Sustainability issues related to forest soils

Gregory van Der Heijden, Arnaud A. Legout, Karna Hansson, Jean-Paul Laclau, Laurent Augusto, Michel Vennetier, Antoine Versini, Jacques J. Ranger

International Scientific Seminar

Sustainable Intensification of planted forests: How Far can we go?

Monday June 13th 2016
Biarritz, France

Sustainability issues related to forest soils

Forest soil fertility: definition and management

Gregory VAN DER HEIJDEN [1], Arnaud LEGOUT[1], Karna HANSSON[1], Jean Paul LACLAU[2], Laurent AUGUSTO[3], Michel VENNETIER[4], Antoine VERSINI[5], Jacques RANGER[1]

1. INRA Nancy, Unité Biogéochimie des écosystèmes forestiers, 54280 Champenoux

2. CIRAD, UMR Eco&Sols, Ecologie Fonctionnelle & Biogéochimie des Sols & Agro-écosystèmes, F34060 Montpellier

3. INRA Bordeaux, UMR Transfert sol-plante et Cycle des Eléments Minéraux, F33883 Villenave d’Ornon

4. IRSTEA Aix en Provence, Unité Ecosystèmes méditerranéens et risques, F13182 Aix en Provence Cedex 5

5. CIRAD, UR Recyclage et risque, F97743 Saint-Denis


Layout

1. **Definitions of Soil Fertility - towards a new concept**
   - Why do forest soils differ from agricultural soils
   - Conventionnal approaches to soil fertility and their limits
   - The importance of nutrient fluxes
2. **Impact of different silvicultural practices on forest soil fertility**
   - Effects of tree species change
   - Effects of soil compaction from forest mechanization
   - Effects of increased biomass harvest (whole-tree harvesting)

Forest soil characteristics

- Forest soils are very different from agricultural soils:
  - Acid soils, nutrient poor to very poor
  - Higher carbon content
  - Waterlogged soils
  - Higher stone content
  - No or little fertilization/compensation

- Production cycles are much longer in Forest ecosystems

Figure 1 - Spatial distribution of french plots from the European Network. The sites used in the comparison between forest and agricultural soils are plotted in black.

Badeau et al., 1999)

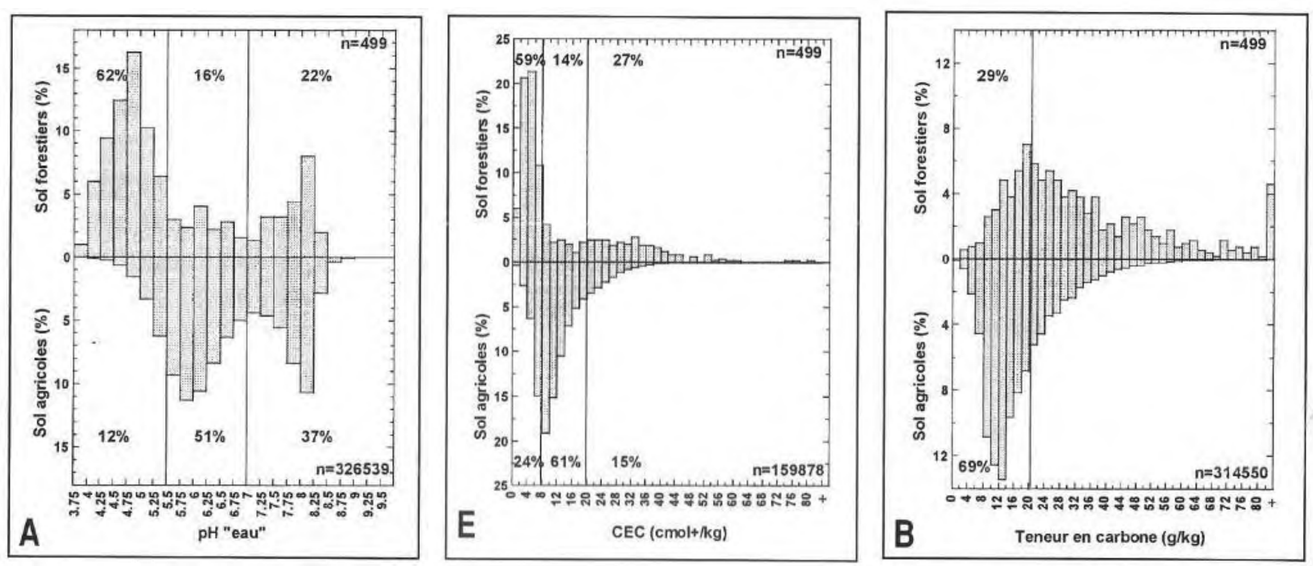
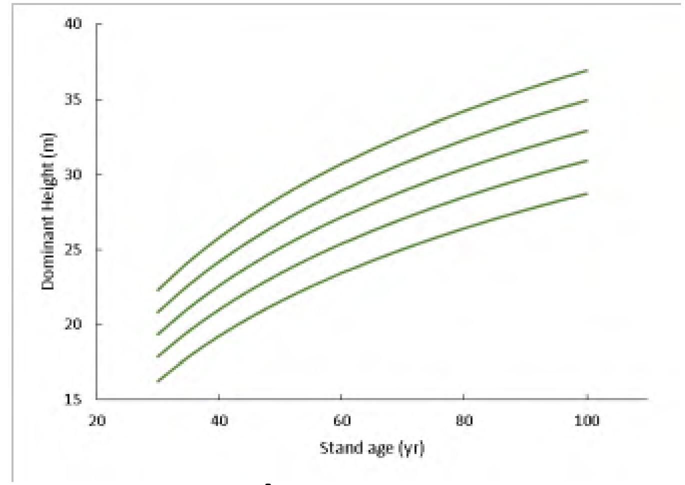


Figure 8 - *Frequency distribution of soil properties between 0 and 20 cm depths for forest and agricultural soils : pH (water) (-A-), organic carbon concentrations (-B-), nitrogen concentration (-C-), C/N ration (-D-), exchangeable cation capacity values (-E-) and base saturation values (-F-).*

Soil fertility definitions…

- Fertility = Capacity of a soil to produce (Barbier, 1955) – Capacity of the soil to supply necessary resources for plant growth
- In forest ecosystems, fertility has been characterized by dominante tree height at a given age



- Forest soil fertility = reservoir of nutrients availiable to plants

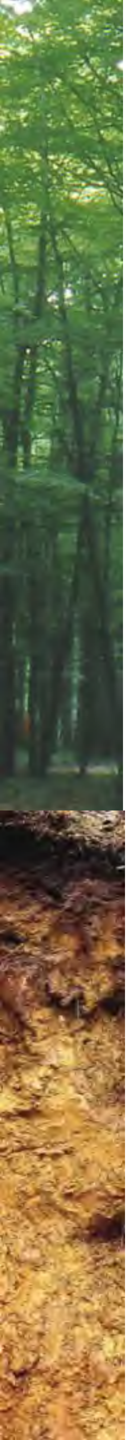
Forest soil fertility classes (*from Bonneau, 1995*)

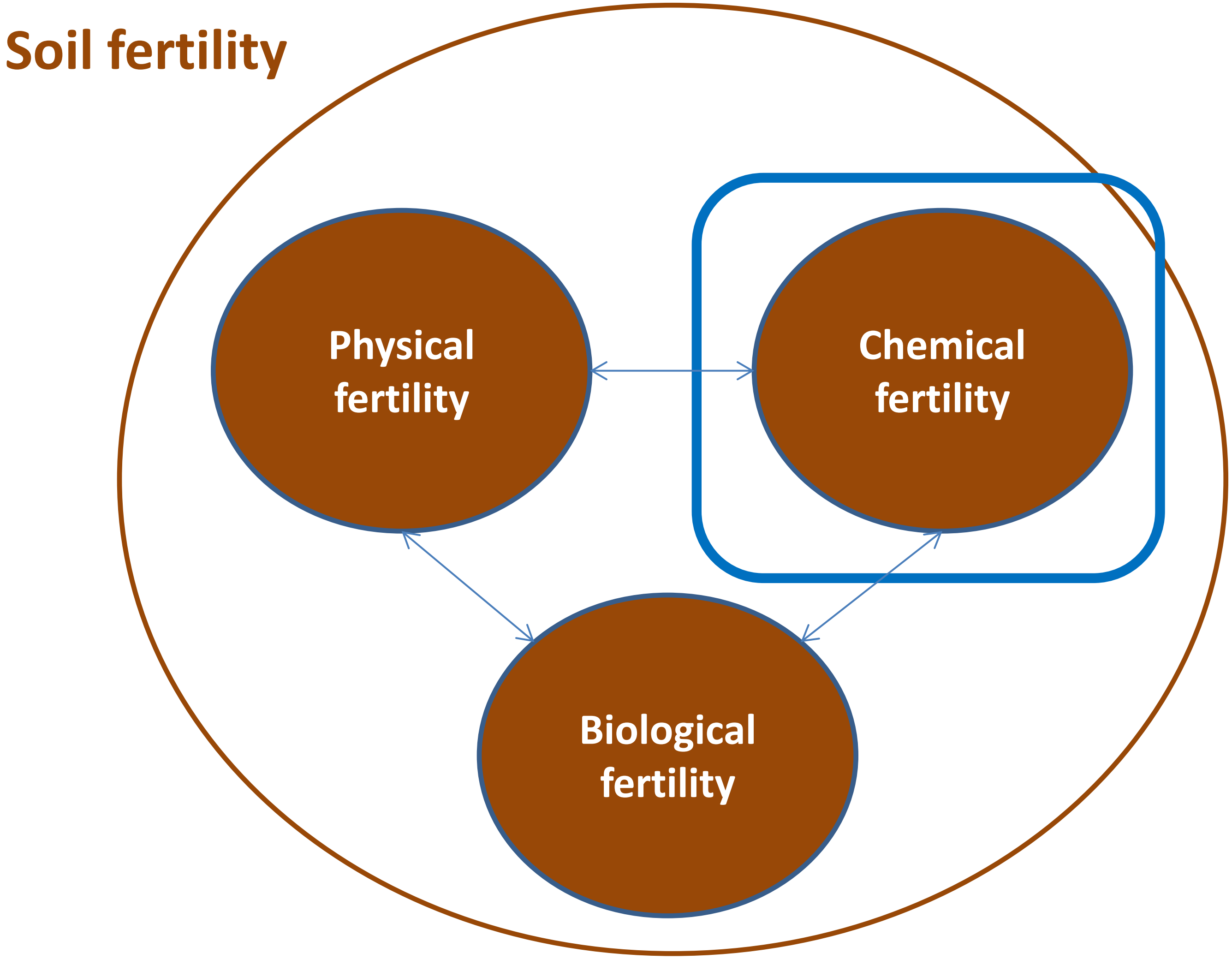
Nutrient levels in the 0-70 cm soil layer expressed in kg/ha

	Diagnosis	Nutrient level (kg/ha)	Diagnosis	Nutrient level (kg/ha)	Diagnosis	Nutrient level (kg/ha)
K	Very insufficient reserves. High risk of deficiency on the short-term	335	Insufficient reserves. High risk of deficiency on the mid-term	465	Optimal reserves compared to requirements	745
Ca		445		645		1785
Mg		120		180		300
P		180		260		480

- Concepts derived from agronomy concepts

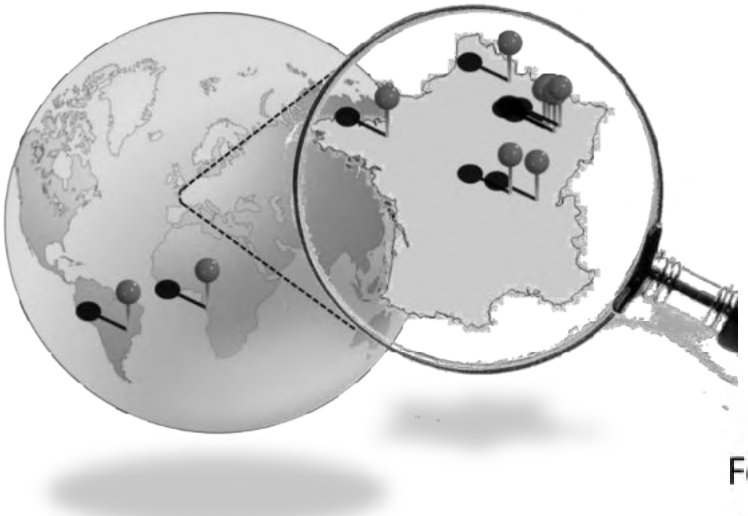
How to define soil fertility for forest ecosystems ?





