International symposium 15 to 18 September 2004 Bordeaux :
Forest soils under global and local changes : from research to practice

Soil carbon dioxide efflux in a mixed stand of oak and beech : abiotic factors and species effects

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I. Context and objectives

Soil respiration

(1) Microbial activity { in the forest floor / in the mineral soil } Heterotrophic respiration

+

(2) Living-root growth and maintenance } Autotrophic respiration

→ partitioning into various contributions

= f(t°, water content, SOM quantity and quality, other effects)

species-dependent factors

→ evaluation of the species effects

II. Materials & methods

a) Study site

Chimay (Belgian Ardennes) :

·elevation : 300m

·mean annual t° : 8°C

·rainfall : 1000mm

·acid brown earth (dystrochrepts)

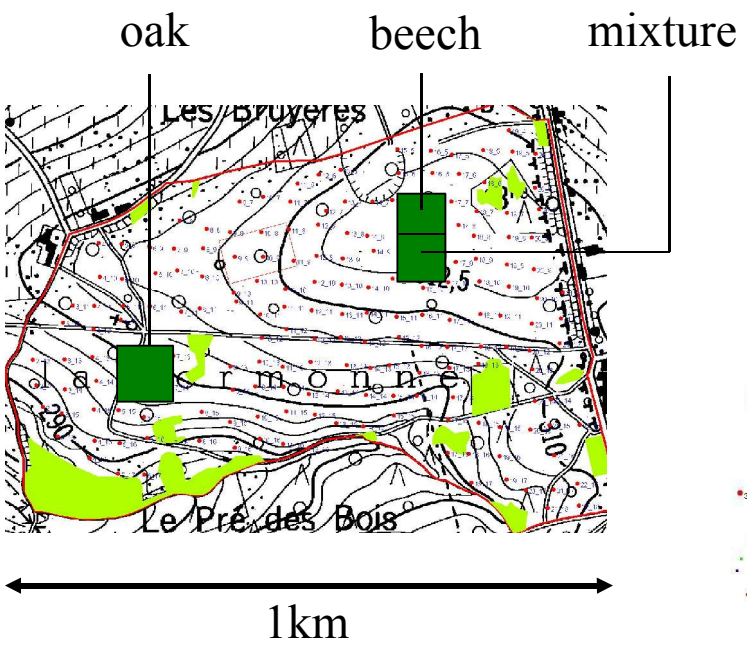
·mixed oak and beech stand (60 ha) :

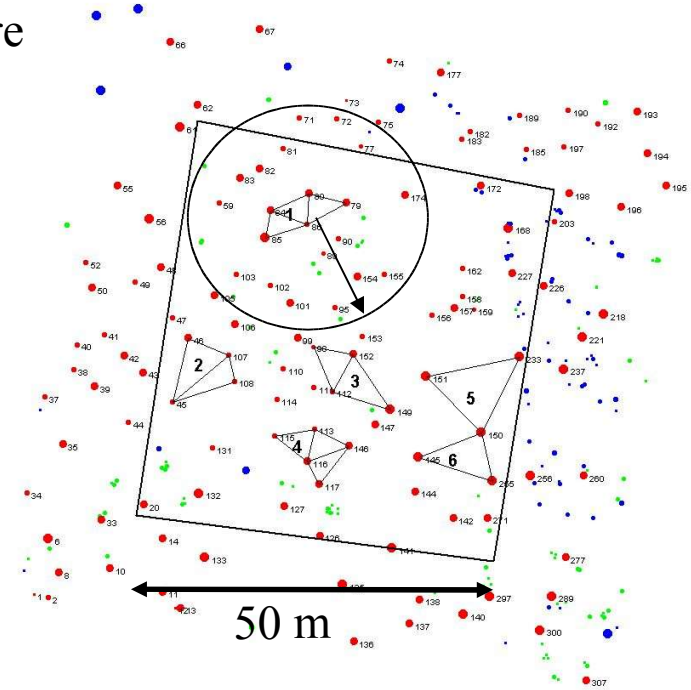
- ·oak : 125 years old
- · beech : 0 to 100 years old

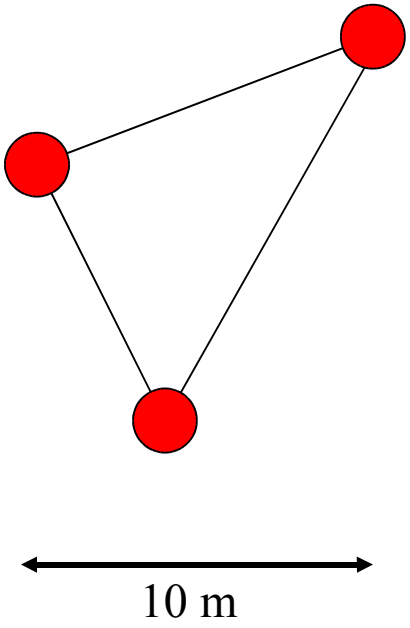
II. Materials & methods

b) Sampling strategy

Site **Experimental plot** **sub-plot**







II. Materials & methods

c) Measurements

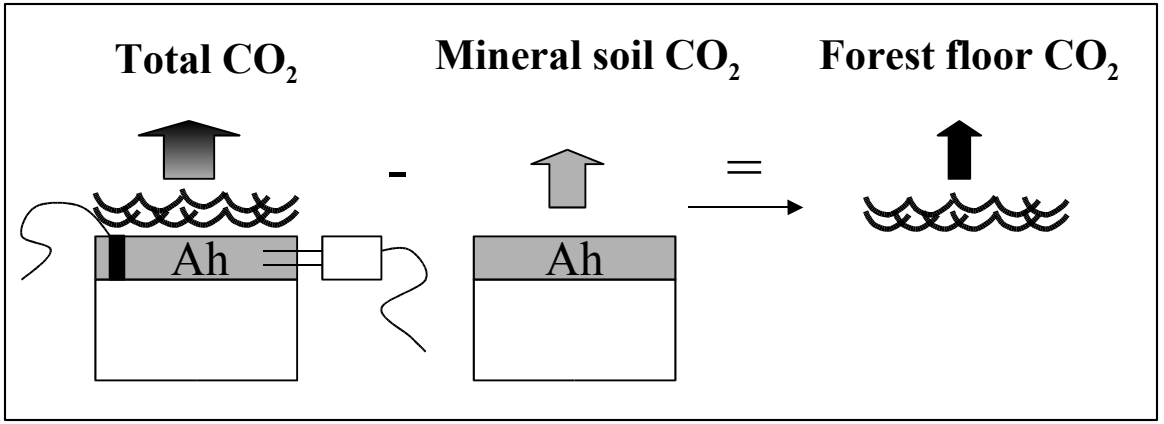
Monitoring period : Nov. 2002 to Nov. 2003

