Soil respiration & stable isotope (^{13}C) fractionation

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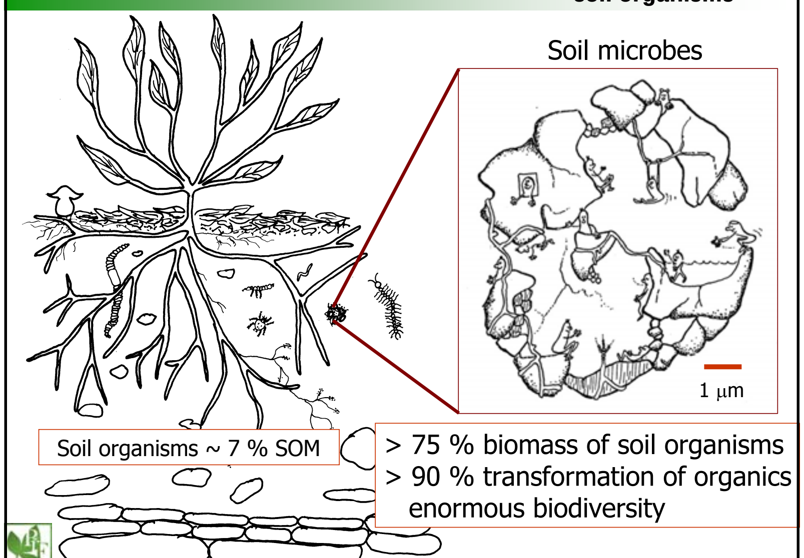
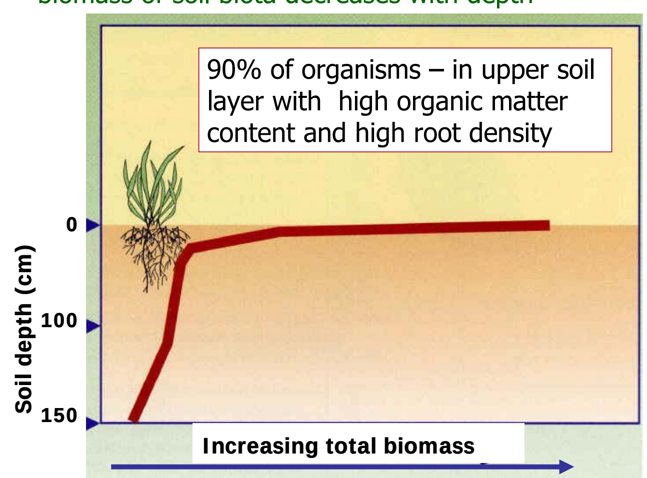
Most of them are heterotrophs – they consume plant debris, use nutrients and carbon for building body and part of them return back to the cycling



In upper part of soil profile

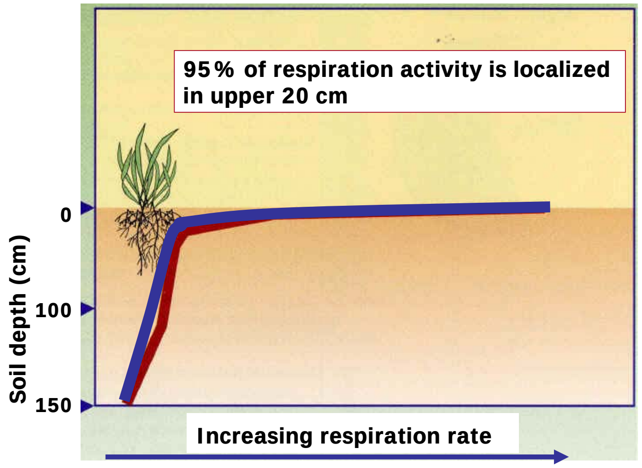
biomass of soil biota decreases with depth