« The chemical fertility is only a component of global soil fertility which also depend on the soil water retention capacity, soil texture and structure, its properties enabling root prospection, presence and abundance of macro and microfauna, fungi » (Bonneau, 1995)

Which fertility indicator to choose?



SOERE

Système d'Observation

d'Expérimentation, sur le long term

pour la Recherche en Environneme

F-ORE-T

Fonctionnement de

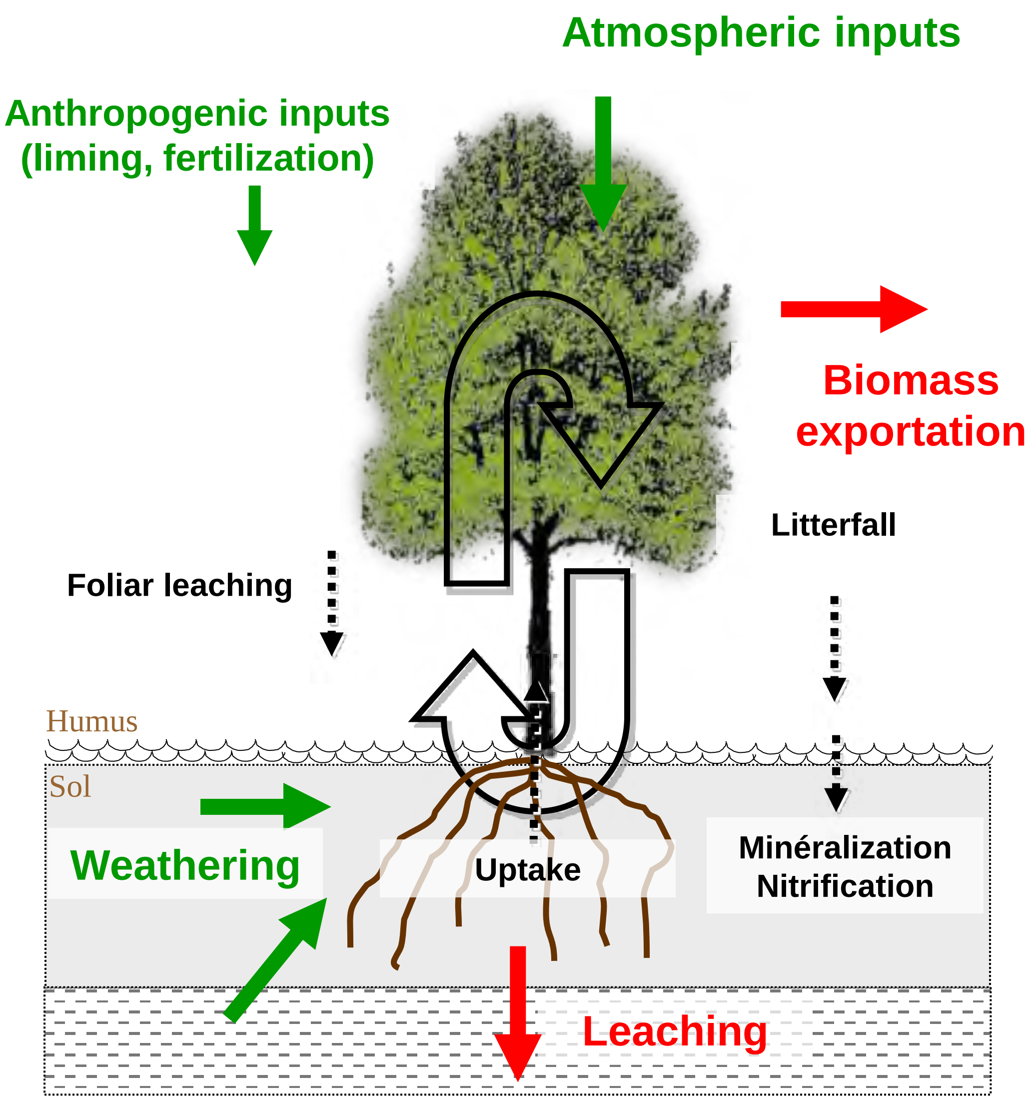
http://www.gip-ecofor.org/f-ore-t/

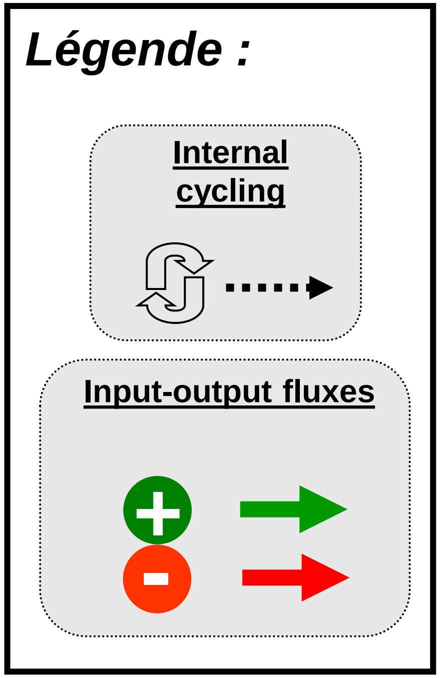
EBC = Pool of exchangeable base cations (Ca+Mg+K+Na)

	EBC, 0-10 cm	EBC, 0-70 cm	pH, 0-10 cm	C/N, 0-10 cm
Fougères	1	4	6	11
Gemaingoutte	2	2	8	5
Vauxrenard	3	1	3	1
Ardennes	4	6	7	2
Bonhomme	5	7	11	7
Aubure 1	6	5	10	3
Aubure 2	7	3	9	6
Abreschviller	8	9	4	9
Breuil	9	8	5	8
Kondi	10	10	1	10
Itatinga	11	11	2	4

→ Inversion of the gradient according to the indicator

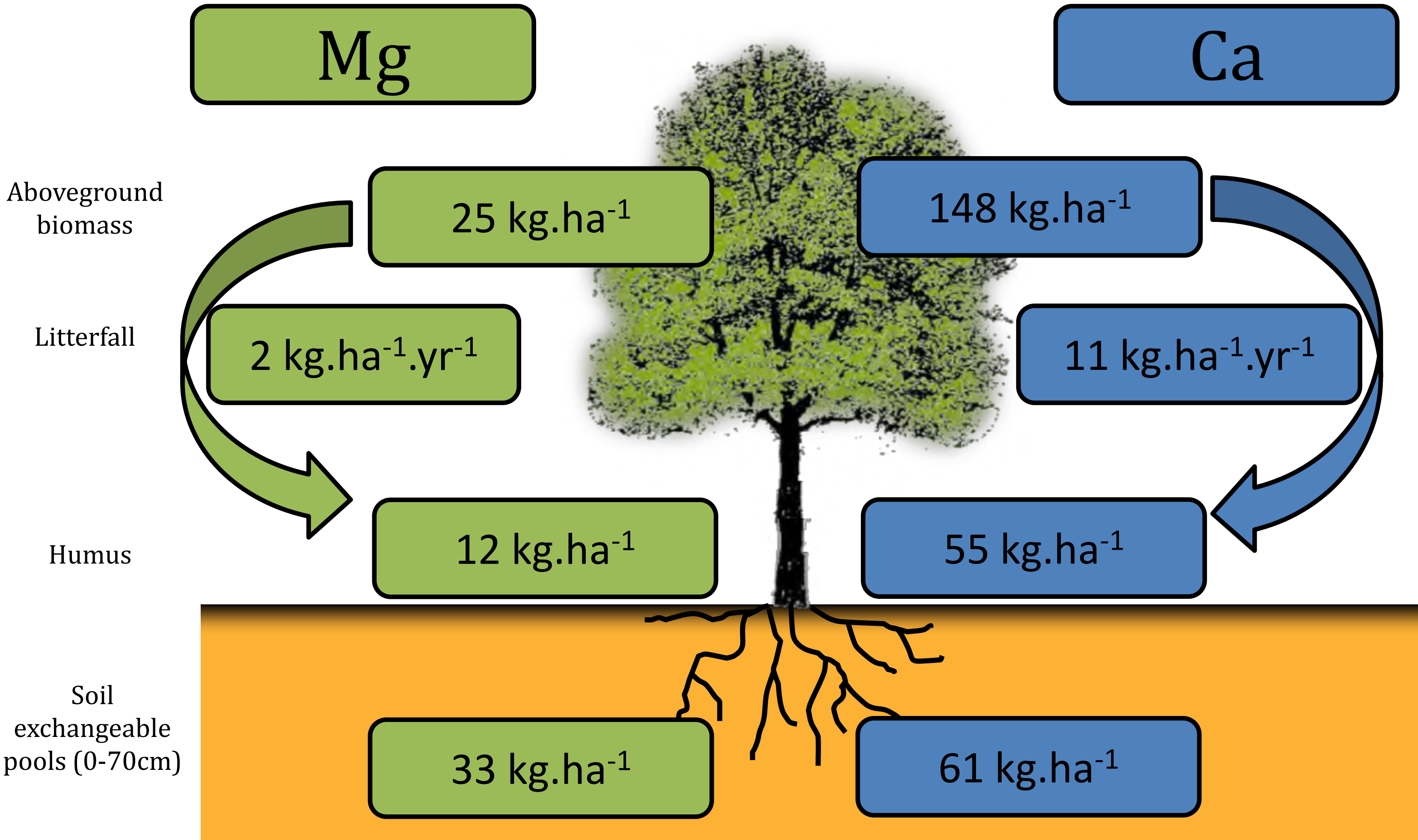
Biogeochemical cycling



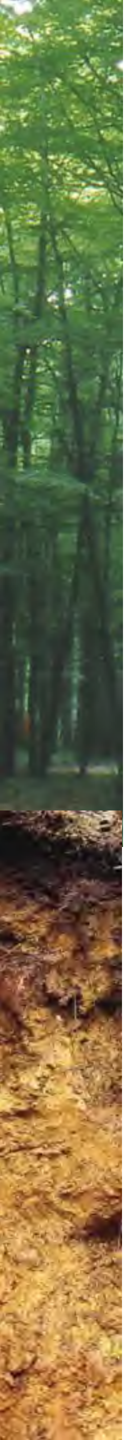


Importance of the biological cycle

Breuil Chenue site
Elevation: 650 m
Climate: continental
Species: Beech, 35 yr-old
Soil: Alocrisol on granite



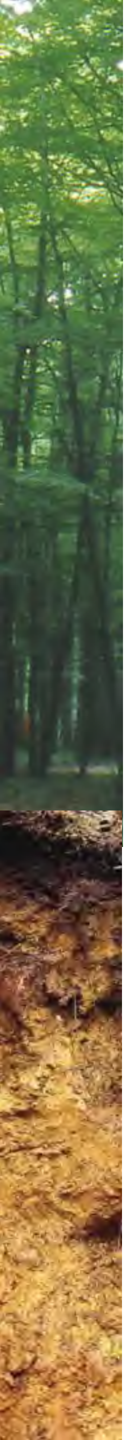
van der Heijden et al., 2013



Short-term soil chemical fertility	Long-term soil chemical fertility
▪ Soil **reservoir** of directly available nutrients ▪ **Nutrient fluxes originating from internal sources** : litterfall and decomposition, foliar leaching, plant internal cycling ▪ Soil **characteristics enabling the retention of nutrients** (cationic exchange capacity, exchange site reactivity, soil particle surface exposure).	▪ Soil capacity to sustain or even restaure short-term soil chemical fertility (buffer capacity) in a given environmental and management context ▪ **Nutrient fluxes** originating from the **weathering** of nutrient bearing minerals, when existant, and **atmospheric inputs.**

The potential or capacity to produce should be considered conjointly with:

- ❖ **The hydrological constraints** (water table, dry season, water excess, deficit…),
- ❖ **Nutrient requirements of tree species** (fonction of autecology, growth rates)
- ❖ **Nutrient uptake strategies** (soil water type, soil depth…) root prospection according to soil physical constraints (compaction, hypoxia, hydromorphic soils…)

