

Synthesis on the trade-offs of C sequestration with water yield and soil fertility after savannah afforestation in Congo

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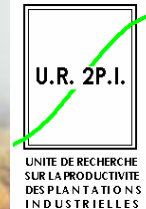
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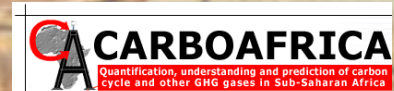
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Eucalyptus
Fibre Congo



République du
Congo



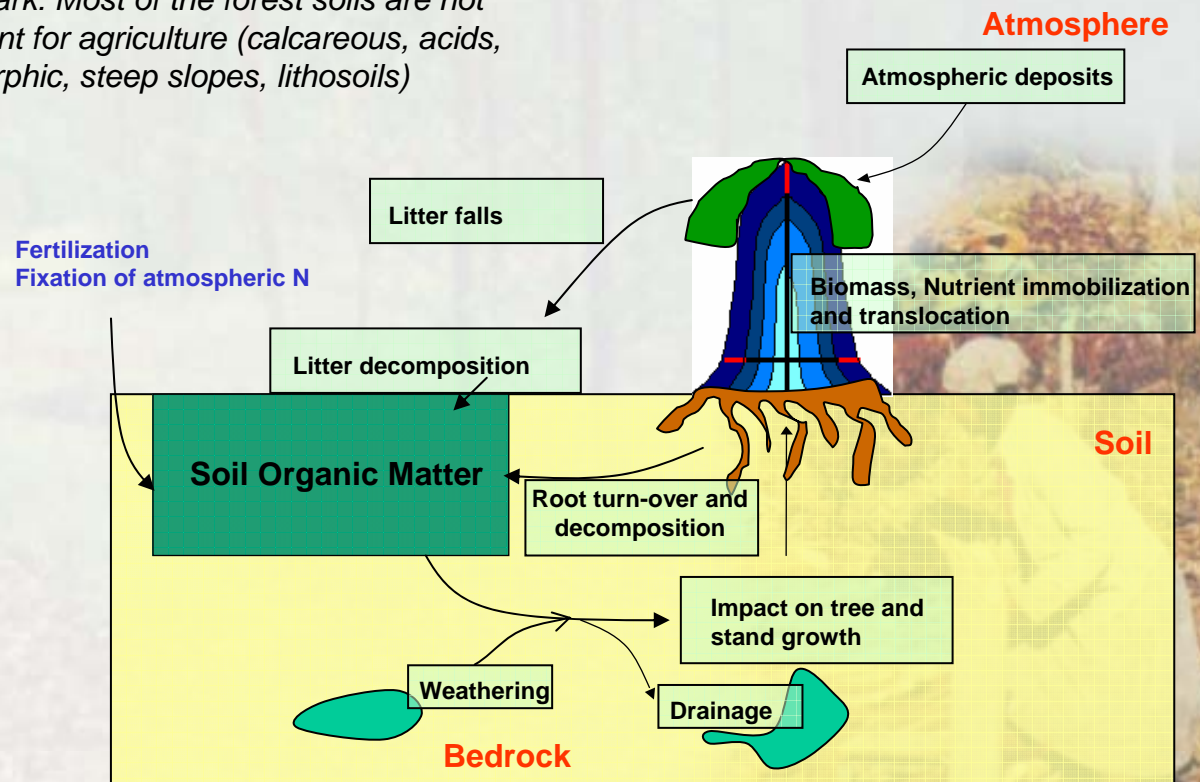
Forest Ecosystems ?

- Stocks and fluxes (C, Water, Nutrients)
- Dynamics of living organisms (trees, fungus, soil micro and macro fauna, etc...) that interact with the atmosphere and the soil
- They lay on a given bedrock in a given topographical situation

One remark: Most of the forest soils are not convenient for agriculture (calcareous, acids, hydromorphic, steep slopes, lithosoils)

- A large variety of forest management are applied (from integral reserves to intensive plantations)

-Forest ecosystems evolve in a changing environment (pollution, climatic changes)



Fast Growing Tree Plantations may be seen as a tool for C sequestration... but ?

