Impacts of afforestation and silviculture on the soil C balance of tropical tree plantations: belowground C allocation, soil CO_2 efflux and C accretion

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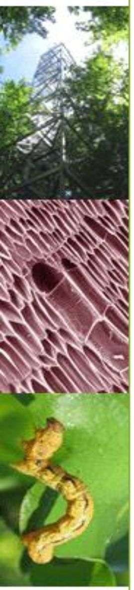
Tropical forest plantations



➔ The wood demand is increasing sharply

- ✓ Forest plantations cover 5% of the total forest area, but provide 33% of collected wood
- ✓ It is a valuable source of income in many developing countries
- ✓ They contribute to land use changes in the tropics that impact the global C cycle.

➔ **Are tropical forest plantations established on previous savannah potential C sinks offsetting anthropogenic CO_2 emissions?**

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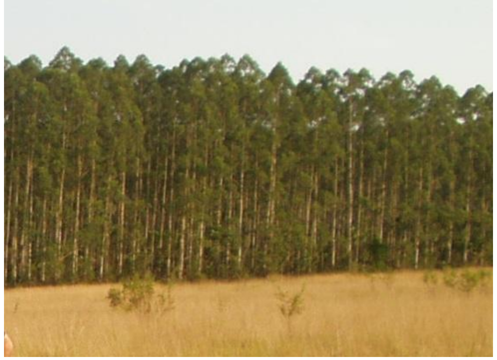
Carbon budget of tropical forest plantations

high	R_A	high	R_H	high	harvest	?
GPP	→	NPP	→	NEP	→	NBP
photosynthesis		*tree growth*		*tree biomass forest floor & soil C*		***forest floor & soil C***

(adapted from Schulze et al. 2000)



- ➔ C stock in the biomass definitely increases after afforestation of grasslands
- ➔ The sink strength depends on rotation length and lifetime of wood products
- ➔ Is the soil another valuable compartment for durable C sequestration?
- ➔ How does it interfere with fertility and tree growth?

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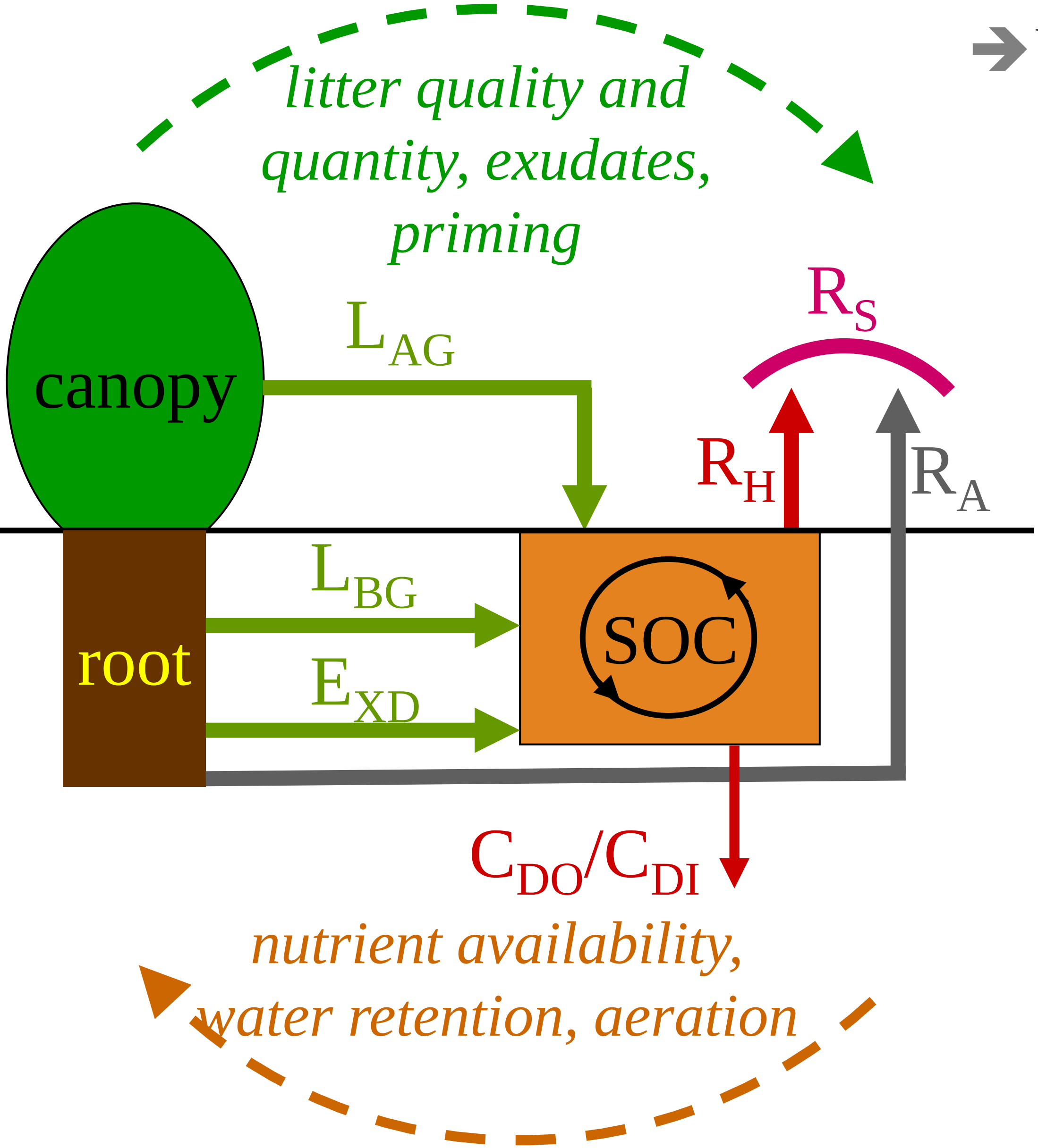
Carbon budget of soils in tropical plantations