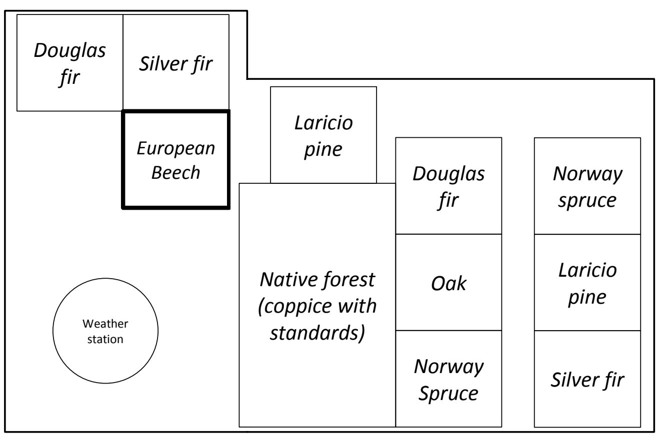


Impact of different silvicultural practices on forest soil fertility

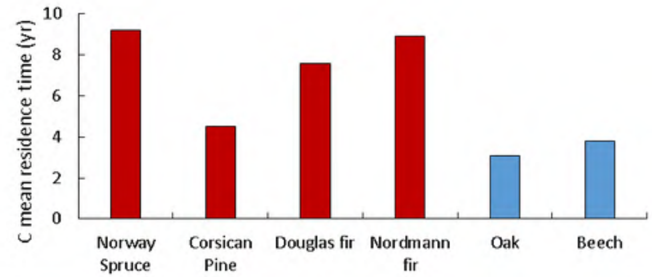
- Tree species change
- Increased biomass exportation
- Forest mechanization and soil compaction
- Forest liming

Tree species effects on soil fertility

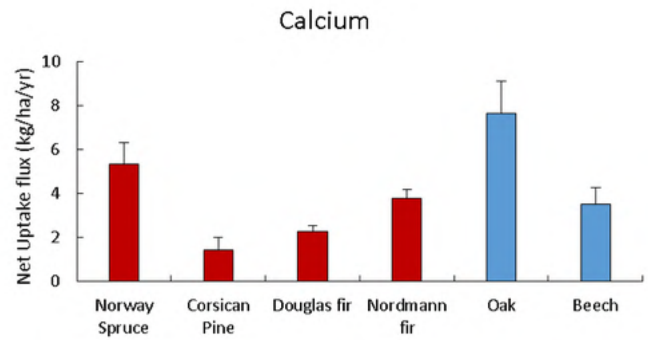
Common garden experiment (Burgundy, France)
6 species planted in 1976 – monospecific stands