Variables :

·CO2 : infrared gas monitor

·t° : thermocouples

·θ : TDR-probes



Experimental design : nb of sampling locations

	oak	mixture	beech	total
dry	2		2	4
normal	3	3	3	9
moistened	2		2	4
total	7	3	7	17

II. Materials & methods

d) Additional measurements

- Litterfall : annual litter collect in 105 litter traps

  (2001, 2002, 2003)

- Forest floor sampling (2002)

III. Results & discussion

a) t° and θ effects

b) Species effects

1. Species effects on soil microclimate

2. Species effects on the temperature and CO_2 relationship

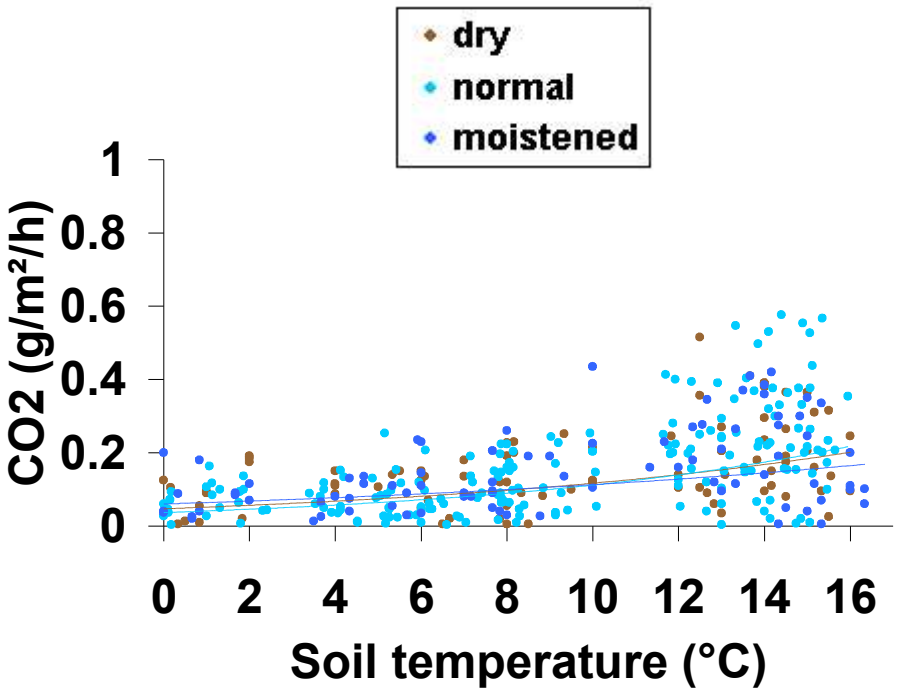
3. Species effects on the t° and θ interaction