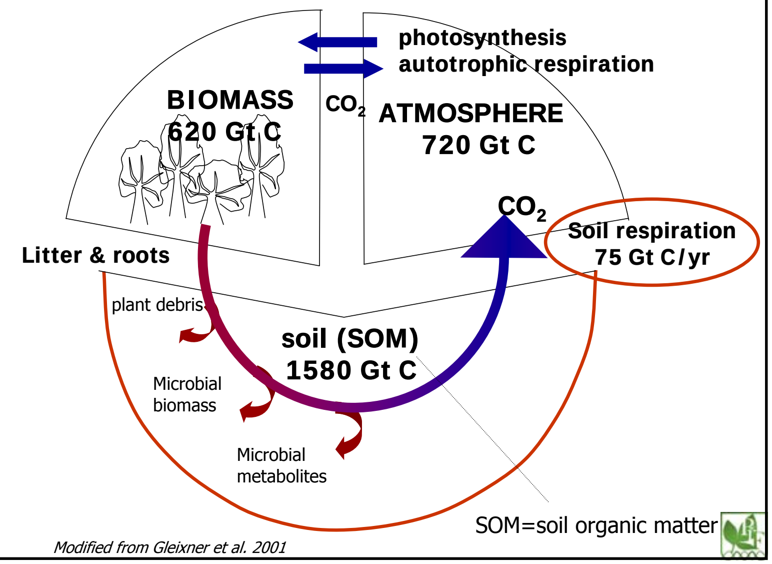
where does respiration come from?

In upper part of soil profile

Heterotrophic respiration decreases with depth



Major processes, pools and fluxes in terrestrial ecosystem



total soil respiration

Soil respiration = autotrophic + heterotrophic

(roots) *(organisms)*

Close correlation to net primary production *(r^2=0,87; Raich & Schlesinger 1992)*

Heterotrophic to total respiration: 40-60%

Hogberg et al. 2001, Nature

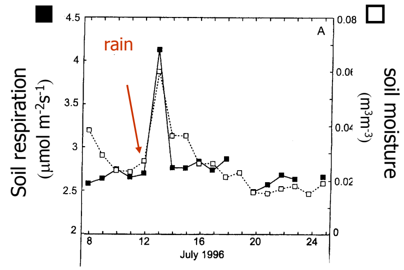
Contribution of soil organisms to respiration

Heterotrophic respiration 100%

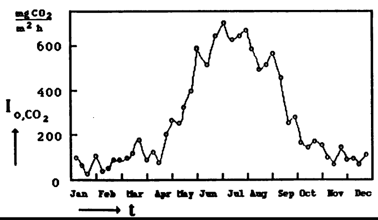
- Microbial respiration > 90%
  - Mycorrhiza & rhizosphere microflora (photosynthates from plant) up to 25%
  - Microbial decomposers (decay of plant debris) > 75%
- fauna respiration > 10%

fluctuation of soil respiration

Soil respiration changes over the day, month

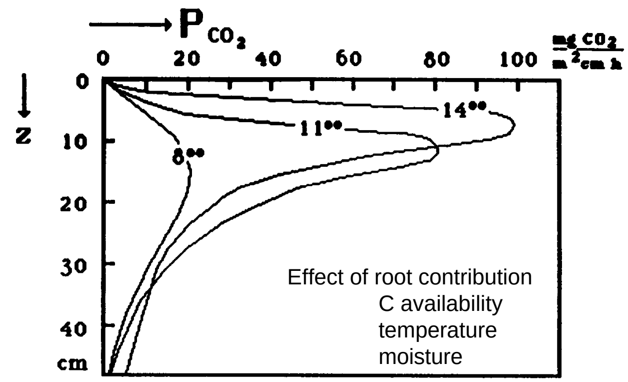


and **year**



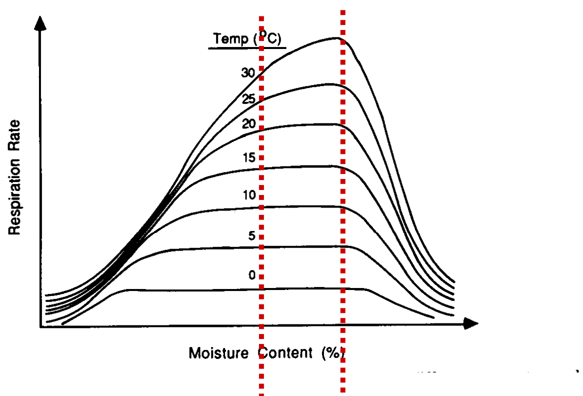
fluctuation of soil respiration

Soil respiration also changes down in the soil profile



fluctuation of soil respiration

Soil (and also heterotrophic) respiration depends on moisture and temperature

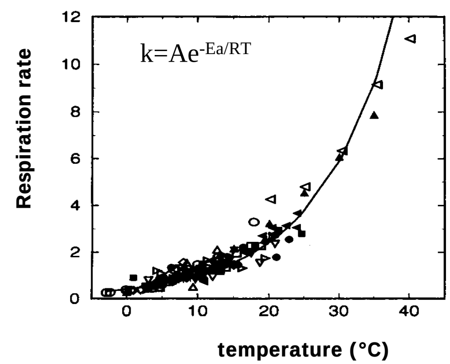


Optimum moisture between 50% to 75 %

fluctuation of soil respiration

The increase of respiration with temperature – exponential

Temperature dependency – Arrhenius type equation



Taylor & Lloyd 1994, Funct. Ecol.

