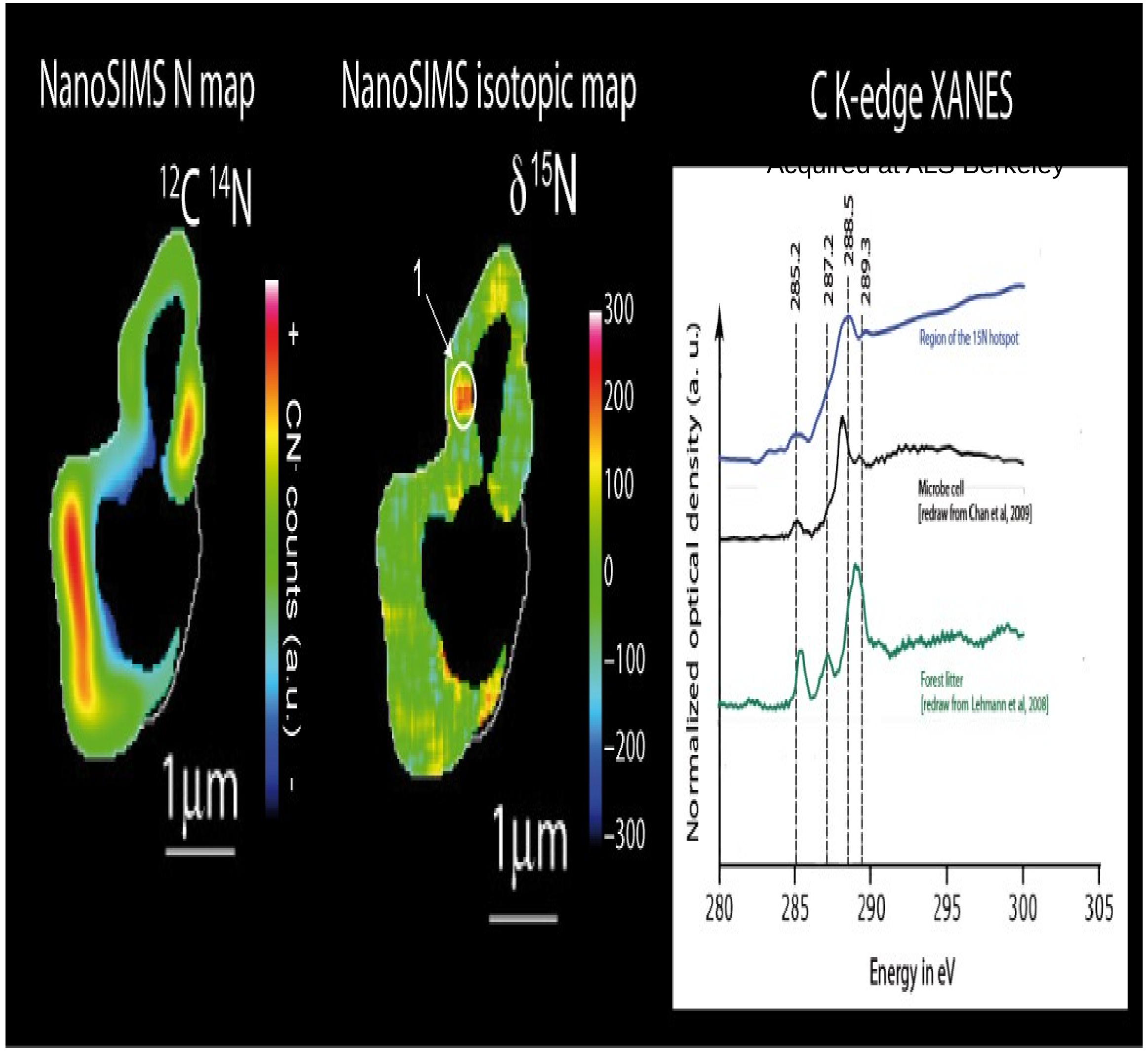


Remusat et al. ES&T 2012

The label seems related to microbial OM.

Experiment 2

1. Study site & soil sampling
   German Beech forest with moder humus-type.
   Acidic dystic Cambisol (Zeller et al., 2001).

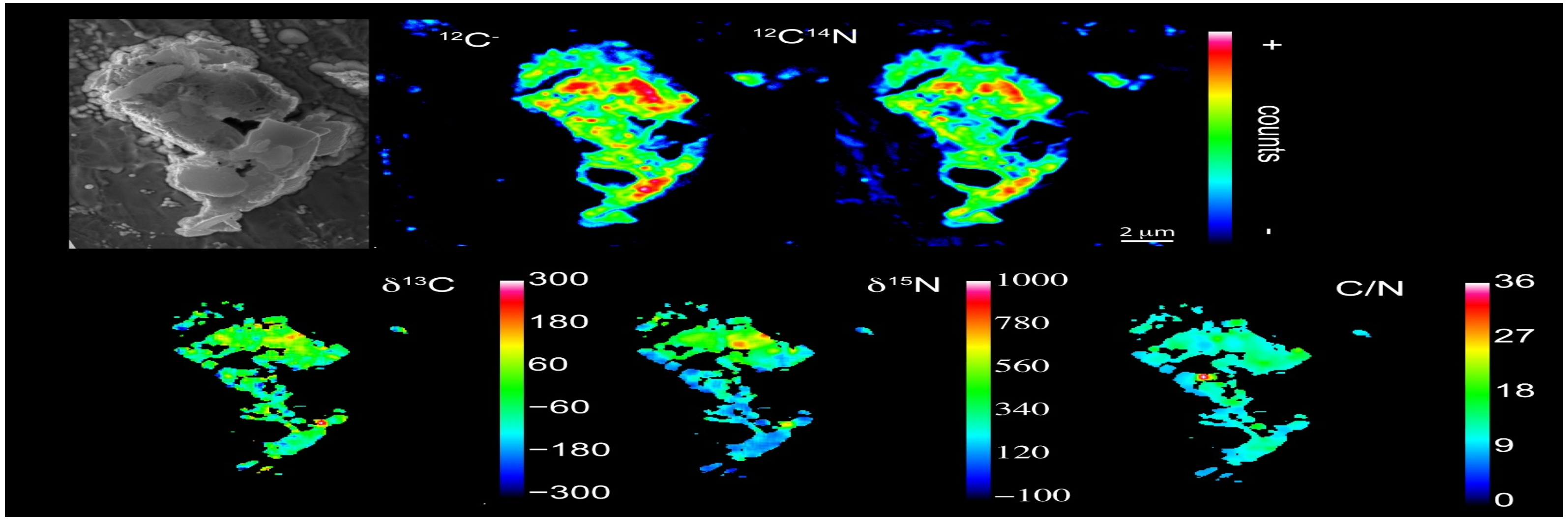
2. Incubation of 13C/15N-labeled glycine (glycine is metabolised within a couple of hours)

=> Tracing of glycine residues at the surface of different types of organo-mineral association by NanoSIMS imaging

Biotic fixation of 13C and 15N derived from glycine after 8 hours of incubation

	Soil Carbon mg g-1 soil	Soil Nitrogen mg g-1 soil	13C % applied	15N % applied
8 hour incubation in non-sterile treatment				
Bulk	28.7 ± 0.3	1.85 ± 0.04	86.2 ± 6.3	98.0 ± 8.2
Attached to soil particules	21.53 ± 0.36	1.25 ± 0.05	7.0 ± 0.5	7.17 ± 0.11
8 hour incubation in sterile treatment				
Bulk	28.7 ± 0.5	1.85 ± 0.03	97.8 ± 3.1	92.3 ± 6.2
Attached to soil particules	21.8 ± 0.29	1.28 ± 0.05	0.70 ± 0.09	1.11 ± 0.04

NanoSIMS images

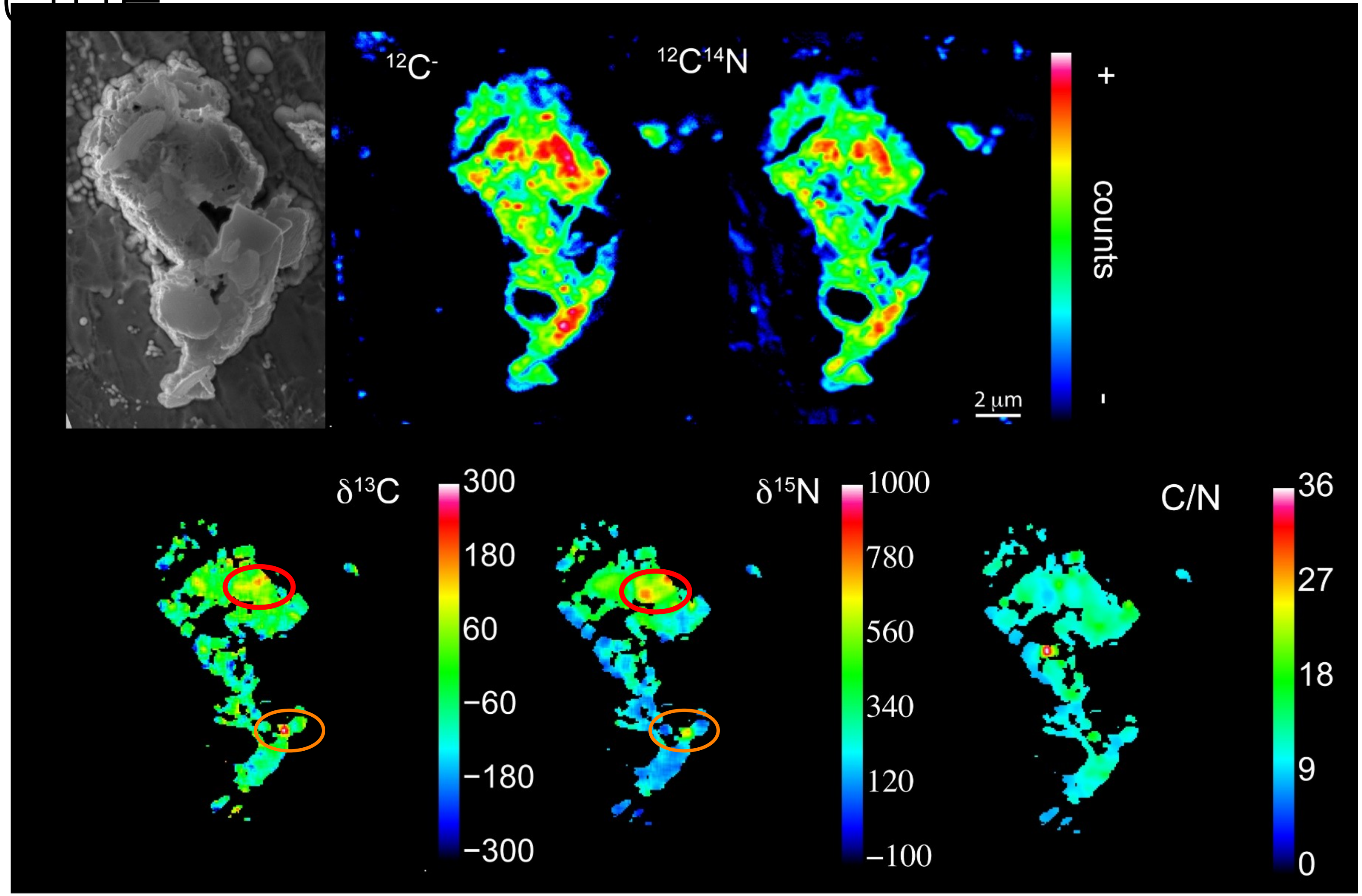


25 particles were imaged (3800 µm2)

Hatton et al. in prep

Micro aggregate from the fraction 1.85 -2.0 g.cm-3

13C and 15N derived from glycine

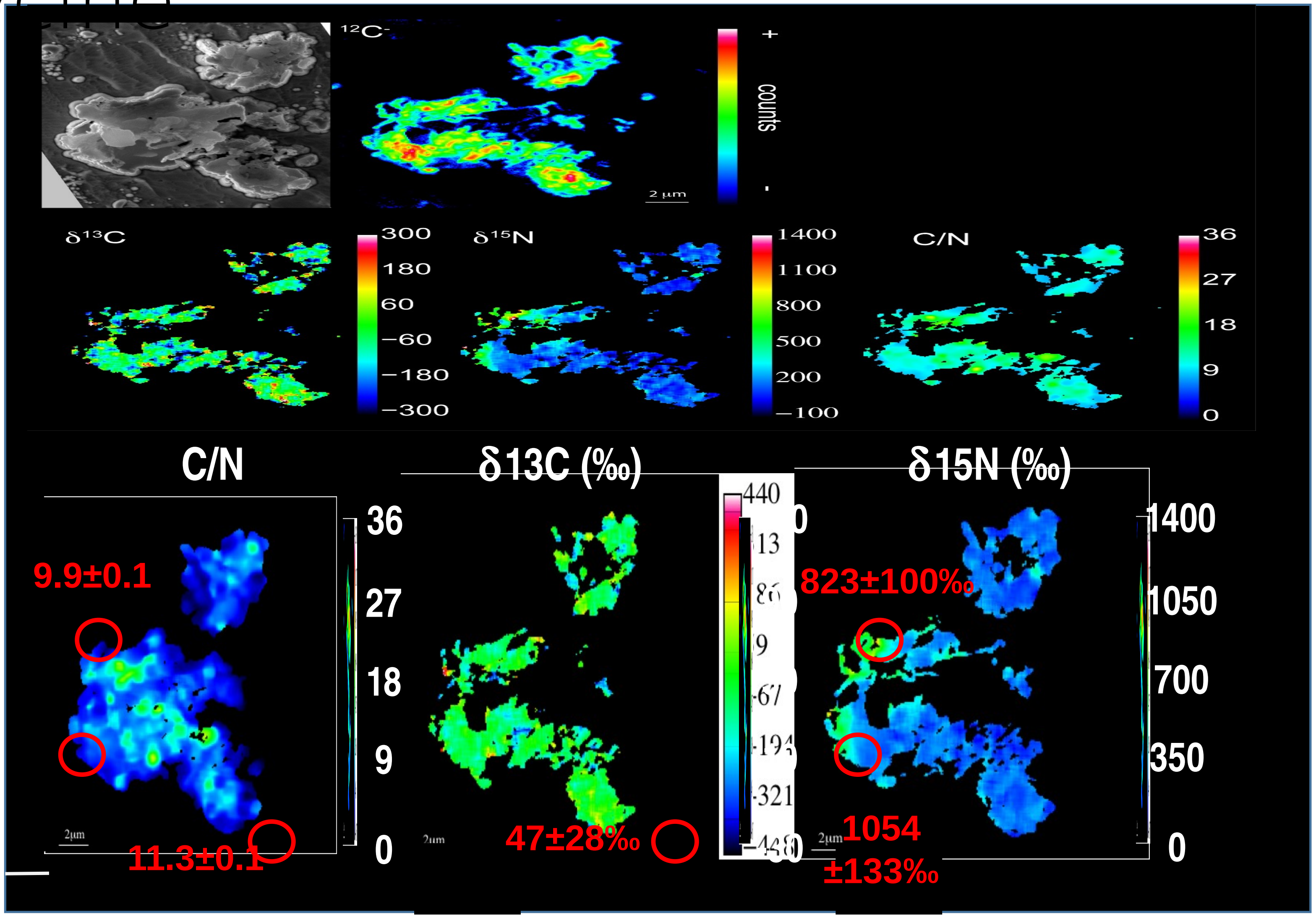


In some cases, 13C and 15N labels are spatially correlated

Hatton et al. in prep

Micro aggregate from the fraction 1.85 -2.0 g.cm-3

13C and 15N derived from glycine



But in many cases, 13C and 15N labels are decoupled

Hatton et al. in prep

Micro aggregate from the fraction 1.85 -2.0 g.cm-3

Conclusions (experiment 1)

NanoSIMS is a powerful tool to study the fate of OM onto small soil structures, at the scale of stabilisation processes

Its elemental maps are a valuable tool to demonstrate

- the discontinuity of the OM cover (definitly not a single layer cover !)
- the spatially variable OM nature;

In combination with isotopic labelling, NanoSIMS generates unique information about the mechanisms controlling the attachment to soil

After 12 years of decomposition in situ we observed N derived from litter likely as microbial matter, in some aggregates where decomposition activity is hampered and cycling slows down.

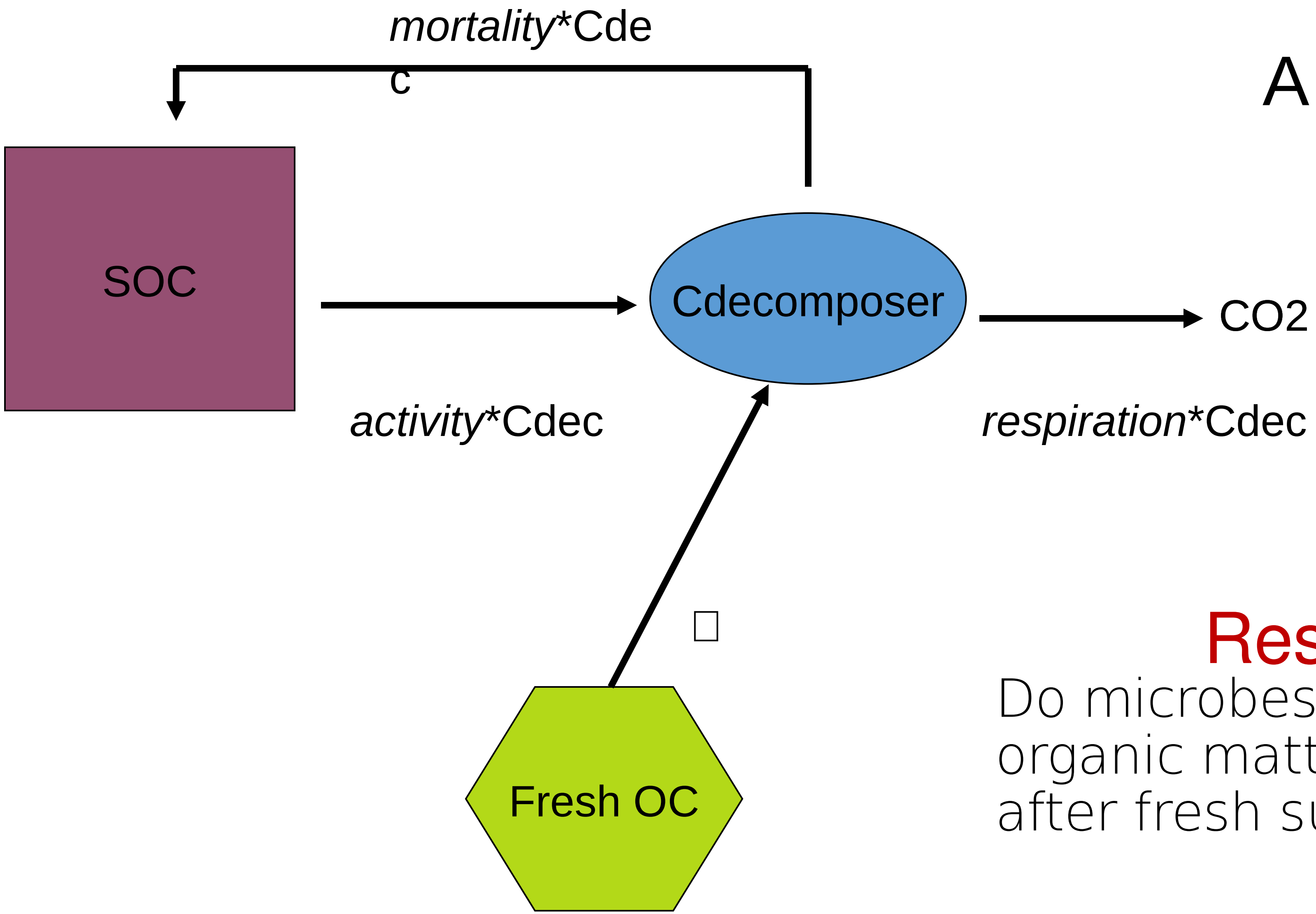
Conclusions (experiment 2)

- Over the 3700 μm2 we imaged : 5 spot of 13C and 28 spots of 15N

- Glycine-derived C is concentrated in few locates, likely in the vicinity of microbial cells (We do not observe any bacteria - consistent with a rather small surface sampled)

- Glycine-derived N is widely spread in soil, presumably as NH4+ or exoenzymes and preferentially attached to mineral-attached OM rich in N

A simple mecanistic model



Allowing investigating the functional diversity of the decomposers using the differences in isotopic signature between the SOC and the fresh OC

Research question

Do microbes destabilise old soil organic matter
after fresh substrate addition?

