Control of the N-mineralising activity by vegetation is a key-parameter for forest management

Jacques RANGER, J.H. JUSSY, J. MOUKOUMI, B. ZELLER (1)

J.P. BOUILLET (21), P. DELEPORTE (22), J.D. NZILA (22), J.P. LACLAU (21) (2)

(3) INRA Biogéochimie des Ecosystèmes Forestiers F-54280 Champenoux

(2) CIRAD-Forêts F-34398 Montpellier (21) - UR2PI BP 1291 Pointe-Noire - Congo (22)

Objectives

- To show in some examples the effect of the 'control' of vegetation on N-mineralisation, and more specifically on nitrification
- To identify the potential consequences of forest management on soil quality
- To discuss the interest of prediction for ecosystem sustainability

Materials and Methods

Three experimental sites where main input, output and internal fluxes of nutrients in the ecosystem, were used:

-A Douglas-fir plantation clear-cut at age 70 in Vauxrenard (Beaujolais - France)

- A comparative set of plantations replacing the native broadleaved forest at Breuil (Morvan-France)

-An industrial plantation of Eucalyptus planted on a previous ‘climacic’ savannah in the coastal plain of Pointe-Noire (Congo)

Douglas-fir in the Beaujolais

- Plantation on previous cultivated land
- 750 m a.s.l ; 1000 mm m.a.rain., 7°C m.a.temp.
- Brown acid and desaturated soils on volcanic tuff (A_{11}: pH=4.3; CEC= 8 cmolc.kg^{-1}) ; loamy texture
- Douglas-fir plantation (40 m H_d; 166 cm mean CBH); clear-cut at age 70 at fall 1998
- Soil non disturbed by logging
- Slashes manually windrowed
- No vegetation control, except around the young Douglas-fir planted in spring 1999

Native forest vs plantations in the Morvan

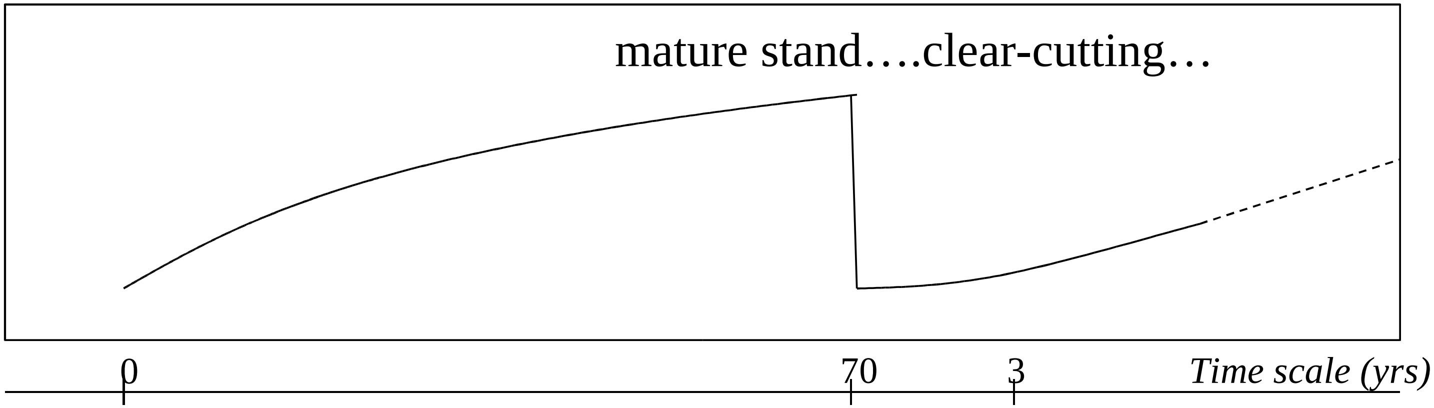
- Plantations on previous forest land
- 650 m a.s.l ; 1100 mm m.a.rain., 9°C m.a.temp.
- Brown podzolic soil, acid and desaturated on granulitic saprolite covered with loam ($A_{11:}$ pH= 3.8; CEC= 9 $cmolc.kg^{-1}$)
- Native broadleaved forest (beech and oak) 150 years old clear-cut in 1975
- Mechanical windrowing before plantation of oak, beech, Norway spruce, Douglas-fir, Laricio pine, Nordmann-fir in 1976
- Soil improvement at plantation (P, Ca) on coniferous plantations
- Manual vegetation control the first years