➔ big issues:

- ✓ identification of key processes that control C sequestration
- ✓ partition of SOC into pools of different origins and residence time
- ✓ tradeoff between C sequestration and SOM mineralization that sustains fertility

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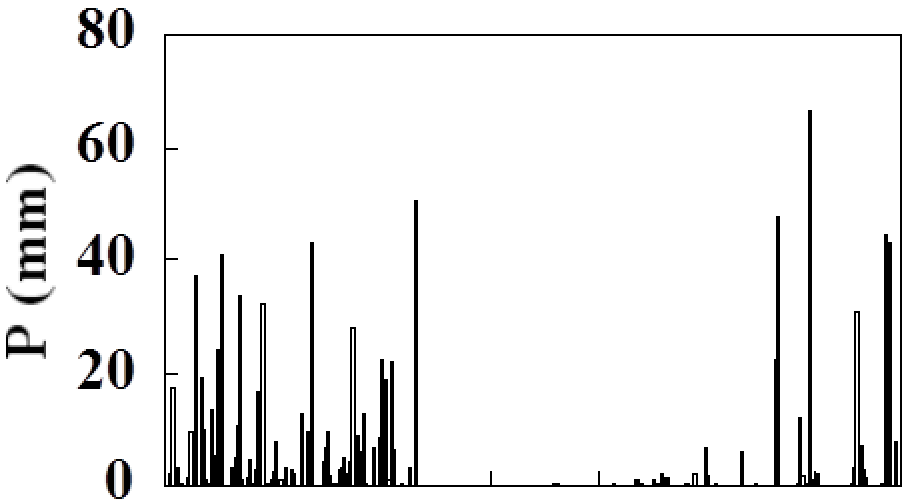
Case study: eucalypt plantations in coastal Congo



➔ sub equatorial climate

- ✓ 85% ± 2%
- ✓ 25° C ± 5° C
- ✓ 1400 mm (1998 - 2003)
- ✓ 5 months dry season

➔ deep ferralic arenosols

- ✓ sand (80-90%), clay (8-10%), silt (2-2.5%)
- ✓ low water retention
- ✓ poor cationic exchange capacity
- ✓ very low level of organic matter

➔ land use change

- ✓ savannah (*Loudetia arundinacea)* burnt annually
- ✓ fast growing *Eucalyptus* hybrids (clones)

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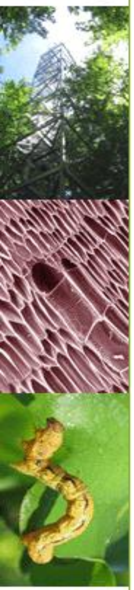

Outline

savannah

eucalypt 1

1 2 3

eucalypt 2 with no slash

4 7

eucalypt 2 with normal slash

5

eucalypt 2 with double slash

eucalypt (100E) in monoculture

6

eucalypt mixed with acacia (50E:50A)

1. Site preparation and soil C balance
2. Litter C inputs after afforestation
3. Soil C dynamics after afforestation
4. Harvest and soil C balance
5. Slash and heterotrophic respiration
6. Soil C in mixed-species plantations
7. Priming of old soil organic matter

1. Site preparation and soil C balance

savannah → eucalypt 1

↑1 yr.

➔ Does mechanical soil disturbance increase SOC mineralization?

	herbicide application	disk harrowing
Tree biomass after one year (kg m^{-2})	**0.50**	**0.65**
Soil CO_2 efflux (R_S, kgC m^{-2} yr^{-1})	**0.66**	**0.65**
Autotrophic R	**0.16**	**0.20**
Heterotrophic R	**0.51**	**0.46**
Input of savannah residues (kgC m^{-2})	**0.43**	
Soil C budget (ΔC, kgC m^{-2})	**-0.08**	**-0.03**

➔ Disk harrowing promotes tree growth without additional SOC loss on sandy soil if no risk of erosion

Nouvellon et al. 2008 For. Ecol. Manag.