Modified from Fontaine et al., 2005

Experimental Approach

Topsoils from Congolese Eucalyptus plantations established for 17yrs on a former

- C4 labelling of SOC older than 17yrs
- C3 labelling of SOC younger than 17yrs

steady state:
13C CO_2:
-26.3‰

C4 Carbon derived from the old savannah 13C = -14.8‰	C3 Carbon derived from the young eucalyptus 13C = -31.2‰

Expected changes in CO_2 - □13C

Increase in the CO_2 - □13C
□ Increase in the mineralisation of old C4-C derived from the savannah

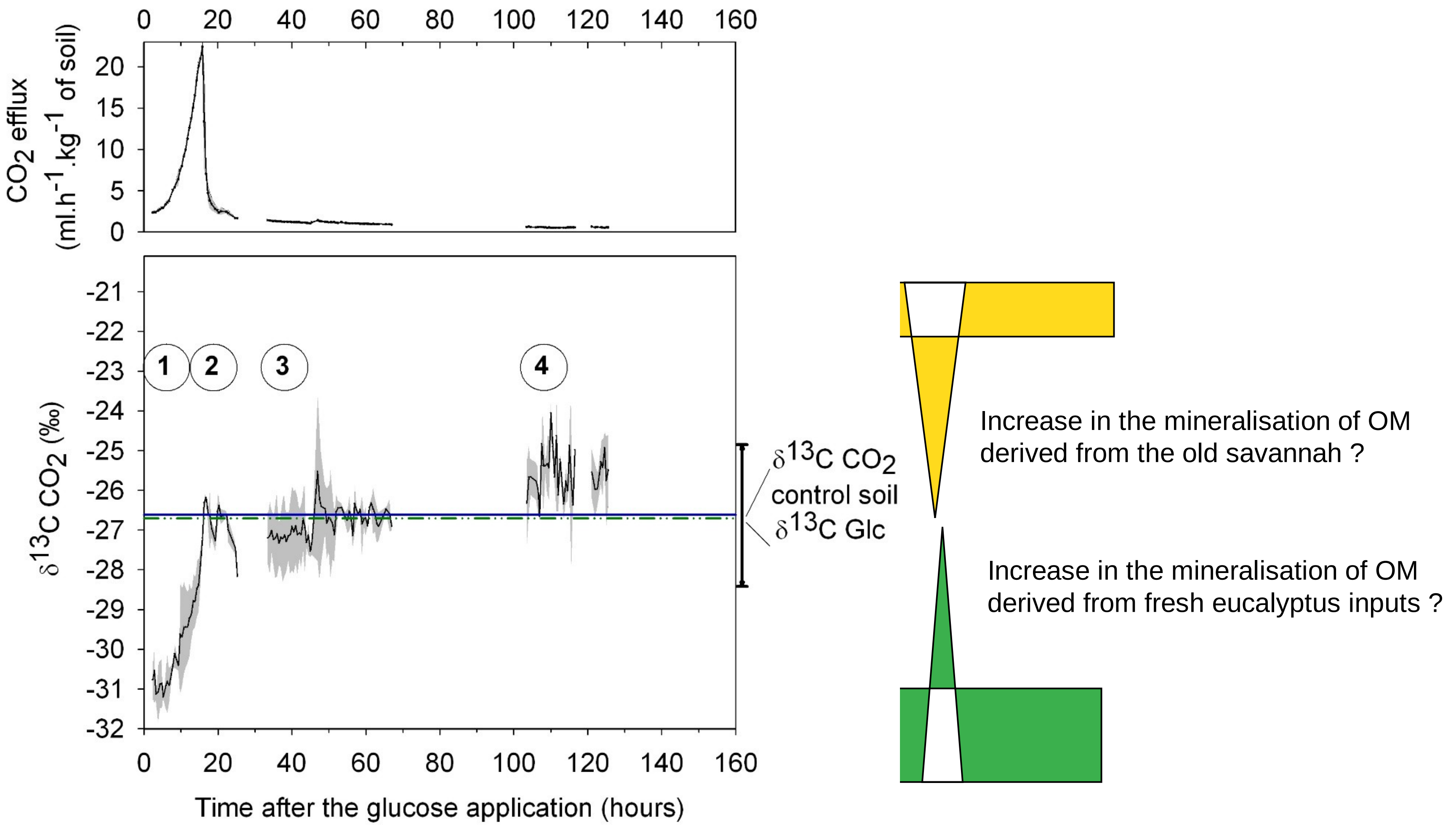
Decrease in the CO_2 - □13C
□ Increase in the mineralisation of young C3-C derived from eucalyptus

Addition of glucose
(200□g/g to induce microbe growth)
Glc-□13C ~ CO_2-□13C steady state (-24,7‰)

Incubation at 25°C for one week
Continuous monitoring of CO_2 and CO_2 - □13C

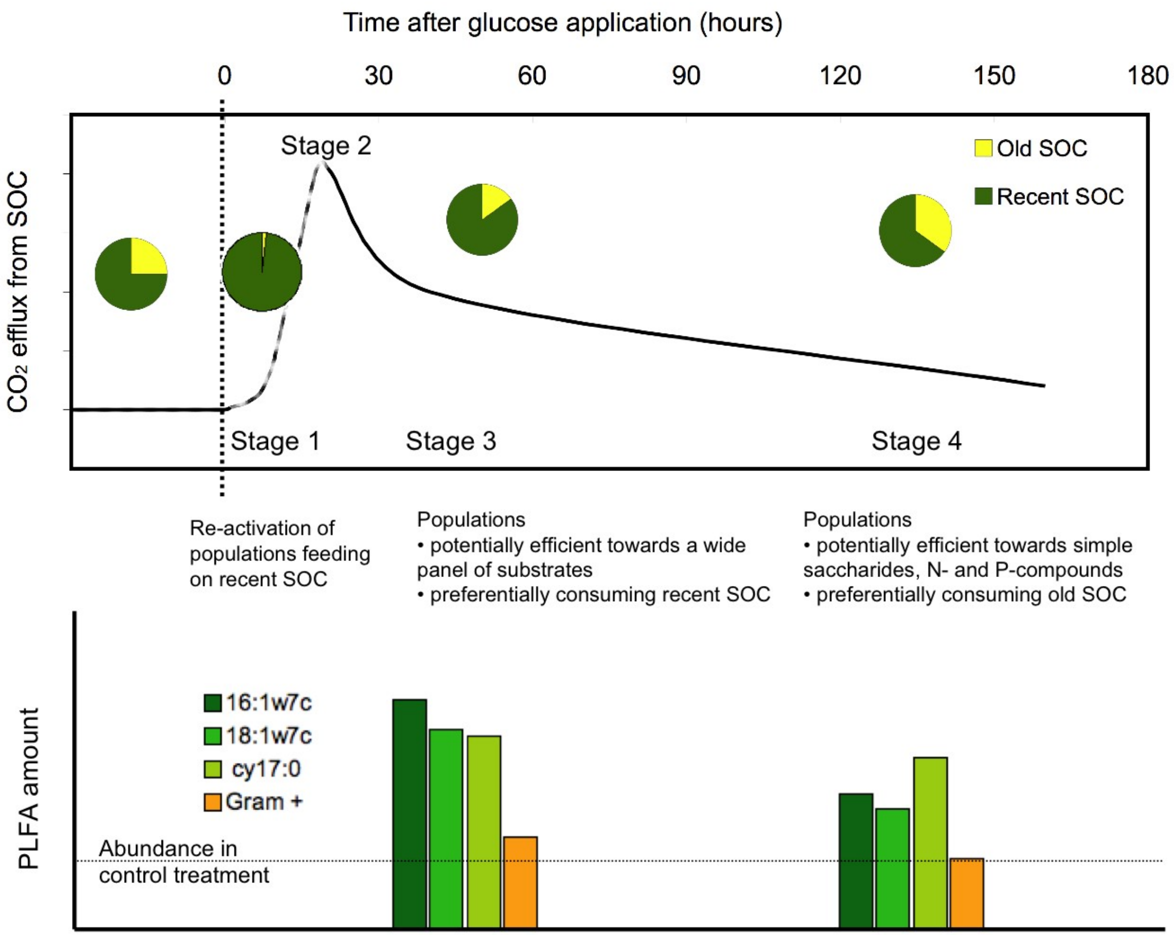
Derrien et al. 2014

Functional diversity of microbial populations



Derrien et al. 2014

Functional diversity of microbial populations



Derrien et al. 2014

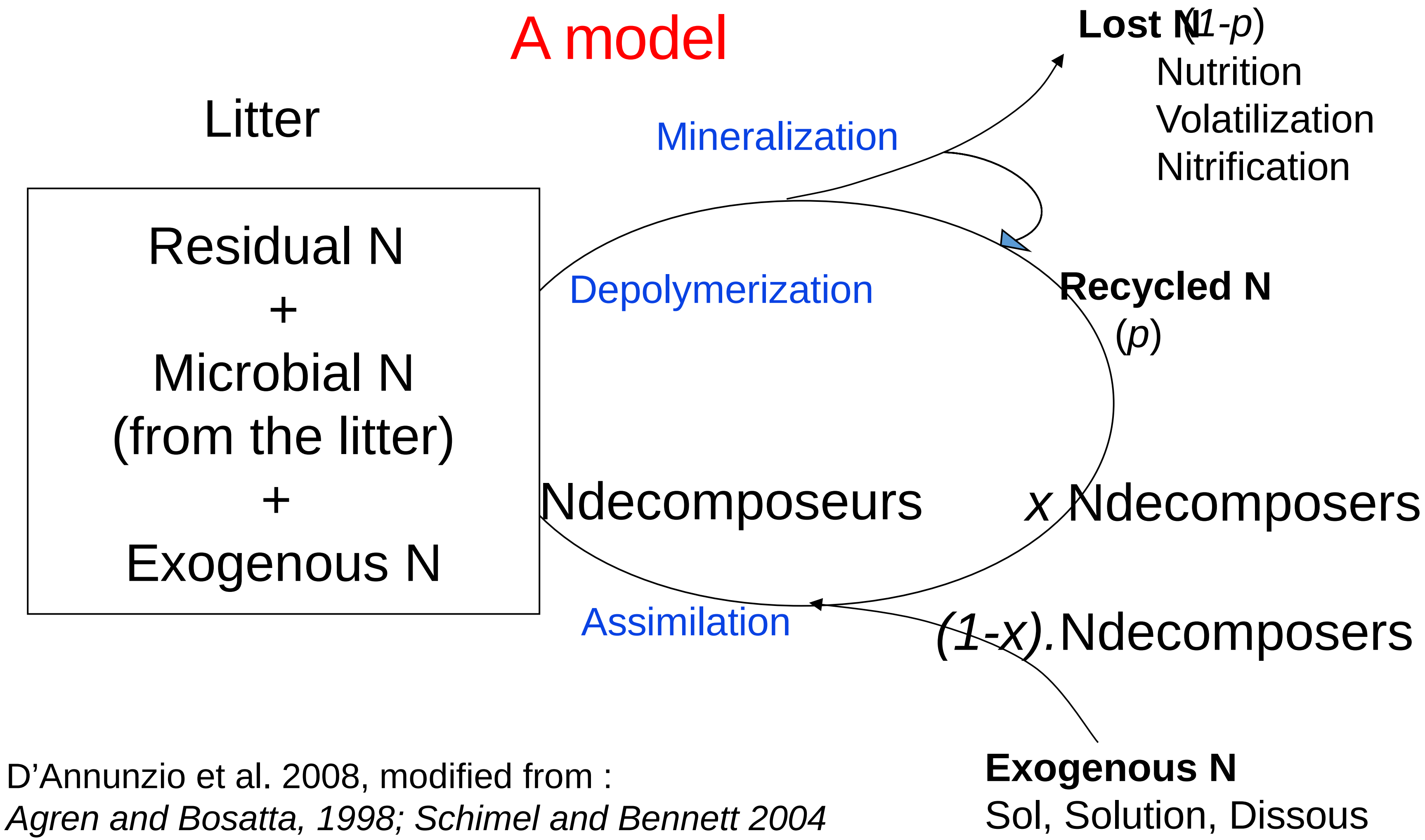
Functional diversity of microbial populations, conclusions and perspectives

- In the N-poor Congolese soil, the pulse input of glucose induced major changes in microbial community structure and SOC utilisation patterns;
- Inducing first a preferential use of recent SOC and then a destabilisation of old SOC, likely to meet needs in N;
- Nitrogen availability would be a key factor controlling microbial activity.

Derrien et al. 2014

Sources of nitrogen for the decomposers ?