Eucalyptus plantations in a previous native savannah in Congo

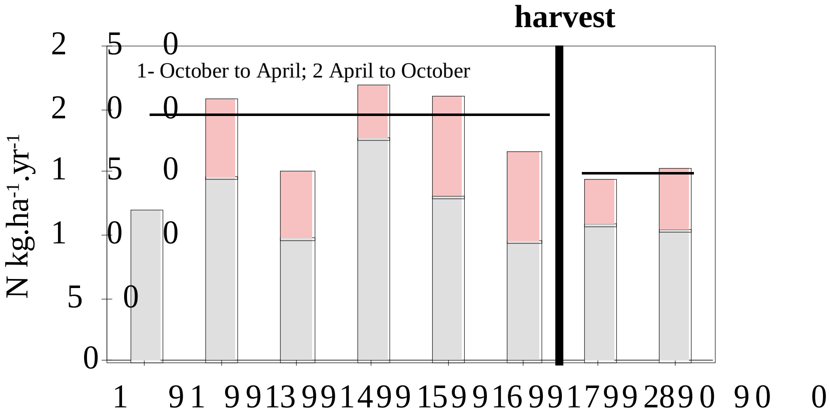
- 80 m a.s.l ; 1200 mm m.a.rain., 25°C m.a.temp.
- Ferralic arenosol developed on sandy Tertiary detrital formations ($A_{1:}$ pH=5.3 CEC=0.6cmolc.kg^{-1})
- Native savannah (*Loudetia arundinacea*)
- Chemical eradication of the savannah vegetation (glyphosate)
- Plantation of Eucalyptus cuttings (PF1 clone ; 666 tree.ha^{-1}); 26 m DH and 20 m^3.ha $^{-1}$.yr $^{-1}$ MAP at age 7
- Soil improvement at plantation (150 g per cutting of NPK 13:13:21)
- Manual and mechanical control of vegetation

Results & discussion

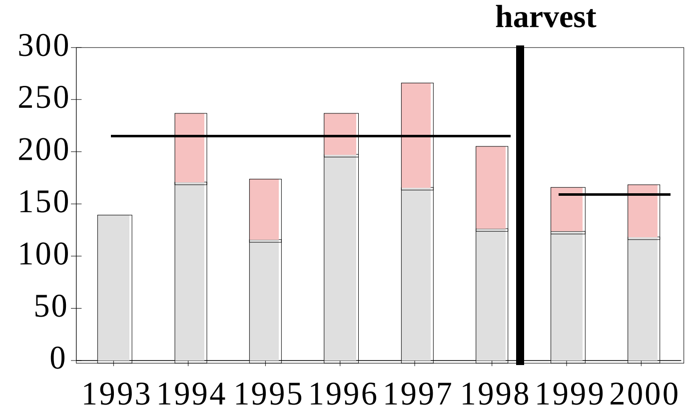
Douglas-fir stand clearcut at age 70 in the Beaujolais ………Potential mineralisation and nitrification



