Biogeochemical cycles in forest ecosystems
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Biogeochemical cycles in Forest Ecosystems
Carbon, water, nutrients and their interactions

Saint-Andre L, Granier A., Loustau D., Legout A., Augusto L.
INTRODUCTION

Forest Ecosystems, owing to their nature, are complex (temporally, spatially, …)

High expectation and pressure from the society (wood production, carbon sequestration, biodiversity, provision of drinkable water,..)

Impacted by global changes but also regulates biogeochemical cycles (climate change mitigation, interactions with the atmosphere, species impact on the biological cycles)

(adapted from Gordon B Bonan et al 2008, Science 320, 1444, DOI:10.1126/science.1155121)
Two Key Programs of Challenge 1 (*Develop the sustainable provisionning service of ecological systems*) and Challenge 2 (*Characterize and optimize ecosystem services*)

- Carbon, water and balances in temperate and tropical forests.
- Nutrient cycling in forests
For which we have a method

Context, socio economic issues

Technological Innovation

Identify bottle-necks and important processes

Knowledge on the processes

Input/output budgets

Comprehensive sites – Highly instrumented

Hypotheses on ecosystem functioning

Interpret, understand

Put things into perspective

Extrapolation

Service-related indicators

Permanent plots, experimental networks

Conceptualization of forest ecosystems functioning

New hypotheses and research questions

Soil-plant models; recommendations to forest managers

SAINT-ANDRE et al. / BIOGEOCHEMICAL CYCLES IN FOREST ECOSYSTEMS
In-situ and in lab consistent tools

**Comprehensive sites**
- SOERE F-ORE-T

**National experimental networks**
- GIS-COOP/PLANTACOMP

**Large database**
- ECOPLANT/ Digitalis

**Platform for FUNCTIONAL ECOLOGY**
- M-POETE (ANAEE-S)

**XYLOFOREST**
- Microdissection
- Laser
- C, N, major, traces
- anatomy, dendrochimie, biomarker minerals

**ECOGENOMIC**
- Genomic
- Microdissection
- Bioinformatic
- HT-DNA sequencing & RNA-Seq

**SAINT-ANDRE et al. / BIOGEOCHEMICAL CYCLES IN FOREST ECOSYSTEMS**

01 / 07 / 2013
models at different scales

Several decades
Several years
Seasonal
Daily
Hourly
Infra-hour

Wood Production
C and nutrients Budgets/fluxes
Water Quantity
Water Quality

Phenomenological models
Process-based models
Biogeochemical models
...models at different scales

Data for calibration, validation and forcing

Remote sensing

National networks of permanent plots
National Forest Inventories (NFI)
Comprehensive sites

Continent
Country
Region
Forest
Stand
Tree

Global models
Spatialized models
Tree and stand models

PnET; Lignum, GreenLab, G'Day, ForSafe, Castanea, GO+

3PG
CO2Fix
ForNBM
PP3, E-Dendro

Empirical
Process-based
.... a strong disciplinary and inter-disciplinary settlement

**Eco-physiology**

**Ecology of tree and stand growth**

**Microbiology**

**Biogeochemical cycles, Soil science**
.... and collaborations through international networks

E.g. ICOS (Integrated Carbon Observation System)

- Ecosystems (50 stations)
- Atmosphere (30 stations)

Data and tools

- Meta-information
- Data for synthesis

Ecosystem Thematic Center

Data and tools

EU projects

INOS

INRA
Snapshots on Carbon, water and balances in temperate and tropical forests
Carbon Allocation in Trees and Soil ANR-07-BLAN-0109
C.A.T.S. (Fontainebleau, Hesse, Landes), 13C Leaf Labeling

Time lag in soil
- Beech: 12 ~ 32 h
- Oak: 14 ~ 26 h
- Pine: 39 ~ 110 h

Peak time in soil
- Beech: 41 ~ 89 h
- Oak: 38 ~ 89 h
- Pine: 89 ~ 278 h

Epron et al. 2012, TREE PHYSIOLOGY 32(6): 776-798
Epron et al. 2011 BIOGEOSCIENCES 8(5): 1153-1168
Impact of weeding and thinning on forest energy balance

Moreaux et al. 2012
Tree Physiology

Coll. Inra, U Grenade,
U McQuarrie Sydney

\[ \beta_w = 1.58 \]
\[ \beta_c = 0.50 \]

\[ \beta_w = 2.18 \]
\[ \beta_c = 2.23 \]

\[ \beta_w = 0.86 \]
\[ \beta_c = 0.92 \]
Carbon balance in different ecosystems, long term trends, and drought effects

Yearly variations of net C balance

- Average NEE: -3.9 ± 1.7 tC ha⁻¹ yr⁻¹
- 30% of GPP (or 60% of NPP) used for tree growth
- High inter-annual variability (7 to 8 years are required to have a good idea of mean Reco; 5 years for GPP and 6 years for NEE

Inter-annual variations of net C balance (Hesse site)

Increasing water deficit

Intrinsic water use efficiency at canopy scale
Evapotranspiration at continental scale - ICOS Ecosystem