→ Ecological impacts of these plantations ?

→ Eucalypt plantations were multiplied by 4 over the last 30 years : now, the total area is about 15 millions ha planted mainly on poor soils (FAO 2001).

→ Many punctual researches :

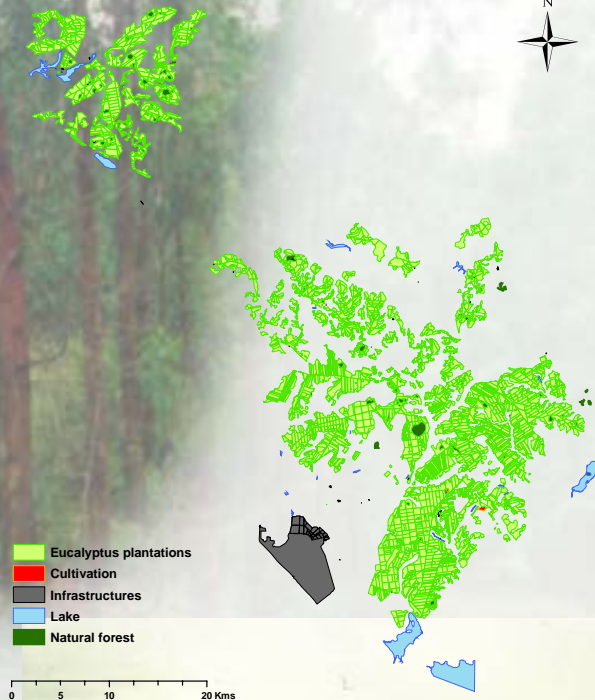
- water consumption,
- nutrient uptakes and accumulations, ...

→ Some meta-analysis :

- e.g. Paul et al. 2002, etc.. for Carbon
- e.g. Jackson et al. 2005 for water, pH and salinization, ...

→ **BUT Few studies deal with the whole ecosystem functioning (where water, nutrient and carbon fluxes are studied together on the same site)**