Nitrification



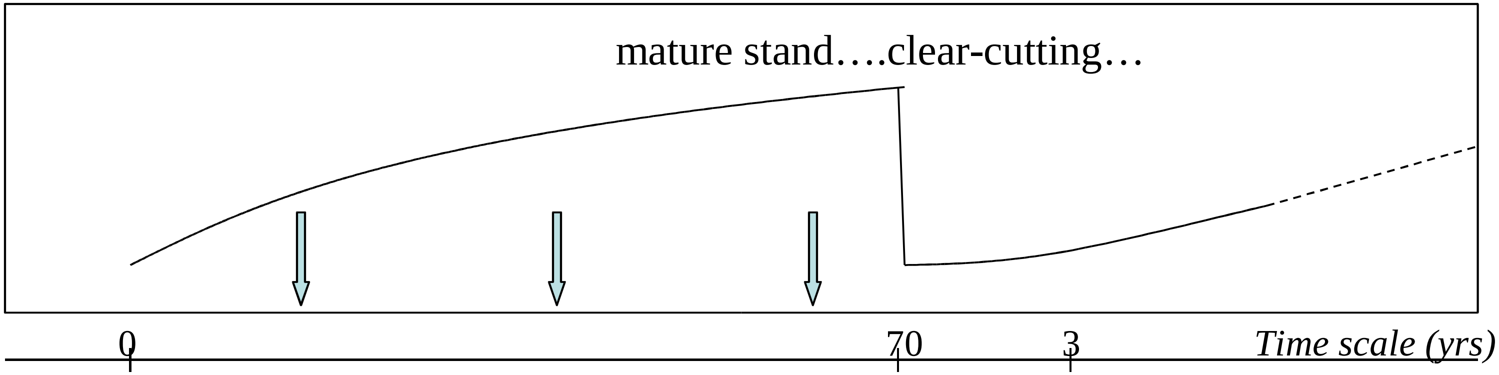
Mineralisation



… very high mineralisation and nitrification rates in this acidic soil

…. mineralisation and nitrification rates reduced after clear-cutting

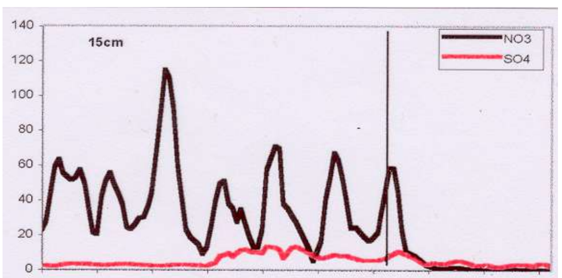
Douglas-fir stand clearcut at age 70 in the Beaujolais ………dynamics of gravitationnal solutions

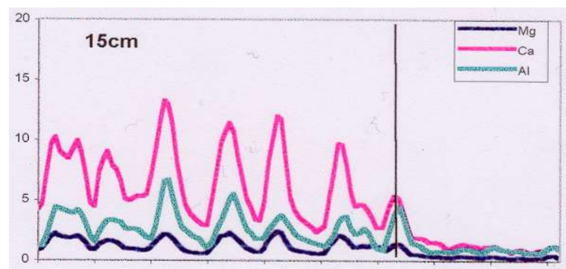


harvest

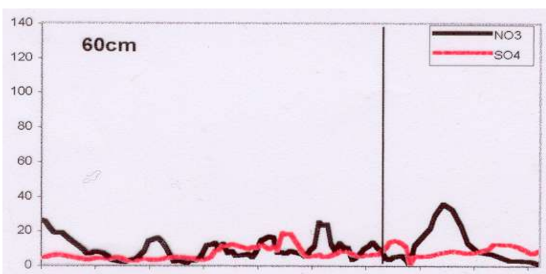
harvest

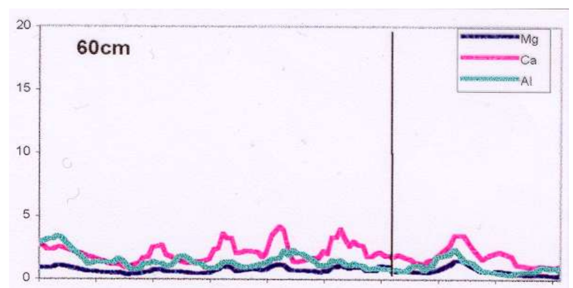
15 cm





60 cm





… strong decrease in nitrates and cations at 15 cm depth

…..no real changes at 60 cm depth

….. moderate changes in the losses in seepage waters after clear-cutting

Douglas-fir stand clearcut at age 70 in the Beaujolais

- Two hypothesis for explaining the high nitrification: **past land use** and/or **control of nitrifiers** by vegetation

- No changes in ground vegetation able to explain an inhibition of nitrifiers

- Favourable situation for increase in nitrification rate after clear-cutting *e.g.* physical factors, high carbon reserves, micro-organisms already present and active, slashes removed reducing the potential for immobilisation…..