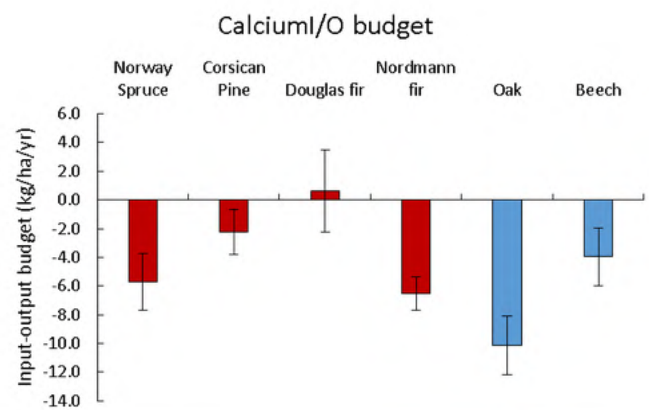
- C mean residence time in humus layer



- Net Uptake fluxes

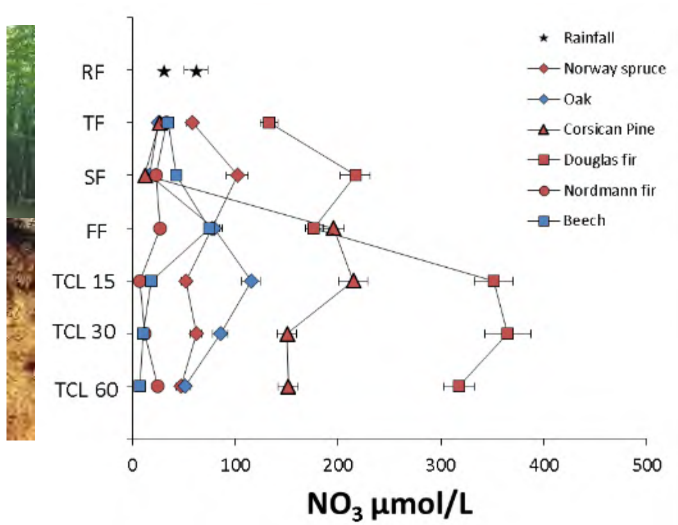


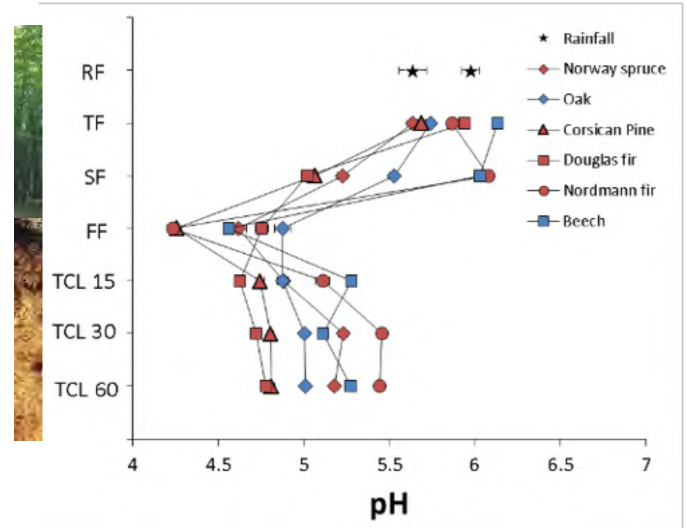
- Input-output budgets

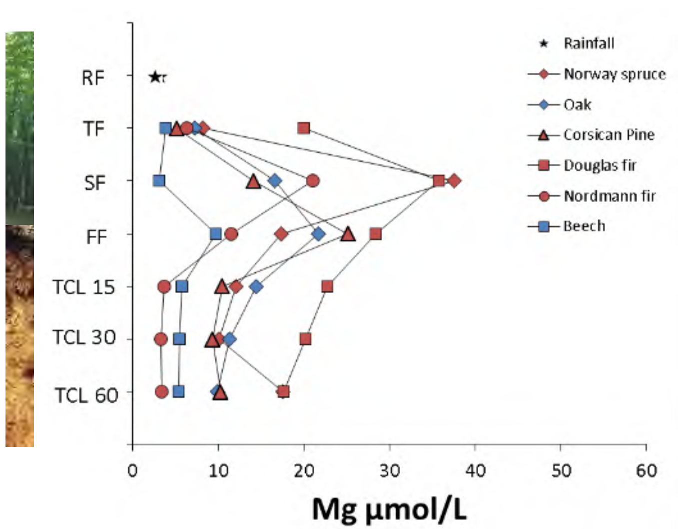


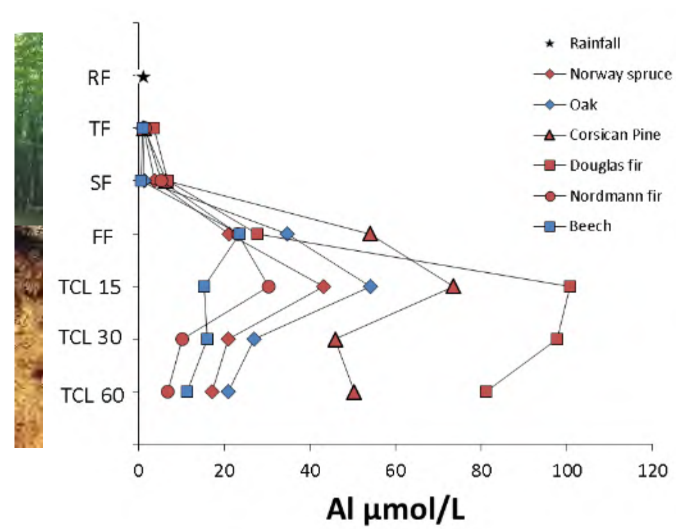
Tree species effects on soil fertility

- Tree species control the nitrogen cycle



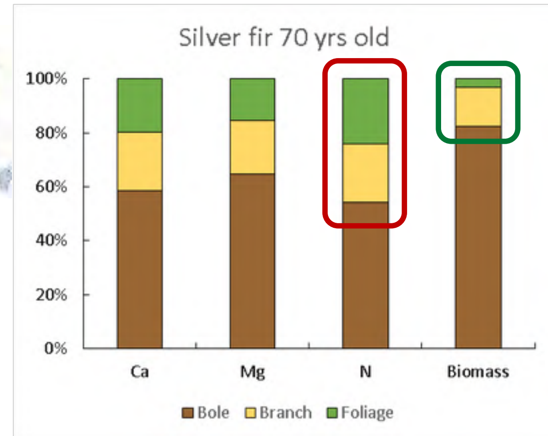




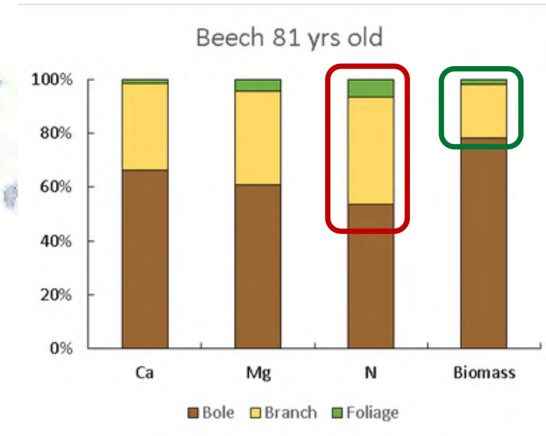


Effects of increased biomass exportation

- Distribution of biomass and nutrients in aboveground biomass

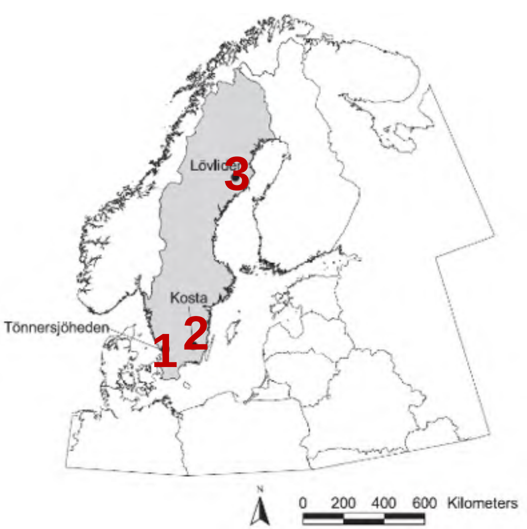


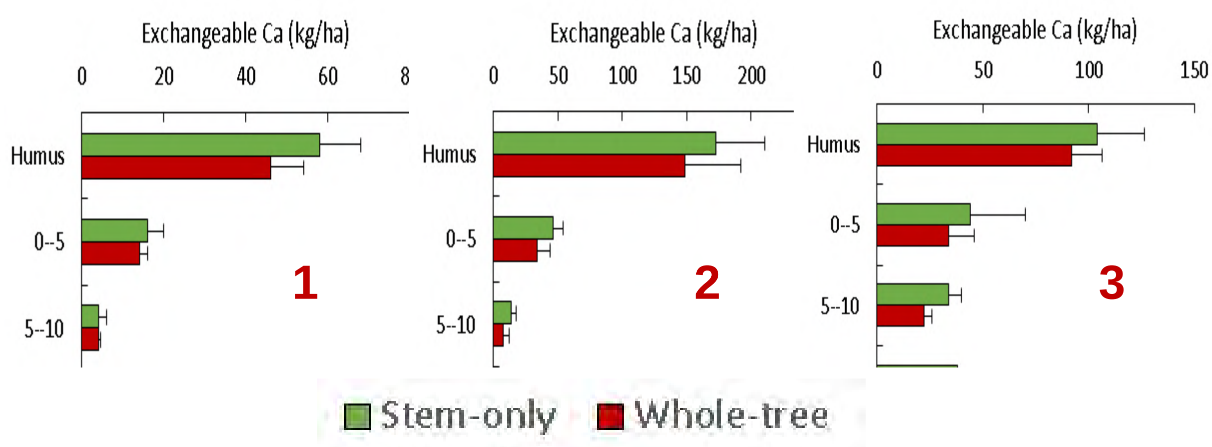
+ 21% biomass
+ 83% N



+ 28% biomass
+ 87% N

- Impact on soil nutrient pools





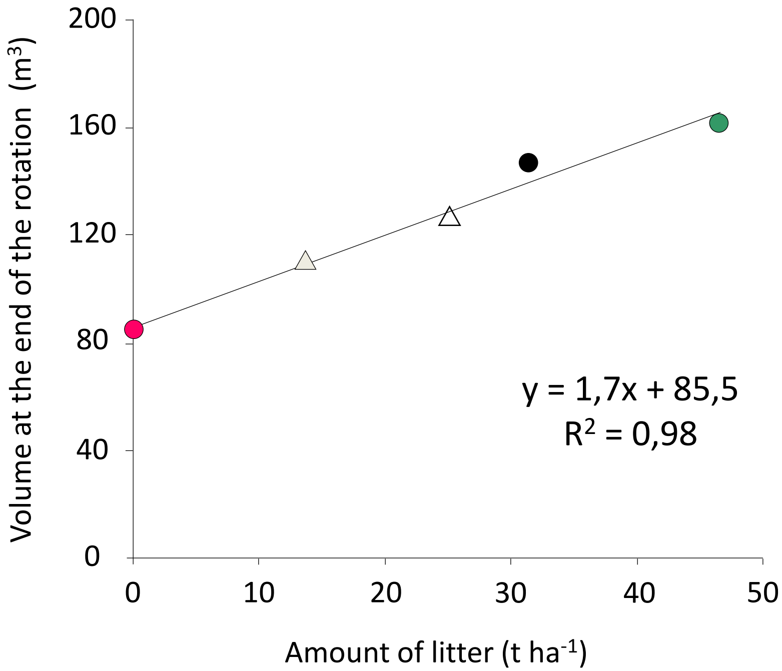
Effects of increased biomass exportation

- Example of a litter manipulation experiment in Eucalyptus plantations in Republic of the Congo

Effects of increased biomass exportation

- Example of a litter manipulation experiment in Eucalyptus plantations in Republic of the Congo

  - Consequences on biomass productivity of plantations



Essai CIFOR, Deleporte *et al.*, 2008

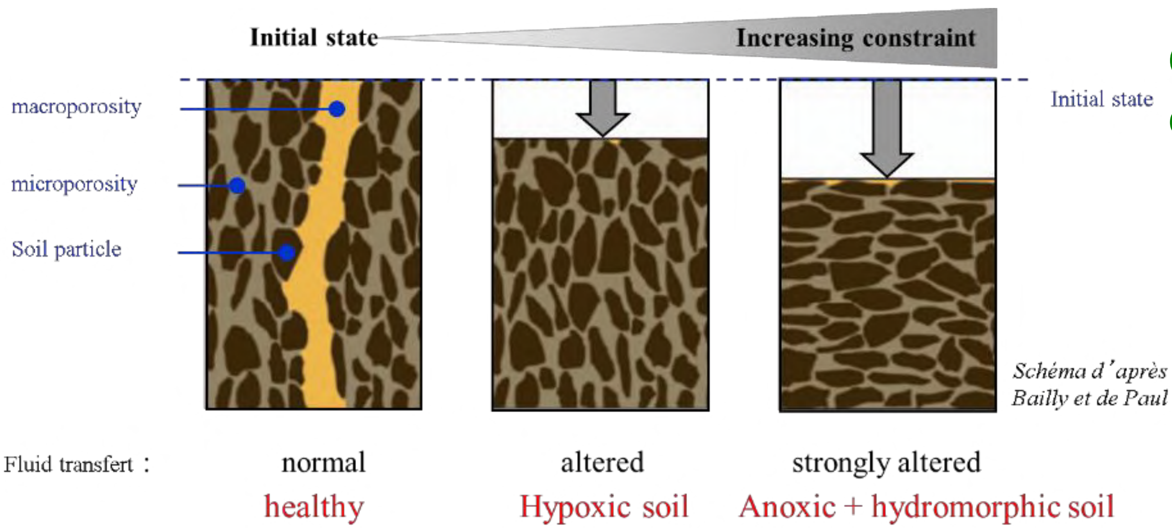
Soil compaction from forest mechanization

Causes for soil compaction

Forest mechanization inescapable to optimize forest operations:

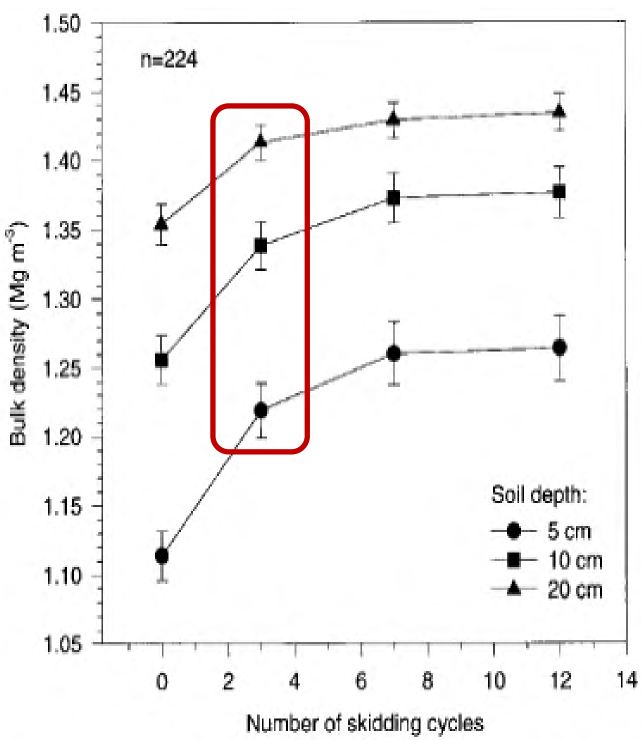
- 80% of coniferous stands
- 10% of broadleaved stands

Soil compaction from forest mechanization



Consequences of soil compaction

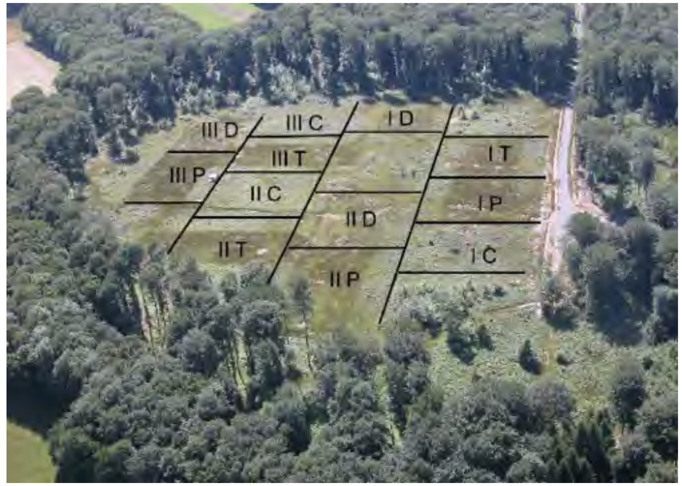
- Increased bulk density and resistance to root penetration
- Loss of macroporosity and soil structure



Soil compaction and number of skidding cycles

Better to go over <u>a path 100 times</u> than <u>once over a 100 paths</u>!

Soil compaction from forest mechanization

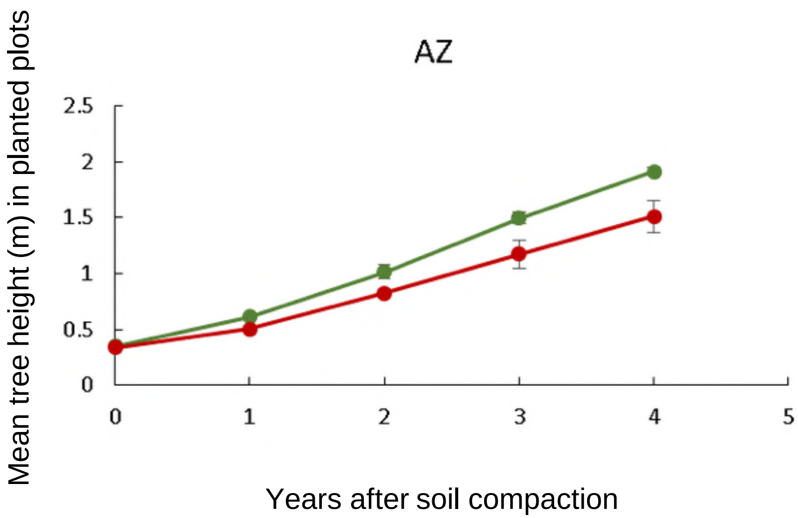


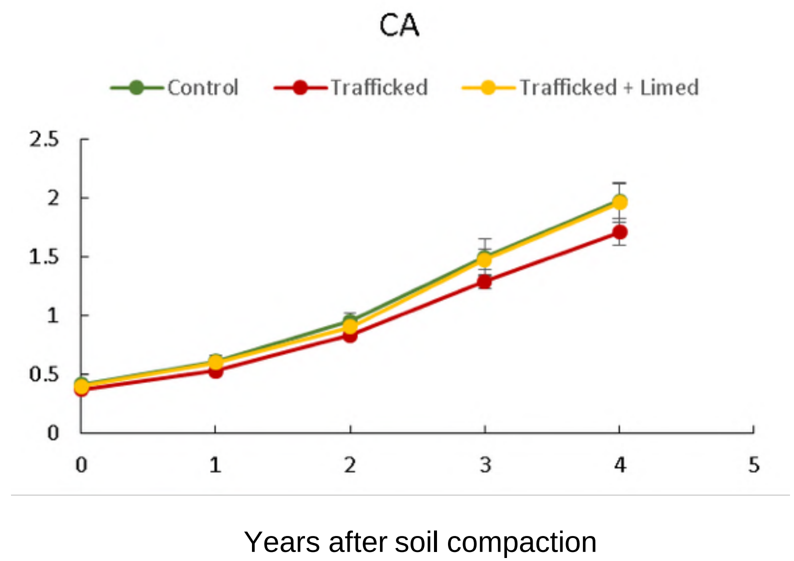
After clear-cut:

- Soil compaction plots
- Control plots
- Compaction + restauration (e.g. liming)