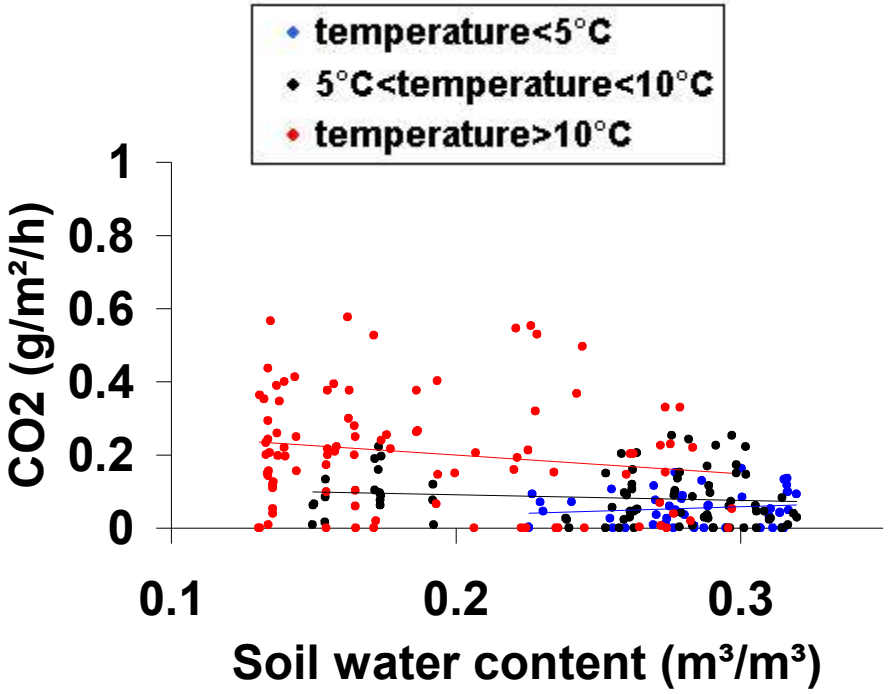
c) Annual fluxes

III. Results & discussion

a) t° and θ effects

1. Forest floor

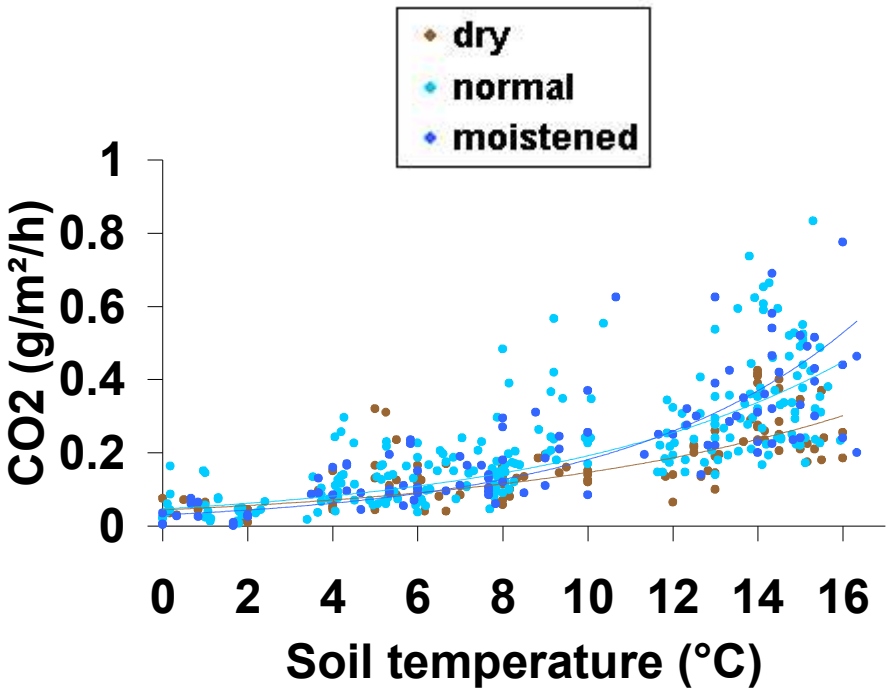


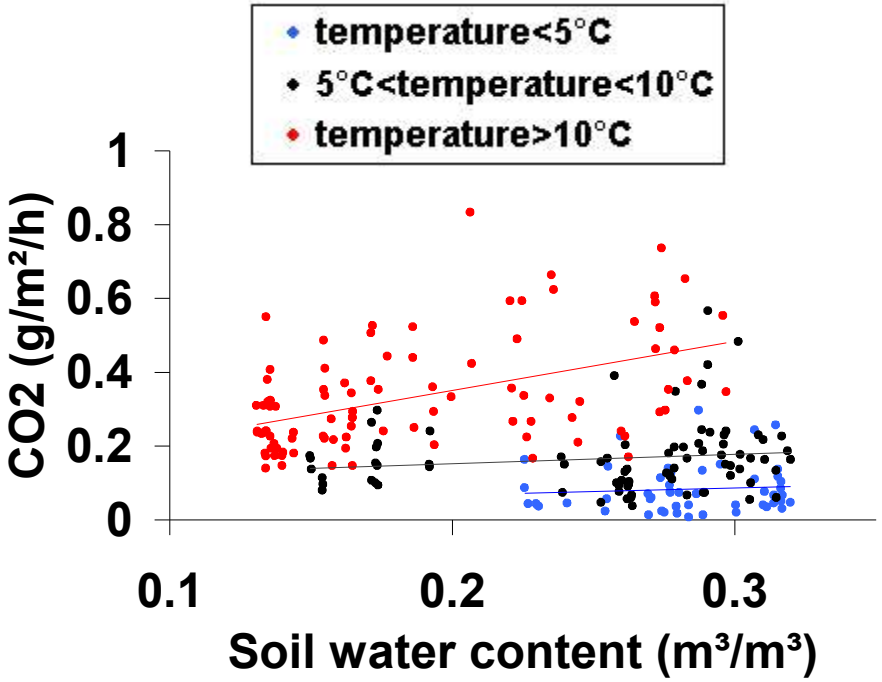


III. Results & discussion

a) t° and θ effects

2. Mineral soil





III. Results & discussion

a) t° and θ effects

	t°	θ	t° x θ
forest floor	+	-	-
	Λ		
mineral soil	+	+	+

III. Results & discussion

b) Species effects

1. Species effects on soil microclimate

Soil temperature (°C) during the summer 2003 (n=18)

	oak	mixture	beech	Pvalue
mean	15.635	15.576	15.167	0.005
standard deviation	0.323	0.147	0.166	
variation coefficient (%)	2.07	0.94	1.09	

Soil water content (m^3/m^3) during the summer 2003 (n=18)

	oak	mixture	beech	Pvalue
mean	0.184	0.158	0.167	0.200
standard deviation	0.028	0.026	0.015	
variation coefficient (%)	15.35	16.66	9.13	