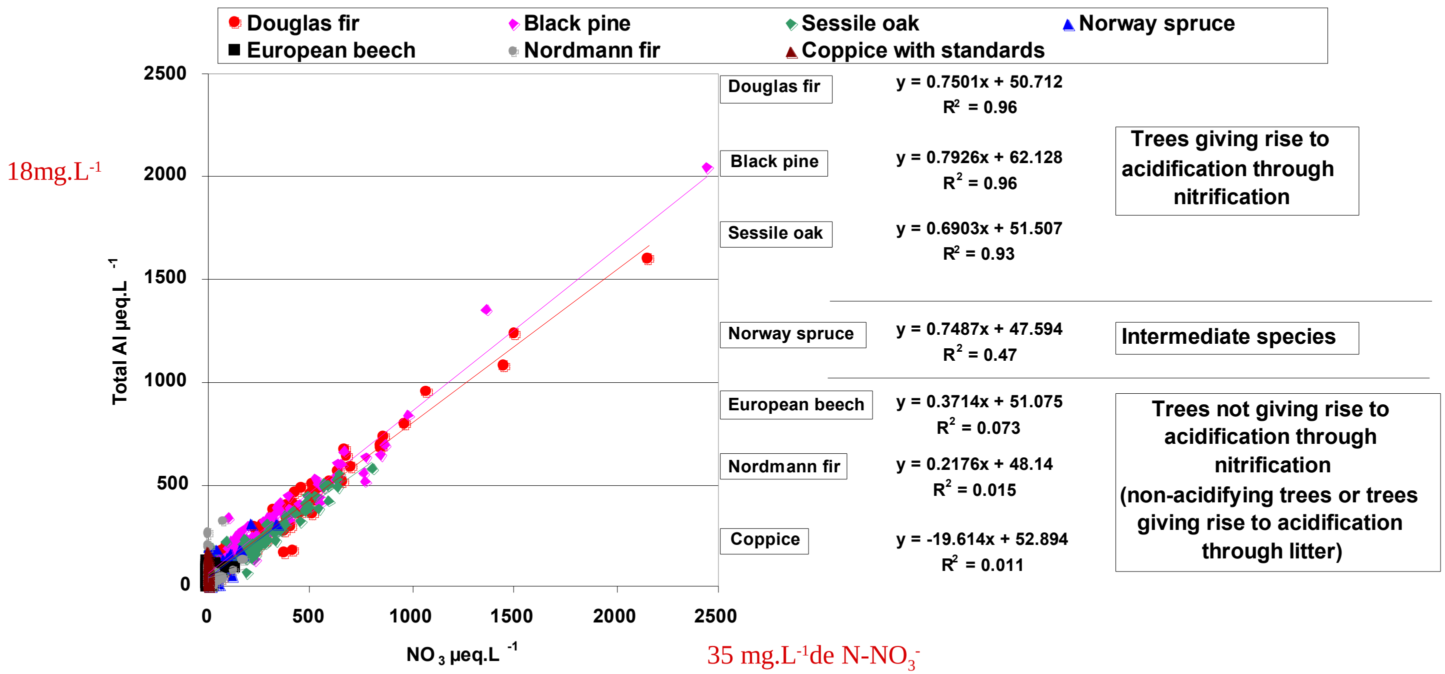
- Observations showed on the contrary a tendency towards reduction in mineralisation rate and decrease in nitrates produced: **the hypothesis of a strong biological stimulation of nitrifiers by Douglas-fir seemed the most relevant to explain this behaviour. Past land occupation only control the rate of N-mineralisation.**

Native forest vs plantations in the Morvan
……N mineralisation pattern

	Native forest	Plantations				
		Beech	Oak	Spruce	Laricio pine	Douglas-fir
Net Nitrification	0.02	1.27	0.65	0.18	0.99	0.24
Net Mineralisation	0.34	1.22	0.56	0.93	1.07	0.85
Gross Nitrification	0.40	1.57	2.32	2.17	5.83	4.77
Gross Mineralisation	1.33	2.05	7.94	6.43	4.19	8.50
Organisation	1.39	2.40	9.70	7.67	8.95	12.4

… Very limited nitrification and limited mineralisation rates in the native forest
…. Nitrification increase in plantations but strongly varied with species
….. Very different pattern between net and gross indexes
….. Organisation is related to gross mineralisation rate