A model

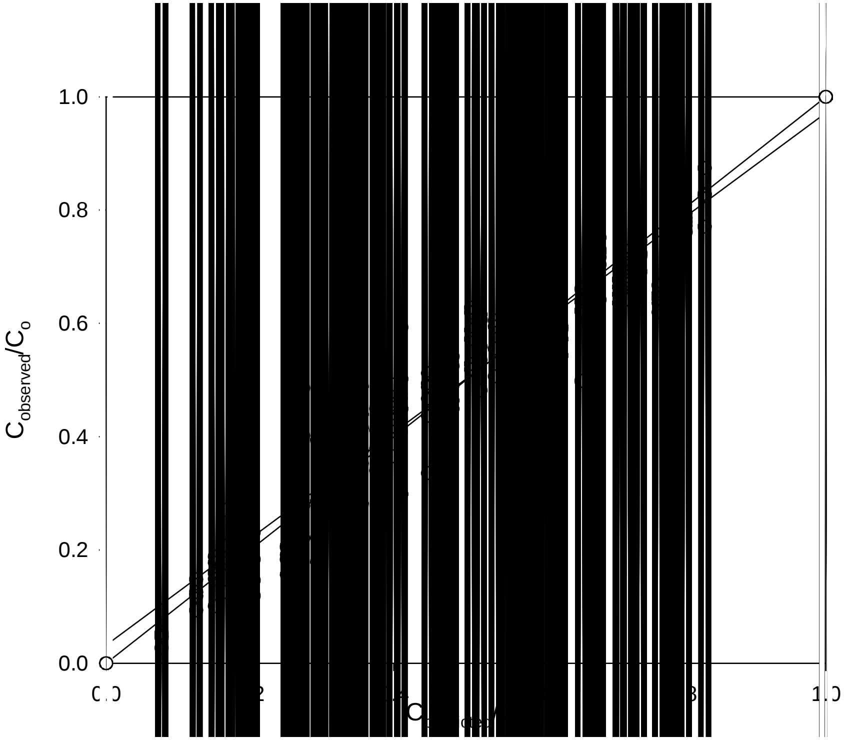


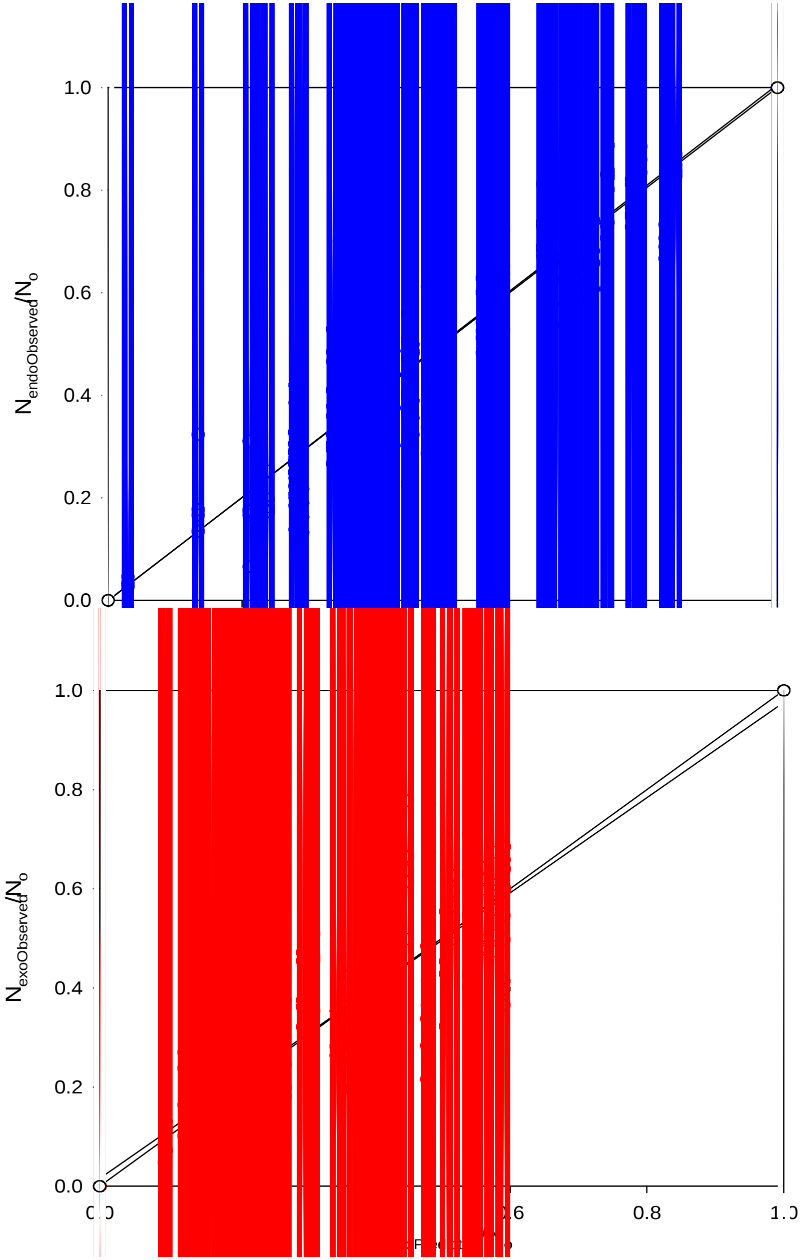
+ 15N labelled litter experiments

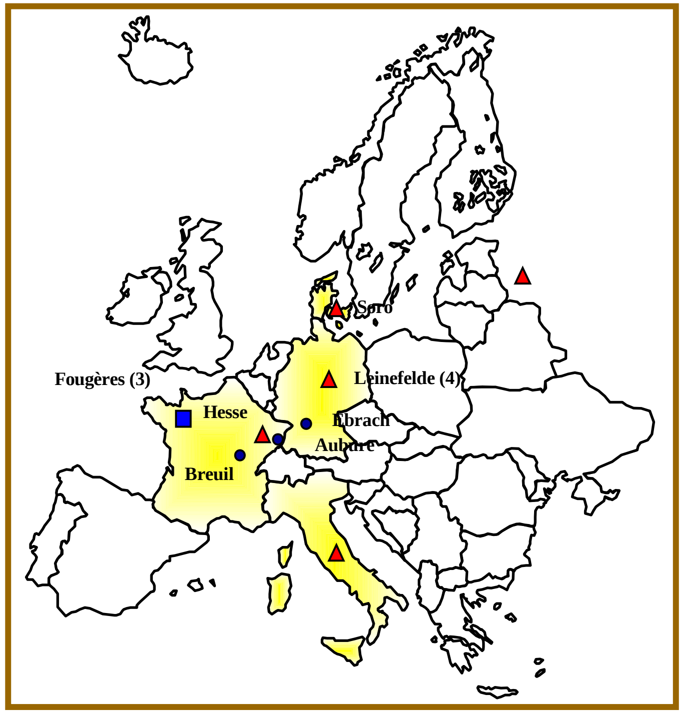
D'Annunzio et al. 2008, modified from :
Agren and Bosatta, 1998; Schimel and Bennett 2004

Soil Organic Matter Processes…….. importance of the site fertility on the control of SOM dynamics

Model fitted in Beech stands in Europe
(the 15N labelling network)

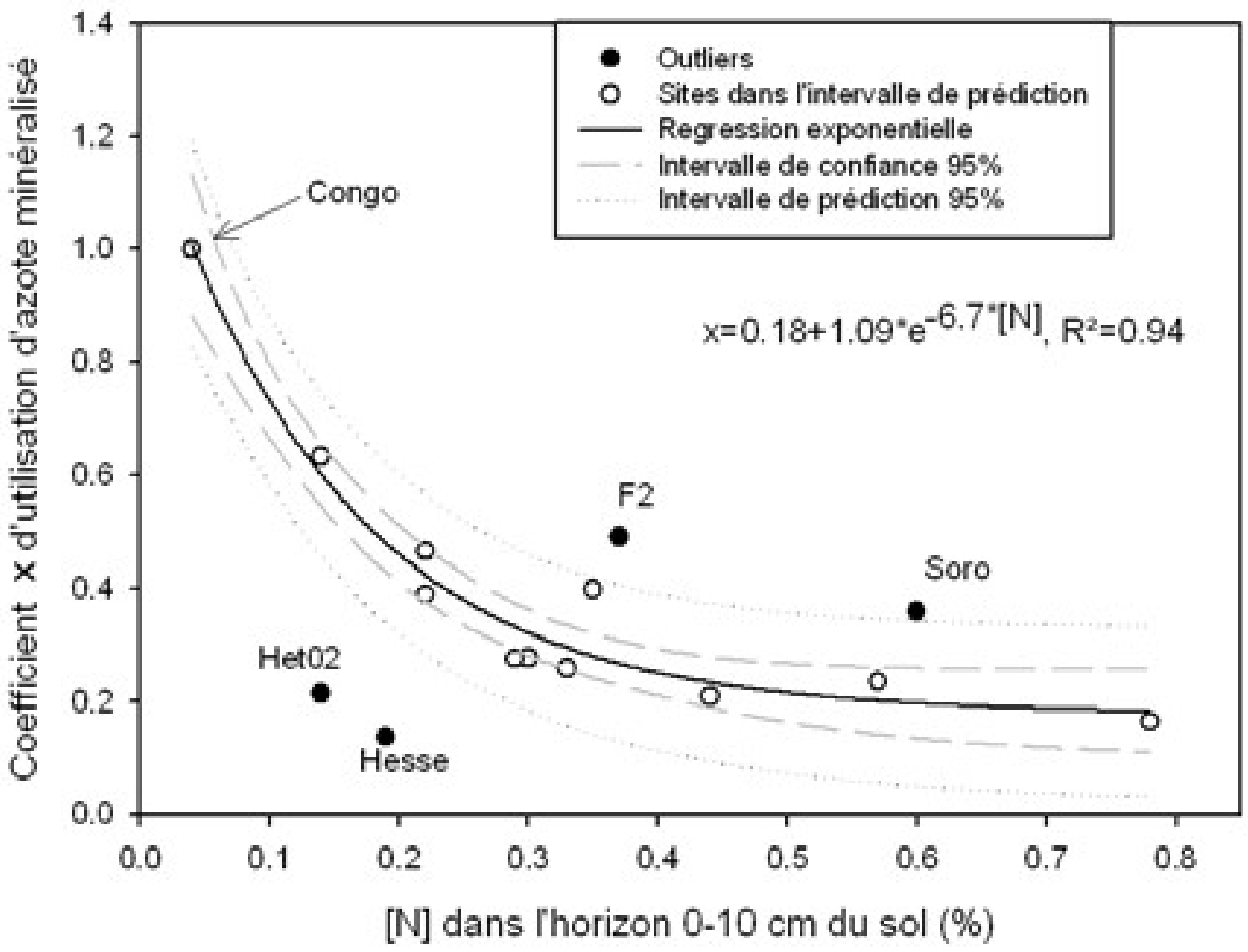




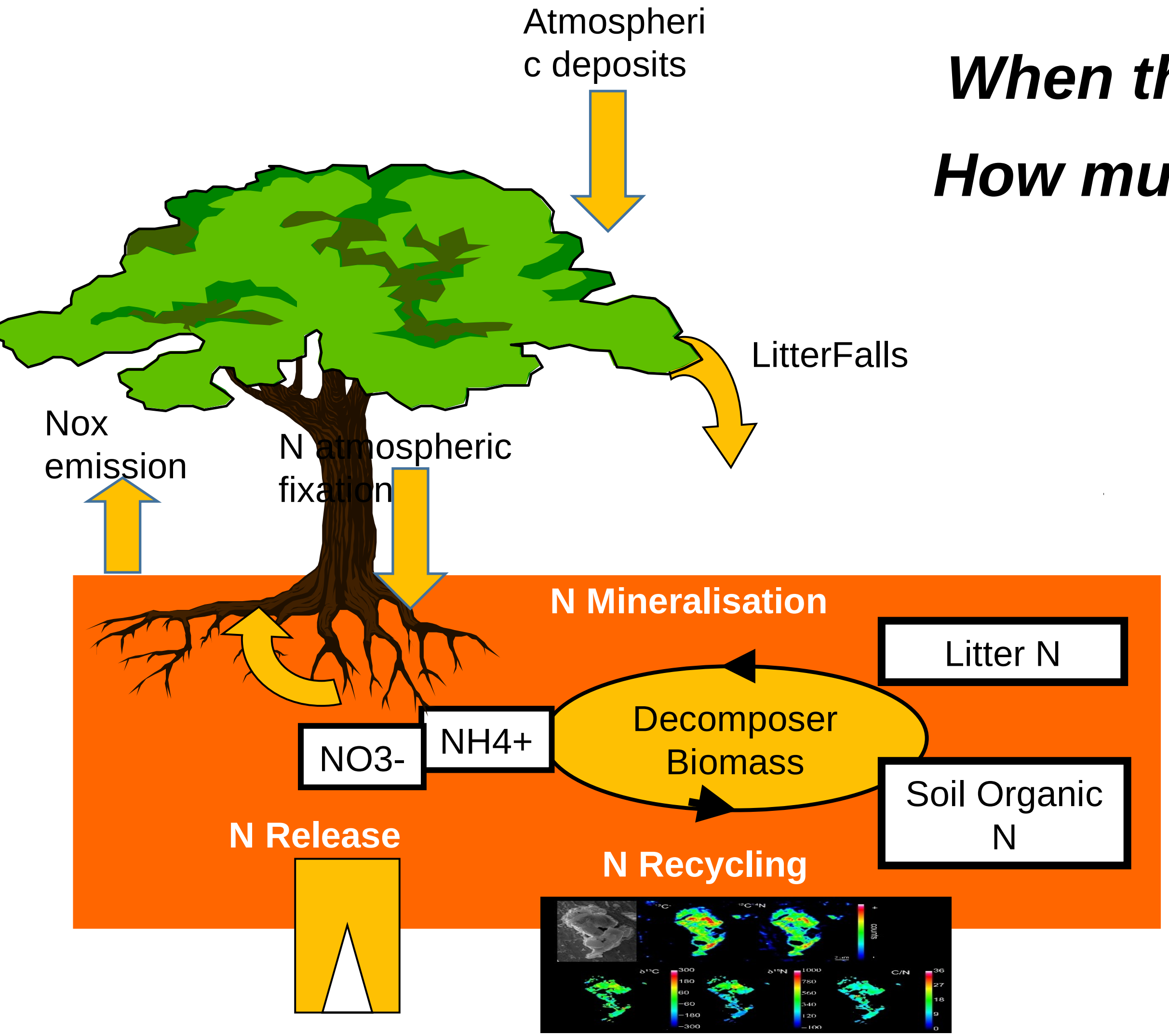


Derrien et al. In prep

The poorer is the soil in nitrogen, the more the decomposers recycle the litter



Derrien et al. In prep



Research questions

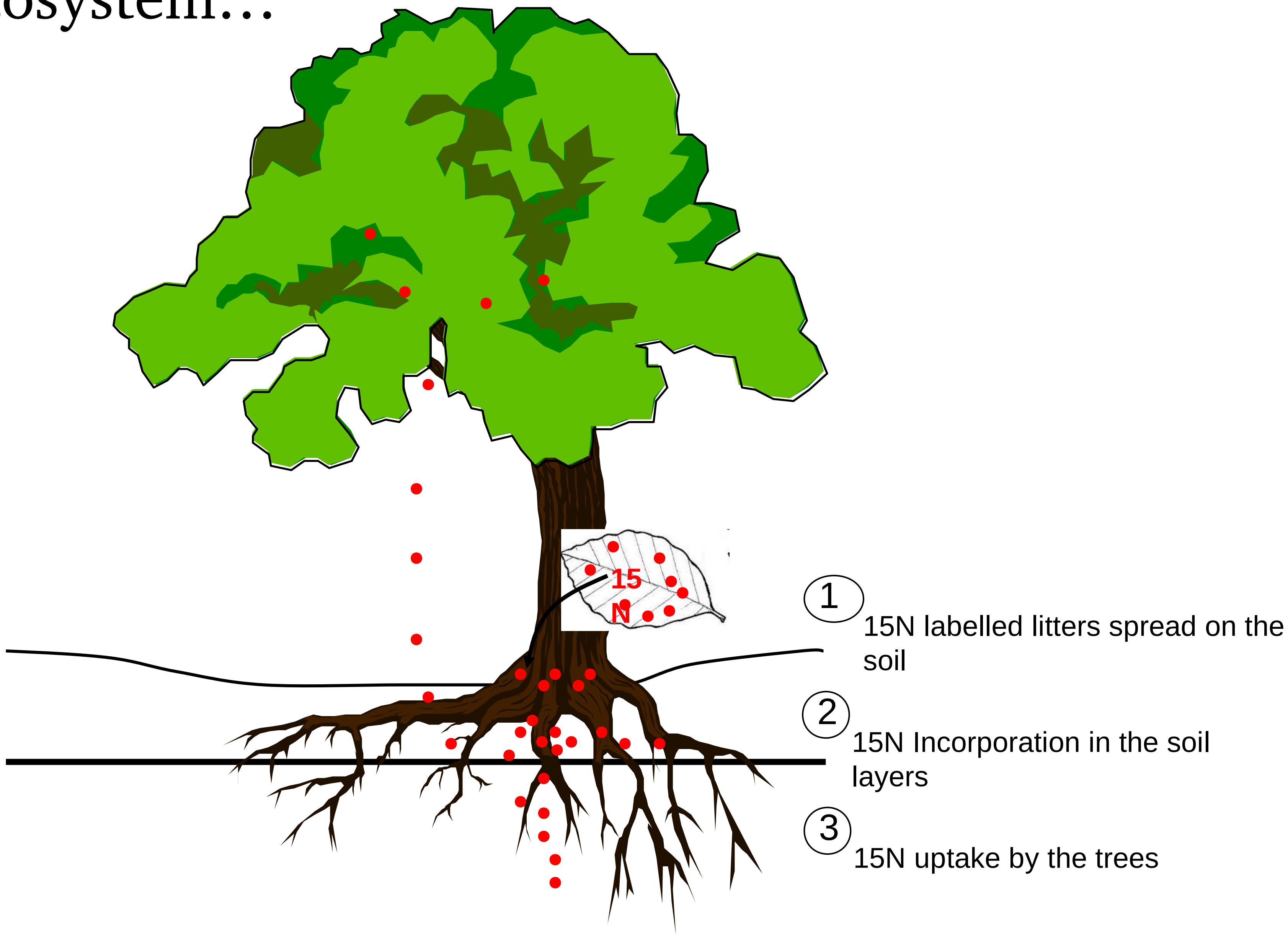
When the mineralized N is available for the trees ?

How much of this N is uptaken by the trees after 10 years of monitoring?

N and other nutrient bio-availability for the trees

Stabilisation/Destabilisation processes of the SOM

The extraordinary adventure of the 15N in the ecosystem…



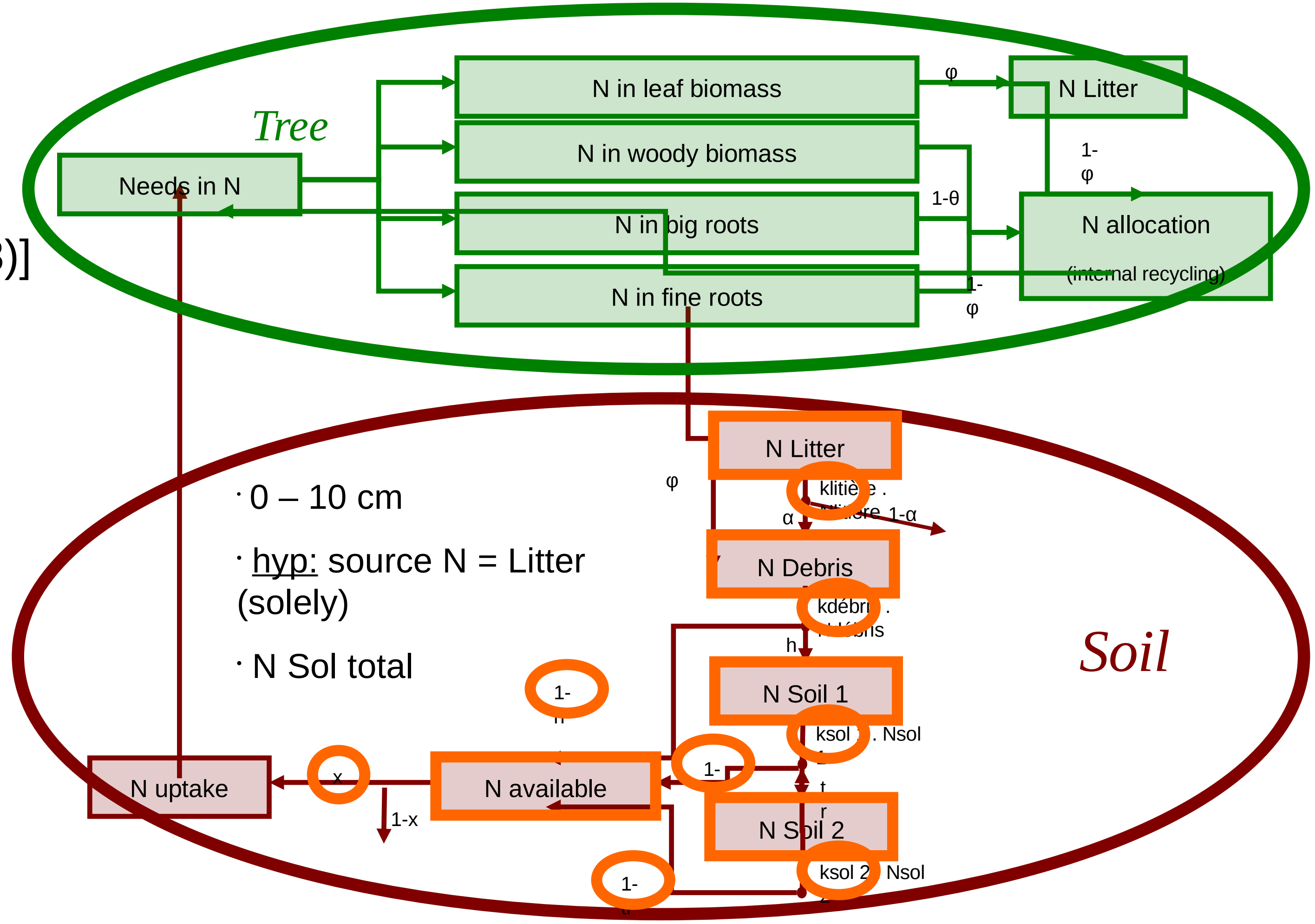
The 15N labelling network

1. Het 02
2. Het 60
3. Aubure
4. Ebrach
5. Het 88
6. Het 55
7. Het 25
8. Het 26
9. Het 30
10. Collelongo

- 1 **species**:
  - Beech (*Fagus sylvatica*)
- 10 **sites**:
  - 7 in France, 3 in Europe
- 2 **networks**:
  - RENECOFOR – NIPHYS/CANIF
- 2 (Renecofor) ou 3 (NIPHYS) **trees** labelled per site
- A 10 year monitoring period:
  - 1994 – 2013
- 3 **compartiments** of the ecosystem measured:
  - Leaves, Litter, Soil