Plots planted with oak

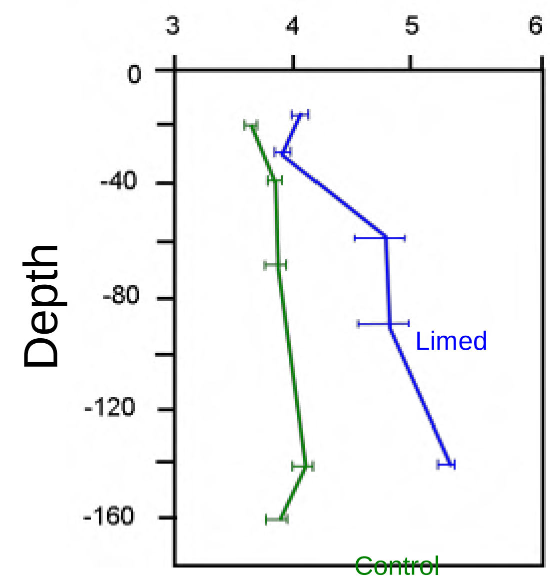
Effect on tree growth

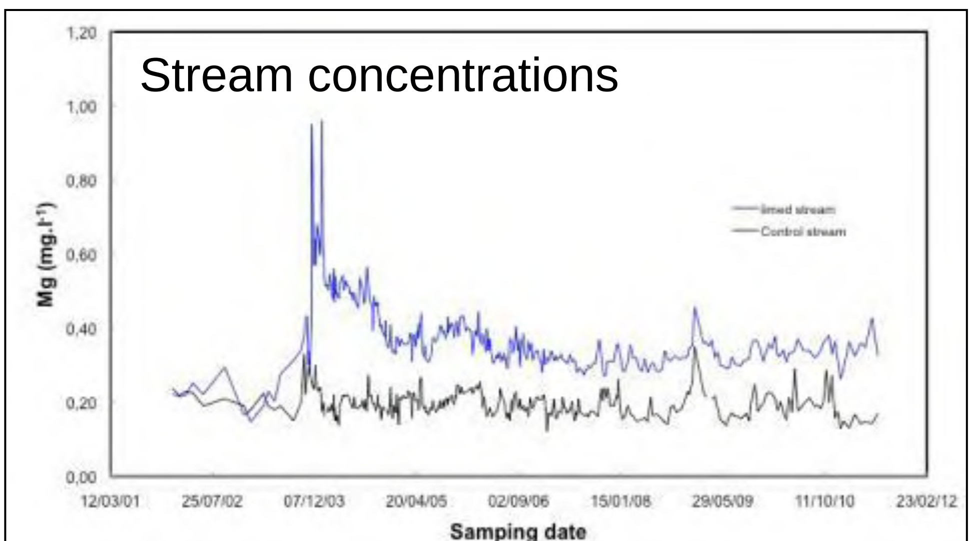


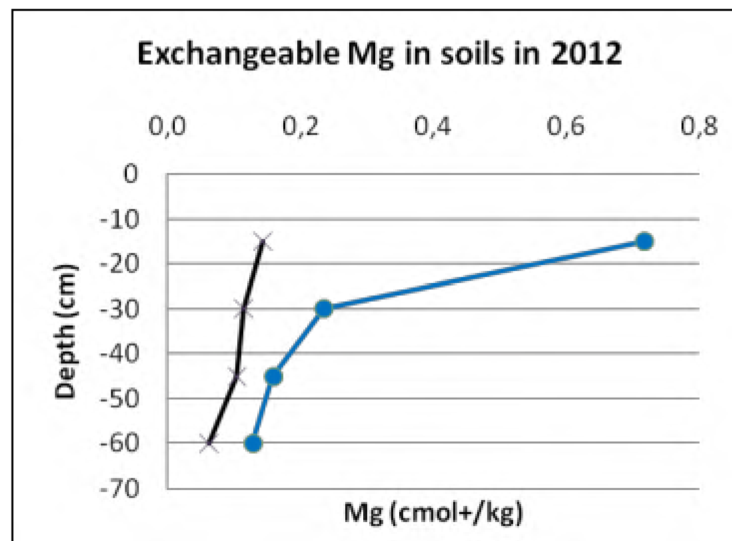


Compensating for the export of nutrients and restoration of degraded soils

- Forest liming with a carbonate rock



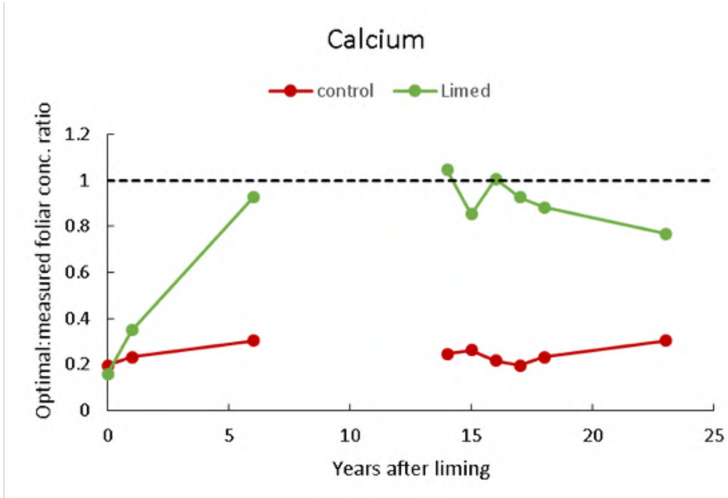


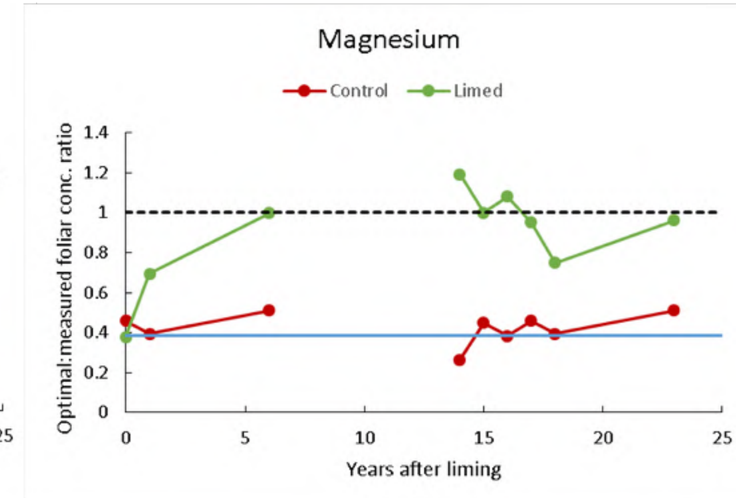


Compensating for the export of nutrients and restoration of degraded soils

- Long-term improvement of forest nutrition

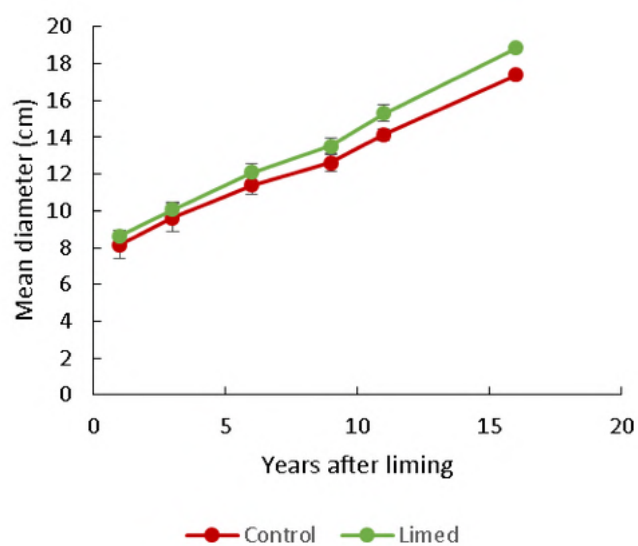
Humont state forest,
Vosges Mountains



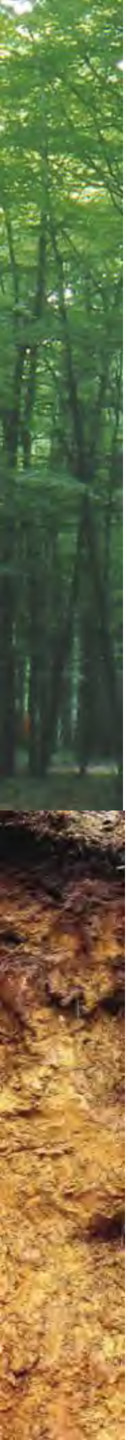


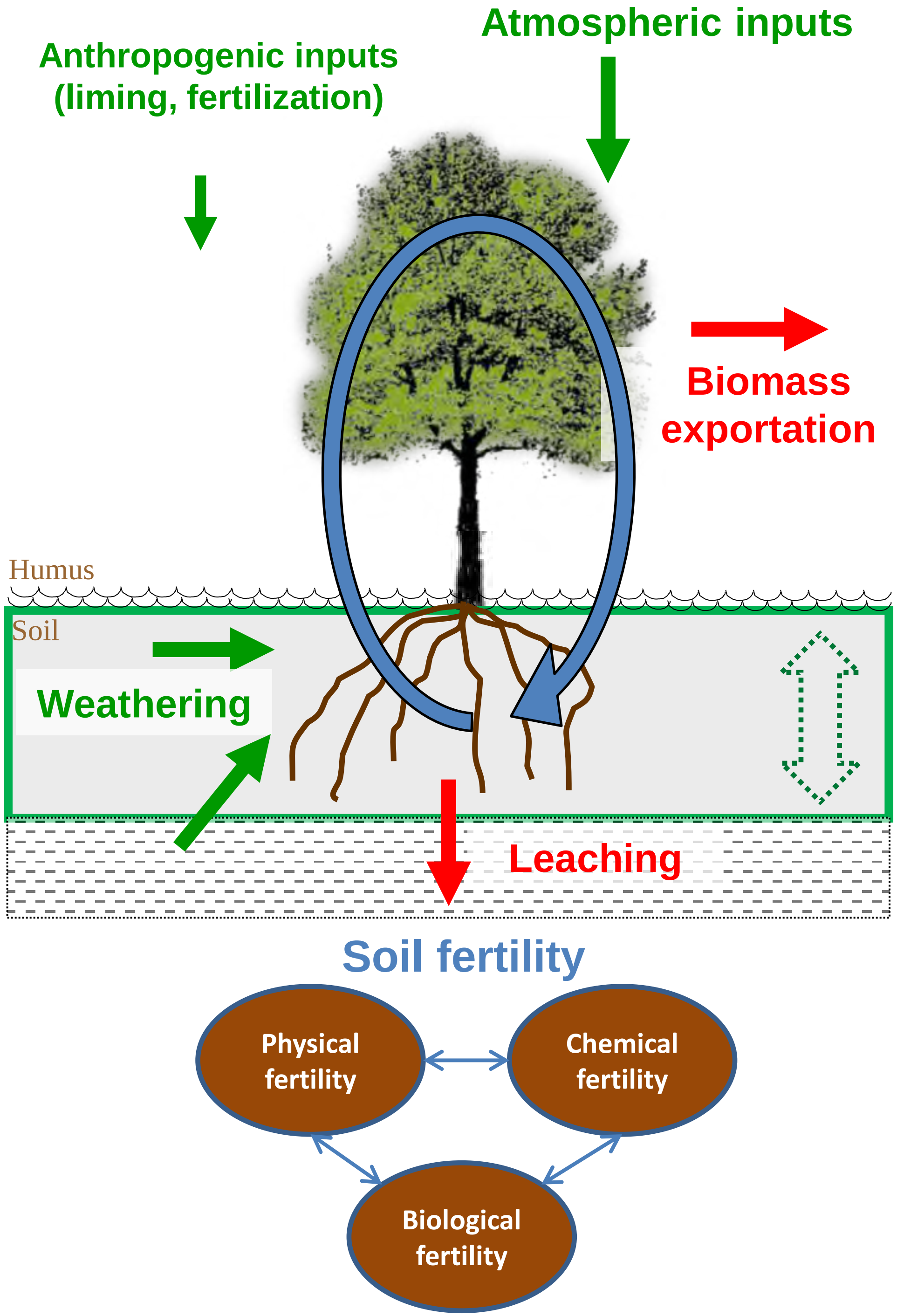
- Long-term improvement of forest growth

Potées state forest,
Ardennes



Conclusions





In most low fertility forest ecosystems, the natural resilience is weak

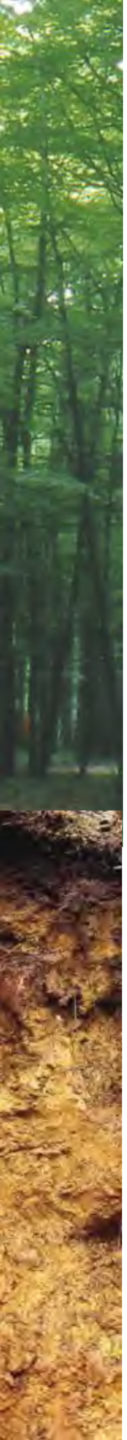
Context of high N deposition and decreasing Ca, Mg, K atmospheric inputs

Silvicultural practices: production cycles, species change, mechanization…

Increasing biomass exportations? Bio-energy production…

The restauration of the chemical fertility of the soil can be costly, best adapt silviculture to site conditions

Thank you!