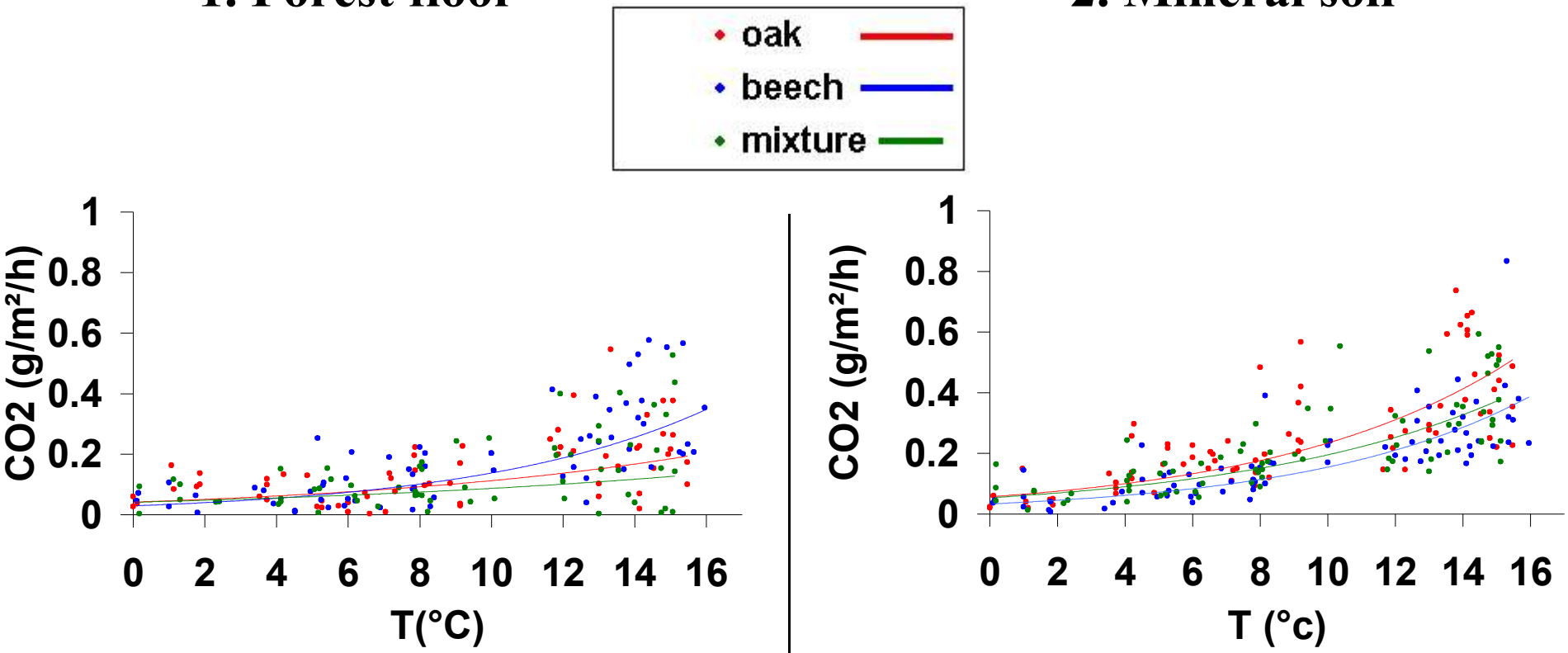
III. Results & discussion

b) Species effects

2. Species effects on the relationship between temperature and CO_2

1. Forest floor

2. Mineral soil

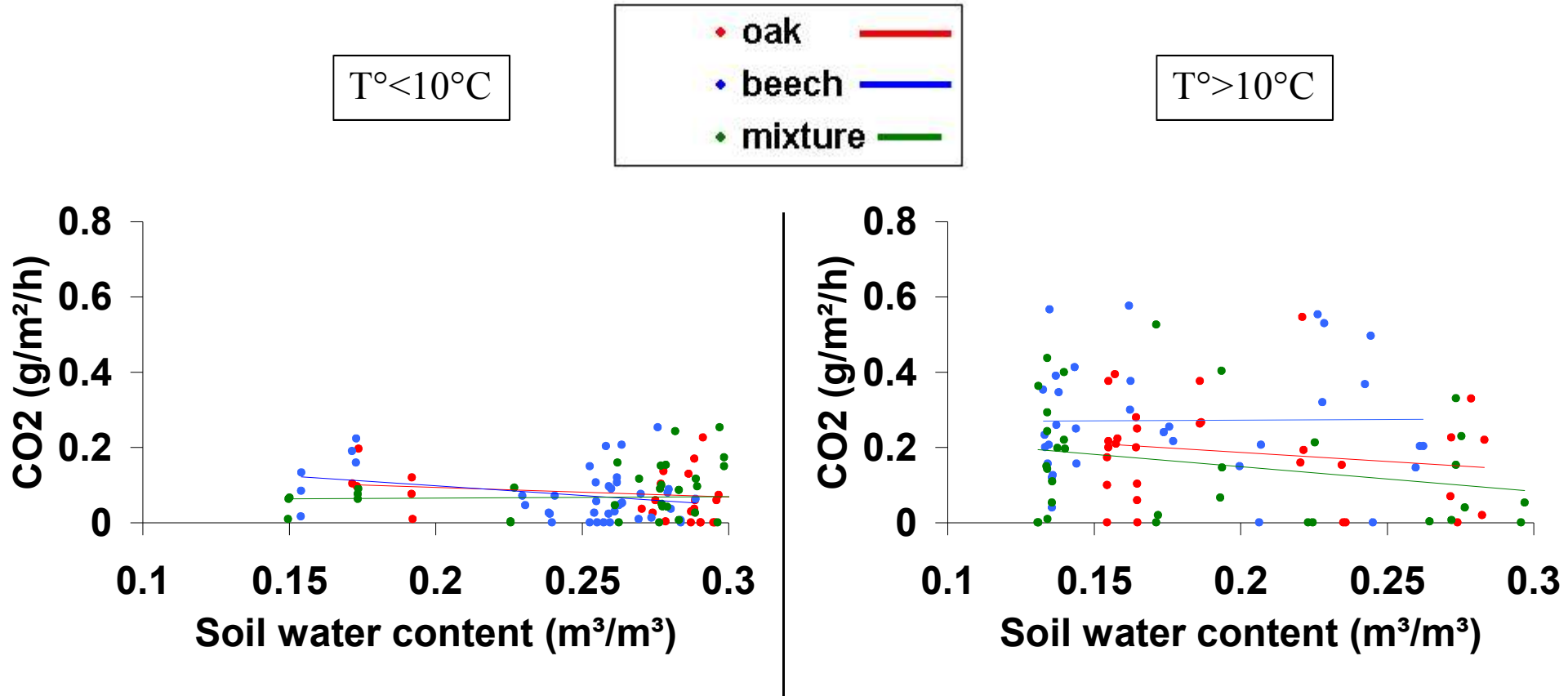


III. Results & discussion

b) Species effects

3. Species effects on the t° and θ interaction