Eucalyptus in Congo

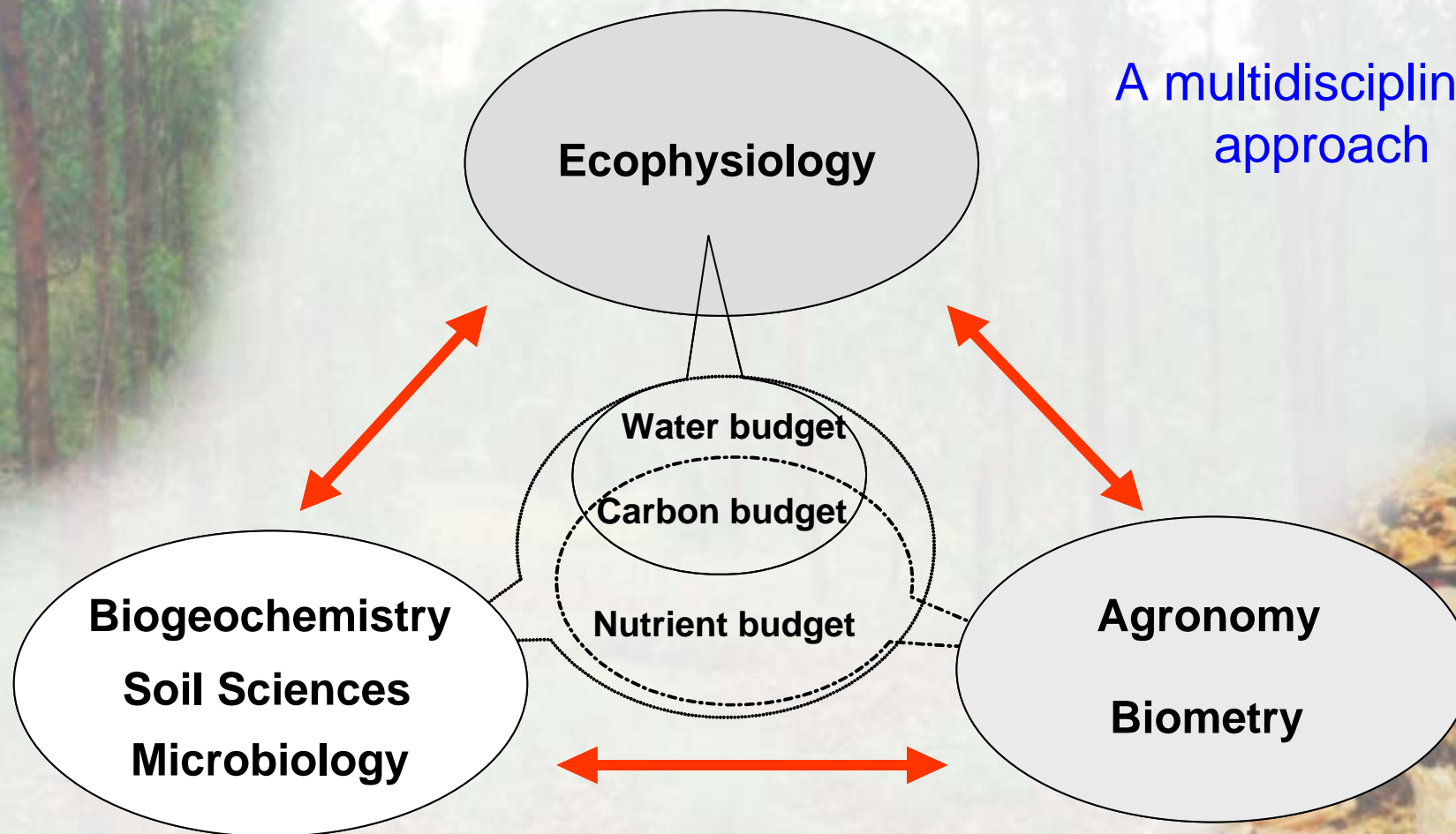


- Afforestation of a savannah (which is burnt every year)
- Plateau at an elevation of 100 m Asl
- Distance from the sea : 10 km
- Geology : thick detritic formations dated from plio-pleistocene
- Soil : Ferralic Arenosol. Sandy, Very deep and poor chemically (except for