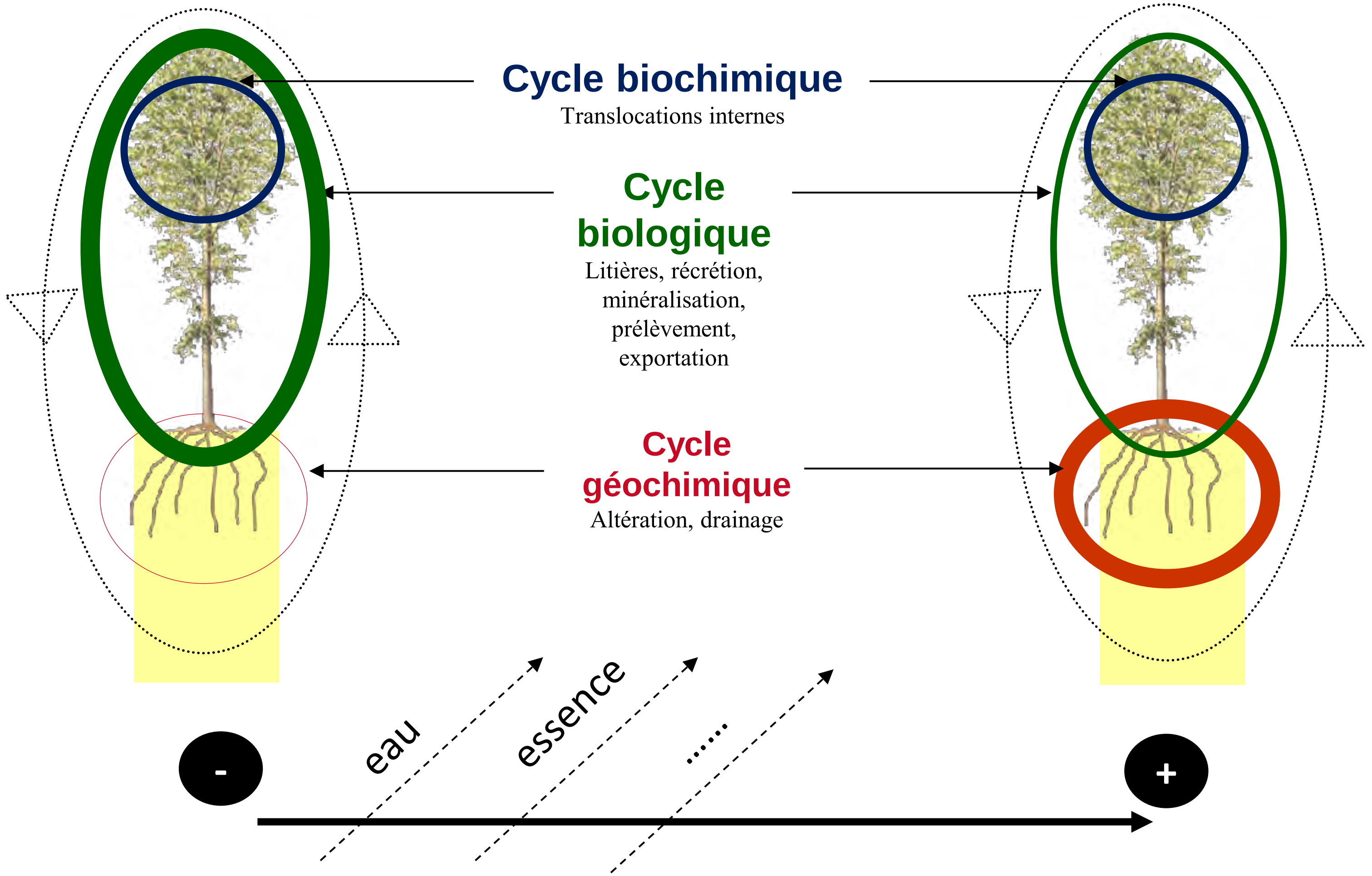


Appendices

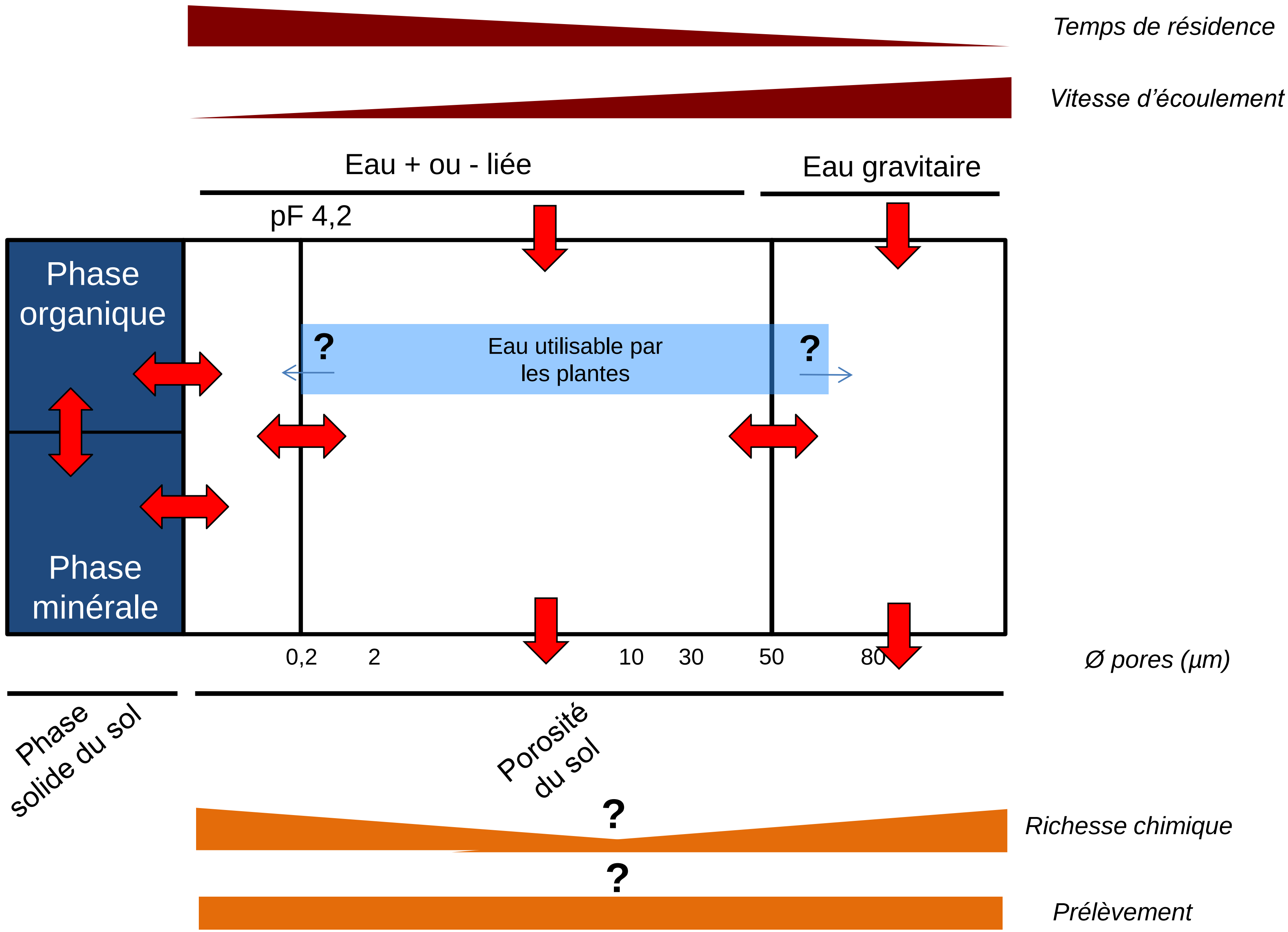
Relation entre la fertilité chimique et le poids des composantes BIO/GEO dans les cycles

Type I – sol pauvre chimiquement:
cycle BIOgéochimique

Type II – sols riches chimiquement :
cycle bioGEOchimique

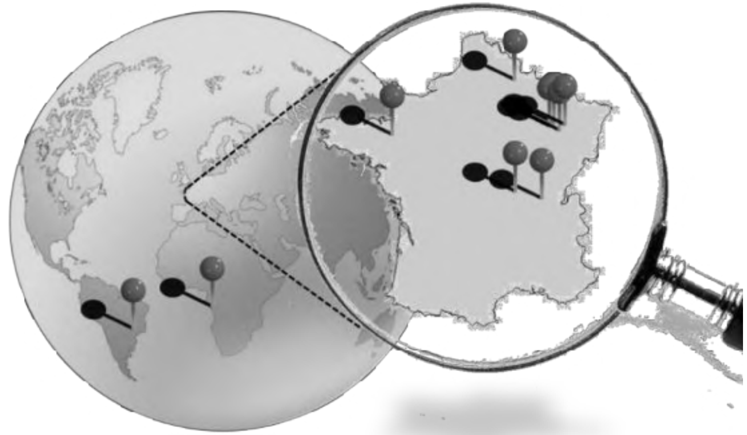


Les différents types d'eau du sol



La biodisponibilité est à géométrie variable

Sites d'études utilisés



SOERE
Système d'Observation
d'Expérimentation, sur le long term
pour la Recherche en Environneme
F-ORE-T
Fonctionnement de
écosystèmes forestie

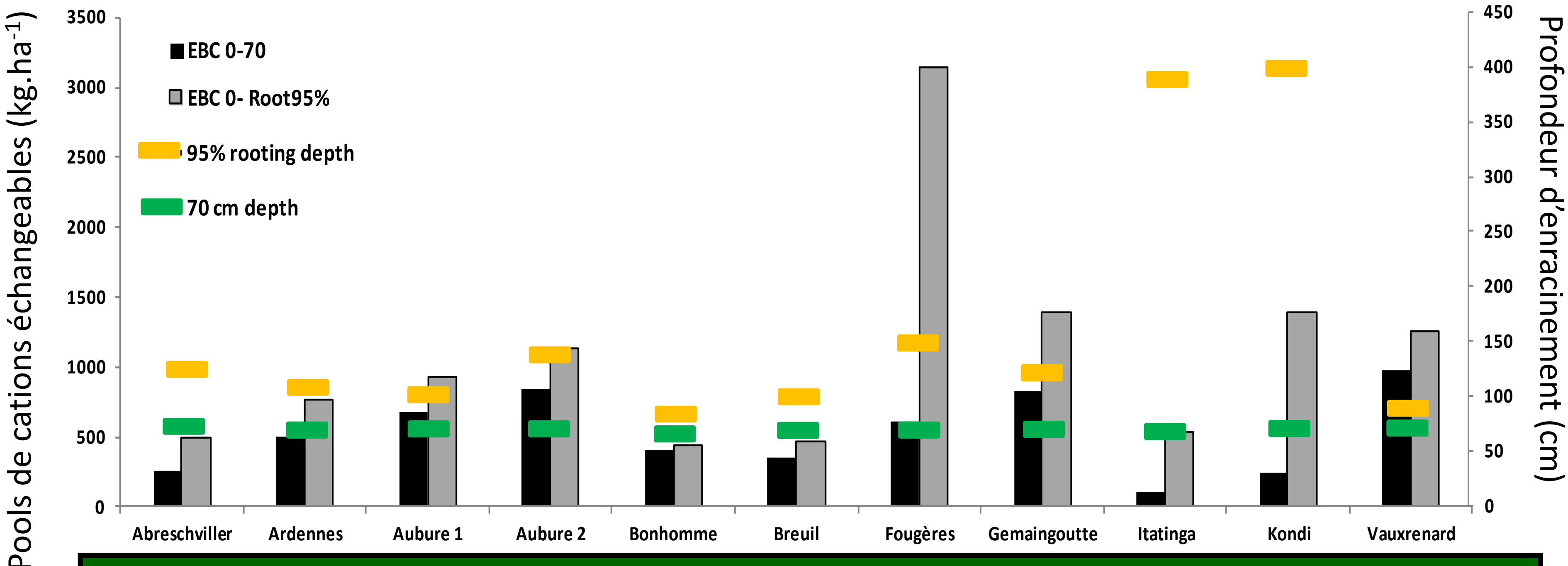
http://www.gip-ecofor.org/f-ore-t/

Sites	Alt. (m)	Pluvio. annuelle (mm)	Temp. annuelle (C°)	Roche mère	Type de sol (WRB)
Abreschviller, Vosges	400	1250	8,5°	Vosgian sandstone	Dystric cambisol
Monthermé, Ardennes	390	1100	8°	Blue-grey phyllites	Dystric cambisol
Aubure 1, Vosges	1080	1400	8,5°	Brézouard granite	Dystric cambisol
Aubure 2, Vosges	1080	1400	8,5°	Brézouard granite	Podzolic cambisol
Bonhomme, Vosges	1100	1544	5°	Valtin leucocrate granite	Podzolic cambisol
Breuil, Morvan	650	1280	9°	Vire type granite	Dystric cambisol
Fougères, Bretagne	175	868	12,9°	Vire type granite	Dystric cambisol
Gemaingoutte, Vosges	650	1120	8,5°	Varied lithology gneiss	Dystric cambisol
Vauxrenard, Beaujolais	770	1000	7°	Vosges Volcanic tuf	Dystric cambisol
Itatinga, São Paulo, Brazil	850	1370	19,2°	Detritic sands	Ferralsol
Kondi, Pointe-Noire, Congo	100	1200	25°	Continental sands	Ferralic Arenosols