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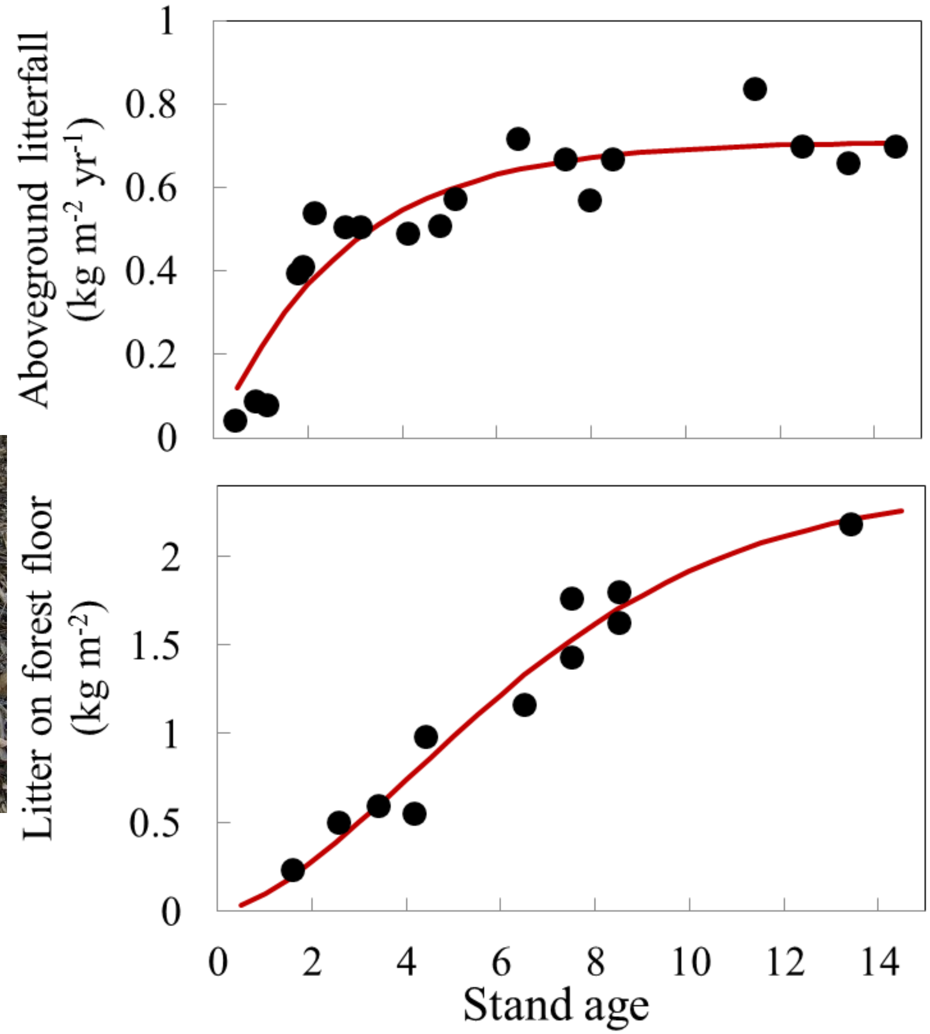
2. Litter C inputs after afforestation

savannah | eucalypt 1

from 0.5 to 14 yr.

➔ Does the increase in aboveground litter input account for age related changes in C stock in the forest floor and soil respiration?



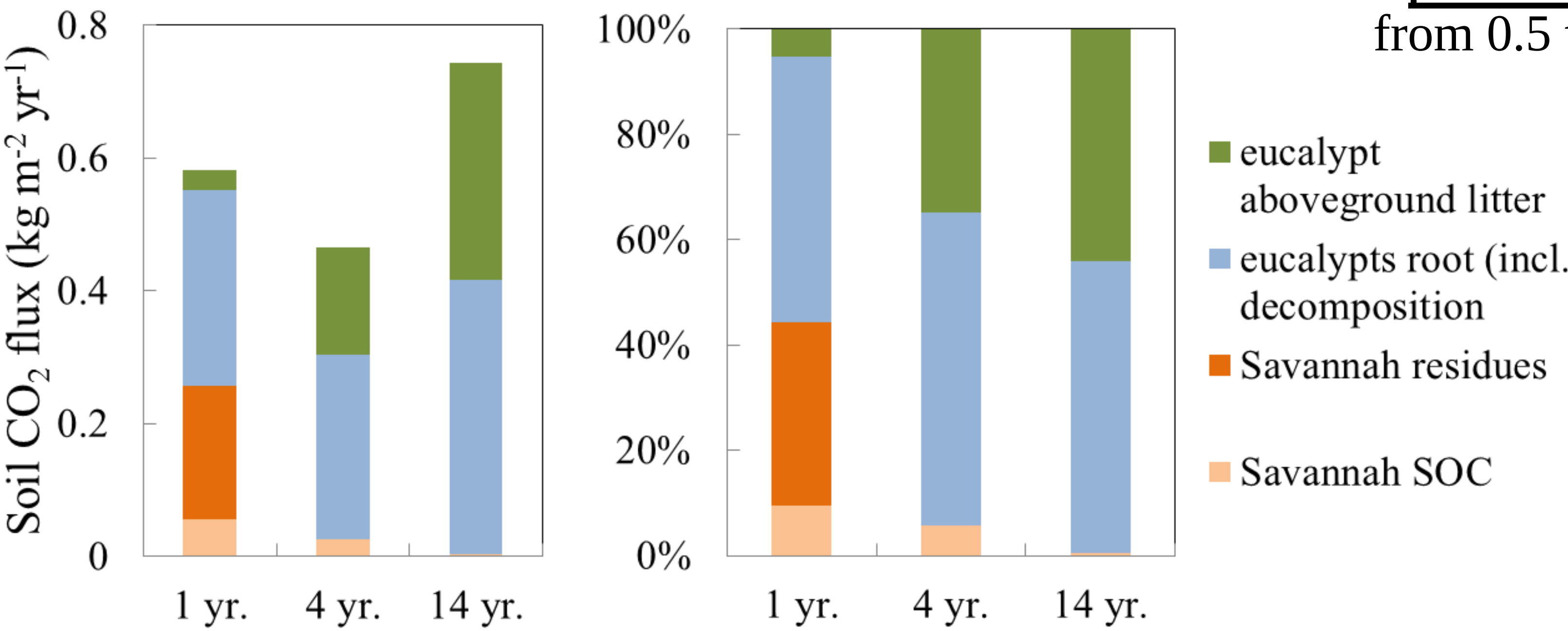
➔ The C stock in the forest floor increases with stand age after afforestation

Nouvellon et al. 2012 Biogeochem.