what to keep in mind

Stable isotope measurement is a tool for studying of various processes, partitioning, sequestration

↓

The natural abundance of stable isotopes is used as a tracer

↓

The natural abundance of stable isotope can be used as a tracer only for those sources that differ sustantially in isotopic signal

The discrimination is of importance only when the source is not limiting

what to remember

Source = substrate → *flux* → Sink = product

The basic terms:

1. fractionation factor = α
   (its deviation from unity indicates isotopic fractionation)

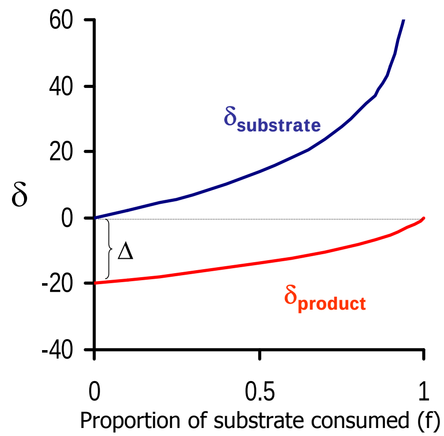
2. fractionation factor expressed on δ scale:
   $\Delta = 1000(\alpha - 1)$
   $\Delta (\varepsilon) > 0$ sink will be depleted compared source
   $\Delta (\varepsilon) < 0$ sink will be enriched compared source

Two basic models which is good to know:

1. Kinetic fractionation model (Rayleigh model)
2. Mixing model

kinetic fractionation model -Rayleith model

$\Delta = 20‰$,
$\delta_{substrate} = 0‰$

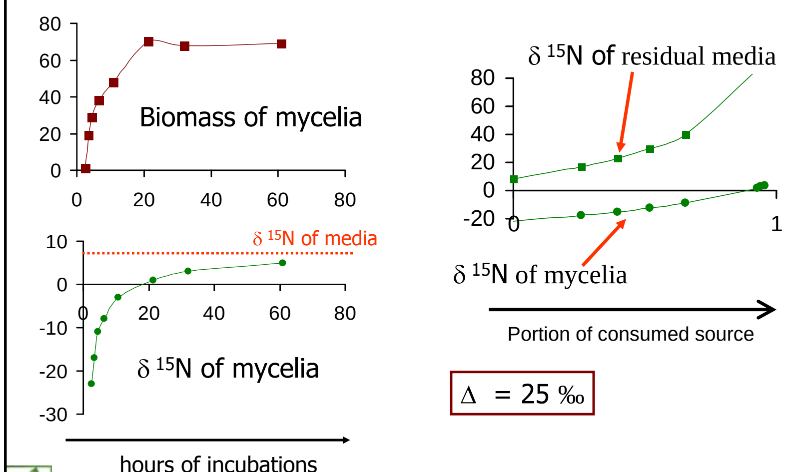


The isotopic signal of the accumulated product (δ_P) is described by:

$$\delta_P = \delta_0 + ((\Delta(1-f) \ln(1-f))/f)$$

Exam of kinetic effect- ^{15}N discrimination in fungal metabolism

Basidiomycetes grown in a closed system



$\Delta = 25‰$

Henn et al. 2004

Mixing models

steady state models, open system, source is in excess

mass balance

$$M_{SOURCE} = M_{SINK(1)} + M_{SINK(2)}$$

Isotopic mass balance (isobalance)

$$M_{SOURCE}\ \delta_{SOURCE} = M_{SINK(1)}\ \delta_{SINK(1)} + M_{SINK(2)}\ \delta_{SINK(2)}$$

source | **sink**

M_{SOURCE} δ_{SOURCE} → $M_{SINK(1)}\ \delta_{SINK(1)}$; $M_{SINK(2)}\ \delta_{SINK(2)}$

$$M_{SOURCE}\ \delta_{SOURCE} = M_{SINK(1)}\ \delta_{SINK(1)} + M_{SINK(2)}\ \delta_{SINK(2)}$$