P), low water retention capacity, release of nutrient neglectible by weathering
- Mean rainfall : 1200 mm
Mean temperature : 25°C
One dry season (4 to 5 months)



Eucalyptus in Congo

A multidisciplinary approach



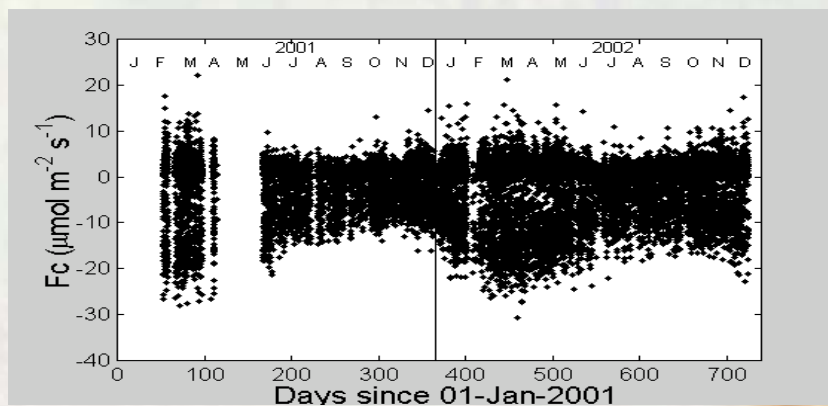
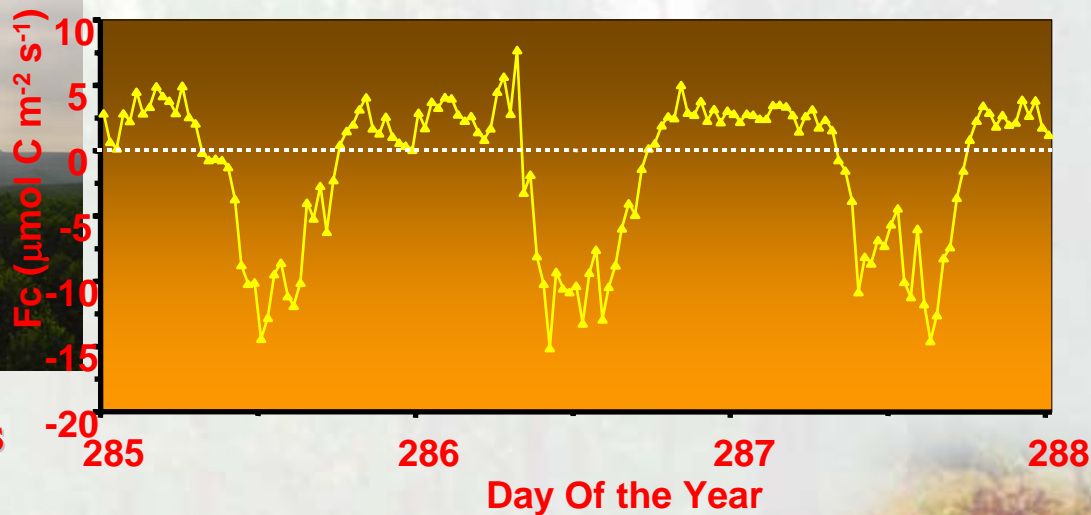
Eucalyptus in Congo, experimental design