Global average: 550 mm/yr
~ 60 Eg/yr (±10-15%)
(1Eg = 1018g ~ 1000 km³)

- Map of mean Evapotranspiration from 1982-2008
- Predicted vs. Observed ET at FLUXNET sites (10-fold cross-validation from MTE training)
- Corroboration against river catchment water balances
- Comparison against GSWP-2 land surface model ensemble (16 models) stratified according to bioclimatic zones

Evapotranspiration leveling off due to water limitation

Jung et al. 2010, Nature
Snapshots on Nutrient cycling in forests
NanoSIMS Study of Organic Matter Associated with Soil Aggregates (Combination with STXM)

15N labelling of the litter
12 years after application:

NanoSims = localisation of 12C, 14N and 15N in the aggregates
STXM = chemical composition close to microbial compounds
Interaction between N and Ca/P cycles

Douglas Fir (control)
30 years old

Douglas Fir (fertilized)
(Ca + P in 1979 and 1983)

Ecosystem saturated by N

Rainfall

Non-saturated Ecosystem

Site FORE-T Breuil Morvan: m.e.p. M Bonneau et Coll. 1976

Role of microbes?
Measuring $^{44}\text{Ca}/^{40}\text{Ca}$ and $^{26}\text{Mg}/^{24}\text{Mg}$ in environmental samples from a tracer experiment using ICP-MS and TIMS

<table>
<thead>
<tr>
<th>15N</th>
<th>44Ca</th>
<th>26Mg</th>
<th>2H</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Concentration</td>
<td>Flux</td>
<td>Isotopic composition</td>
</tr>
<tr>
<td></td>
<td>meq.L$^{-1}$</td>
<td>kg.ha$^{-1}$</td>
<td>%</td>
</tr>
<tr>
<td>Nitrate</td>
<td>26.7</td>
<td>1</td>
<td>99</td>
</tr>
<tr>
<td>Calcium</td>
<td>9.6</td>
<td>0.53</td>
<td>96.45</td>
</tr>
<tr>
<td>Magnésium</td>
<td>29.6</td>
<td>0.96</td>
<td>99.25</td>
</tr>
<tr>
<td>Deutérium</td>
<td>-</td>
<td>-</td>
<td>99.85</td>
</tr>
</tbody>
</table>

Monitoring in situ and measurement of isotopic ratios $^{26}\text{Mg}/^{24}\text{Mg}$ et $^{44}\text{Ca}/^{40}\text{Ca}$ (ICP-MS)

| Humus, sol, biomasse microbienne |
| Pluie incidente, écoulement de tronc, pluviolessivats, solutions de sol |
| Racines fines, feuilles.... |

44Ca Two years after application

Van der Heijden G., et al. 2013, Geoderma
Van der Heijden G., et al. 2013, Plant and soil
Measuring and modeling 15N, 42Ca and 26Mg movement in tree xylem from a tracer experiment using ICP-MS and TIMS

<table>
<thead>
<tr>
<th></th>
<th>Concentration</th>
<th>Isotopic enrichment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrate</td>
<td>4.3</td>
<td>99.0</td>
</tr>
<tr>
<td>Calcium</td>
<td>1.4</td>
<td>79.0</td>
</tr>
<tr>
<td>Magnesium</td>
<td>2.1</td>
<td>98.8</td>
</tr>
</tbody>
</table>

Monitoring in situ (2 years) and measurement of isotopic ratios: \( \delta^{15}N, 26Mg/24Mg \) and \( 42Ca/40Ca \) (ICP-MS)

Modeling of Ca transport in tree xylem (homothetic upsaling approach):

\[
TRSP_{H_2O-field} = TRSP_{H_2O-lab} \times \frac{[Ca]_{sol-field}}{[Ca]_{sol-lab}} \times \frac{VOL_{sap-field}}{VOL_{sap-lab}}
\]

15N quickly transported to foliage by sap convection

42Ca slowly transported successive cation exchanges along the xylem vessels

EFPA funding

Coll. Inra, Macaulay Institute, UK
US Forest Service, USA

Using radiotracers $^{32}$P and $^{33}$P to assess phosphorus nutritive status in forest soils


Coll. Inra, Tomsk Univ., Russia
Novosibirsk Univ., Russia

Incubation experiments
Batch experiments
Greenhouse experiments

(soil-solution suspensions with $^{32}$P)

Complete assessment of P nutritive status

soil inorganic P

microbial P

water P

soil organic P

Forest floor (soil)
Mineral soil (soil)
Soil

Solution

Soil

P in solution

P fraction

Organic P

Inorganic P

Modeling and Meta-

ACCAF Meta-Program

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CONCLUSION

Large advances have been made

Next challenges –

Interaction between cycles,
Data model integration,
Robust service-related indicators,
Mapping of forest ecosystem services

But we are already on the road…… –

ESFRI road maps (ICOS, EXPEER)
LABEX (ARBRE, COTE, CEBA)
EQUIPEX (XYLOFOREST)
Infrastructure (ANAEE-S)