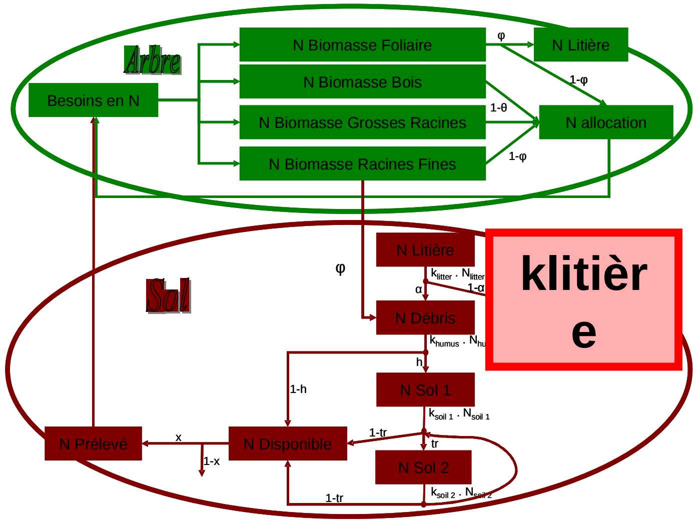
A soil-plant model to follow the 15N

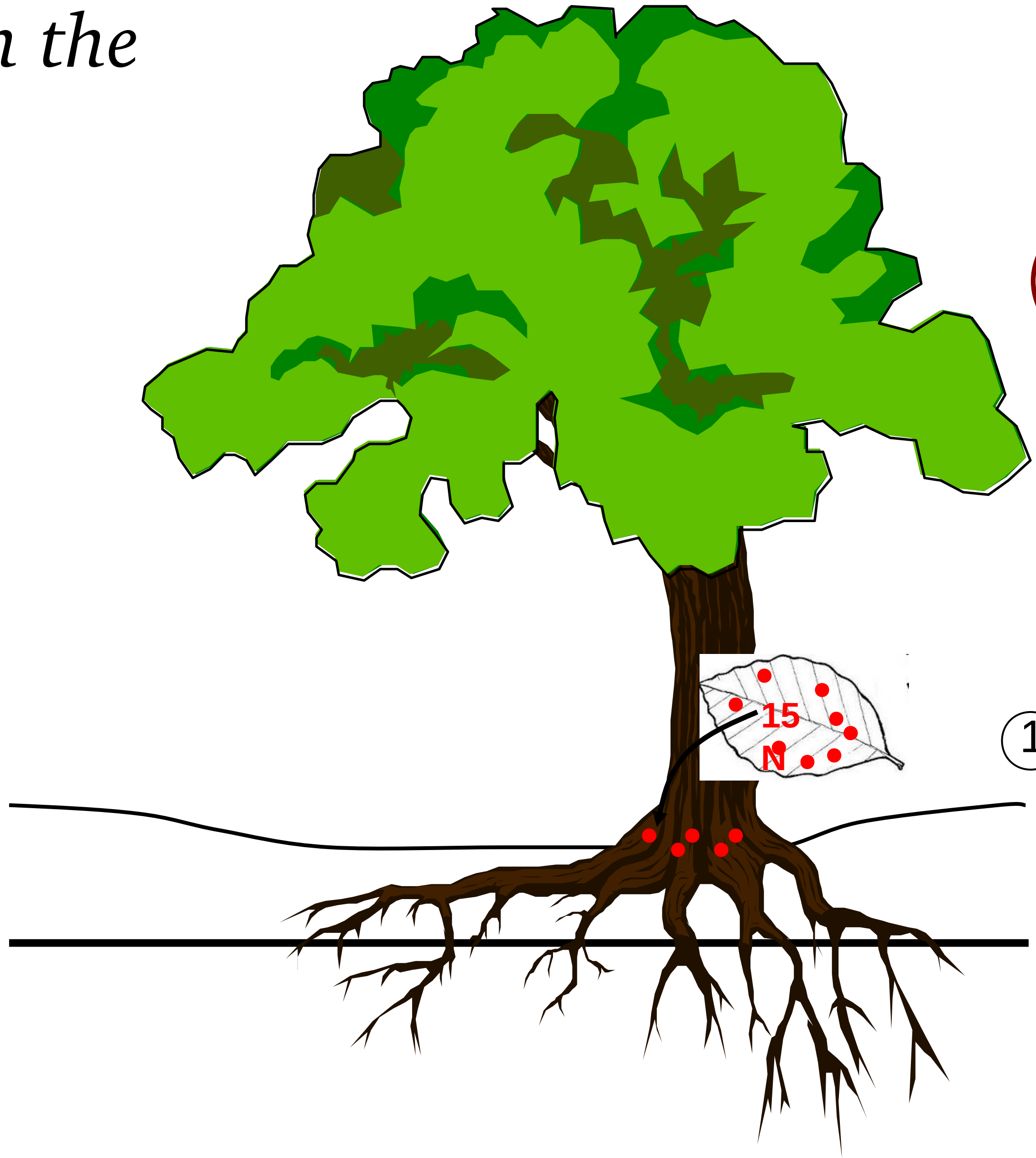
Combining Fagacée
[improved for biomass and nutrient content
Genet et al. (2011), Wernsdörfer et al. (2013)]



And a soil module specifically built for the study

Mean residence time of 15N in the litter



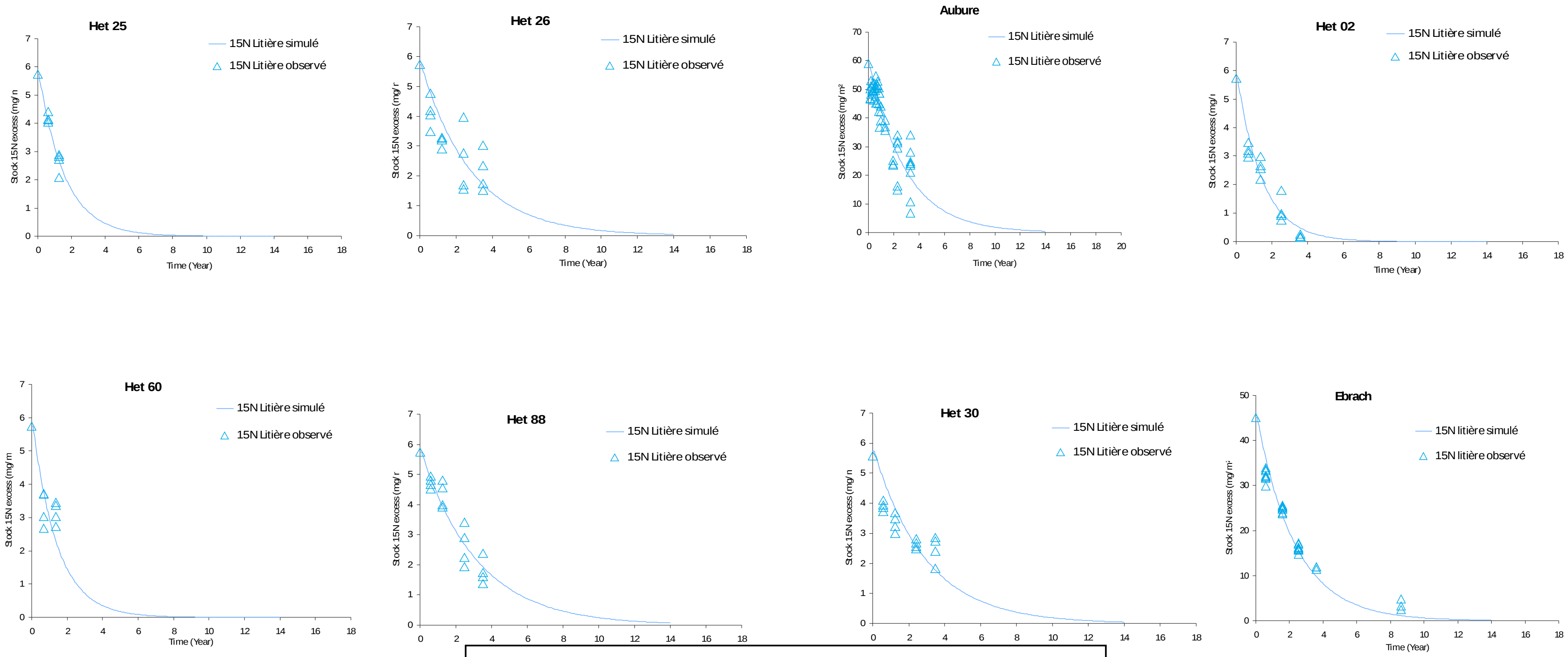


① Mean residence time of 15N in the litter

Fit on litter data sets

Mull

Moder



NLitière = No . exp(- kLitière . t)

Mean N residence time

- MRT = 1 / k

⇒ With k – 15N, the cinetic parameter of N litter decomposition

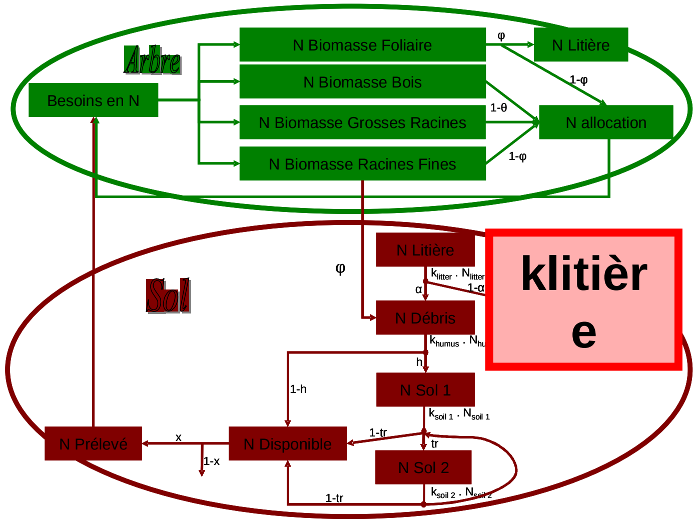
	Aubure	Ebrach	Collelongo	Het 02 ✦	Het 25	Het 26 ✦	Het 30	Het 55	Het 60	Het 88 ✦
k – 15N (an-1)	0.34	0.43	0.23	0.71	0.67	0.36	0.35	0.50	0.71	0.31
MRT 15N (ans)	2.9	2.3	4.4	1.4	1.5	2.8	2.9	2.0	1.4	3.2