$M_{SOURCE(1)}\delta_{SOURCE(1)}$; $M_{SOURCE(2)}\delta_{SOURCE(2)}$ → $M_{SINK}\ \delta_{SINK}$

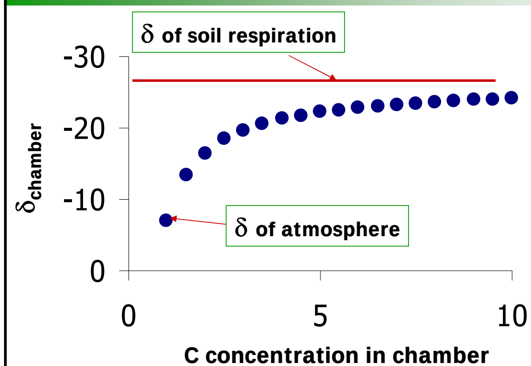
$$M_{SOURCE(1)}\ \delta_{SOURCE(1)} + M_{SOURCE(2)}\ \delta_{SOURCE(2)} = M_{SINK}\ \delta_{SINK}$$

Keeling plot – mass (concentration) of one source is unchanging but mass of the other source can change

$$M_{SOURCE(1)}\ \delta_{SOURCE(1)} + M_{SOURCE(2)}\ \delta_{SOURCE(2)} = M_{SINK}\ \delta_{SINK}$$

$$C_{soil\ CO2}\ \delta_{soil\ CO2} + C_{atm}\ \delta_{atm} = C_{chamber}\ \delta_{chamber}$$

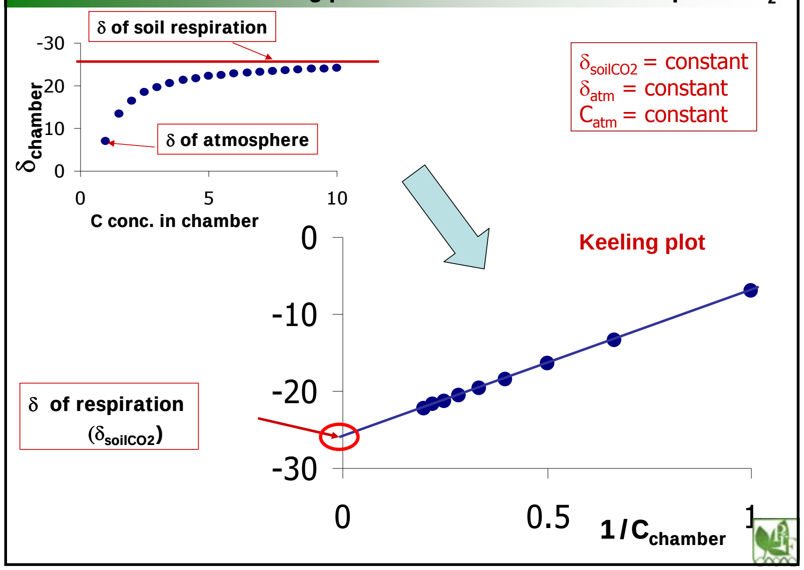
$\delta_{soilCO2}$ = constant
δ_{atm} = constant
C_{atm} = constant



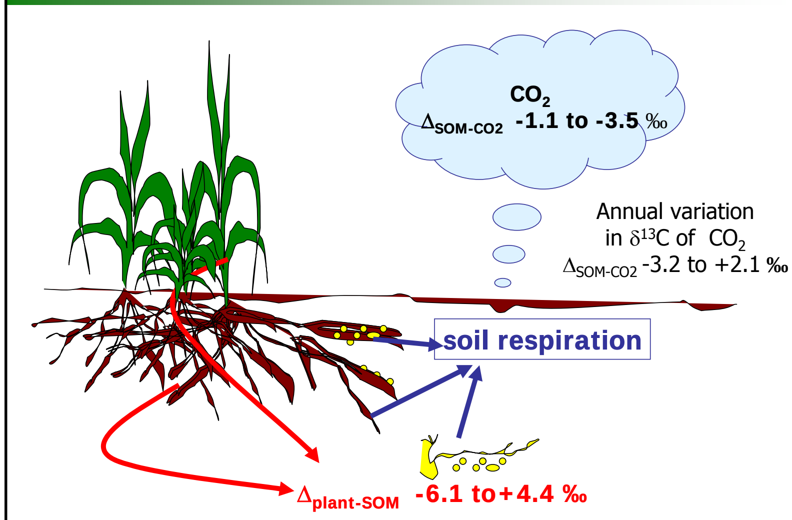
$\delta_{soilCO2}$ = constant
δ_{atm} = constant
C_{atm} = constant