Eucalyptus in Congo, experimental design



Eddy-covariance measurements
of CO₂ fluxes



Eucalyptus in Congo, results

Recharge of water table

Annual water fluxes (mm) in the *Eucalyptus* stand and the savanna of Kondi, estimated from the Hydrus 1D model

	P	Th	Sf	In	Ru	AET	Dr
<i>Eucalyptus</i> stand							
1998	1680	1531	16	133	27	1089	618
1999	1406	1273	13	120	23	990	500
2000	1469	1335	13	121	24	994	404
Mean	1518	1380	14	125	25	1024	507
Savanna							
1998	1691	1510	–	181	6	933	701
1999	1435	1260	–	175	5	852	613
2000	1470	1294	–	176	5	936	495
Mean	1532	1355	–	177	5	907	603
Ratio (<i>Eucalyptus</i> /savanna)	0.99	1.02		0.71	5.0	1.13	0.84

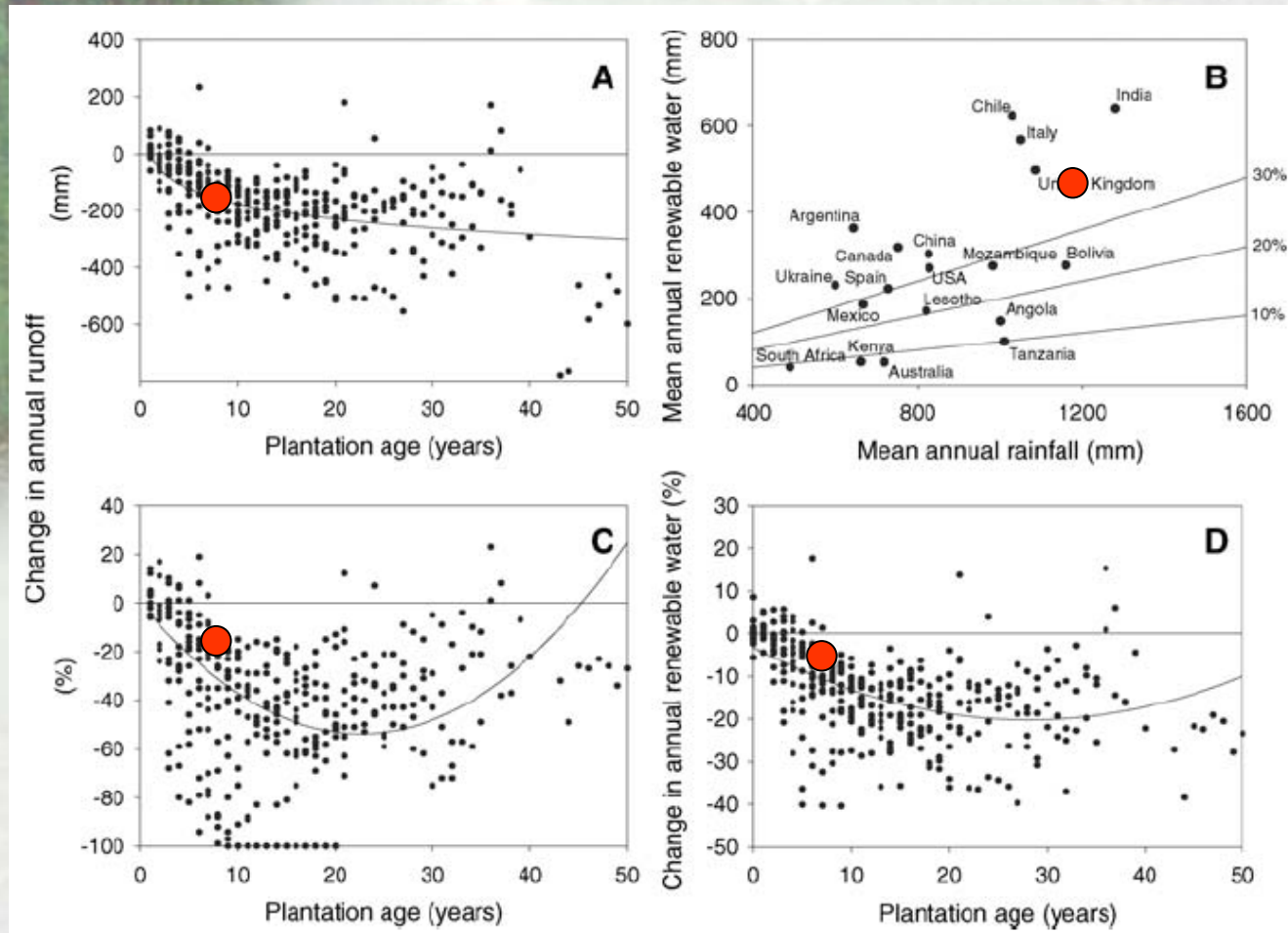
P: precipitation; Th: throughfall; Sf: stemflow; In: interception; Ru: surface run off; AET: actual evapotranspiration; Dr: deep drainage at the depths of 6 and 4 m in the *Eucalyptus* stand and the savanna, respectively.

- Water uptake is deeper in plantation than in savannah
- Net annual loss by drainage averaged 500 mm in the *Eucalyptus* stand and 600 mm in the savannah.
- BUT low risks of depleting the water table recharge in this region
 - annual rainfall of 1200 mm
 - mosaik Plantations - Savannah – Natural forest that prevent a too large surface area planted with eucalyptus