2. Litter C inputs after afforestation

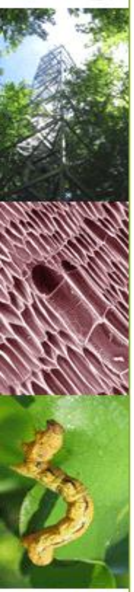
savannah | eucalypt 1

from 0.5 to 14 yr.



- → Soil respiration first decreases due to savannah residue depletion, and then increases because of an increasing amount of decomposing eucalypt litter.
- → The aboveground litter layer is as a major source of CO_2 in old stands

Nouvellon et al. 2012 Biogeochem.



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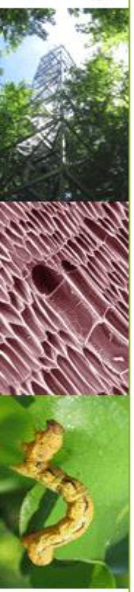

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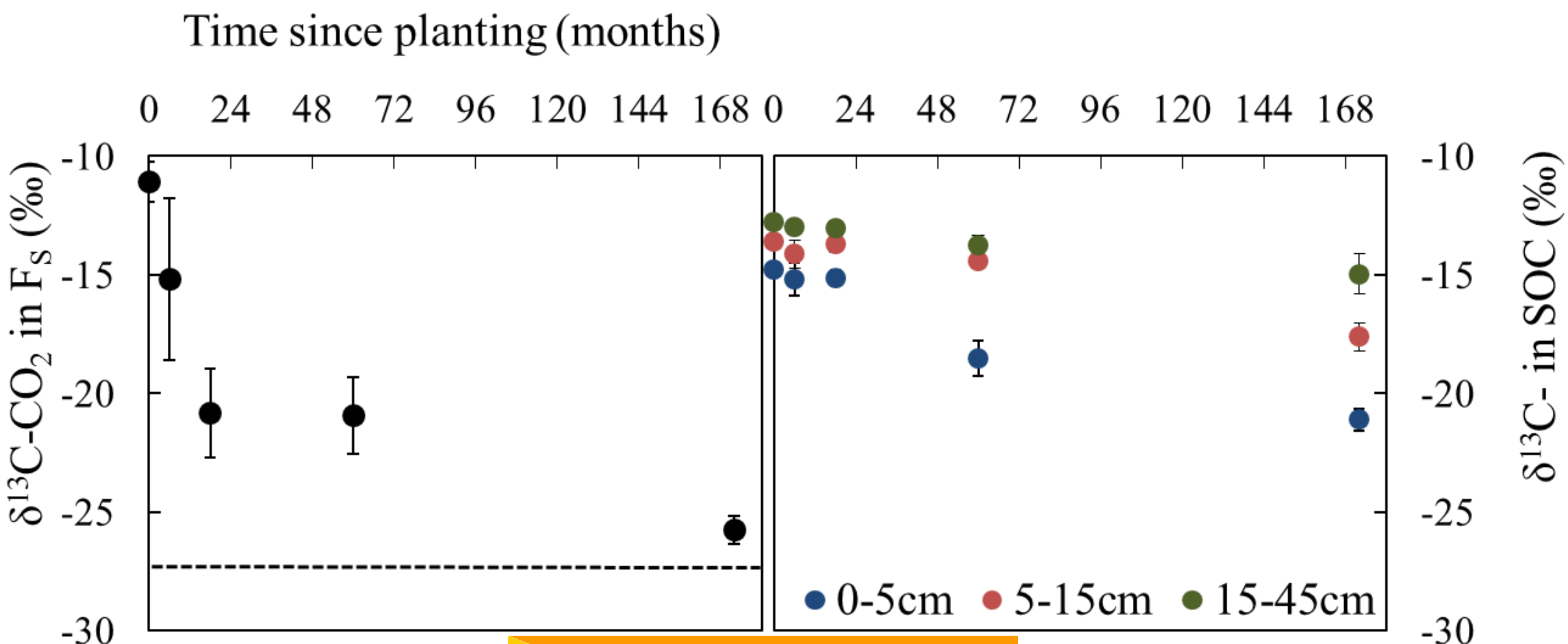
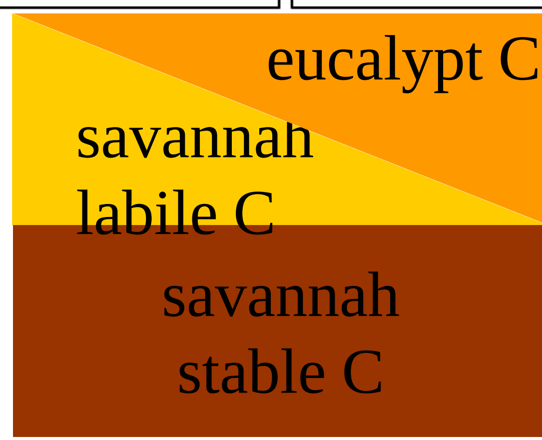
3. Soil C dynamics after afforestation

savannah → eucalypt 1 (from 0.5 to 14 yr.)