$$\delta_{soil} = [(\delta_{cham} \cdot C_{cham}) - (\delta_{atm} \cdot C_{atm})] / C_{soil}$$

Keeling plot – estimation of δ ^{13}C of respired CO_2



what is documented



SOM = soil organic matter

the shift in δ ^{13}C of CO_2

What is the explanation?

- physico-chemical phenomena in soil
- input of organic material with different $\delta^{13}C$
- fractionation associated with metabolism of soil biota that results of different processes:
  - selective consumption of substrates
  - metabolic discrimination (internal processing)

!!!! Heterotrophic metabolism never brings isotopic shift which would be comparable with isotopic effect of photosynthesis!!!!

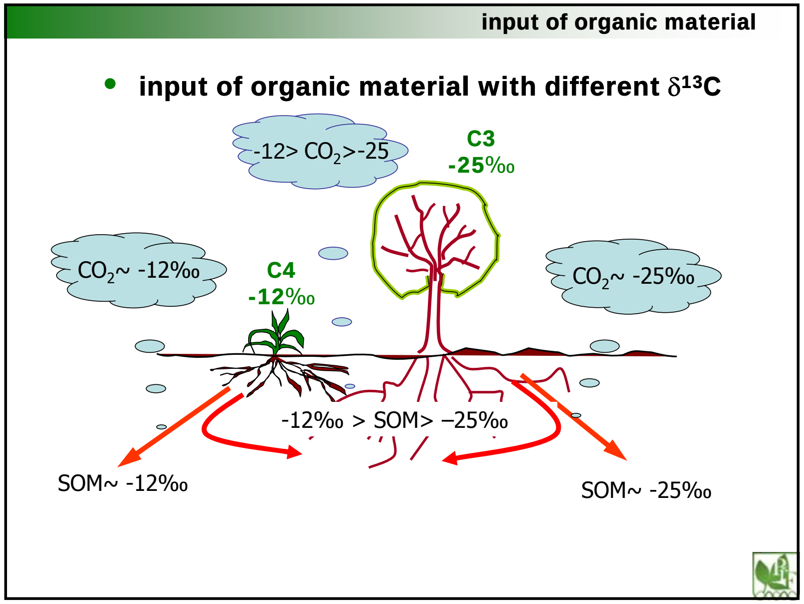
physico-chemical properties

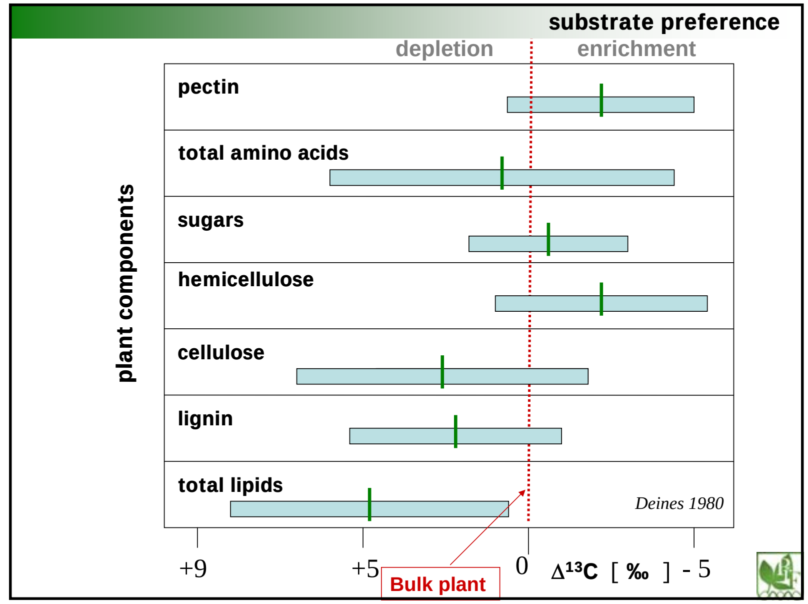
- **physico-chemical phenomena in soil**