Native forest vs plantations in the Morvan ……soil solution behaviour



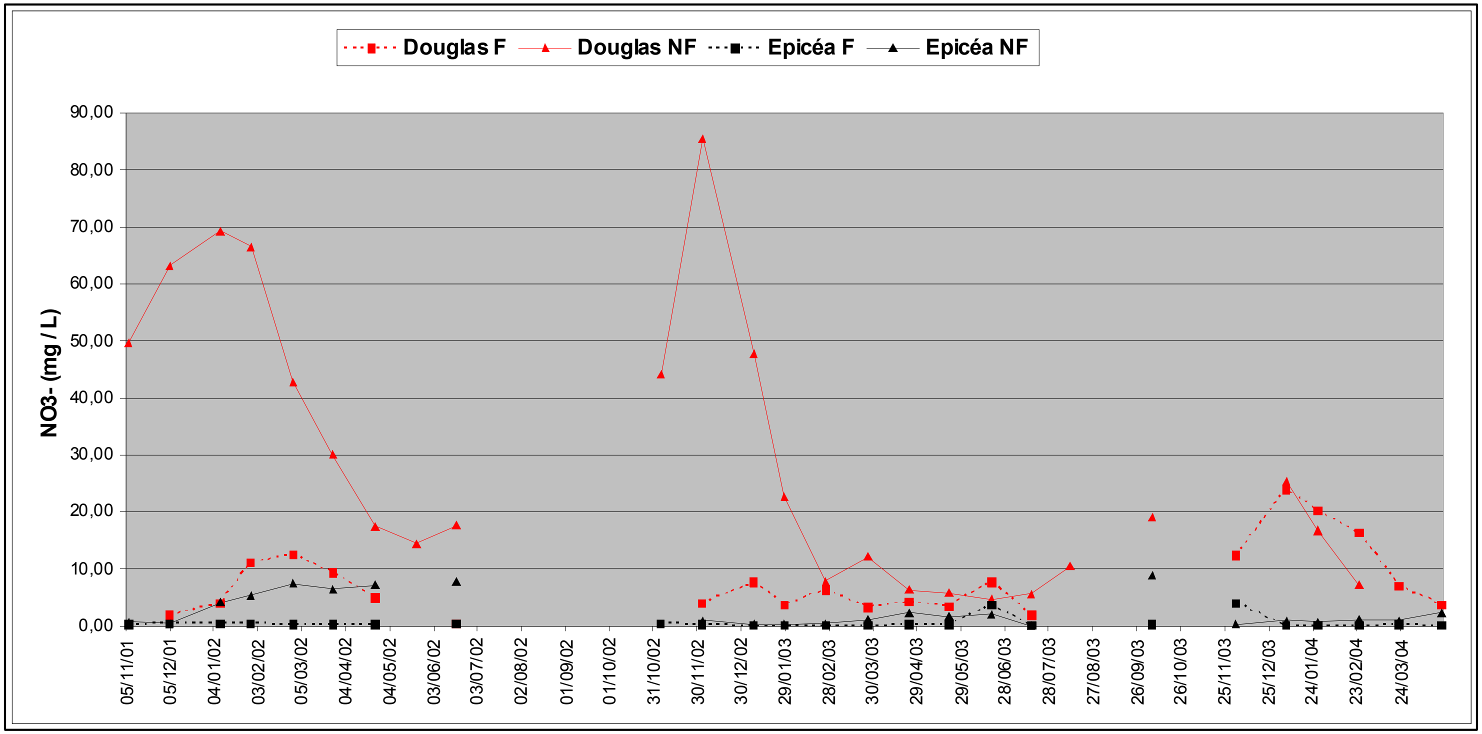
…. Excess nitrification leads to protons neutralised in ion exchange or weathering reactions

… Significant global relationship between surplus nitrates and total Al in the soil solution

…. Rather clear discrimination of species

….. Discrimination in very good agreement with gross nitrification

Native forest vs plantations in the Morvan
…… fertilisation and soil solution behaviour



…. Fertilisation reduced the residual nitrates…..and cations in solutions

…..Time series are not enough long to have a correct mean value due to annual variability