3.1 Forest floor

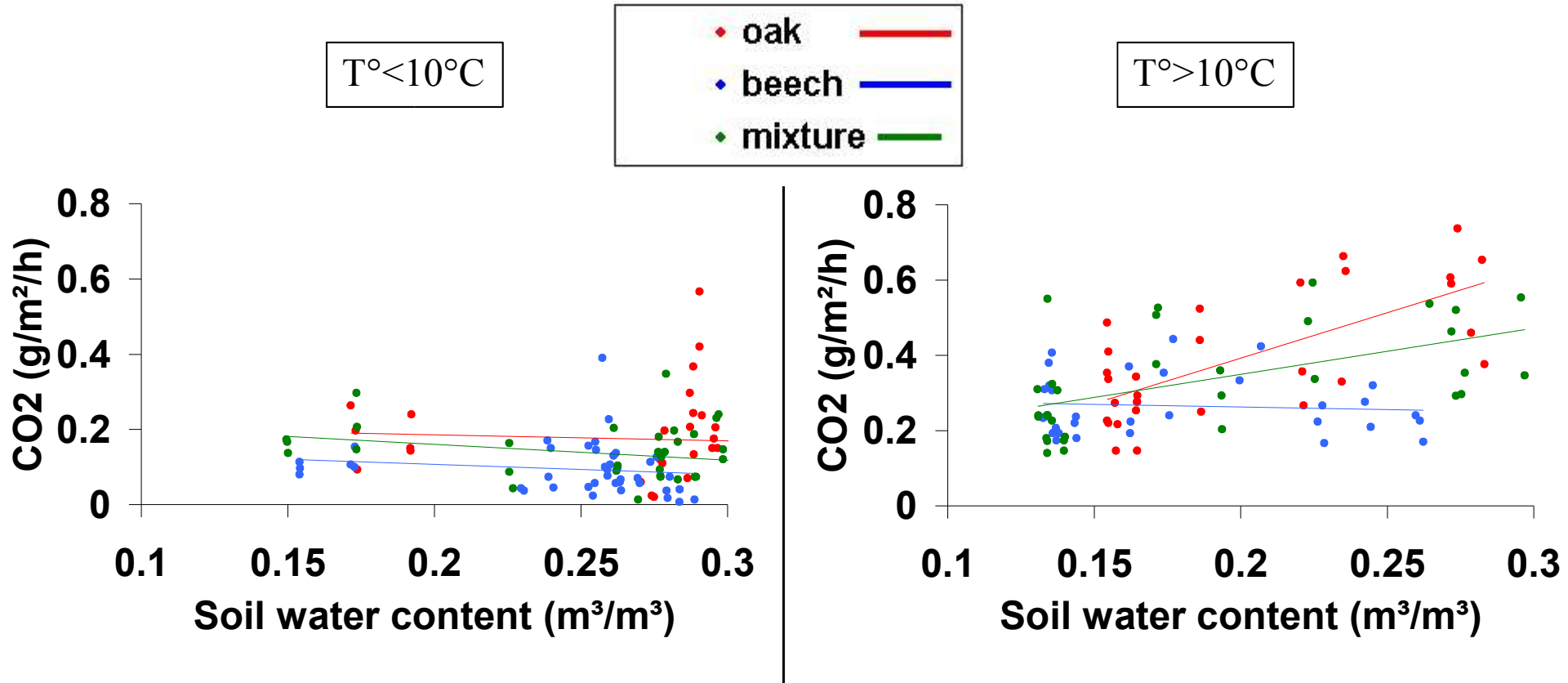


III. Results & discussion

b) Species effects

3. Species effects on the t° and θ interaction

3.2 Mineral soil



III. Results & discussion

b) Species effects

1. Forest floor

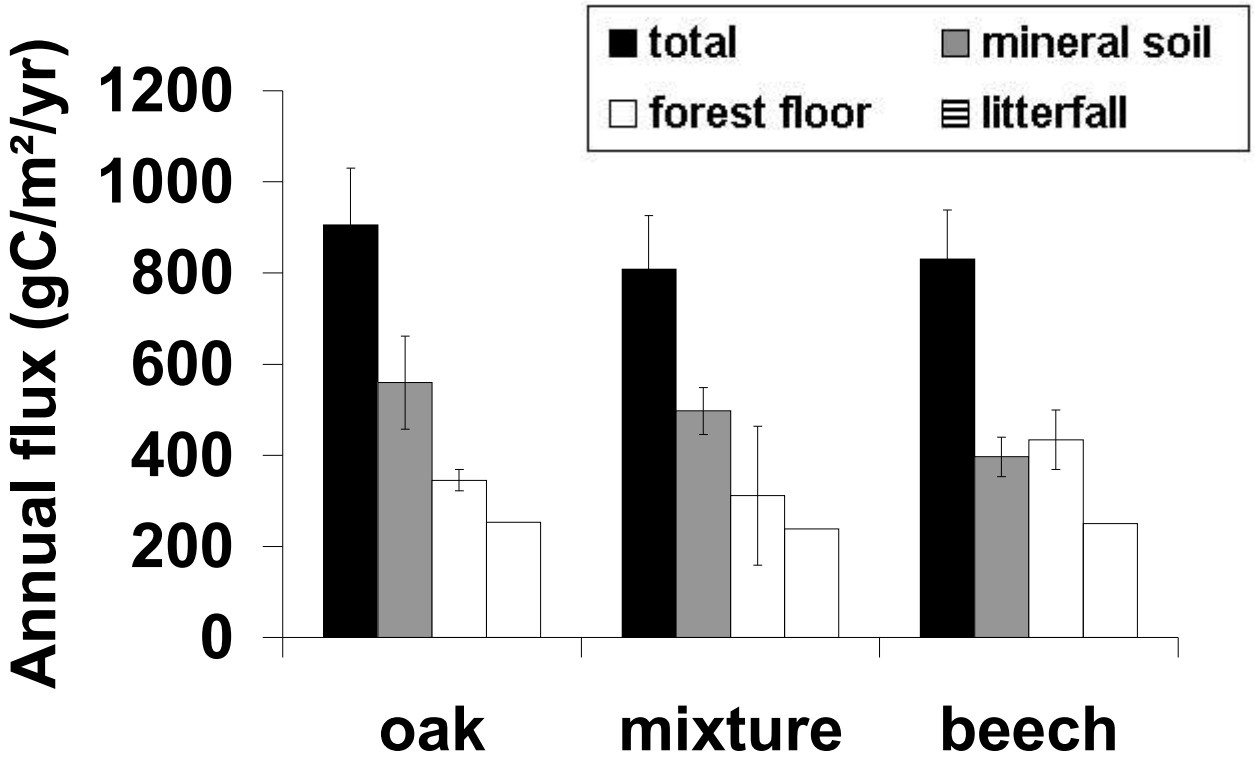
	t°	θ	t° x θ
oak	+	-	-
mixture	+	-	-
beech	+ ∧	0	0