Taille du réservoir à considérer pour évaluer la fertilité chimique

→ Pools de cations échangeables (kg.ha^{-1}) : Ca+Mg+K+Na

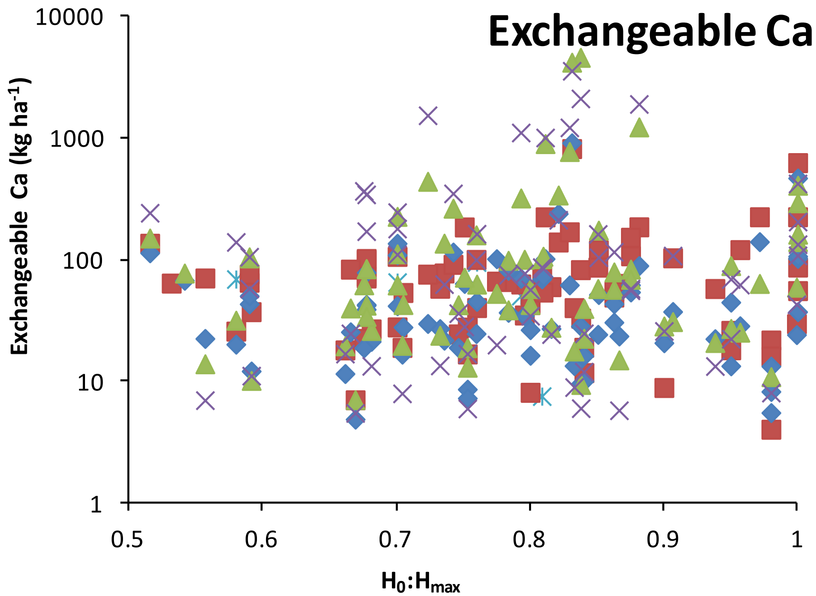
→ réservoir : de 0 à 70 cm et de 0 à 95% de l'enracinement maximum (racines fines <2mm)

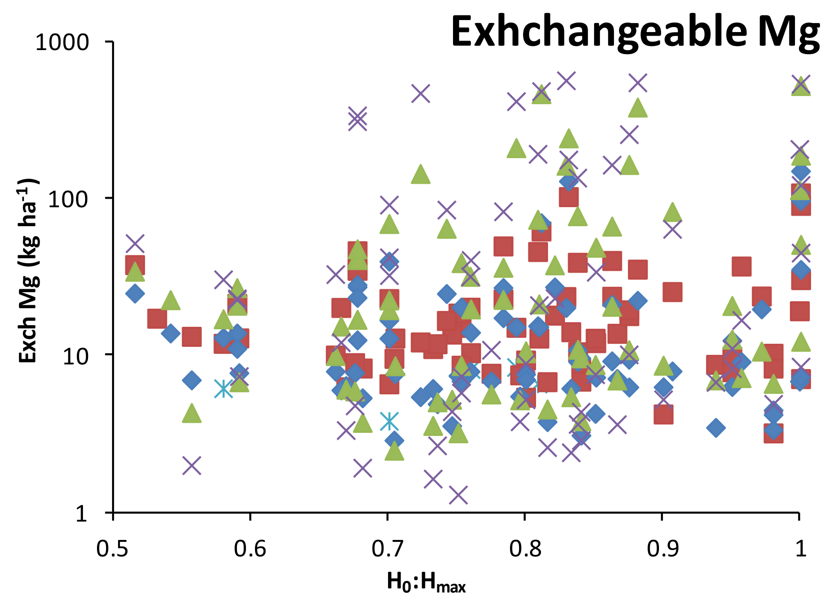


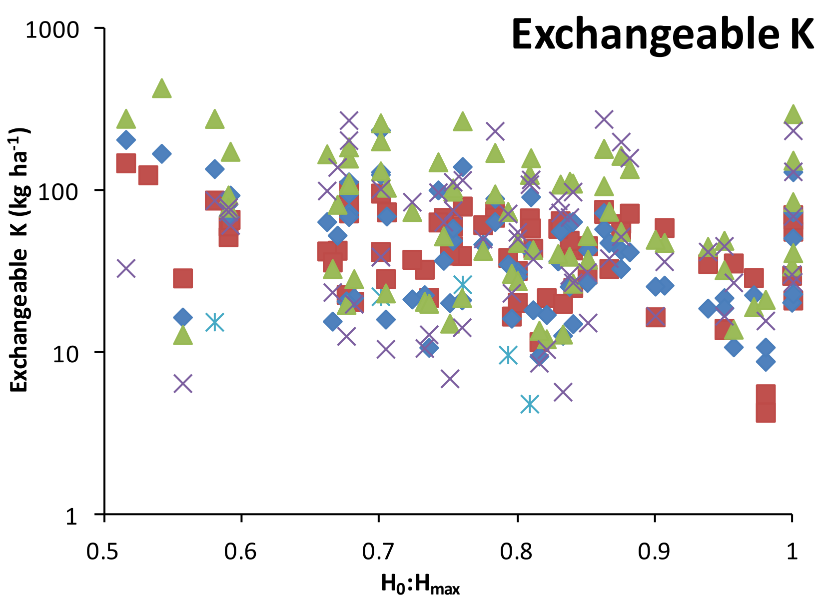
Il est difficile de définir la taille du 'réservoir' de nutriment à disposition….

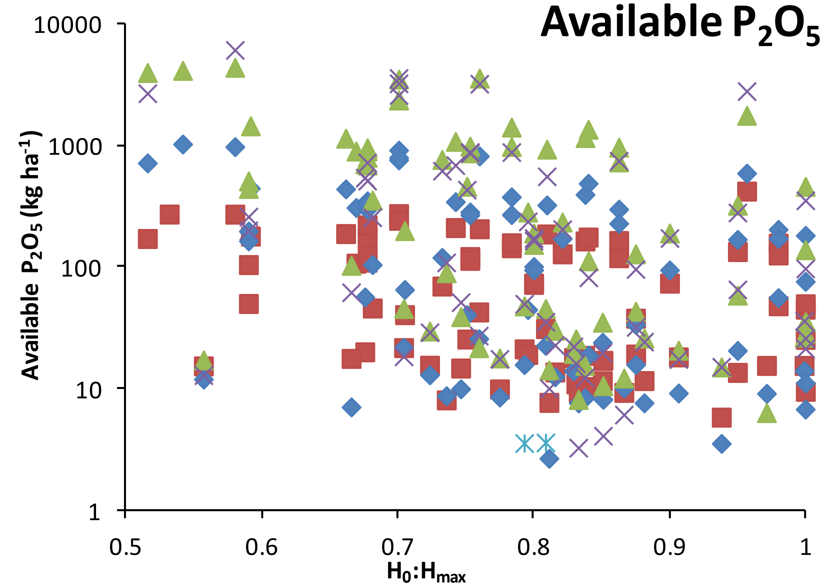
La présence de racines n'implique pas forcément un prélèvement effectif de nutriments…. Sol 'bulk' vs 'sol rhizosphérique'….

Relation between soil fertility indicators & forest growth (H0:Hmax)

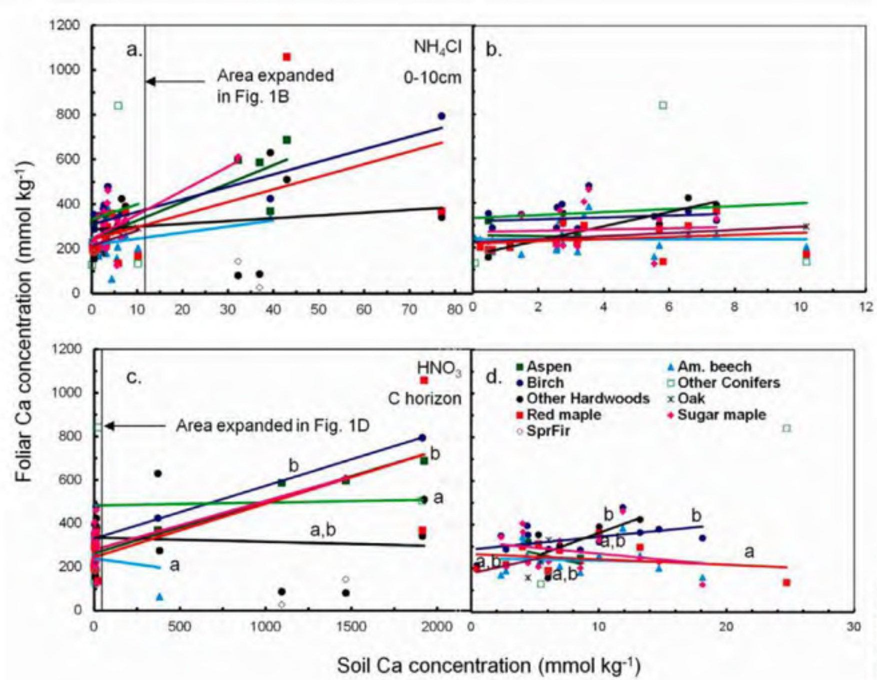


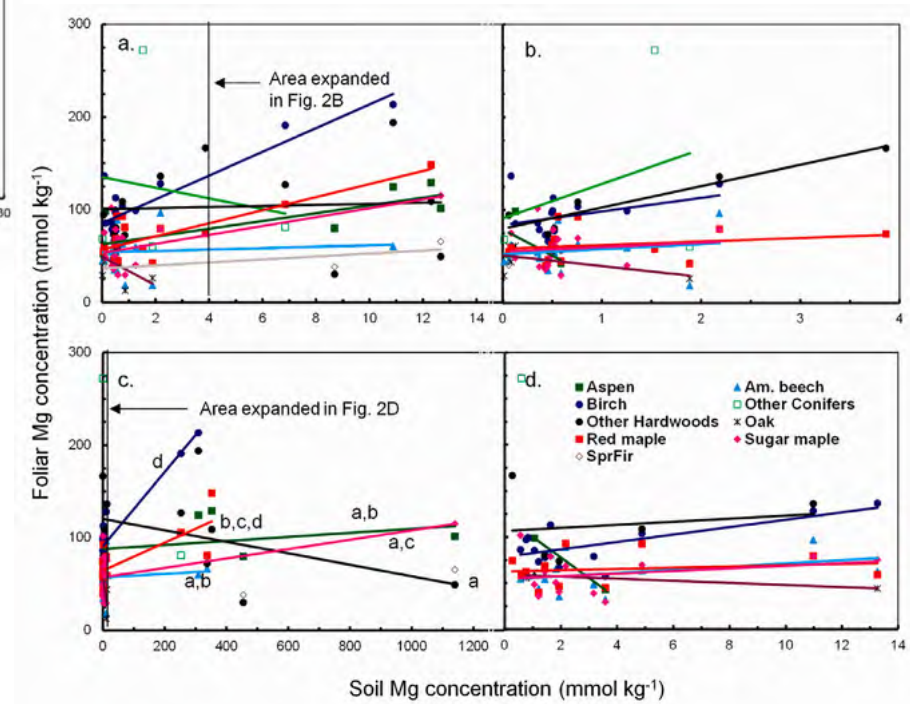






Effet de l'indicateur choisi sur le gradient de fertilité obtenu





Lucash MS *et al.* (2012) Soil Sci. Soc. Am. J. 76(2): 674-683

Le maintien de la fertilité en forêt n'est pas une préoccupation récente…..