➔ How fast eucalypt-derived C replace savannah C?



savannah grasses: $\delta^{13}C \approx -12‰$



eucalypt trees: $\delta^{13}C \approx -28‰$

$\delta^{13}C$ of R_S
=> labile savannah C

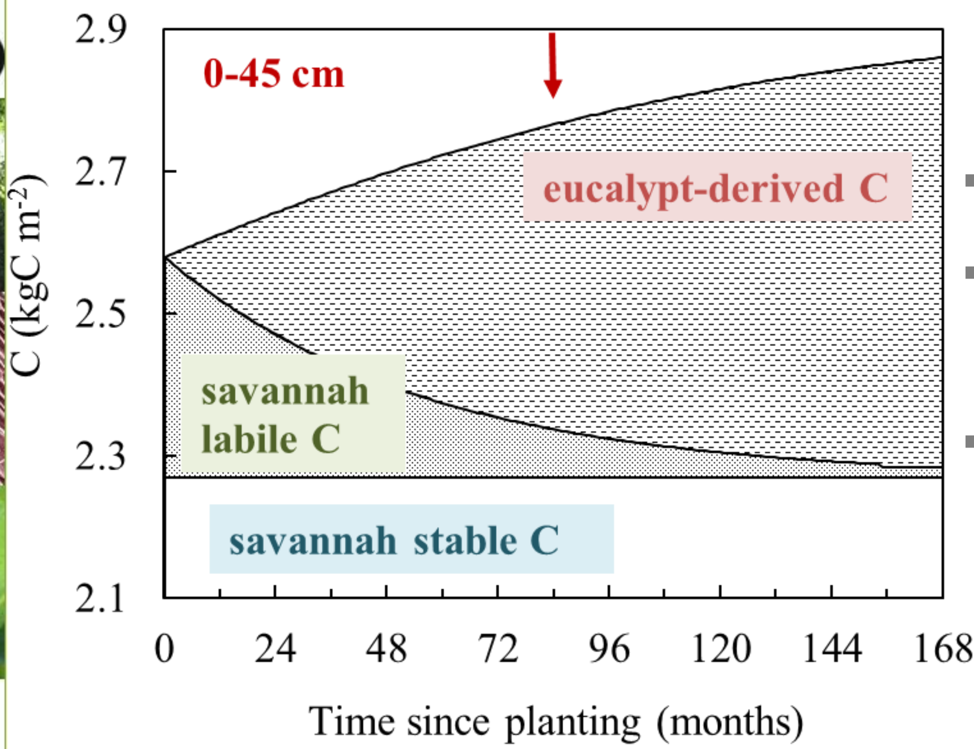
$\delta^{13}C$ of SOC
=> total savannah C

Epron et al. 2009 Plant Soil

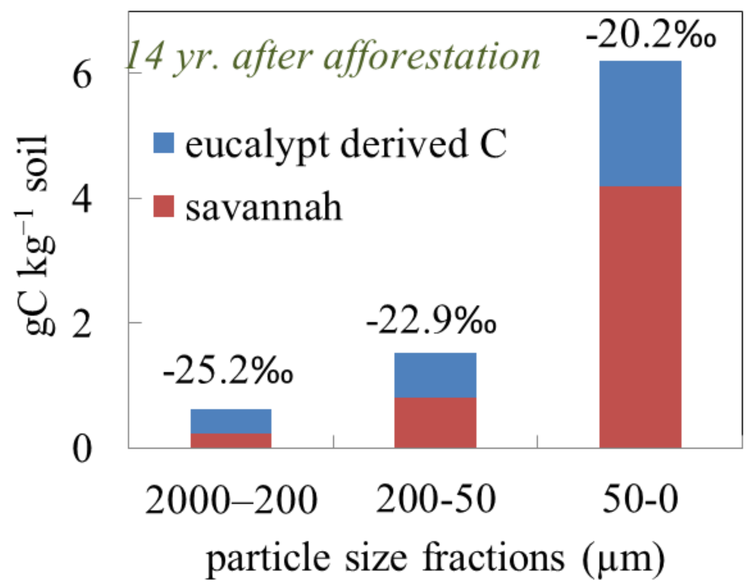
3. Soil C dynamics after afforestation

savannah → eucalypt 1

from 0.5 to 14 yr.



- → most of savannah C is stable
- → the labile savannah C has a mean residence time of 5 yr.
- → little C accretion occurs



→ Most of eucalypt-derived C is associated with the clay and fine silt fractions

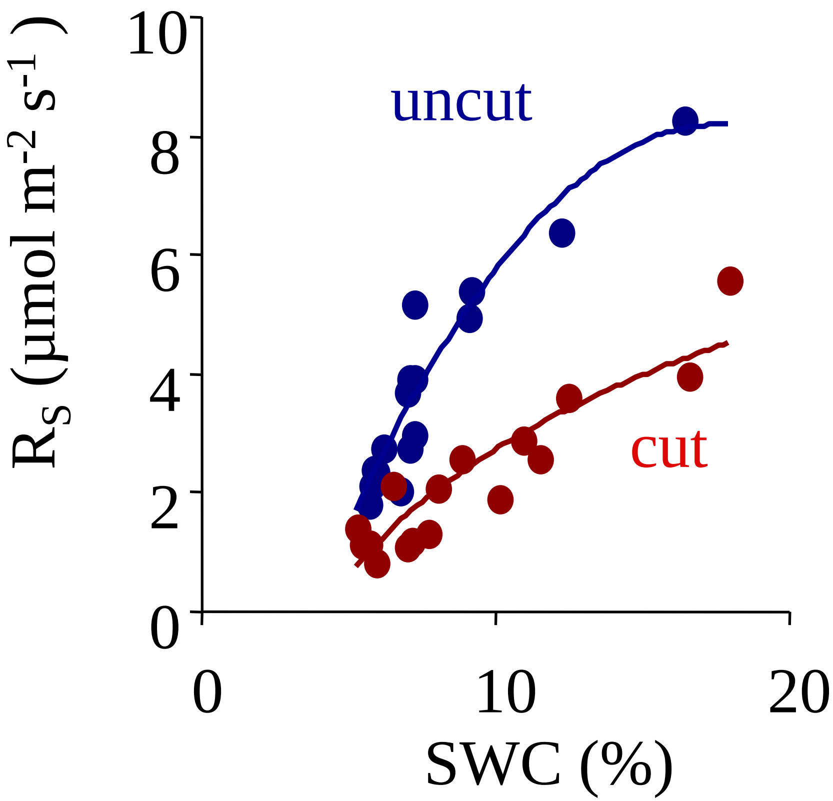
Epron et al. 2009 Plant Soil

4. Harvest and soil C balance

savannah | eucalypt 1

7 yr.↑

➔ Does soil loose C after clearcutting?