Native forest vs plantations in the Morvan

- **No interaction of previous cultivation** in Breuil
- **Limited nitrification in the native forest** is a conservative process, difficult to associate with steady-state ecosystem because it has been hardly harvested for fuel-wood

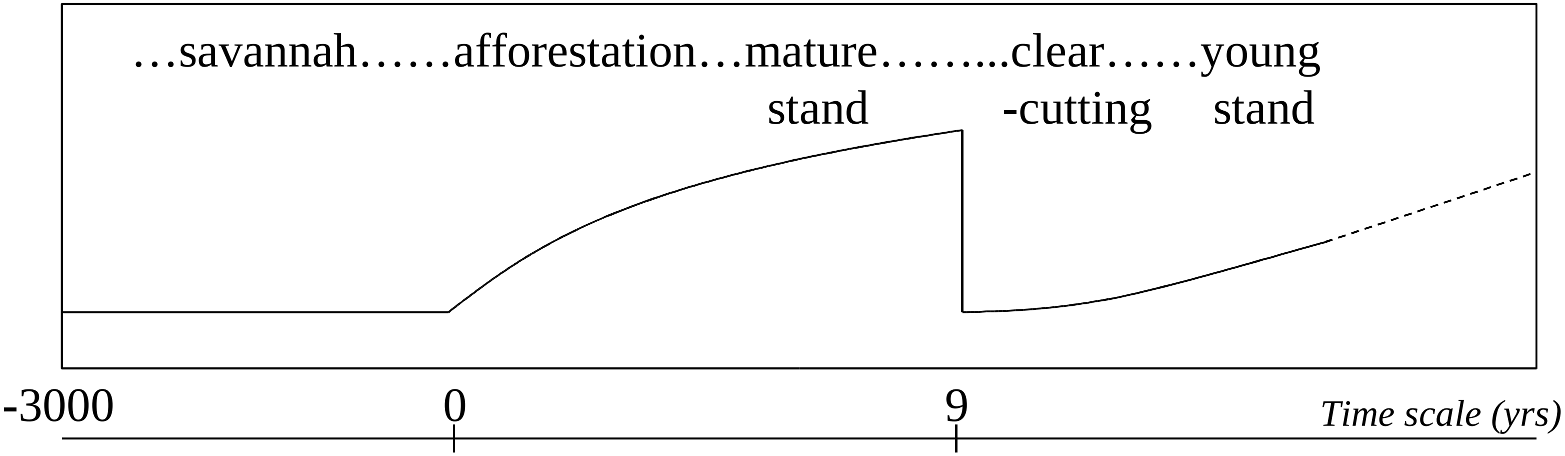
- Nitrification appeared in the plantations: residual effect of clear-cutting maintained according to species or specific active effect of forest species?

- Incubation tests tend to demonstrate that nitrifiers varied from native forest to plantations and between plantations (autotrophic vs heterotrophic)

- Soil improvement effect was the result of uptake by trees or of a different control on nitrifying populations?

- Multiple control of nitrifiers appears: **physical** (clear-cutting, fertilisation) and **biological** (tree species)

Native savannah vs Eucalyptus plantations in Congo ….Potential N-mineralisation and nitrification rates

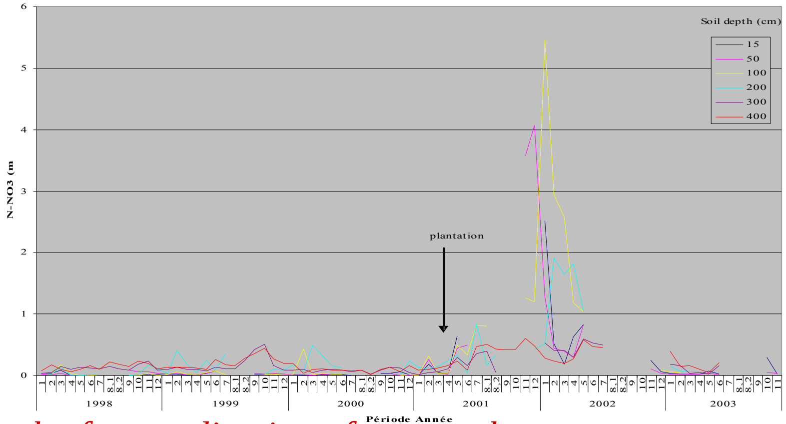


NO_3^--N	**1**	**38**	**25**	**64**	**23**
NH_4^+-N	**23**	**34**	**7**	**23**	**13**
N-mineral.	**24**	**72**	**32**	**87**	**36**
NO_3^--N %	***4***	***53***	***78***	***73***	***64***