2. Mineral soil

	t°	θ	t° x θ
oak	+ ∧	+ ∨	+ ∨
mixture	+ ∧	+	+
beech	+	0	0

III. Results & discussion

c) Annual fluxes



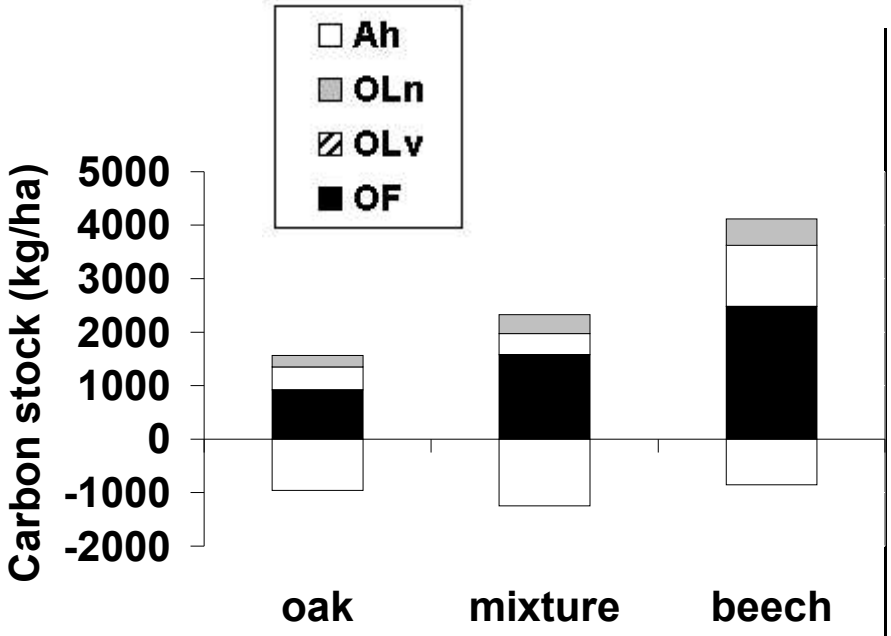
Proportions

	oak	mixture	beech
mineral soil	62	61	48
forest floor	38	39	52

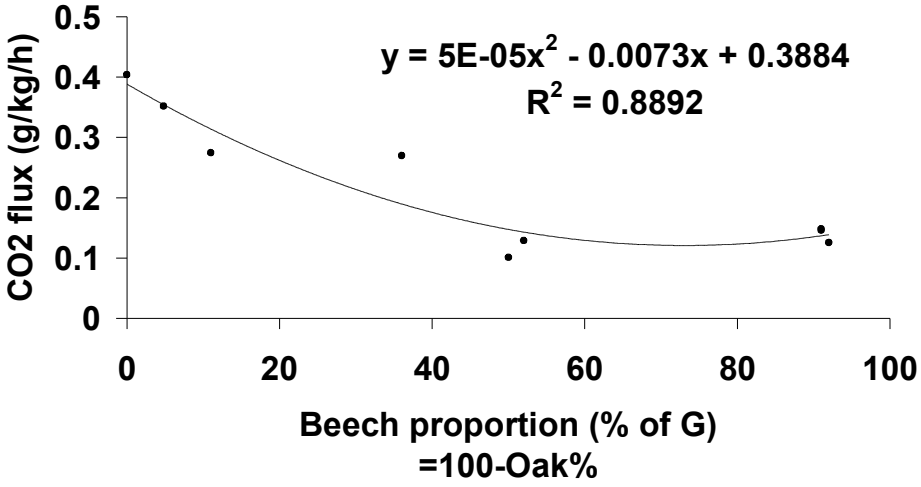
III. Results & discussion

c) Annual fluxes

Stocks of the forest floor



Forest floor respiration weighted by the dry matter stock



better litter decomposition under oak than under beech

IV. Conclusion

Species effects : synthesis

· the **microclimatic differences** among stands explain less than 3%

of the heterogeneity

· **effects of abiotic factors** : beech < > (mixture and oak) :

·t° effect more pronounced in the forest floor

·no negative effect of θ in the forest floor

·no positive effect of θ in the mineral soil

} root presence in the beech forest floor

·slower **decomposition rate** of beech litter => larger storage in the forest floor

II. Materials & methods :

Modelling approach

Arrhénius : $R_s = A \cdot \exp\left(\frac{-E_a}{(R \cdot T)}\right)$

Logarithmic transformation : $\ln(R_s) = \ln(A) \cdot \left(\frac{-E_a}{R}\right) \cdot \frac{1}{T}$

Inclusion of others variables : water content and species composition and addition of random effects (time and place) :

$$\ln(R_s) = I_1 + I_{2i} + \overbrace{A_1 \cdot \theta + A_{2i} \cdot \theta}^{\theta} + \overbrace{B_1 \cdot \frac{1}{T} + B_{2i} \cdot \frac{1}{T}}^{1/T} + \overbrace{C_1 \cdot \theta \cdot \frac{1}{T} + C_{2i} \cdot \theta \cdot \frac{1}{T}}^{1/T\,.\,\theta} + \tau + \pi + \varepsilon$$

with i going from 1 to 3 : 1 for oak, 2 for mixture and 3 for beech

III. Results & discussion

Model selection and fitting

Total soil respiration and mineral soil respiration

$$\ln(R_s) = I_1 + A_{2i} \cdot \theta + C_{2i} \cdot \theta \cdot \frac{1}{T} + \tau + \pi + \varepsilon \qquad (R^2=0.84 \text{ and } 0.83)$$

Forest floor respiration

$$\ln(R_s) = I_1 + A_{2i} \cdot \theta + B_1 \cdot \frac{1}{T} + C_{2i} \cdot \theta \cdot \frac{1}{T} + \tau + \pi + \varepsilon \qquad (R^2=0.32)$$

Results of the model fitting : parameter estimation

	int.	1/T	oak x θ	mixture x θ	beech x θ	oak x θ x 1/T	mixture x θ x 1/T	beech x θ x 1/T	τ	π
total CO_2	-1.1		136	138	191	-38186	-39013	-54051		
	(0.15)		(12)	(13)	(14)	(3233)	(3514)	(3793)	(0.01422)	(0.01467)
mineral soil CO_2	-1.9		194	178	207	-54267	-50052	-58480		
	(0.19)		(15)	(16)	(18)	(4099)	(4436)	(4817)	(0.02404)	(0.03297)
forest floor CO_2	62.21	-18193	-160	-203	-87	44839	56725	24811		
	(28.22)	(8031.17)	(107)	(115)	(125)	(30331)	(32469)	(35364)	(0.04940)	(0.01546)

III. Results & discussion

Activation energy and Q_{10} value

Activation energy
for θ = 0.23m³/m³

	oak	mixture	beech
total	73	75	103
mineral soil	104	96	112
forest floor	66	43	104

Q_{10} value
for θ = 0.23m³/m³

	oak	mixture	beech
total	3.1	3.1	4.9
mineral soil	4.9	4.3	5.6
forest floor	2.7	1.9	4.9