R_S = 1.57 kg$_C$ m^{-2} y^{-1}

R_H = 0.65 kg$_C$ m^{-2} y^{-1}

R_S = 0.91 kg$_C$ m^{-2} y^{-1}

R_H = 1.18 kg$_C$ m^{-2} y^{-1}

(including coarse woody debris decay)

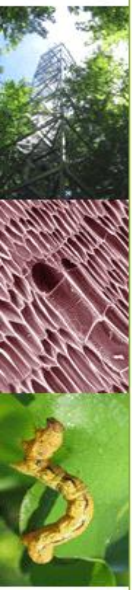
Input of residues = 1.72 kg$_C$ m^{-2}

(Leaves, barks, bole tops and small branches were left on the ground)

ΔC = +0.54 kg$_C$ m^{-2}

➔ the importance of residue management at harvest for soil carbon sequestration

Epron et al. 2006 Glob. Change Biol.



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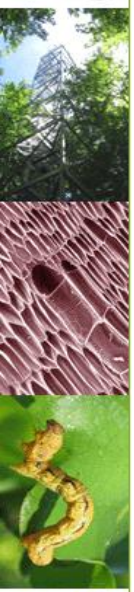

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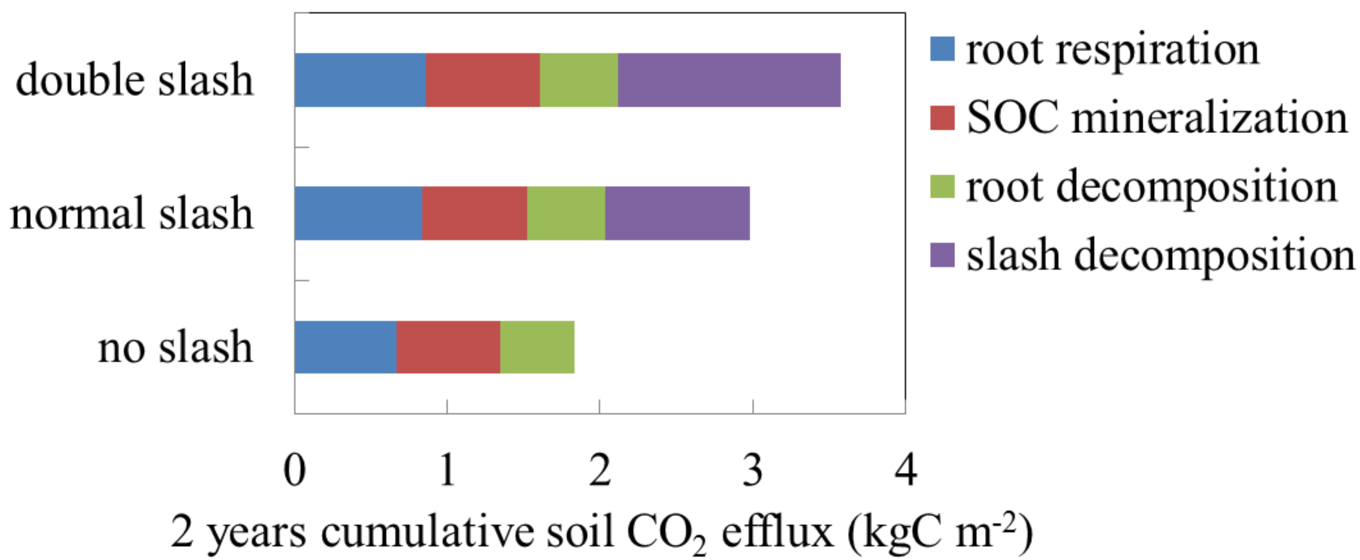
5. Slash and heterotrophic respiration

savannah → eucalypt 1 → no slash / normal slash / double slash

↑ 2 yr.

➔ Does heterotrophic respiration increase with the amount of slash and does it stimulate tree growth?



Versini et al. 2013 For. Ecol. Manag.