…Mineralisation rate increased in plantations especially during the regeneration phases
… Nitrification rate strongly increased after eradication of the savannah vegetation

Native savannah vs Eucalyptus plantations in Congo
….nitrates and ammonium in soil solutions

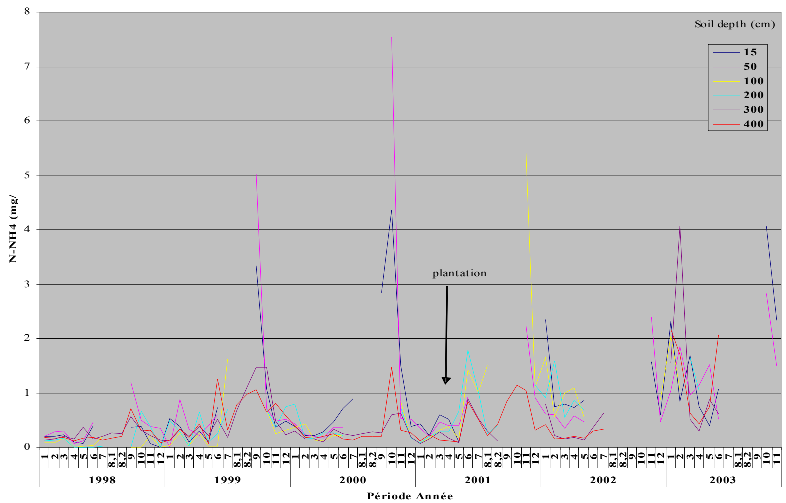
….nitrates



…Nitrates flush after eradication of savannah

...Nitrates taken up by Eucalyptus

….ammonium

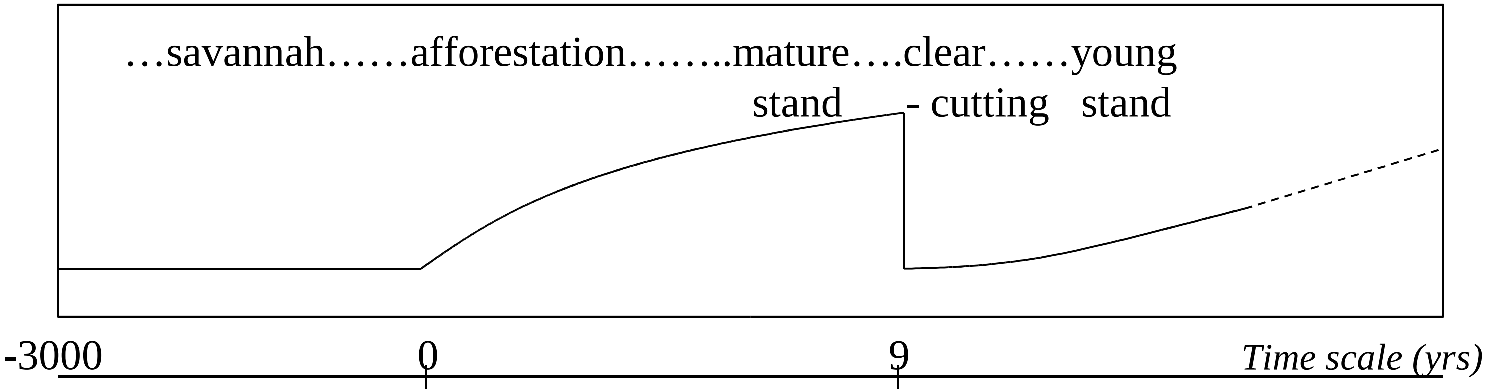


…No ammonium flush after eradication of savannah

…High concentration of ammonium in soil solutions at the beginning of the wet period

...Euc. PF1 prefers nitrates over ammonium?