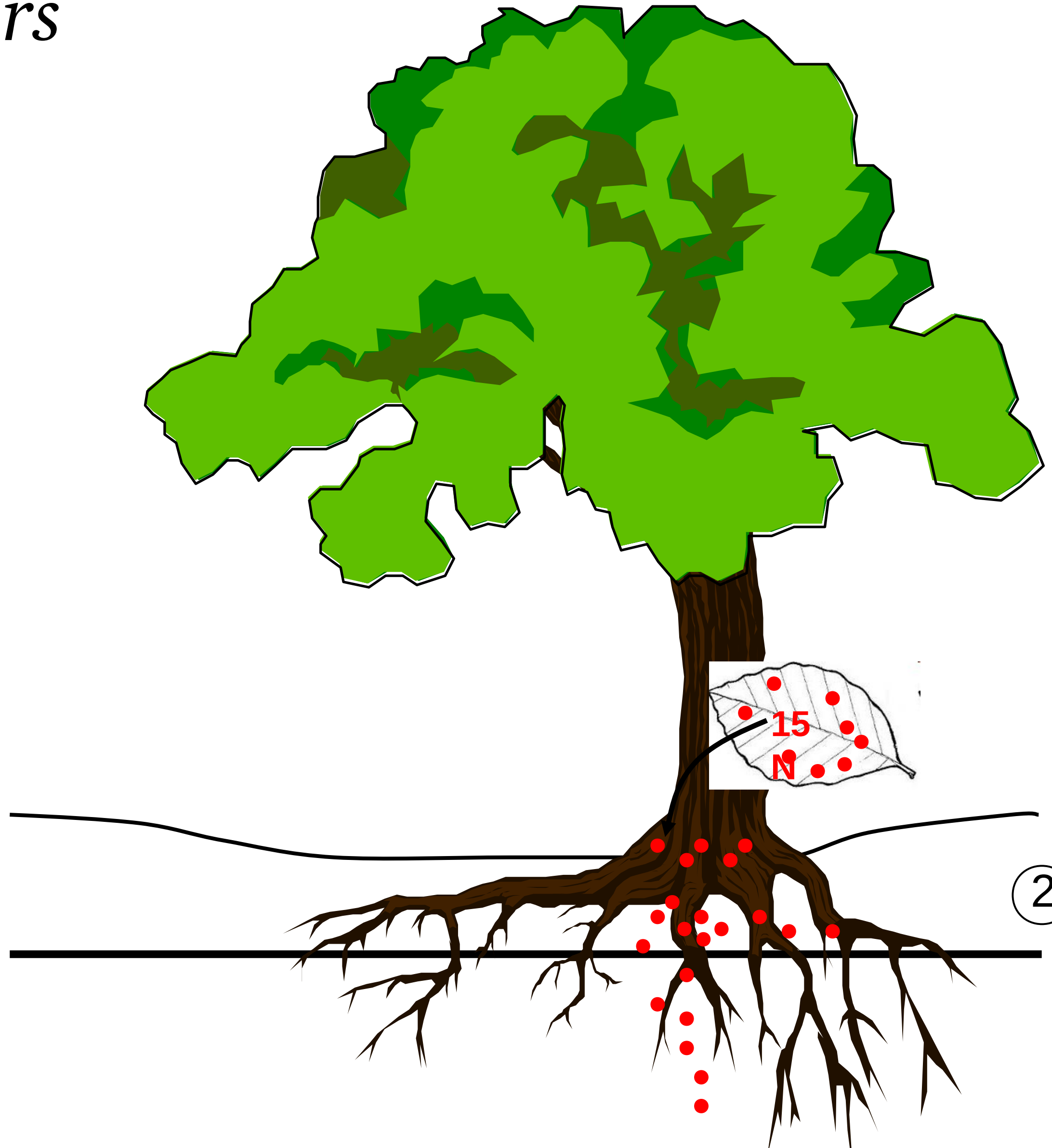
Mull

Moder – High altitude, high rainfall

MRT contrôlé par les conditions climatiques

15N incorporation into soil layers

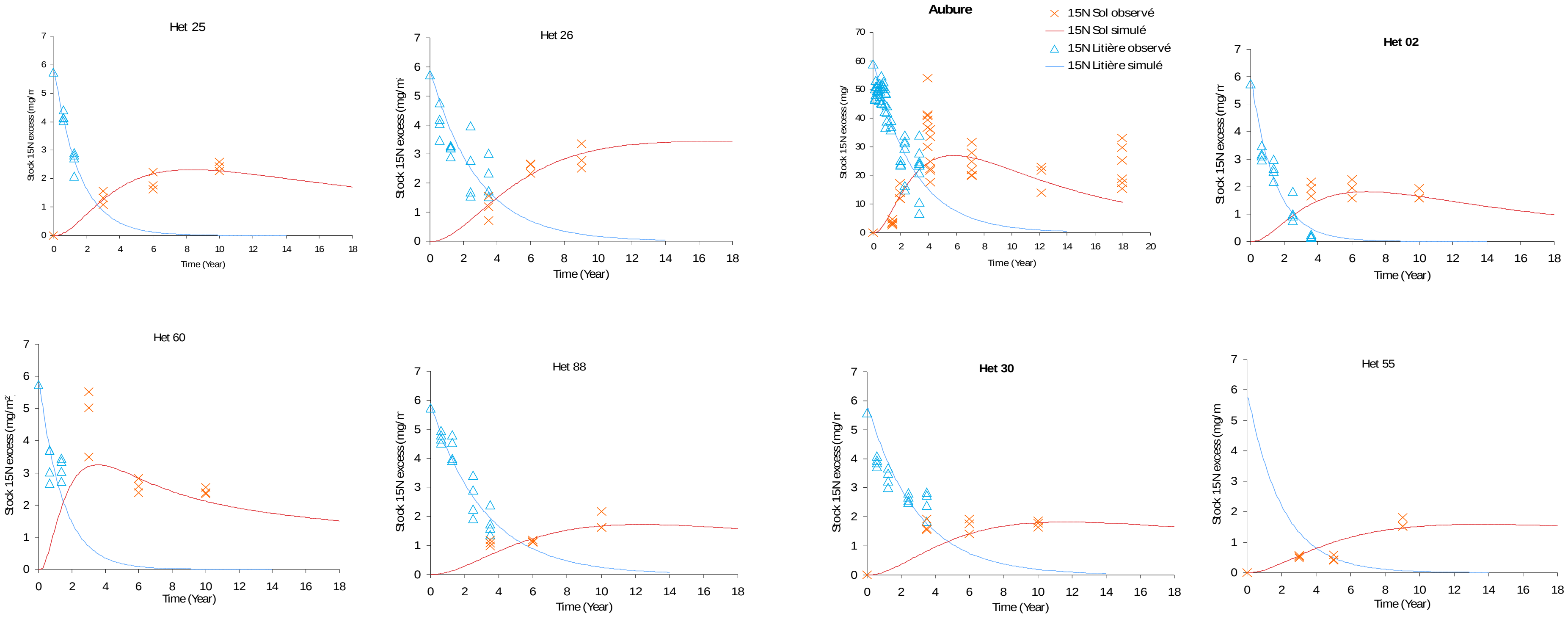




② 15N incorporation into soil layers

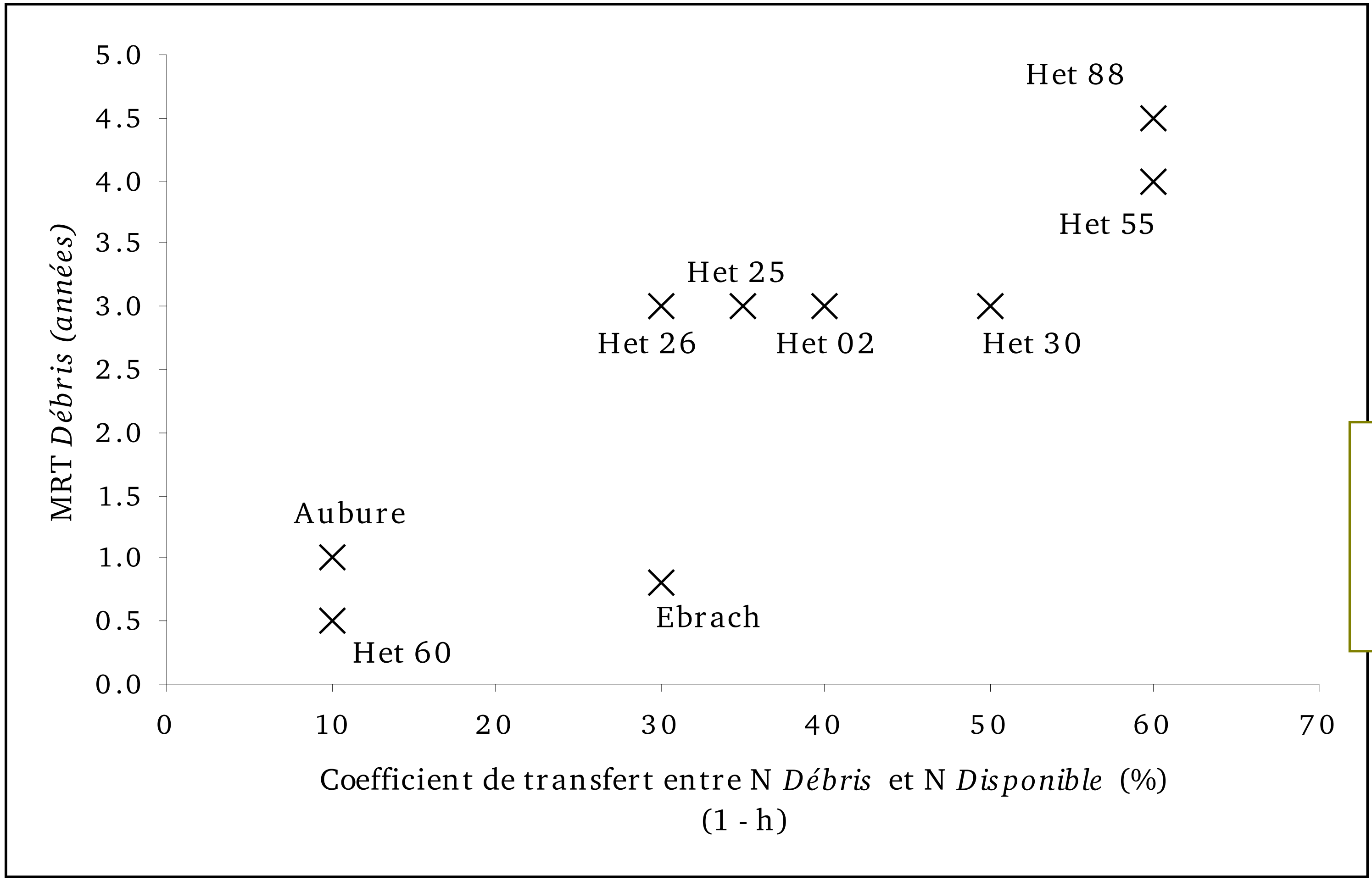
Fit on soil datasets (0 – 10 cm) – R2 from 0.70 to 0.98

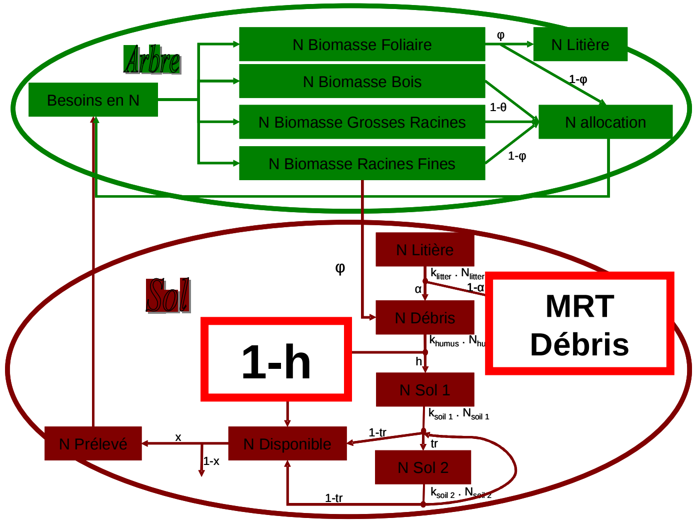
Mull | Moder



N *Sol* = N *Sol 1* + N *Sol 2*

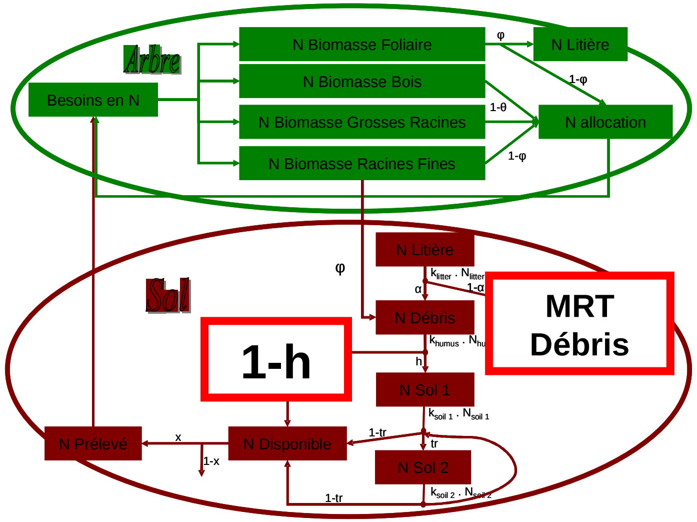
Sequestration of 15N in woody debries.





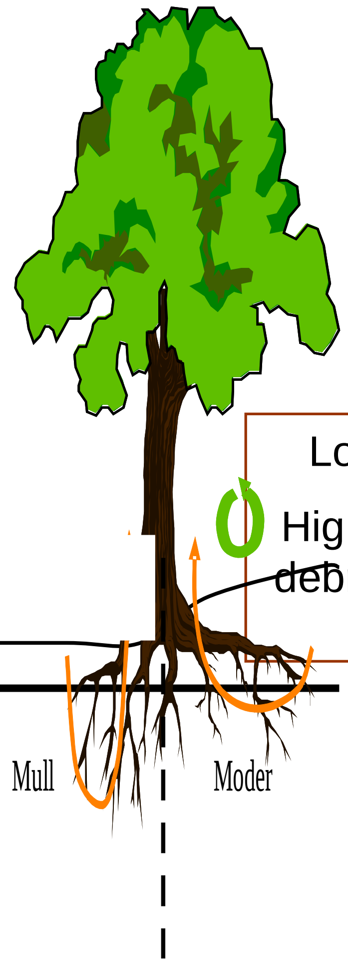
The higher 15N MRT in woody debries is, the higher is N bio-availability for trees in the same laps time

Sequestration of 15N in woody debries.



High N Stock (≥ 2.5 t.ha-1)

Low transfert between woody debries and N available for the trees (≤ 35%)



Low *N stocks* (≤ 1.8 t.ha-1)

High transfert between woody debries and N available for the trees (≥ 40%)

Het 25

Het 26

Het 60

Stock *N sol* petit (≤ 1.8 t.ha-1)

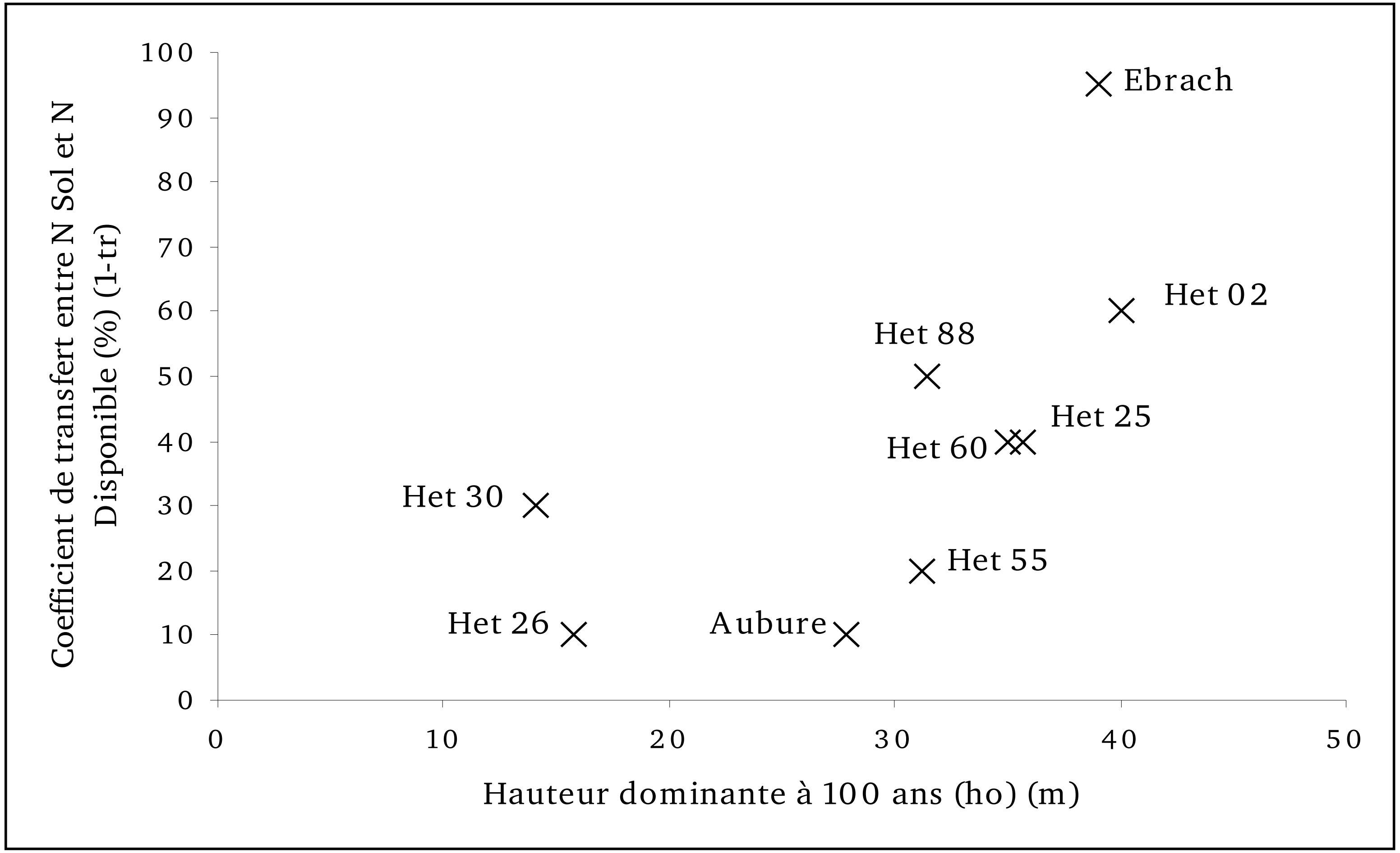
Transfert entre *N Débris* et *N disponible* fort (≥ 40%)

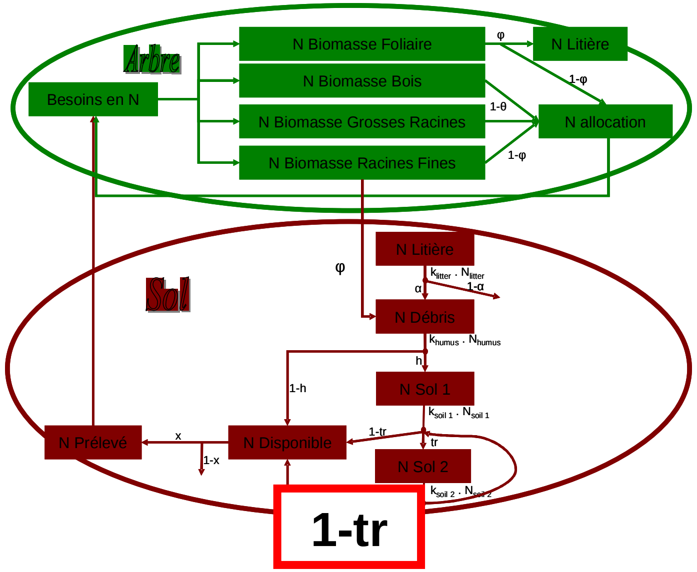
Het 02

Het 30

Consistent with X-ratio study (High recycling of litter inputs) – both decomposers and trees uptake N from the litter when other sources are low

15N incorporation and site fertility



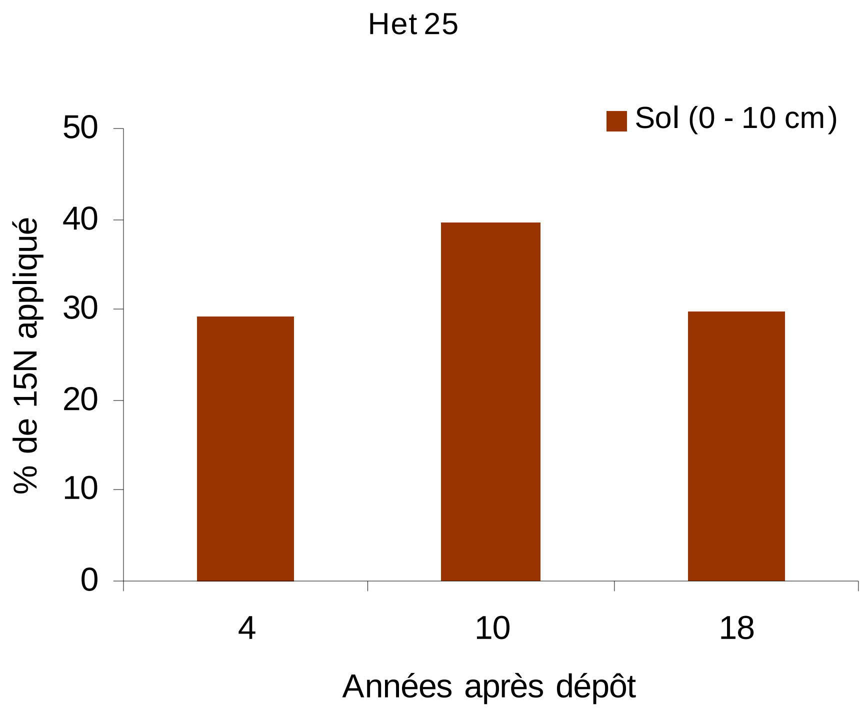


Again, consistent with X-ratio study – trees uptake N from the soil when this resource is available

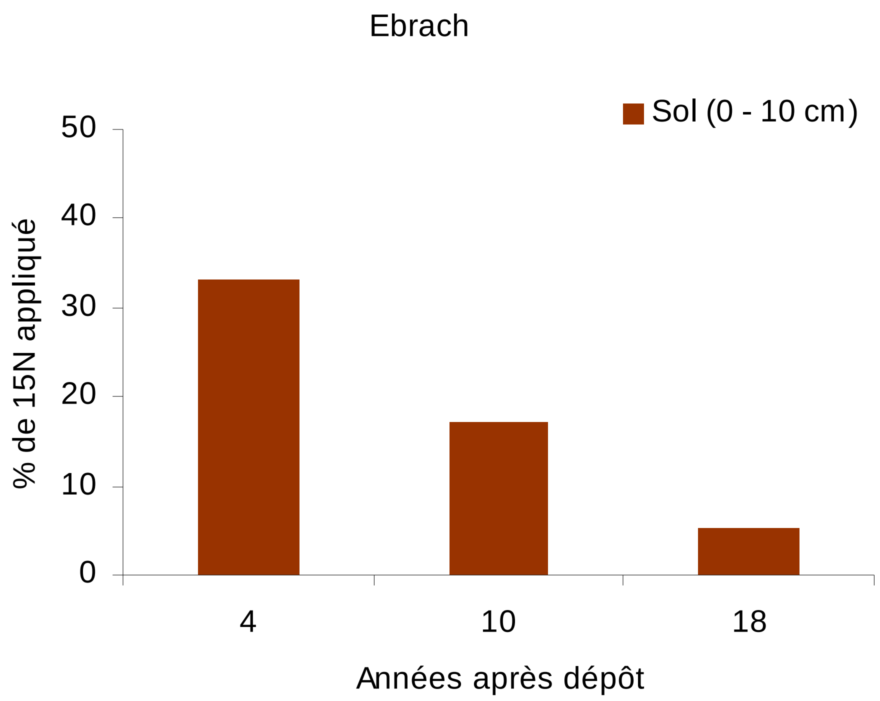
Transfert between N soil and site fertility index (dominant height at 100years)

15N budget from the model outputs

Mull



Moder

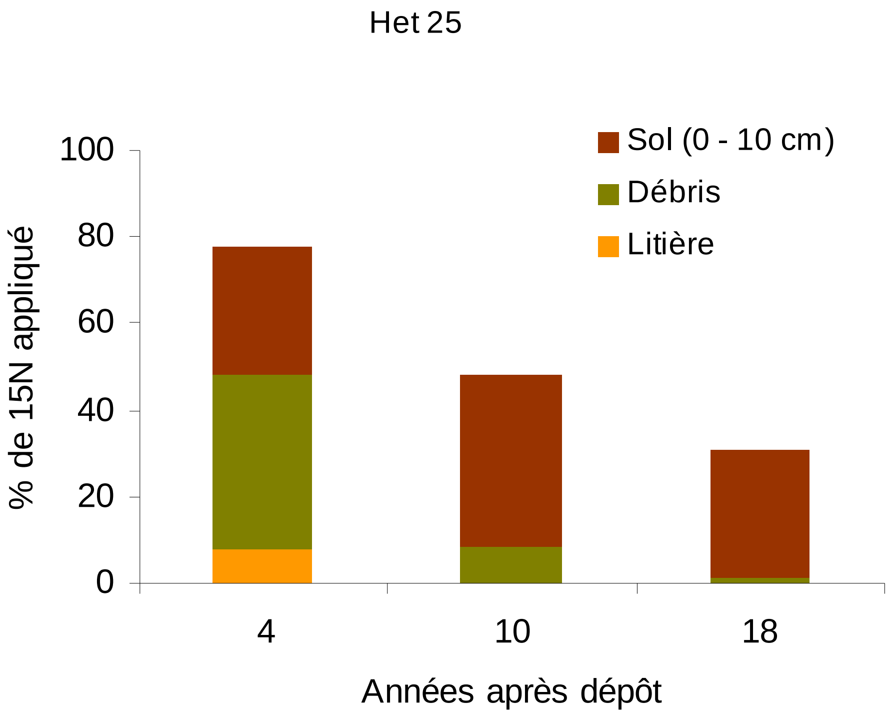


MULL: Impact of macro-fauna (hearthworm), formation of agregates, SOM sequestration