5. Slash and heterotrophic respiration

savannah | eucalypt 1 | no slash / normal slash / double slash

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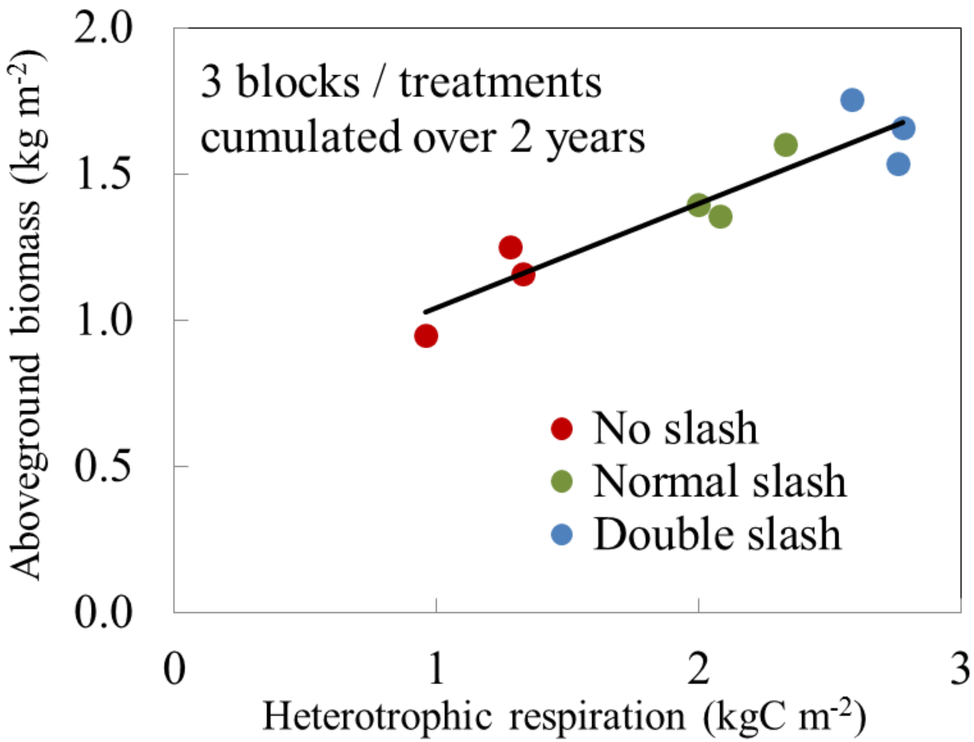

➔ Heterotrophic respiration increases with increasing slash amounts

➔ Strong relation between heterotrophic respiration and tree growth: early growth of eucalypt largely dependent on the nutrients released by the decomposition of organic residues

Versini et al. 2013 For. Ecol. Manag.

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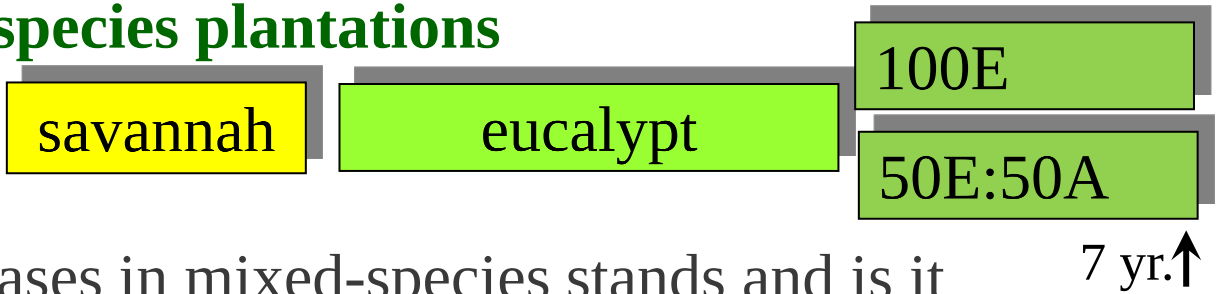
7. Soil C in mixed-species plantations



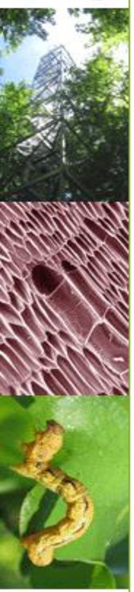
➔ Does soil C increases in mixed-species stands and is it related to a higher productivity?

($t\ ha^{-1}$)	Nitrogen		Carbon	
	100E	50E50A	100E	50E50A
Soil stock (0-25 cm)	1.19±0.02	1.28±0.03 ↑	15.9±0.4	17.8±0.7 ↑
Annual litterfall	0.030±0.004	0.063±0.001 ↑	2.9±0.3	3.2±0.1 ≈

➔ The increase in soil C in the mixed-species stand may be related to a slowdown of SOM mineralization due to N enrichment

➔ less priming or negative priming?

Koutika et al. in revision



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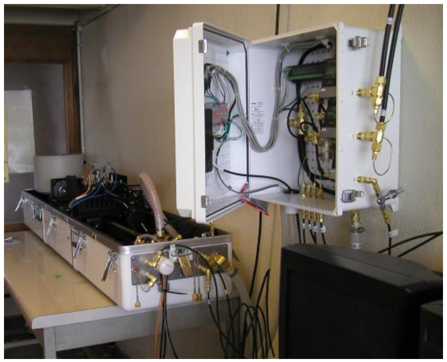
7. Priming of old soil organic matter

savannah | eucalypt 1 | eucalypt 2

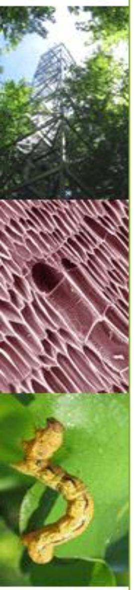
7 yr.↑

➔ Does input of fresh C destabilize the stable savannah SOC?