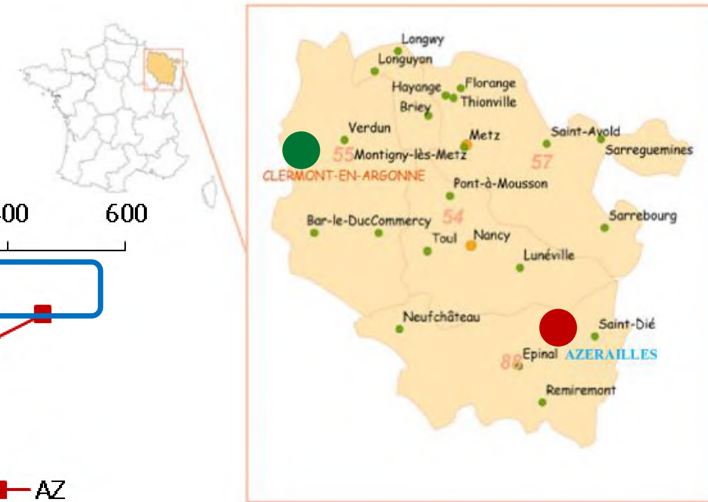
La perte provenant de l'exportation du bois, quoique faible, est réelle et amènerait à la longue l'appauvrissement des sols forestiers si elle n'était largement compensée, comme nous l'avons déjà dit, par le passage incessant d'une partie de la réserve du sol à l'état assimilable.

Si la provision de matières nutritives assimilables descend au-dessous d'un certain minimum, la production du sol diminue aussitôt.

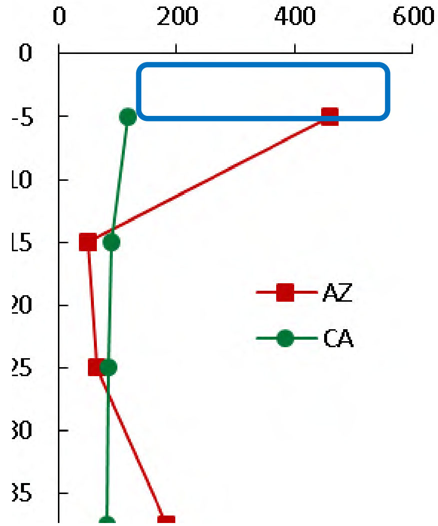
On dit qu'un sol est <u>épuisé</u> quand il est privé d'un ou plusieurs des éléments nutritifs. Il est clair que l'épuisement arrive plus vite pour les matières qui n'existent dans le sol qu'à faible dose

Cours de Henry à l'Ecole Nationale des Eaux et Forêts, 1894

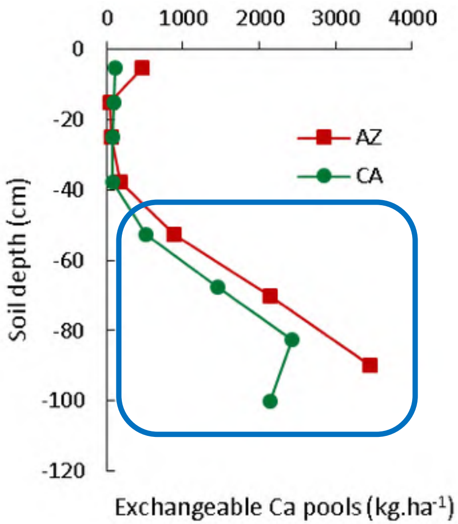
Example of the importance of soil depth

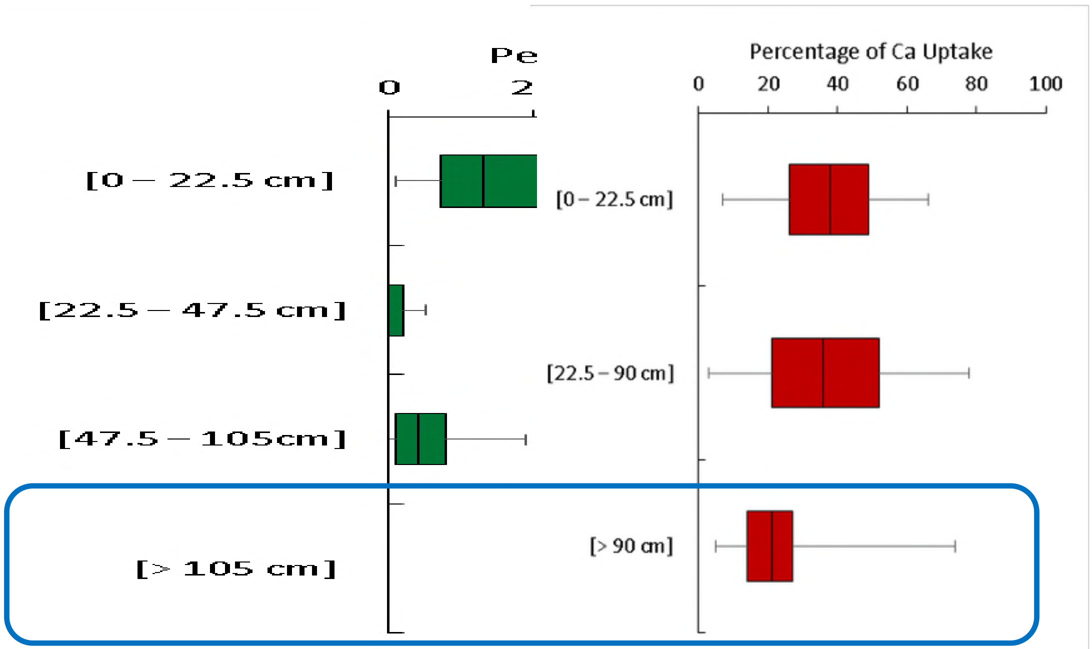


- Different exchangeable Ca pools in the soil profile
- Similar Ca foliar concentrations:
  - AZ – 1743 ± 484 µg.g^{-1}
  - CA – 2089 ± 312 µg.g^{-1}



Uptake from deep soil layers

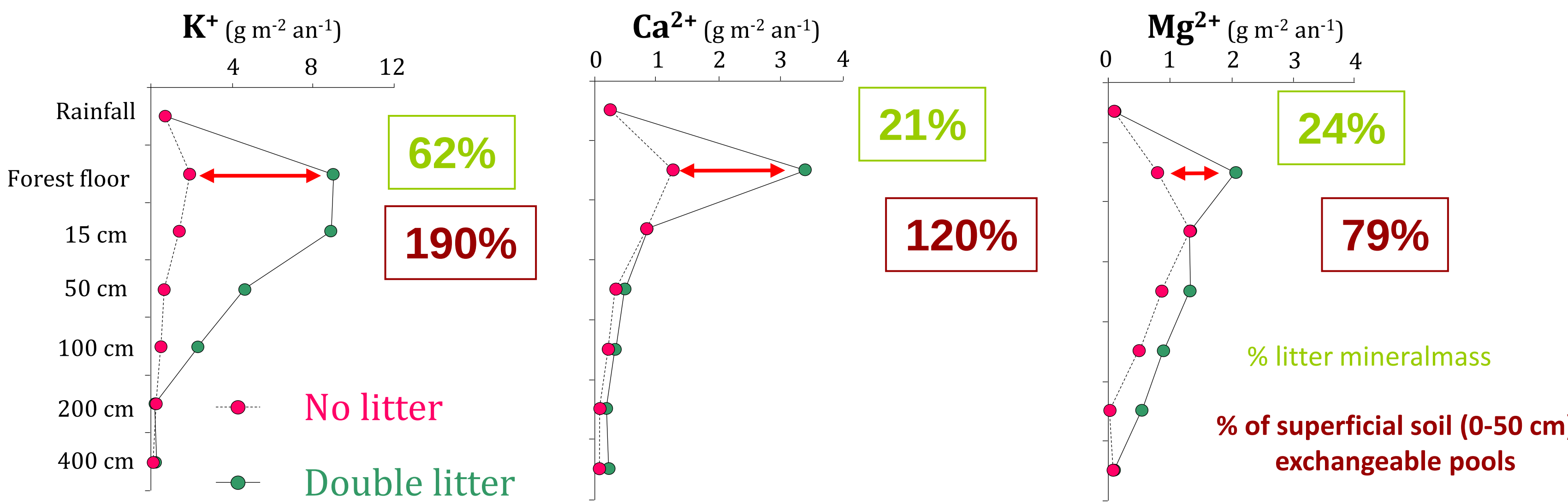




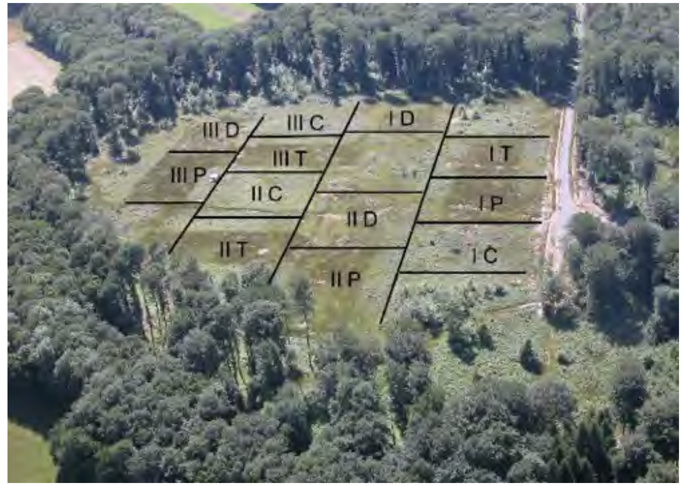
Effects of increased biomass exportation

- Example of a litter manipulation experiment in Eucalyptus plantations in Republic of the Congo

- Nutrient fluxes (year 1)



Soil compaction from forest mechanization

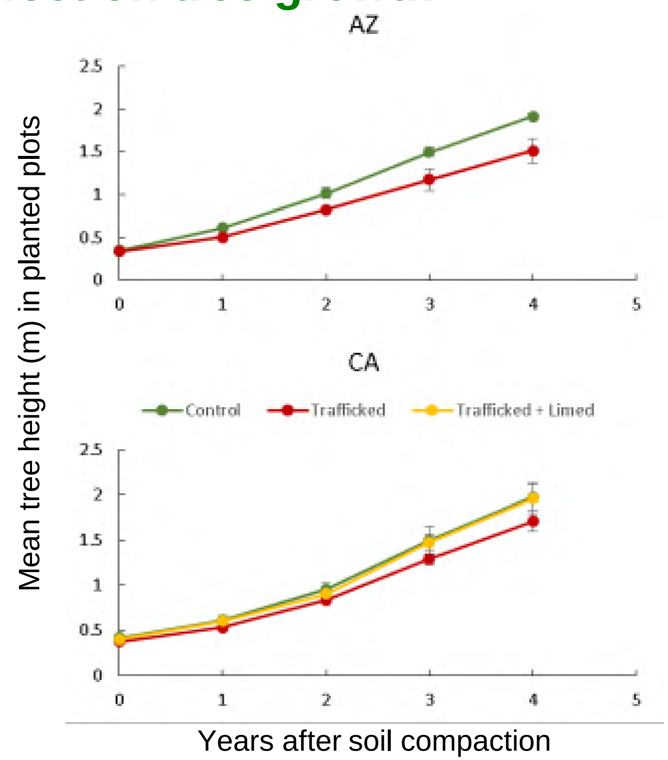


After clear-cut:

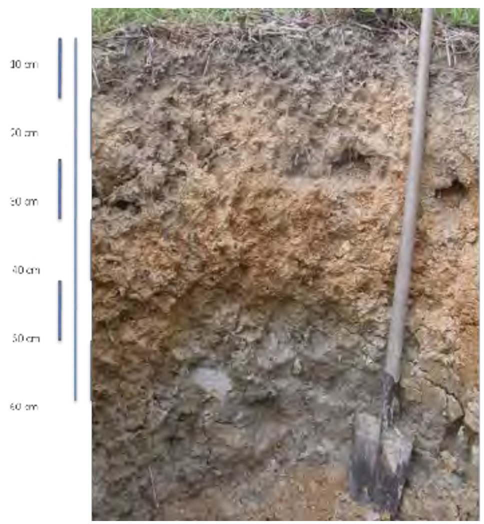
- Soil compaction plots
- Control plots
- Compaction + restauration (e.g. liming)

Plots planted with oak

Effect on tree growth



Control plot



Trafficked plot