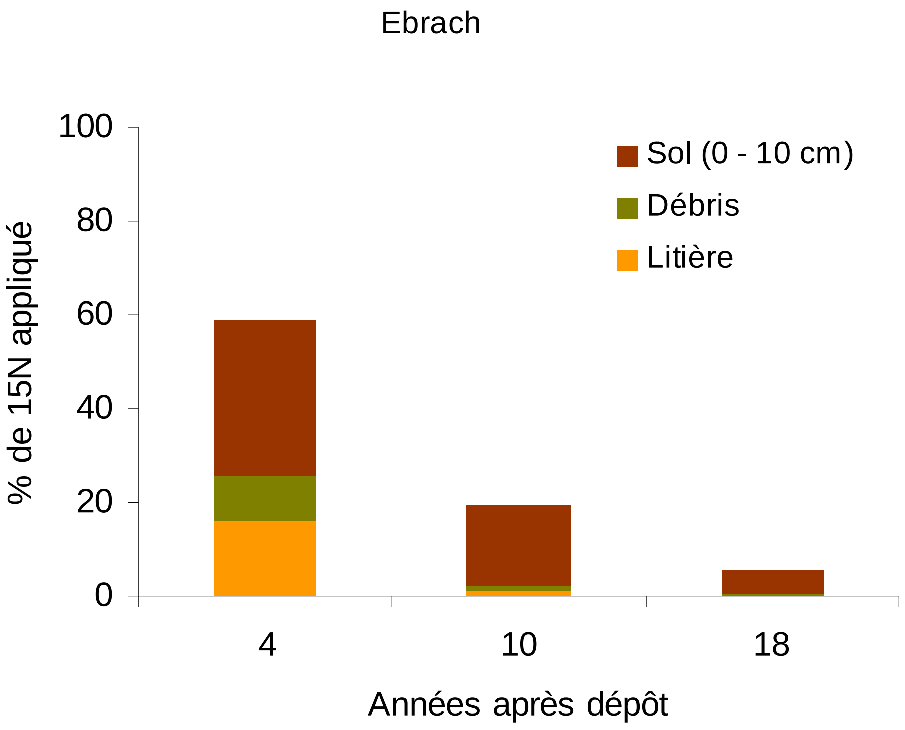
⇒ Stabilisation and conservation of 15N into the soil layers

15N budget from the model outputs

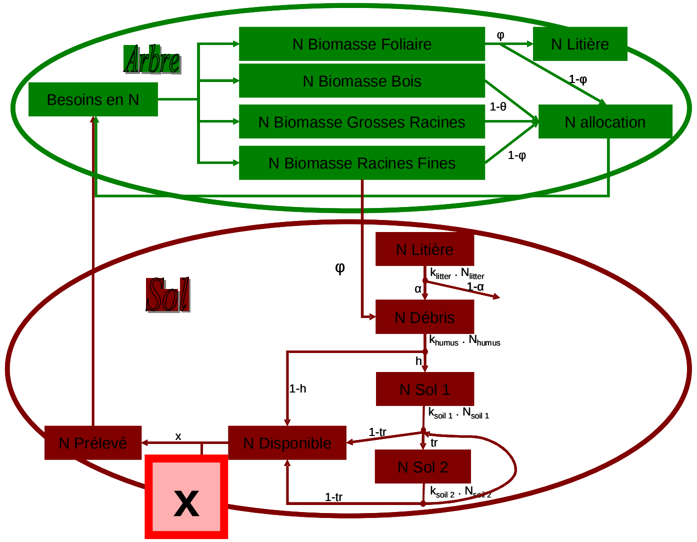
Mull

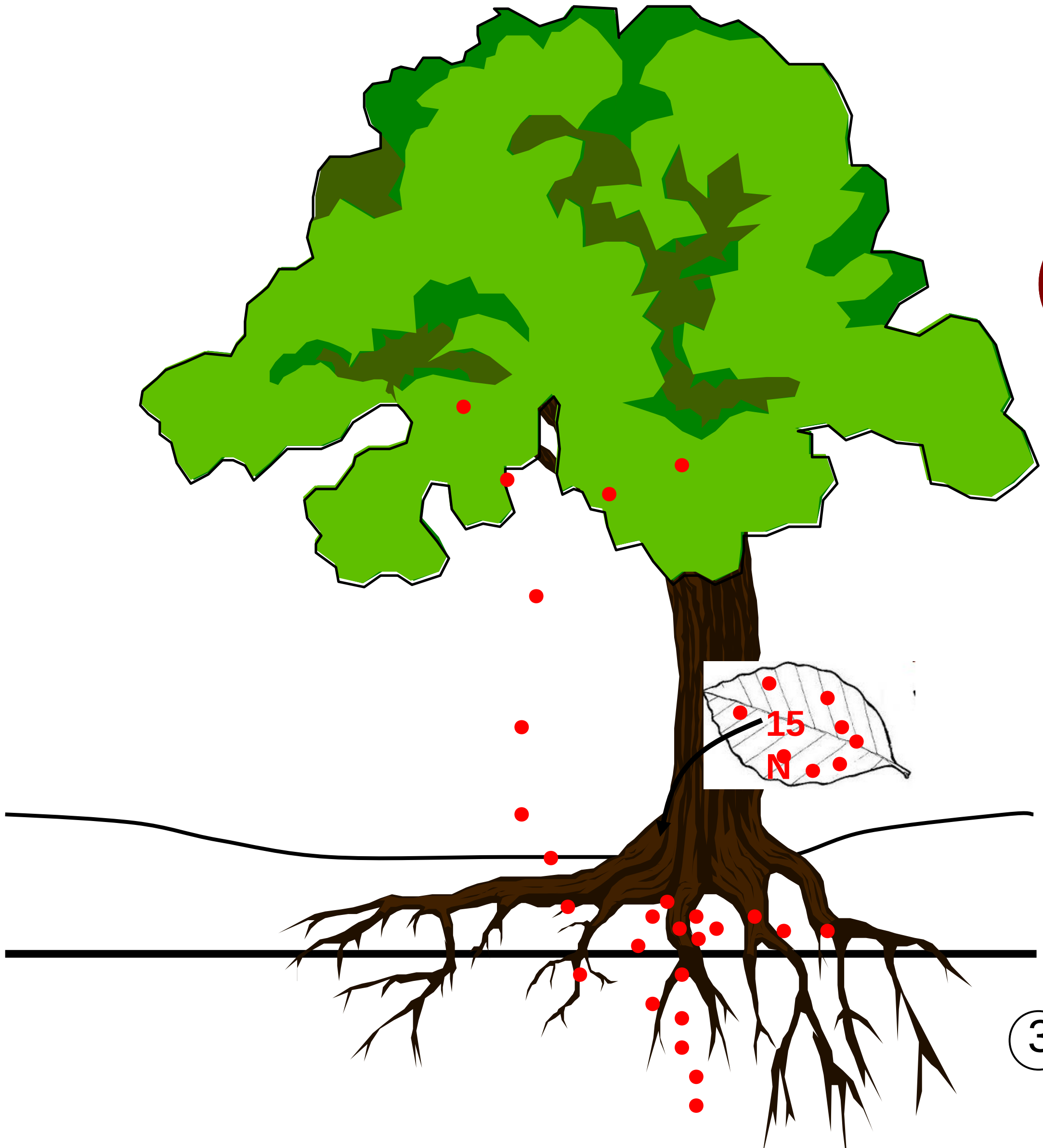


Moder



Are the trees N sinks of the available N in the soil (for both MULL and MODER)





③ 15N uptake by the trees

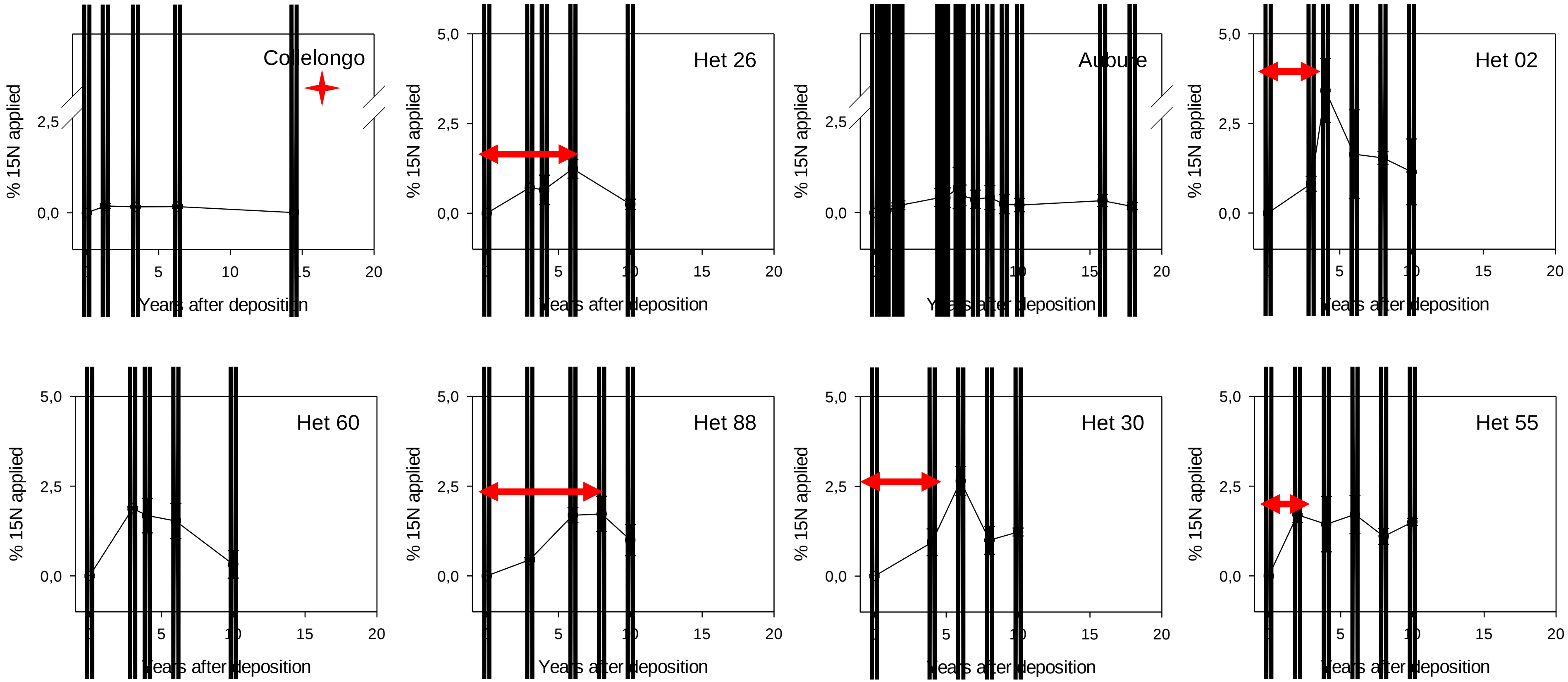
15N incorporation in the leaves

- 2 incorporation phases:

1) Increase of the biodisponibility of 15N for the trees

2) Decrease of this biodisponibility (stabilisation / immobilisation)

Mull	Moder



slow use of N from the litters (long phase 1)

rapid use of N from the litters (short phase 1)

Conclusion

Favourable climate conditions

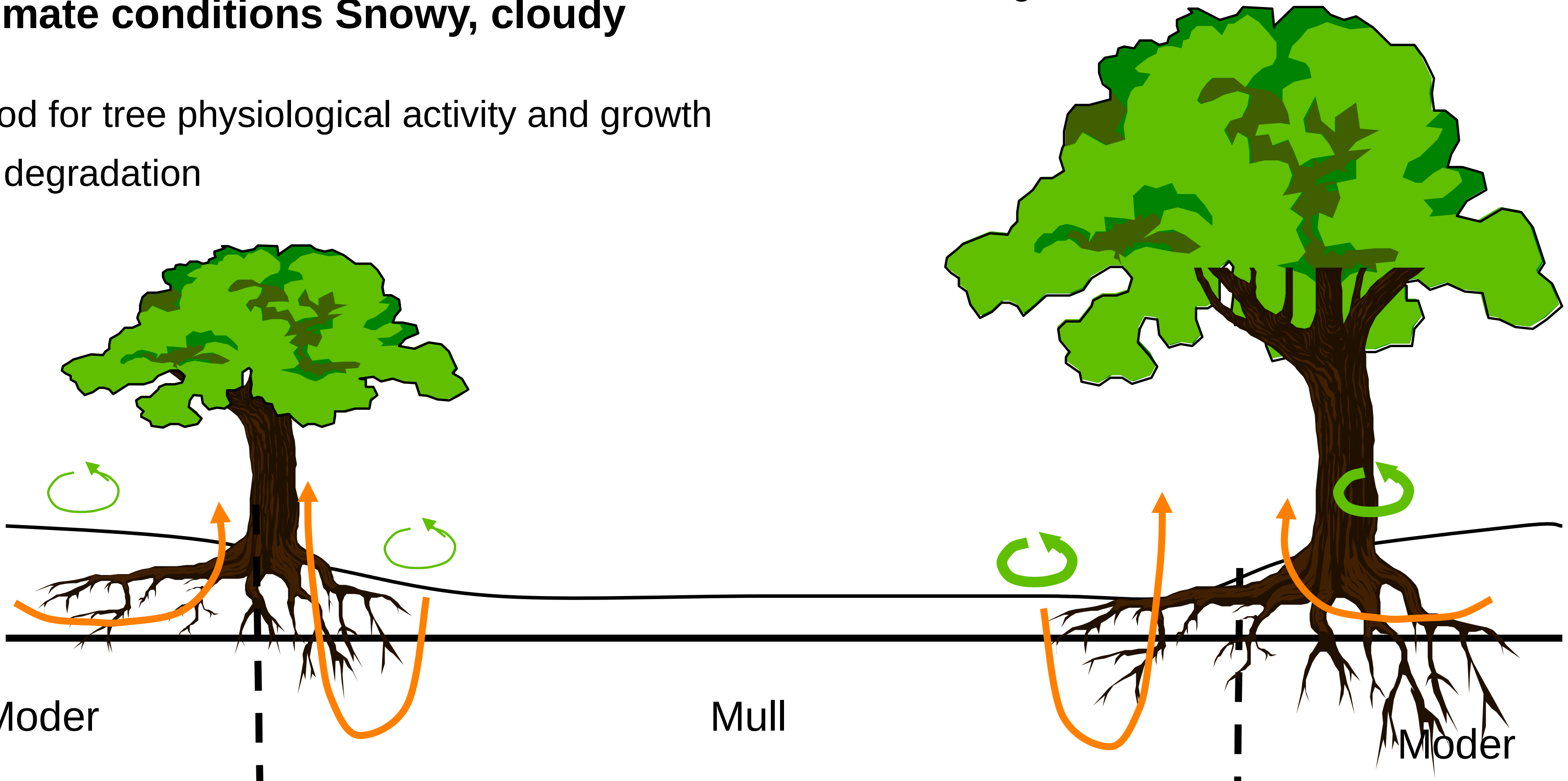
Long period for tree physiological activity and growth

Fast litter degradation

Unfavourable climate conditions Snowy, cloudy

Short period for tree physiological activity and growth

Slow litter degradation



Amount of 15N accumulated after 10 years (% of 15N applied) :

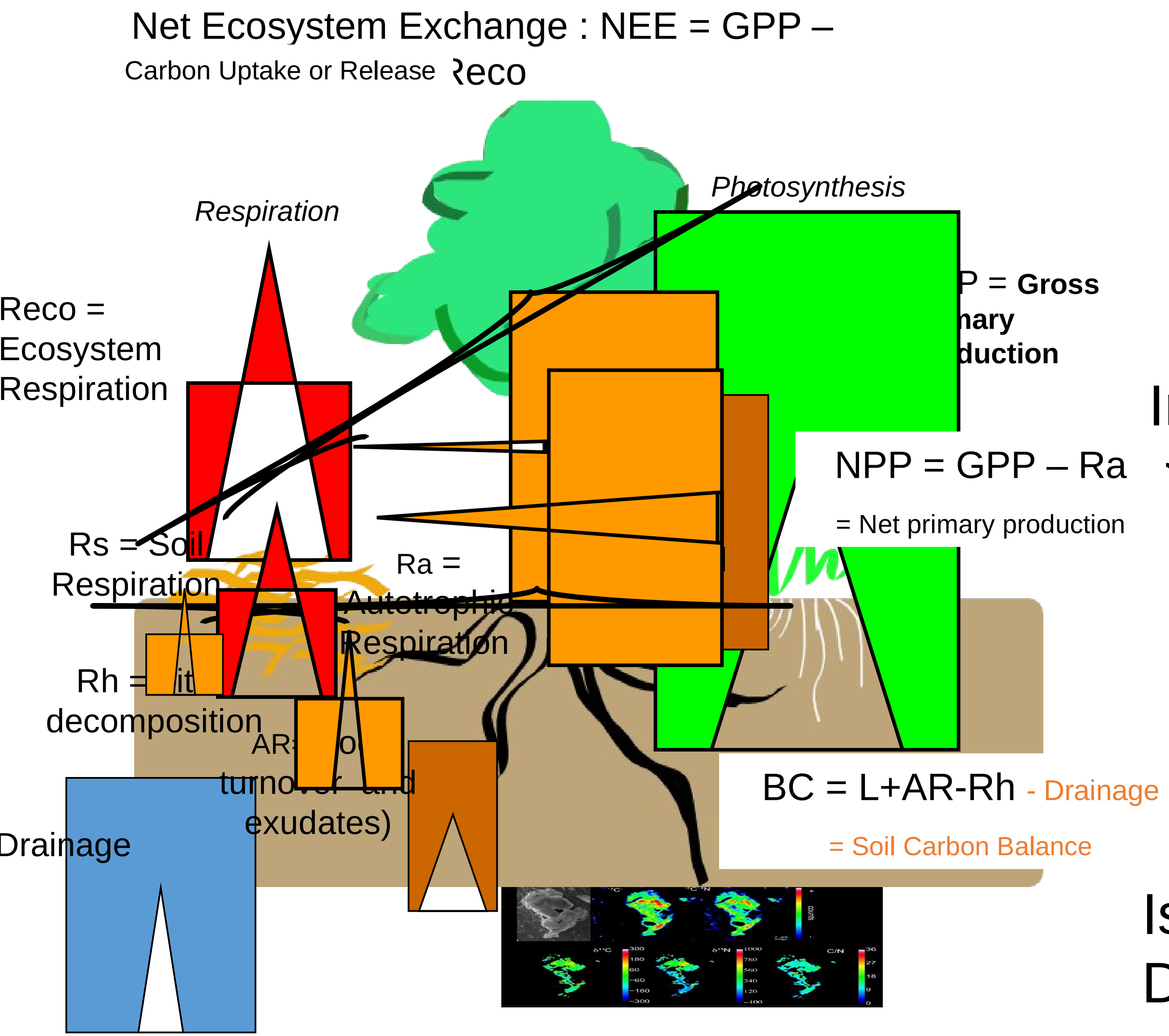
Aubure (3.0)
Het 30 (14.8)