- We incubated soil samples with either C3-labelled or C4-labelled glucose
- We tracked changes in $\delta^{13}C$-CO_2 in microbial respiration at high temporal resolution with a tuneable laser diode spectrometer
- We partitioned microbial respiration into
  - glucose mineralization
  - C3-SOC mineralization
  - C4-SOC mineralization

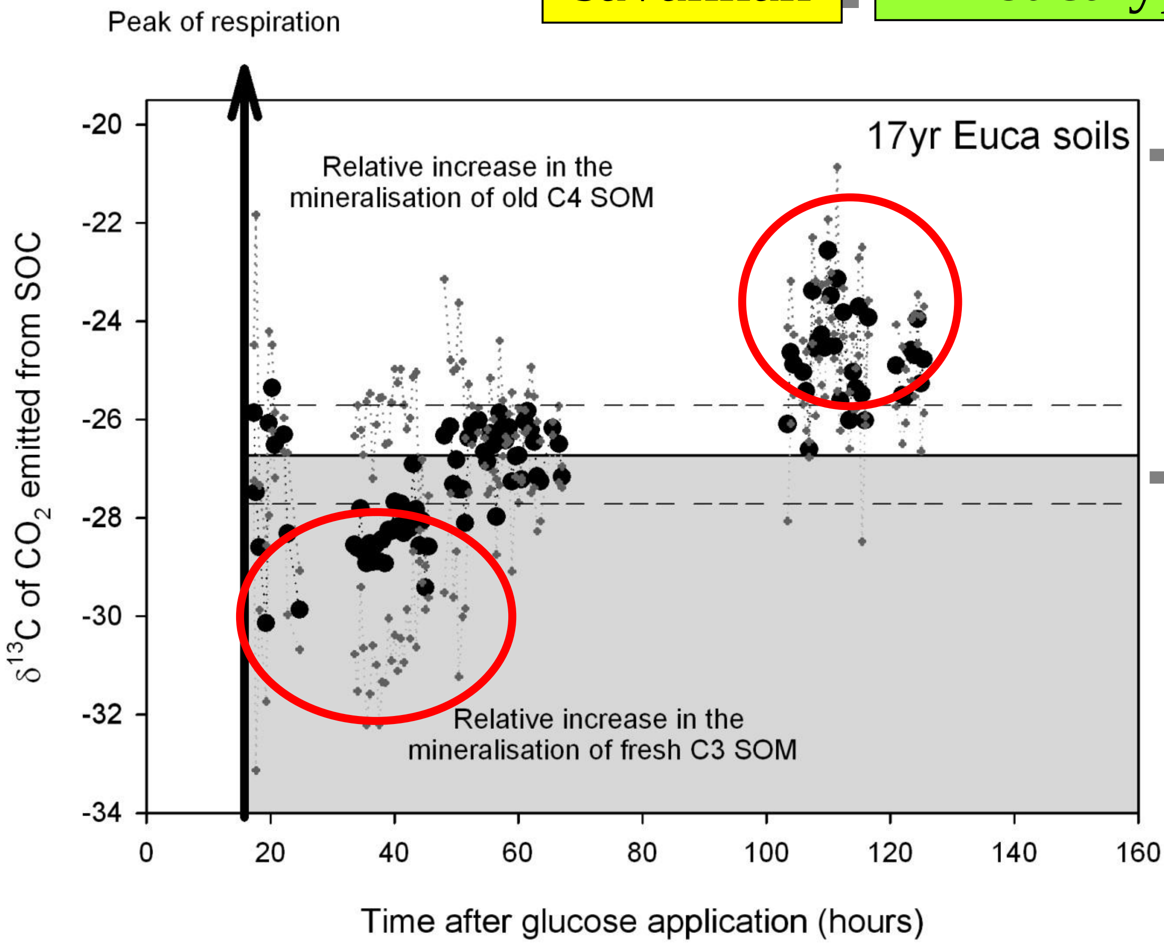
Derrien et al. submitted



7. Priming of old soil organic matter

savannah | eucalypt 1 | eucalypt 2

7 yr.



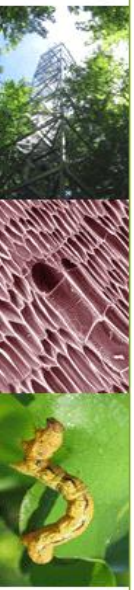
➔ Over-mineralization of C3-SOC 2 days after glucose addition

➔ Over-mineralization of C4-SOC 5 days after glucose addition

➔ the stable savannah SOC can be destabilized by fresh labile C substrates

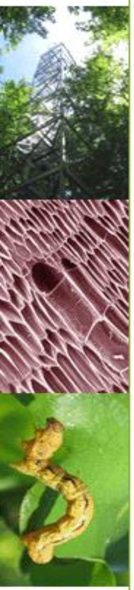
Derrien et al. submitted

Afforestation of a tropical savannah with eucalypts on poor sandy arenosols



➔ What did we learn from our case study?

- ✓ we observed little C accretion in the soil after afforestation:
  - despite low potential for sequestrating C of sandy soils with low activity clay minerals (kaolinites)
  - not C saturated because of savannahs were burnt annually?
- ✓ the management of harvest residues is a key issue for sustainable wood production and C accretion in the soil
- ✓ most of savannah-derived soil C is stable but
  - its mineralization might be primed by addition of fresh C
  - this priming effect might be modulated by management options that increase N availability
- ✓ biomass and forest floor are the main C stocks that are modulated by rotation length



Afforestation of tropical soils

➔ new challenges that need to be addressed:

- ✓ heterotrophic respiration counterbalance net primary productivity but also sustains NPP
- ✓ high productivity on nutrient poor soil may promote old SOM mineralization (priming effect by the input of fresh C)
- ✓ management options that improve fertility may also favor the stabilization of SOC
- ✓ stoichiometric characteristics of input materials (C:N:P) versus microbial biomass
- ✓ plasticity of microbial C use efficiency

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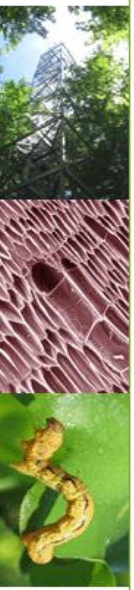

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