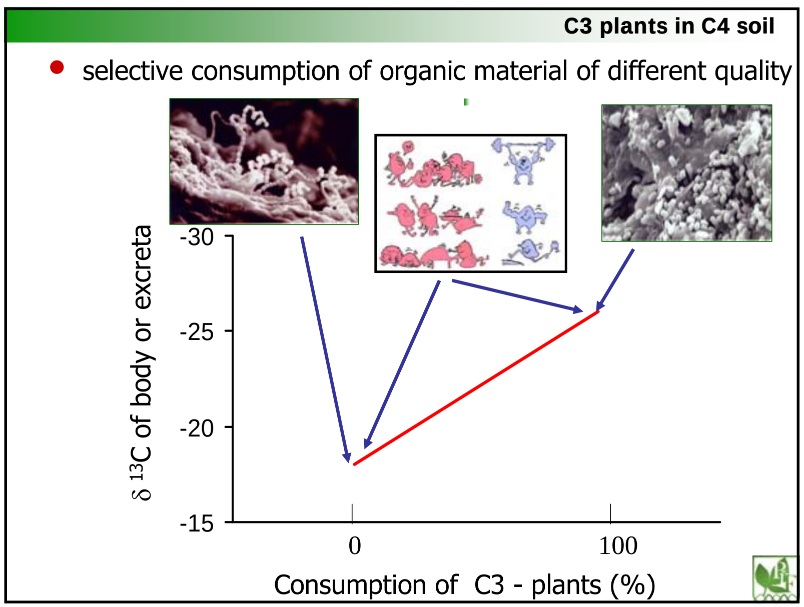
diffusion Δ ~ 4‰

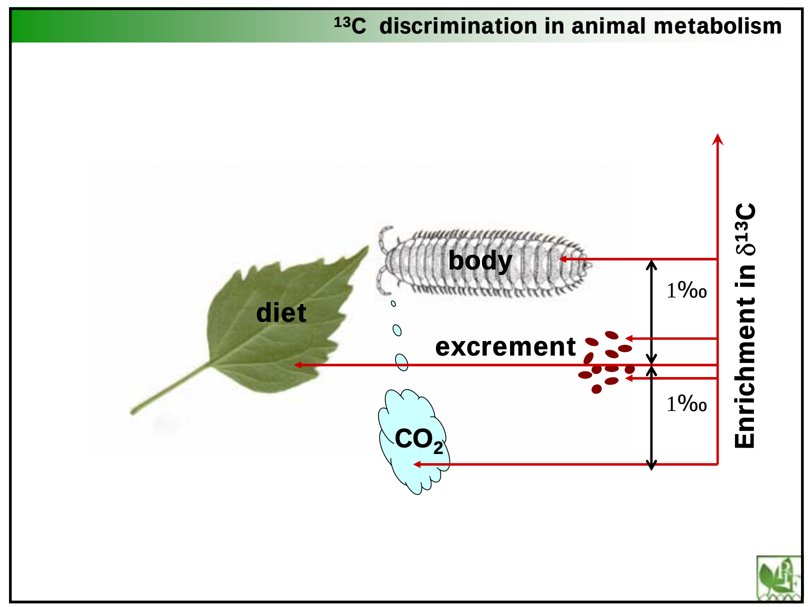
equilibrium system CO_2 (g) ⟶ HCO3 ~ Δ 9‰ (20°C)

equilibrium syst. CO_2 (g) ⟶ solid carbonate ~ Δ 10 ‰ (20°C)


input of organic material
input of organic material with different δ13C
-12> CO2>-25
C3
-25‰
CO2~ -12‰
C4
-12‰
CO2~ -25‰
-12‰ > SOM> –25‰
SOM~ -12‰
SOM~ -25‰

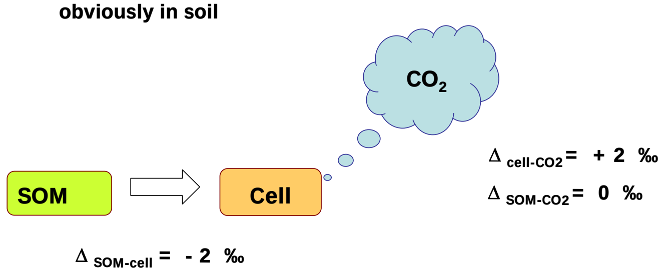

substrate preference
depletion
enrichment
plant components
pectin
total amino acids
sugars
hemicellulose
cellulose
lignin
total lipids
Deines 1980
+9
+5
0
Δ13C [‰] - 5
Bulk plant