From Laclau et al. 2005

Eucalyptus in Congo, results

Recharge of water table, comparison with other sites around the world

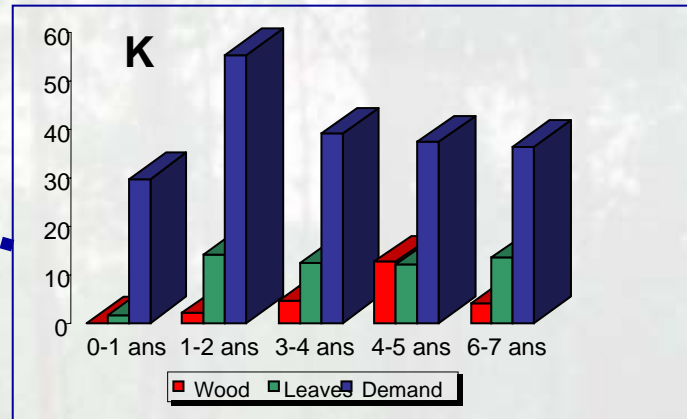
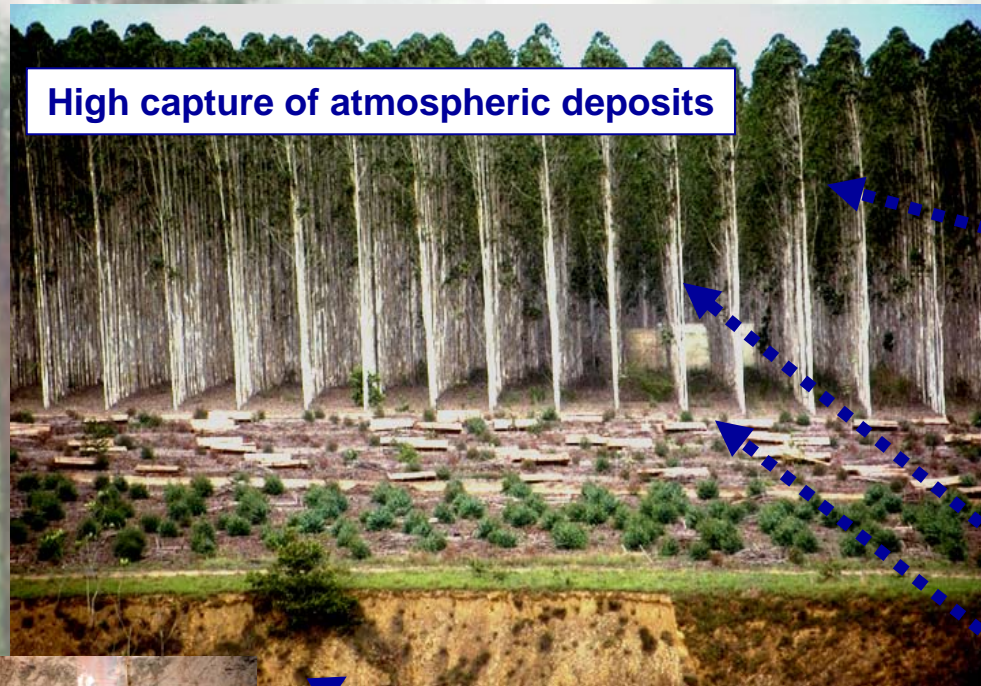


The congolese site does not differ from the pattern observed by Jackson et al.

Thank to the concentration of rainfall events in a few months and the high hydraulic conductivity of soils, impacts on water resources are limited

From Jackson et al. 2005

Trade-offs of C sequestration with water yield and soil fertility after savannah afforestation in Congo



Efficiency of internal translocations

Substitution of K by Na in tree physiology

High nutrient restitution by litter falls



Deep root
prospersion
(>8 m)

→ Immobilization within wood < uptakes ≤ needs

→ Two phases in tree and stand growth :

< 2 years → Tree establishment until canopy closure

> 2 years → High Restitution by litterfalls for N, Ca et Mg

Translocations
K > N ≈ P > Mg ≈ 0 > Ca

High rates of mineralization, directly used by the trees through root mats



Trade-offs of C sequestration with water yield and soil fertility after savannah afforestation in Congo

Eucalyptus in Congo, results

Fluxes in kg ha⁻¹ years⁻¹

Eucalyptus **Savannah**

	N	P	K	Ca	Mg
INPUTS					
Atmospheric deposits	12,3 4,9	0,8 0,3	7,1 2,8	8,4 3,4	3,7 1,4
Fertilisation	5,1 0	2,4 0	6,7 0	0 0	0 0
Weathering	-	0 0	0,3 0,1	0 0	0 0
N-Atmospheric fixation	0 21,5?				
OUTPUTS					
Run-off	0,0 0,0	0,1 0,0	0,2 0,1	0,4 0,2	0,1 0,0
Leaching	13,9 3,0	0,5 0,1	2,5 0,6	2,2 0,5	2,2 0,2
Harvest	27,1	4,1	10,0	5,0	3,3
Burning	23,4	1,5	2,4	2,6	2,9
Budgets	- 23,7 0 ?	- 1,6 -1,3	1,4 -0,2	0,8 0,1	-1,9 -1,7