Het 26 (4.5)

Het 88 (9.5)

Het 25 (11.3)
Het 60 (14.3)

Ebrach (19.4)
Het 02 (11.4)
Het 55 (7.3)

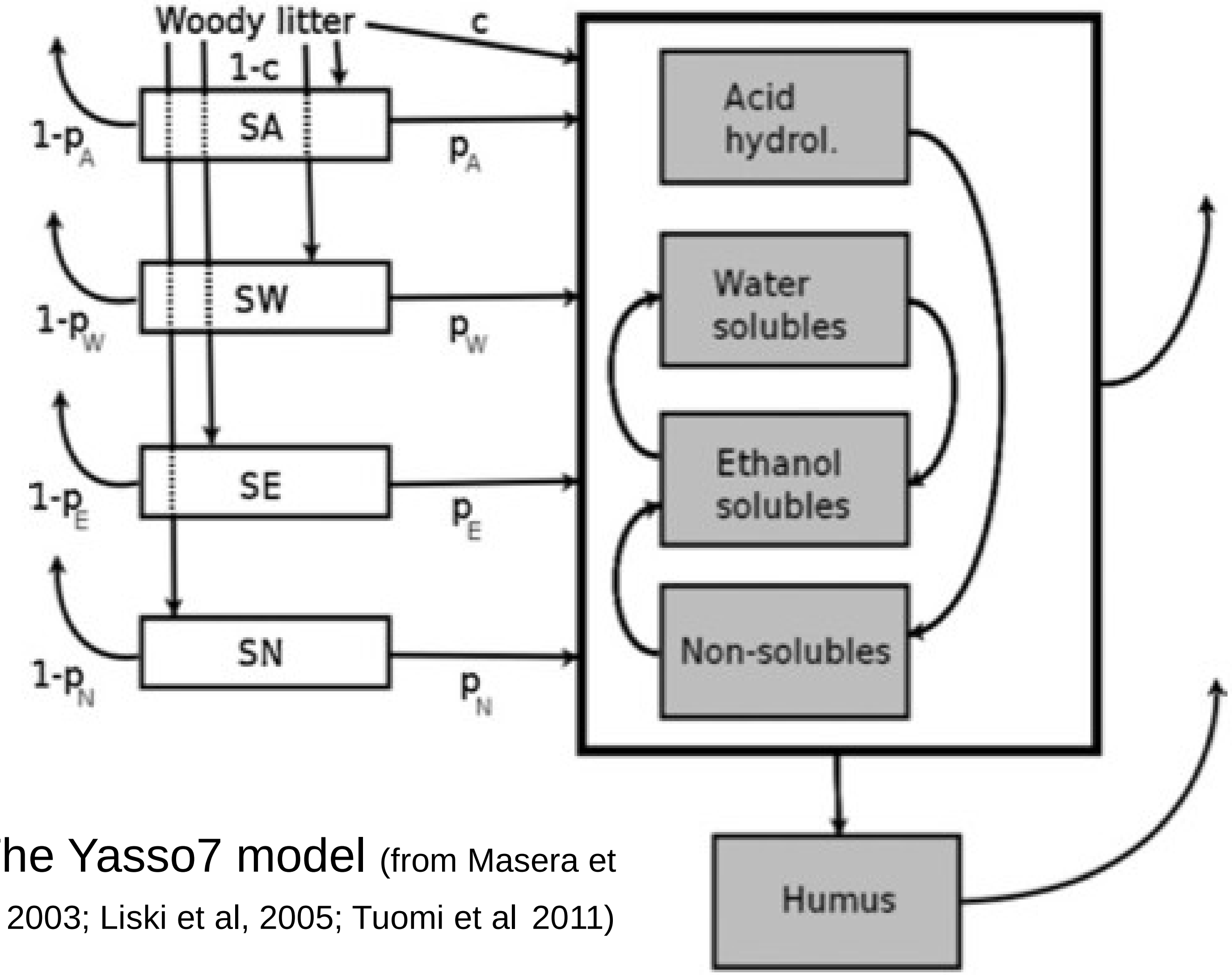


Soil productivity, storms events and climate variations

Impact on litter inputs and SOM mineralisation

Research question

Is there a Stabilisation or a Destabilisation of the SOC after 15 years monitoring in forest soils?



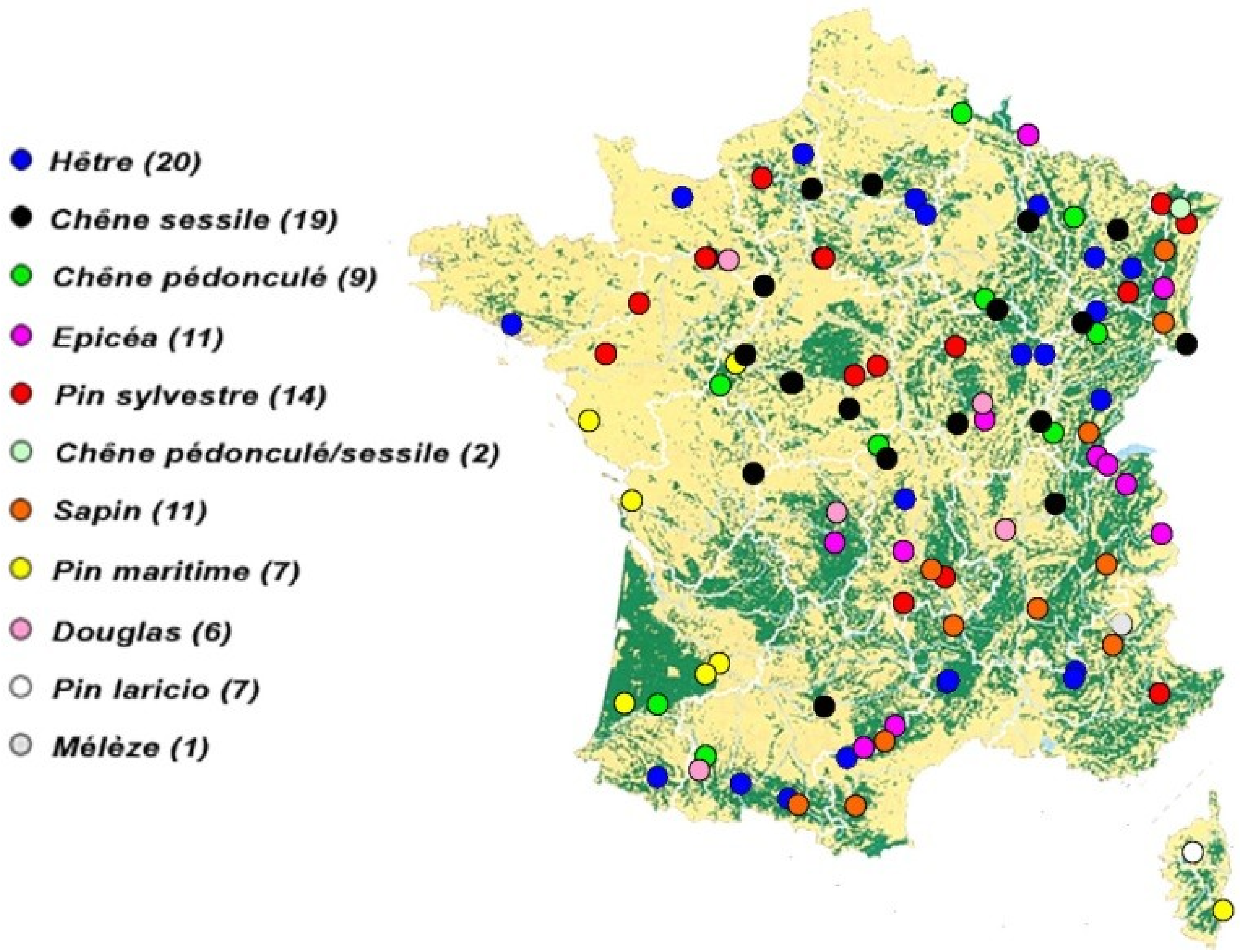
The Yasso7 model (from Masera et al, 2003; Liski et al, 2005; Tuomi et al 2011)

Specifically designed for forest growth and yield models

Based on the biochemical composition of the litter inputs (for both above and belowground)

Takes climate into account

Makes the hypothesis that soil fertility and its impact on SOC dynamics is fully transmitted by the amount of litter input



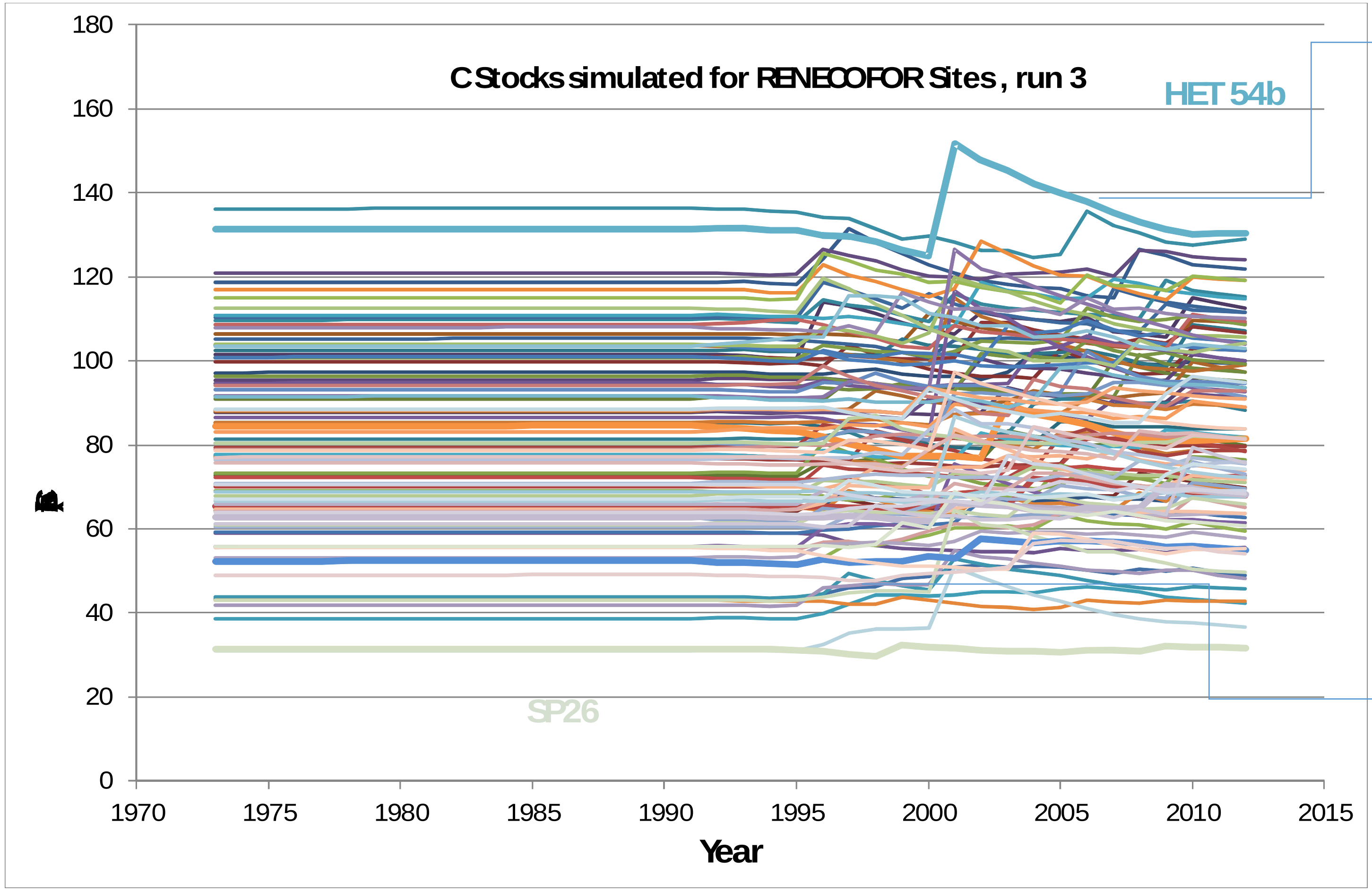
102 plot of the RENECOFOR Network

An unique dataset in forest ecosystems

- Cover the main tree species in France
- Aboveground litterfalls measured between1994-2008 (leaves, branches, fruits et miscellaneous).
- Regular forest inventories combined with biomass models (above- and below-ground biomass) allowed to estimate the inputs after each thinning and each storm
- Soil carbon stocks have been measured in 93-95 and in 07-12.
- Climatic datasets are coming from RENECOFOR own recording and Meteo France.

Good results in average

Spinup procedure with average climate and litter inputs



1999 storm, plot HET 54b

Thinning

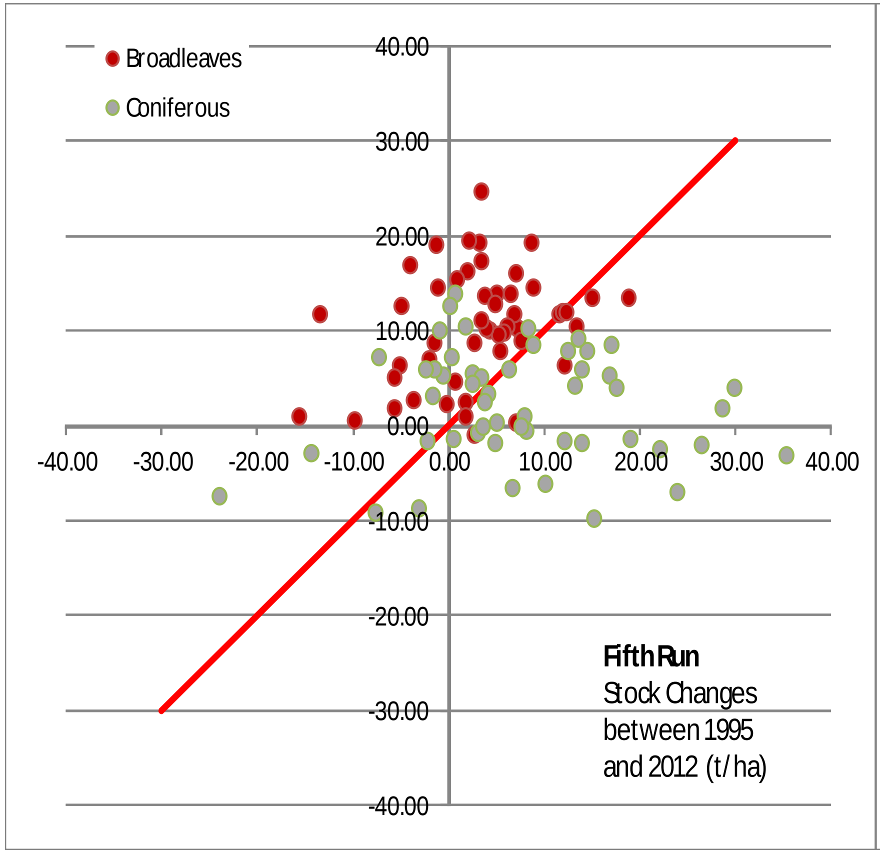
	Observed (tC/ha)	Yasso07-6rdRun (tC/ha)
Mean	80.9	81.6
SD	29.9	22.8
CV	37%	28%

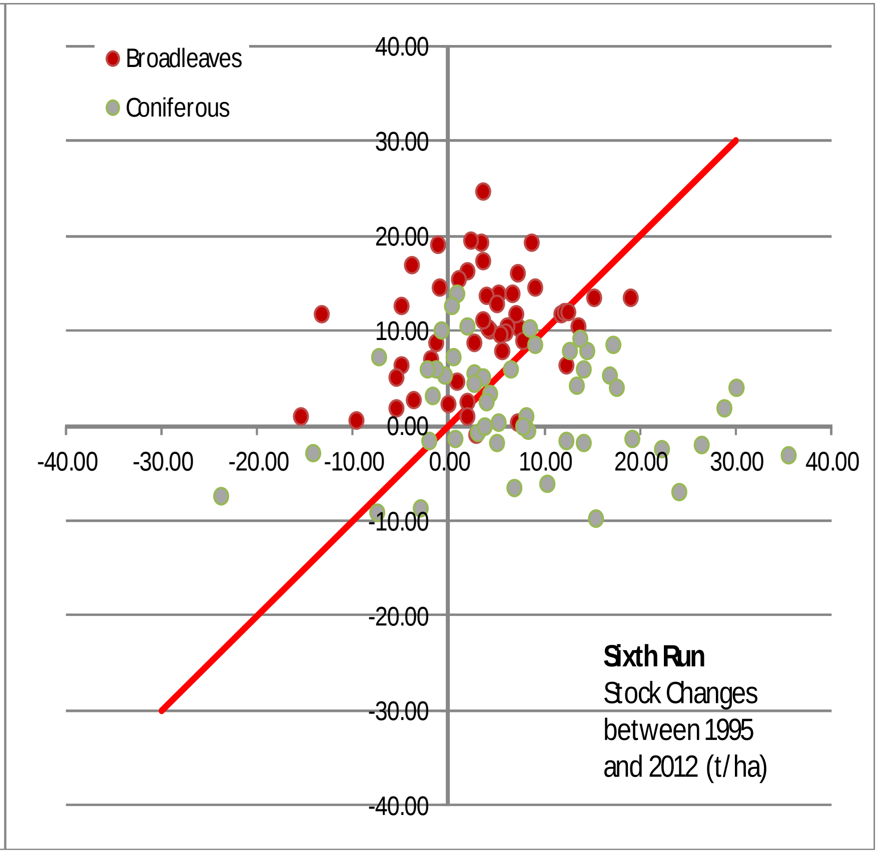
Actual climate and litter inputs (evaluation of the stock changes)

	Observed (tC/ha/period)	Yasso07-6rdRun (tC/ha/period)
Mean	5.6	6.1
SD	9.5	7.2
CV	170%	118%

BUT, not at the stand / species level…….