Native savannah vs Eucalyptus plantations in Congo ….nitrates and ammonium in seepage waters



depth	3 m	5 m	5 m	5 m	5 m	
NO_3^--N	0,9	1.0	0.1	1.9	1.8	
NH_4^+-N	2.1	1.0	2,6	4.1	4.6	
total	3,0	2,0	3,7	6,0	6.4	

Flux of nitrates and ammonium in seepage waters

….Losses in seepage waters did not increase significantly at the limit of the rooting zone under E. plantation but it is the case after re-plantation due to NH_4 losses

….Deep rooting and quick development of roots are key parameters in a soil not able to retain either nitrates or ammonium.

Native savannah vs Eucalyptus plantations in Congo

- **Drastic changes in the control** of nitrification process resulting from eradication of savannah vegetation (competition or allelopathy ?)
- **Importance of the soil characteristics** where both nitrates and ammonium ions were not retained by the soil solid phase
- **Preferential uptake of nitrates** by Eucalyptus leading to an increase of NH_4 in seepage waters
-**Efficiency of deep root** system to take up mineral-N in both ecosystems

Consequences :
- N-cycle is not completely **conservative** in the Savannah ecosystem (it is for energy conservation and uptake; it is not for potential losses in seepage waters)… Same thing in plantations but for different reason (it is not for energy conservation, it is partially if potential losses in seepage waters are considered).
- Potential risk of N depletion if soil is maintained bare for long time but risk minimized by the deep rooting (10 m depth) of Eucalyptus (but also Savannah) and the quick root development of the young tree root system (5 m the first year)

Nitification process is known for years but development of an operationnal simulator for identifying the undesirable effects requires more knowledge, especially in the field of its biological control….

A set of 2 types of conditions is required for simulating nitrate behaviour in soils:

1- Identifying the favourable conditions for nitrate production

2- Identifying the process able to limit the nitrate availability and mobility

1- Favourable conditions for N-mineralisation and nitrate production

Environment factors	- **climate** (water, temperature) **- soil** . physical properties (water retention) . characteristics of the carbon substrate (C/N, Norg/lignin…) . high base cation saturation . low acidity - occurrence of adequate populations and activity - no ammonium volatilization - ammonium in **atmospheric deposits**
Past land occupation	- time since **agriculture** abandon - ecosystem **disturbance** regime
Biology	- competition - **tree** species (allelopatic contro l) - **ground vegetation** (allelopatic control) - presence of nitrifiers **-** occurrence of **N-fixing** species
Forest treatments	- frequency of thinning operations and clear -cut - selection of species - rotation length - harvest intensity - slashes treatment - control of ground vegetation

2- Processes able to limit the nitrate availability and mobility

Soil physico-chemical factors	- biochemistry of SOM - ammonium fixation in clays - nitrate retention in oxides and/or physical adsorption - nitrate retention in soil fine porosity - deficit in water drainage
Biological factors	- competition for substrate - immobilisation by micro-organisms - allelopathy - vegetation uptake - denitrification - reduction of nitrates to ammonium

Conclusions (1)

1 - Management have potentially major effects on forest ecosystems through changes on the N-cycle.

> direct effects on all components of soil quality

> all soil functions have to be considered (production, ecology, environment)

Conclusions (2)

2 - Relevant ecological questions require more research

- Functionnal ecology
  - > changes in organisms (population; autotophy vs heterotrophy)
  - > competition between organisms *vs* allelopathy
  - > reciprocal relations between biology and geochemistry and resulting coupling or decoupling between cycles
  - > role of fertility level
  - > dynamic of the processes
  - > effect of disturbances
- General ecology
  - > conservative vs non conservative changes
  - > role of N-mineral form uptake on competition between trees and ground vegetation

Conclusions (3)

3 - Predictive simulation require

> generalisation of conclusion
> better understanding of processes and identification of key parameters of the control
> sites for validation
> development of coupled models between biology and geochemistry

Conclusions (4)

4 - Strongly necessary to transfer results to managers

> development of simplified simulators is required

> sites for demonstration and formation