C3 plants in C4 soil
selective consumption of organic material of different quality
δ 13C of body or excreta
-30
-25
-20
-15
0
100
Consumption of C3 - plants (%)


13C discrimination in animal metabolism
body
diet
excrement
CO2
1‰
1‰
Enrichment in δ13C

^{13}C discrimination in microbial metabolism

obviously in soil

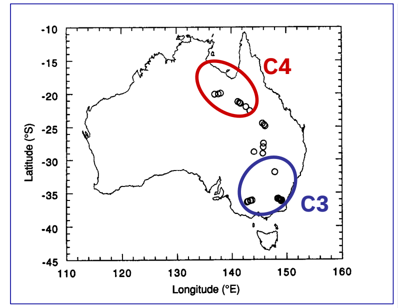


If one product becomes depleted in the heavier isotope, the other products must be enriched.

Important note: there might exist discrimination caused by microbial metabolism in soil, but for the sake of simplicity, it is often neglected

what was measured – world ecosystems

Australian transect



Canadian transect

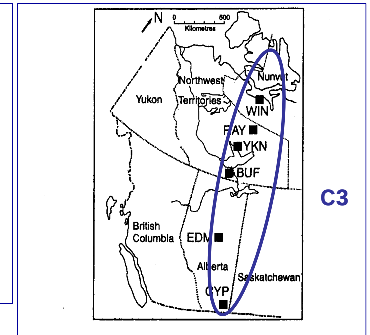
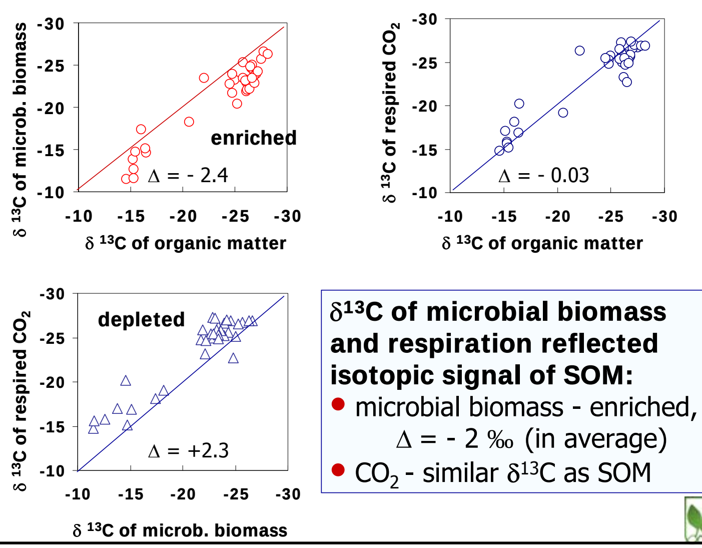


Figure 1 Location of the areas sampled.

C_{tot}, $\delta\,^{13}C_{tot}$
C_{CO2}, $\delta\,^{13}C_{CO2}$
$C_{MICROBIAL\ BIOMASS}$, $\delta\,^{13}C_{MICROBIAL\ BIOMASS}$

Santruckova et al. 2000, Bird et al. 2002

what was measured –world ecosystems



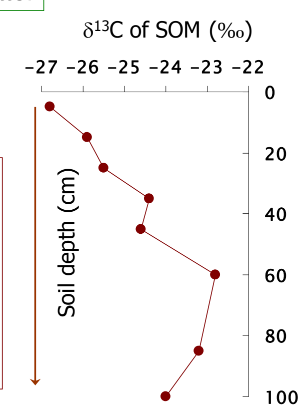
$\delta^{13}C$ of microbial biomass and respiration reflected isotopic signal of SOM:

- microbial biomass - enriched, Δ = - 2 ‰ (in average)
- CO_2 - similar $\delta^{13}C$ as SOM

what can heavier microbial biomass bring about?

Enrichment of soil organic matter

- The older the soil is, the more 13C enriched the soil becomes
- $\delta\,^{13}C$ of soil increases down in soil profile



Bird et al. 2001

Thanks for your attention !