Arrhénius : $R_s = A \cdot \exp\left(\frac{-E_a}{(R \cdot T)}\right)$

$$Q_{10} = \frac{R_S(t+10°C)}{R_S(t)}$$

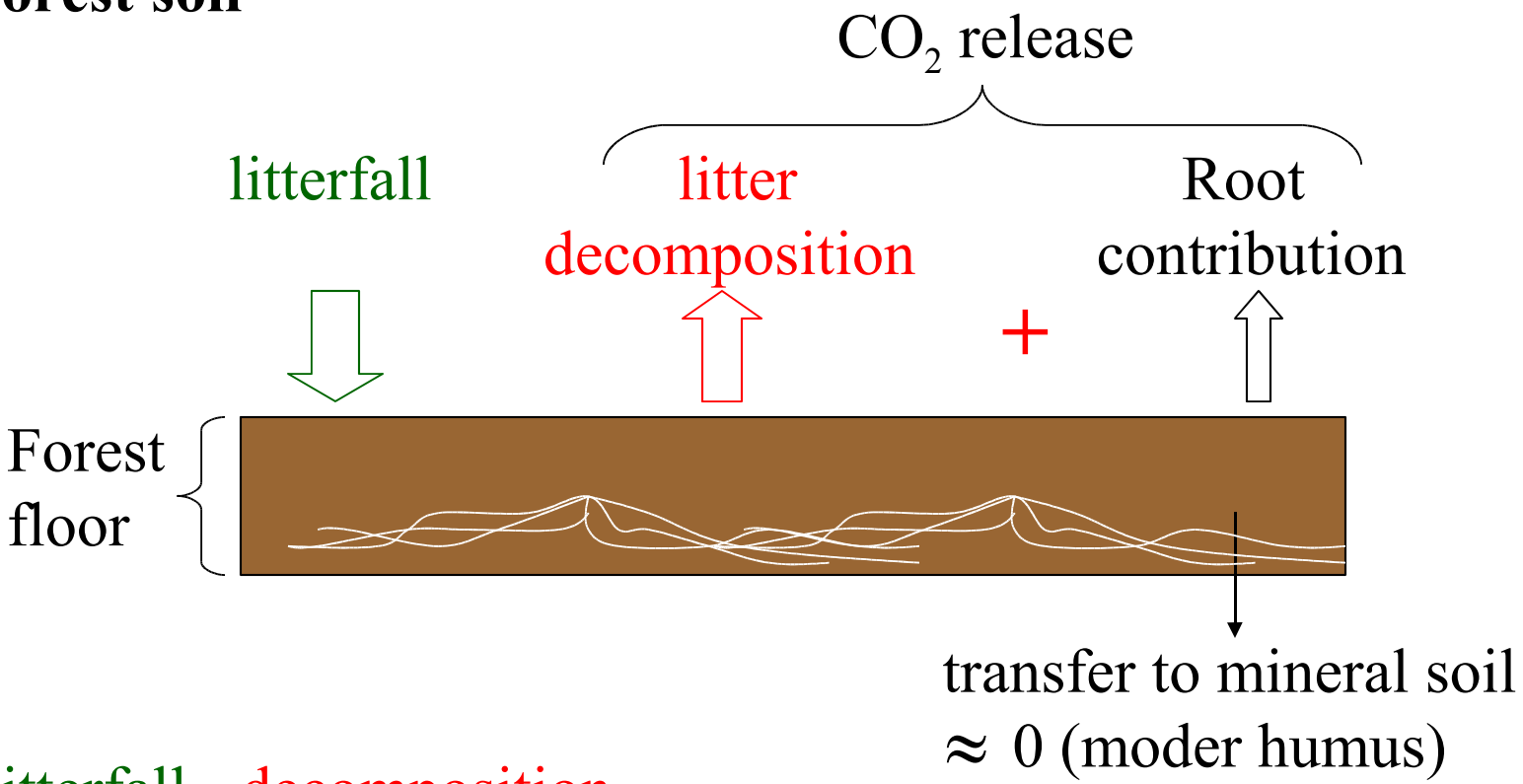
Heterotrophic respiration : 2.5

Autotrophic respiration : 4.6

III. Results & discussion

Carbon budget approach

1. Forest soil



Δ C = litterfall - decomposition

= litterfall - [CO_2 release - root contribution]

III. Results & discussion

Carbon budget approach

1. Forest soil

$\Delta C_{Nov02\ to\ Nov\ 03}$ = litterfall - [CO_2 release - root contribution]

($gC/m^2/yr$)

	oak	mixture	beech
ΔC **IN - litterfall** **OUT - decomposition**			
root contribution **CO_2 release**			

III. Results & discussion

Carbon budget approach

1. Forest soil

$\Delta C_{Nov02\ to\ Nov\ 03}$ = litterfall - [CO_2 release - root contribution]

($gC/m^2/yr$)

	oak	mixture	beech
ΔC			
IN - litterfall	**253**	**238**	**251**
OUT - decomposition			
root contribution			
CO_2 release	**343**	**324**	**419**

III. Results & discussion

Carbon budget approach

1. Forest soil

$\Delta C_{Nov02\ to\ Nov\ 03}$ = litterfall - [CO_2 release - root contribution]

($gC/m^2/yr$)

	oak	mixture	beech
ΔC			
IN - litterfall	**253**	**238**	**251**
OUT - decomposition			
root contribution	**0**	**0**	
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III. Results & discussion

Carbon budget approach

1. Forest soil

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OUT - decomposition	**343**	**324**	
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III. Results & discussion

Carbon budget approach

1. Forest soil

$\Delta C_{Nov02\ to\ Nov\ 03}$ = litterfall - [CO_2 release - root contribution]

($gC/m^2/yr$)

	oak	mixture	beech
ΔC	-90	-86	
IN - litterfall	253	238	251
OUT - decomposition	343	324	
root contribution	0	0	
CO_2 release	343	324	419

III. Results & discussion

Carbon budget approach

1. Forest soil

$\Delta C_{Nov02\ to\ Nov\ 03}$ = litterfall - [CO_2 release - root contribution]

under **beech** : root contribution $\neq 0$

If similar t° effect on decomposition under beech, mixture and oak

=> $\Delta C_{beech} = \Delta C_{mixture} = \Delta C_{oak}$

	oak	mixture	beech
ΔC	**-90**	**-86**	
IN - litterfall	**253**	**238**	**251**
OUT - decomposition	**343**	**324**	
root contribution	**0**	**0**	
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III. Results & discussion