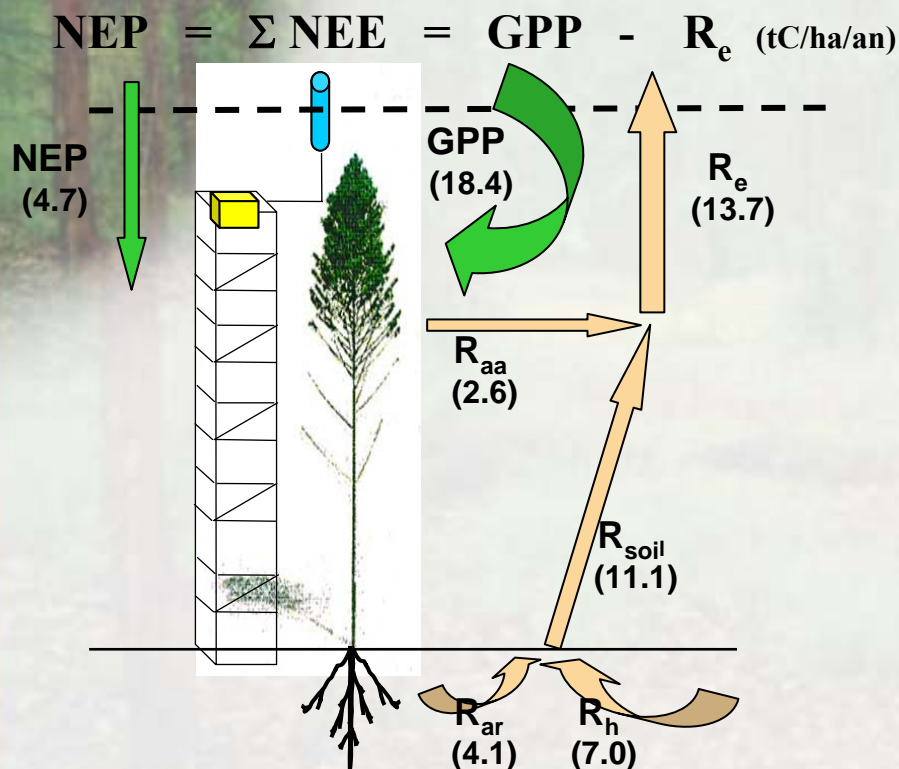
Carbon budget

Eucalyptus in Congo, results

At planting

- No effect of site preparation (either mechanical disturbance by disk harrowing or herbicide) on soil CO₂ effluxes when the slope is not pronounced

Assessment on a 3- to 4-year-old Stand



Plant compartment	ΔS	Litter production	NPP tDM/ha/year	NPP tC/ha/year
Stem, branch + bark	8.55	1.44	9.99	5.00
Leaves	0.02	4.77	4.79	2.40
Total aboveground	8.57	6.21	14.78	7.39
Stump	0.84	0.00	0.84	0.42
Coarse + medium roots	1.17	0.00	1.17	0.59
Fine roots	0.41	5.10	5.51	2.76
Total belowground	2.42	5.10	7.52	3.76
TOTAL	10.99	11.31	22.30	11.15