Without considering species biochemistry of the litters

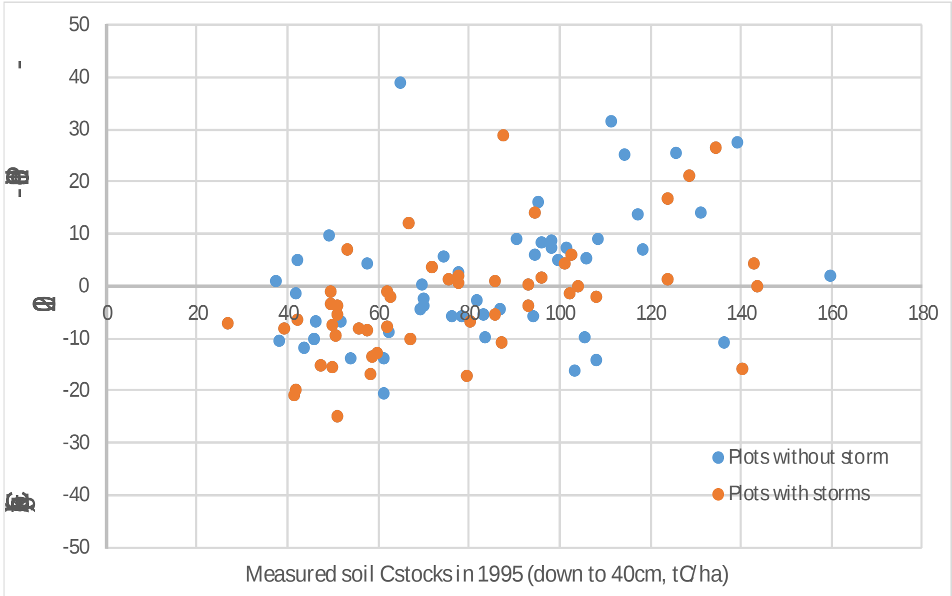




Taking species specific biochemistry of the litters

Same results for both stocks and stock changes……..

Error tracking…….



- Error well correlated to the initial stock

  Past history ? But also wrong estimate of the partitionning of SOM into the biochemical components

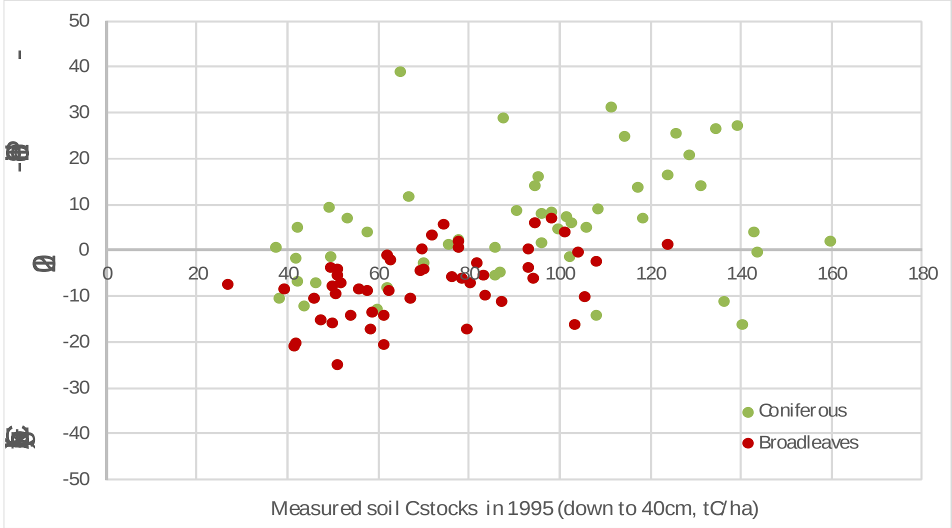
- Species effect (on the intercept and interaction with the stand productivity)

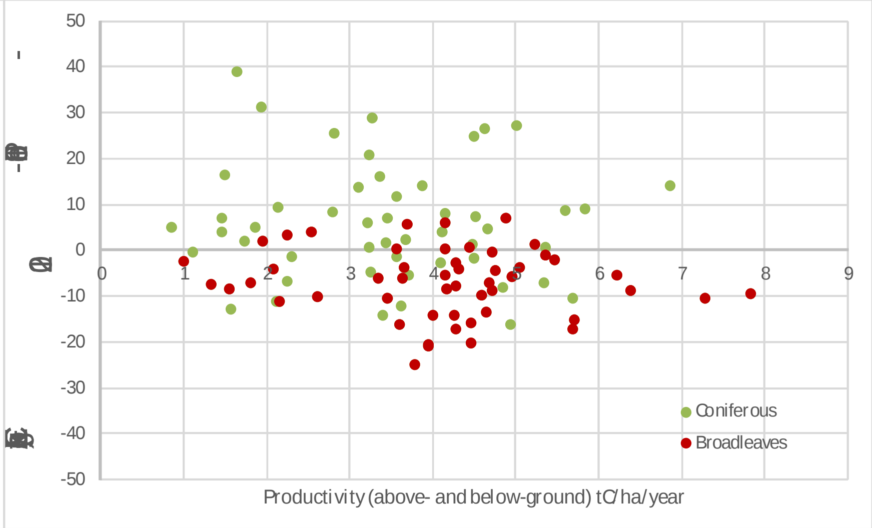
  Biogeochemistry of the litter not well taken into account

  Too much emphisize on the amount of the litter

- Fertility effect (slight)

  The litter inputs do eliminate most of the impact of soil fertility on SOC dynamics, but not all. It remains a slight effect of soil properties





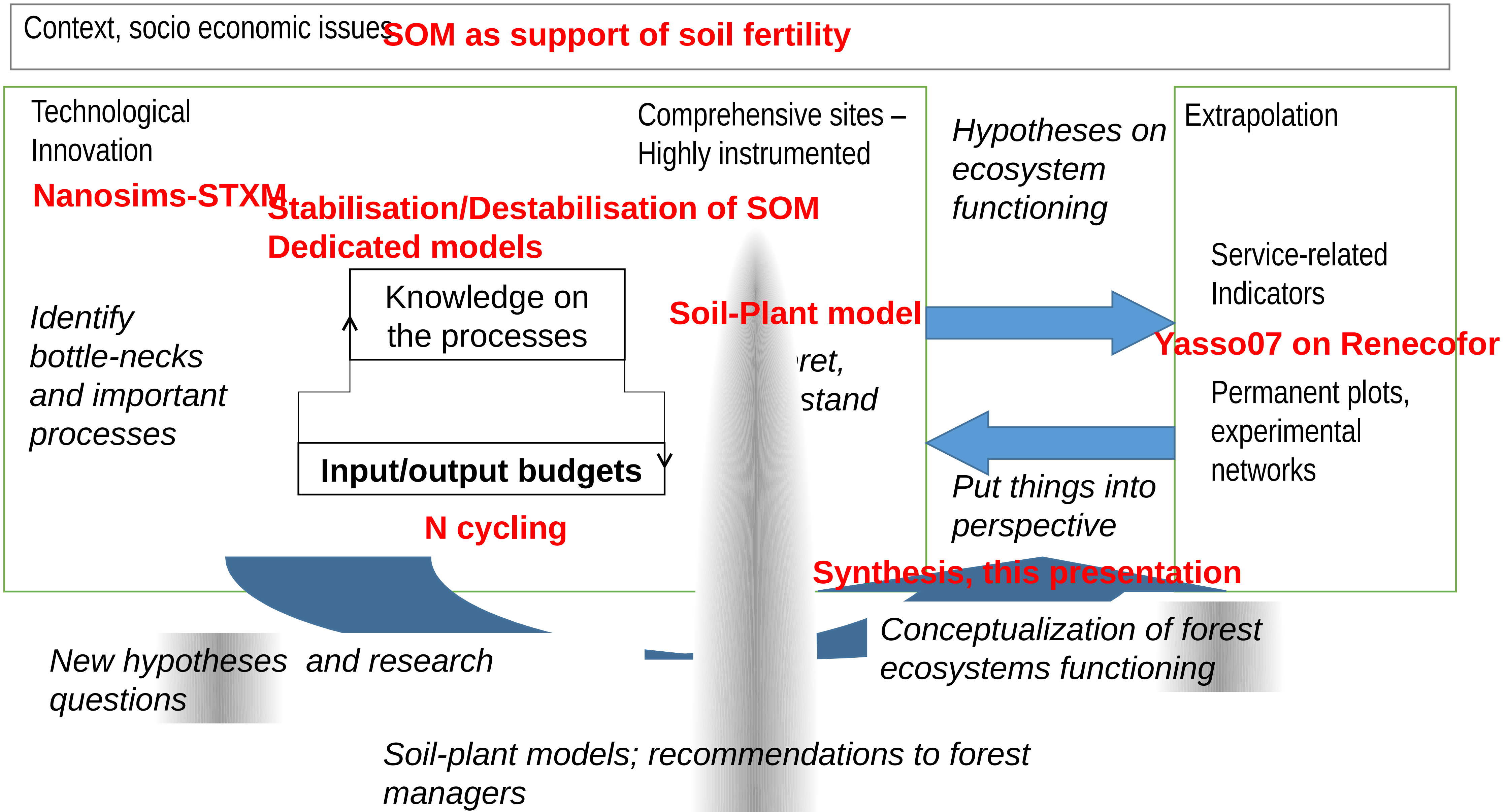
Conclusion on the Yasso model

The architecture of Yasso based on a biochemical partitioning of SOC is particularly relevant to tackle the challenge of assessing assess fluxes at decades to centuries time scale

But it need to be reparametrized for French application with more contrasted values for the Acid, Ethanol and Non soluble pools (like in Tuomi et al., 2011a Ecological Modelling; 2011b, Environmental Modeling and Software)

And also may be an improvement to take, at least, humus type into consideration (cf work of J. Salleles)

General conclusion



Perspectives

Climate change and soil fertility – Western Siberian

Context

Current projections for climate change indicate that the huge territory of the western Siberian plains will become suitable for agriculture. However, the projections do not consider the soil fertility, whereas it is a relevant issue. The intention is to test whether the predicted increase in snow precipitations will change the soil water fluxes but also the patterns of soil organic matter decomposition and the rate of nutrient release through reduced soil freezing.

Hypotheses

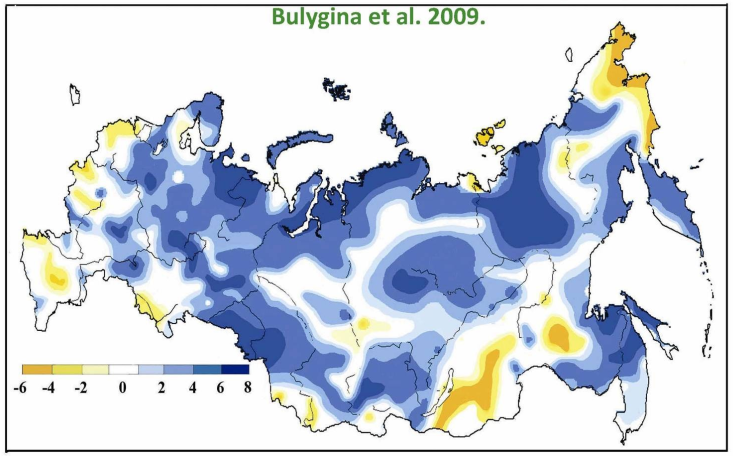
the predicted increase in snow precipitations will
- reduce soil freezing
- Modify the soil water fluxes

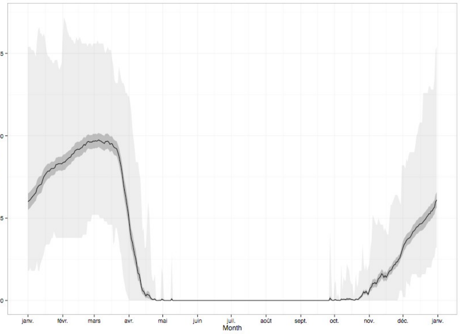
And as a result, change
- the patterns of soil organic matter decomposition
- the rate of nutrient release.

Methods :

snow manipulation, experimental sites on a snow gradient
T°C, moisture record
15N litter decomposition
Enzyme measurement

Number of days with deep snow cover on the ground (> 20 cm).
Linear trends for the 1951-2006 period; [days/10yr].

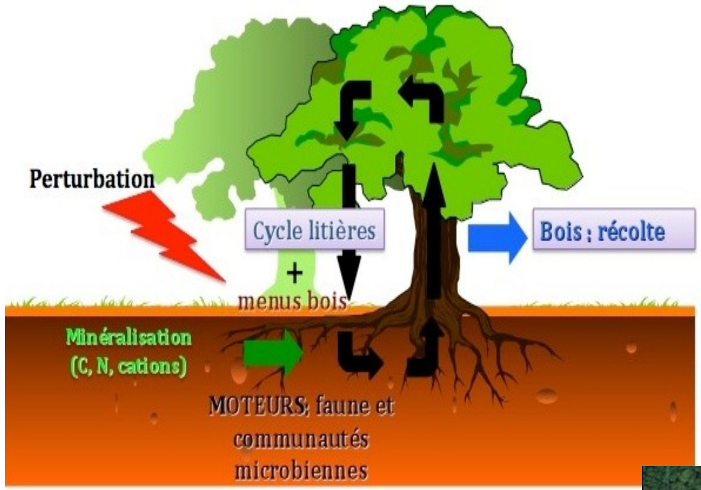


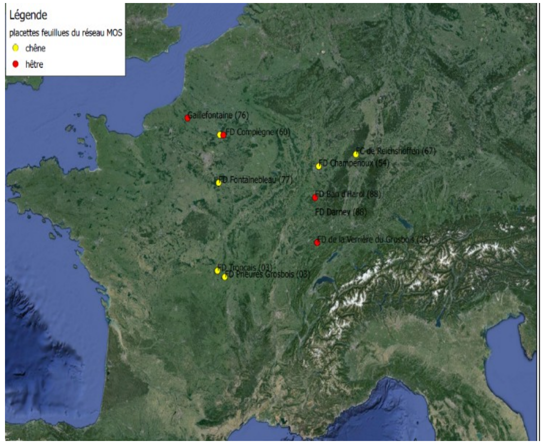


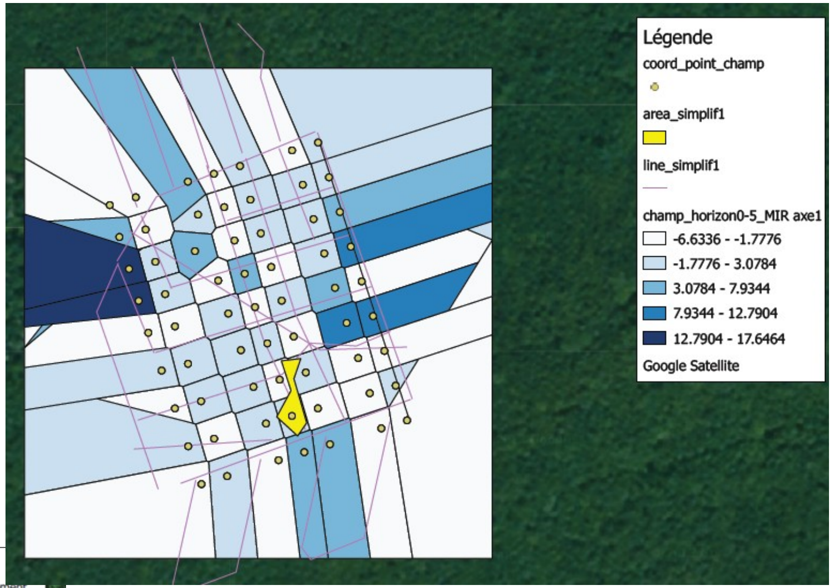
phD Polina Nikitich

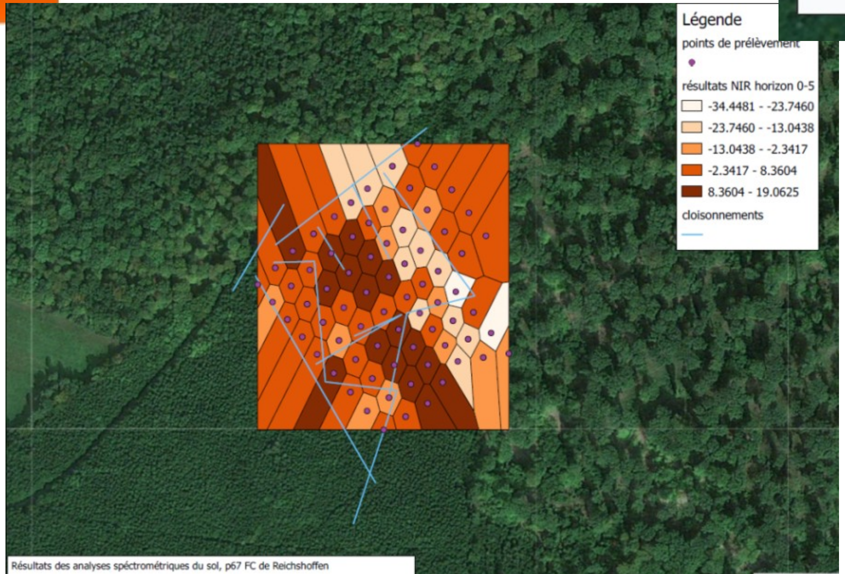
Perspectives

mpact of Slash management on soil fertility and soil biodiversity (structure and function)









phD Emila Akroume