Carbon budget approach

1. Forest soil

$\Delta C_{Nov02\ to\ Nov\ 03}$ = litterfall - [CO_2 release - root contribution]

under **beech** : root contribution $\neq 0$

If similar t° effect on decomposition under beech, mixture and oak

$\Rightarrow \Delta C_{beech} = \Delta C_{mixture} = \Delta C_{oak}$

	oak	mixture	beech
ΔC	**-90**	**-86**	**-88**
IN - litterfall	**253**	**238**	**251**
OUT - decomposition	**343**	**324**	
root contribution	**0**	**0**	
CO_2 release	**343**	**324**	**419**

III. Results & discussion

Carbon budget approach

1. Forest soil

$\Delta C_{Nov02\ to\ Nov\ 03}$ = litterfall - [CO_2 release - root contribution]

under **beech** : root contribution $\neq 0$

If similar t° effect on decomposition under beech, mixture and oak

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	oak	mixture	beech
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IN - litterfall	**253**	**238**	**251**
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root contribution	**0**	**0**	
CO_2 release	**343**	**324**	**419**

III. Results & discussion

Carbon budget approach

1. Forest soil

$\Delta C_{Nov02\ to\ Nov\ 03}$ = litterfall - [CO_2 release - root contribution]

under **beech** : root contribution $\neq 0$

If similar t° effect on decomposition under beech, mixture and oak

=> $\Delta C_{beech} = \Delta C_{mixture} = \Delta C_{oak}$

	oak	mixture	beech
ΔC	**-90**	**-86**	**-88**
IN - litterfall	**253**	**238**	**251**
OUT - decomposition	**343**	**324**	**339**
root contribution	**0**	**0**	**80**
CO_2 release	**343**	**324**	**419**

III. Results & discussion

Carbon budget approach

1. Forest soil

global change impact

under dry and warm microclimatic conditions

=> reduction of the dry matter stock of the forest floor

during the summer 03 : 6% reduction under oak,

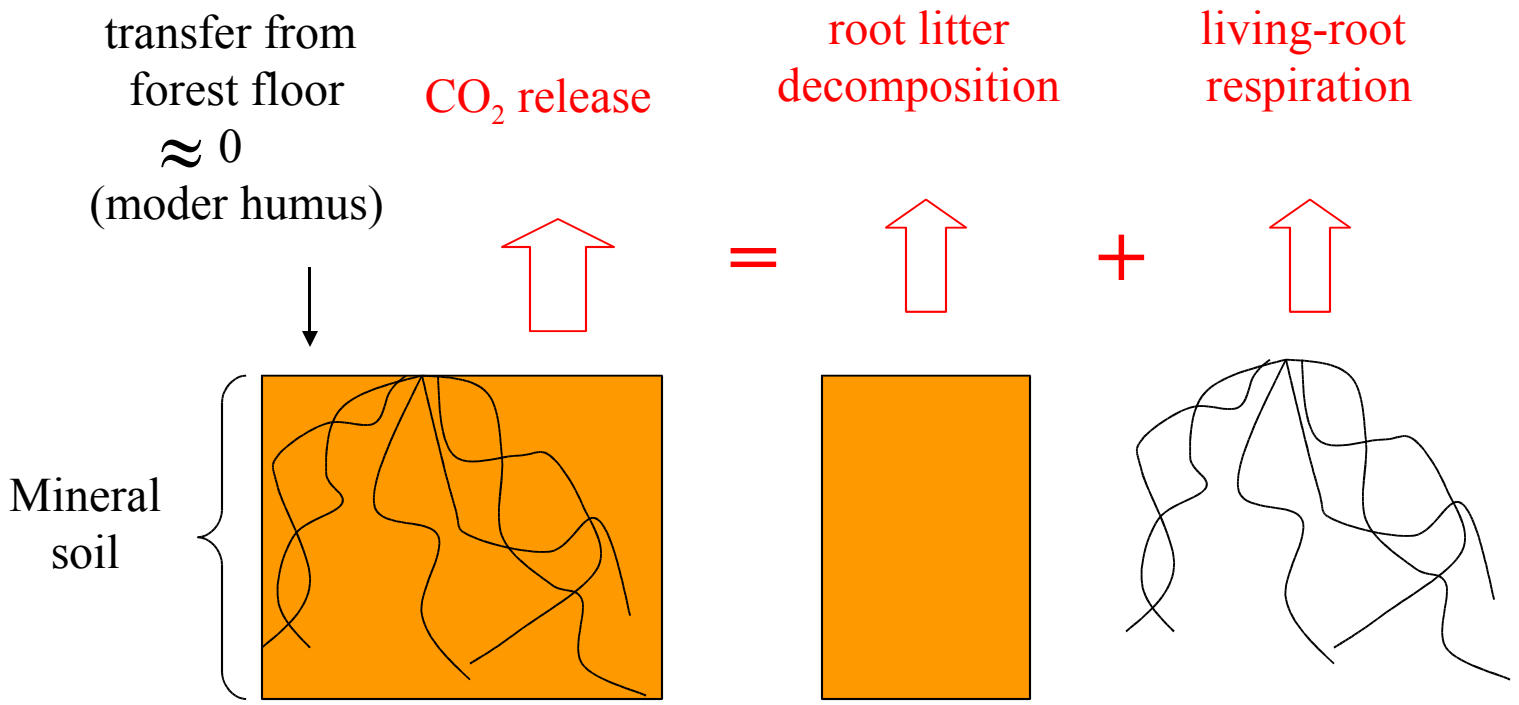
4% for the mixture,

2% under beech

III. Results & discussion

Carbon budget approach

2. Mineral soil



CO_2 release from mineral soil + root contribution to forest floor respiration

= Total root C allocation

III. Results & discussion

Carbon budget approach

2. Mineral soil

Total root C allocation = CO_2 release from mineral soil + root contribution to forest floor respiration

	oak	mixture	beech
CO_2 release from mineral soil	548	480	386
root contribution to forest floor respiration	0	0	80
total root carbon allocation	548	480	466

III. Results & discussion

Carbon budget approach

Soil respiration = total root carbon allocation + litter decomposition

⇨ total root carbon allocation : 58 to 62 % of soil respiration

⇨ litter decomposition : 38 to 42 % of soil respiration

III. Illustration

Roots in the forest floor