Eucalyptus in Congo, results

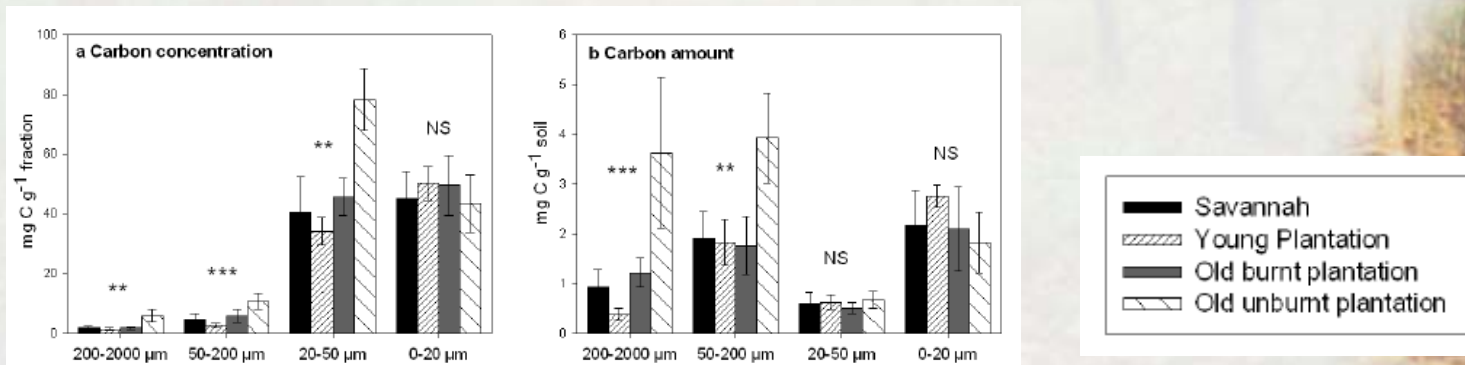
At harvesting

The mean amount of carbon that can be exported at the end of a seven year-rotation was estimated at 36.7 tC (134.5 tCO₂) ha⁻¹ which represents an average of 5.2 tC.ha⁻¹.year⁻¹

Land-use change from savannah to eucalypt plantations

Increase in the carbon stocks of the afforested area: a total of 28.8 tC.ha⁻¹ (24.4 tC ha⁻¹ in biomass, 4.4 tC ha⁻¹ in litter, and 0 tC ha⁻¹ in soils).

BUT strong impact of running fires on the soil C



D'Annunzio et al. 2007

Eucalyptus in Congo, Conclusion

Carbon = Biomass : positive
Litter on the soil : positive
Soil : balanced or little positive if plantations are prevented from fires coming from savannahs

Nutrients = Balanced except for Nitrogen but mixed-species plantations of eucalypt with acacia grow well and may counterbalance the nitrogen deficit (studies are ongoing)

Water = quantities : Limited effect
qualities : positive impact

Other concerns = -contribute to the social and rural economy
-limit the exportation of firewood from natural forests
(More than 50% of firewood used in Pointe-Noire come from plantations)
-host early-regrowth natural forest species (Loumeto and Huttel 1997)

Eucalyptus in Congo, recent related literature

Marsden C., et al 2007. *Two independent estimations of stand-level root respiration on clonal Eucalyptus stands in Congo. Accepted in New Phytologist (July 2007)*

D'Annunzio R et al 2007. *Pairwise comparison of soil organic particle-size distributions under native savannahs and Eucalyptus plantations in Congo. Accepted in Forest Ecology and Management (May 2007).*

Laclau J.-P et al. 2007. *Modifications of the biogeochemical cycles of nutrients in a Congolese savanna after afforestation with eucalypts. (Accepted in New Research on Forest Ecology)*

Epron D., et al. 2006. *Soil carbon balance in a clonal Eucalyptus plantation in Congo: effects of logging on carbon inputs and soil CO₂ efflux. Global Change and Biology 12:1021-1031*

Laclau J-P et al. 2005. *Nutrient cycling in a clonal stand of Eucalyptus and an adjacent savanna ecosystem in Congo. 3. Input-output budgets and consequences for the sustainability of the plantations. Forest Ecology and Management 210:375-391*

Safou-Matondo R et al. 2005 *Hybrid and clonal variability of nutrient content and nutrient use efficiency in Eucalyptus stands in Congo. Forest Ecology and Management, 210, 193-204.*

Saint-André L et al. 2005. *Age-Related equations for above- and below-ground biomass of a Eucalyptus hybrid in Congo. Forest Ecology and Management 205:199-214.*

Laclau et al. 2004. *The function of the superficial root mat in the biogeochemical cycles of nutrients in Congolese Eucalyptus plantations. Annals of Botany, 93, 249-261.*

Epron D et al. 2004. *Spatial and temporal variation of soil respiration in a Eucalyptus plantation in Congo. Forest Ecology and Management 202:149-160*