Tracking Carbon sequestration with Isotopes

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Definitions

- Isotopes are atoms of an element that having the same amount of protons (Z) differ in the number of neutrons (N)

- Heavier isotopes form
  - stronger chemical bonds,
  - have lower reaction rates in enzymatic reactions,
  - diffuse more slowly and
  - are often found in lower-energy phase states in equilibrium reactions, such the phase between vapor and liquid water

  - Radioctive isotopes, such as ^{14}C, provides another tracer, particularly useful for dating biological material.

Isotopes of common elements and their natural abundances

Element	Isotope	Abundance (%)	Reference Std	Ter. Range in ‰
Hydrogen	^{1}H	99.985	V-SMOW	δD= -450 to +50
	^{2}H	0.015		
Carbon	^{12}C	98.89	PDB	$\delta^{13}C$= -120 to +10
	^{13}C	1.11		
	^{14}C	< 0.001		
Nitrogen	^{14}N	99.63	AIR	$\delta^{15}N$= -20 to +30
	^{15}N	0.37		
Oxygen	^{16}O	99.759	V-SMOW	$\delta^{18}O$= -50 to +40
	^{17}O	0.037		
	^{18}O	0.204		
Sulfur	^{32}S	95.00	CDT	$\delta^{34}S$= -65 to +90
	^{33}S	0.76		
	^{34}S	4.22		
	^{36}S	0.014		

V-SMOW: standard mean ocean water, Atomic Energy Commission, Vienna ($^{2}H/^{1}H$=0.00015595; $^{18}O/^{16}O$=0.0020052); PDB: Pee Dee Belemnite in NC ($^{13}C/^{12}C$ =0.0112372); AIR:Atmospheric Nitrogen ($^{15}N/^{14}N$=0.0036765); CDT: Canyon Diablo Troilite ($^{34}S/^{32}S$=0.0450451). Oxygen isotopes PDB (carbonates) or V-SMOW (water and silicates).

Delta (δ) notations are referred to arbitrary standards

- Isotopic composition of stable isotopes is often expressed as a ratio between the heavier and the lighter isotope relative to an std:

- $\delta\ ^{13}C$ vs. [std] = $(R_{sample}/R_{standard} - 1) \times 1000‰$

- Where: $R_{sample} = {}^{13}C\ /{}^{12}C$; $R_{standard} = {}^{13}C/{}^{12}C$ PDB
- PDB = Pee Dee Belemnite International Std.

- In contrast, ^{14}C is expressed as activity as percent modern C. By convention modern C activity is defined as the background activity in 1950.

Photosynthesis discrimination

- Discrimination of ^{13}C during photosynthesis in C3 plants is caused by fractionation during diffusion through stomatal pores and fractionation by RuBisco (Farquhar et al., 1982).
  - Diffusion = 4.4‰
  - Enzymatic fractionation = 25‰

- Discrimination of ^{13}C in C4 plants also depends on PEP carboxylase = -5.7‰

Isotopic fractionation in C_3 plants

$$\Delta = a + (b-a) * \frac{c_i}{c_a}$$

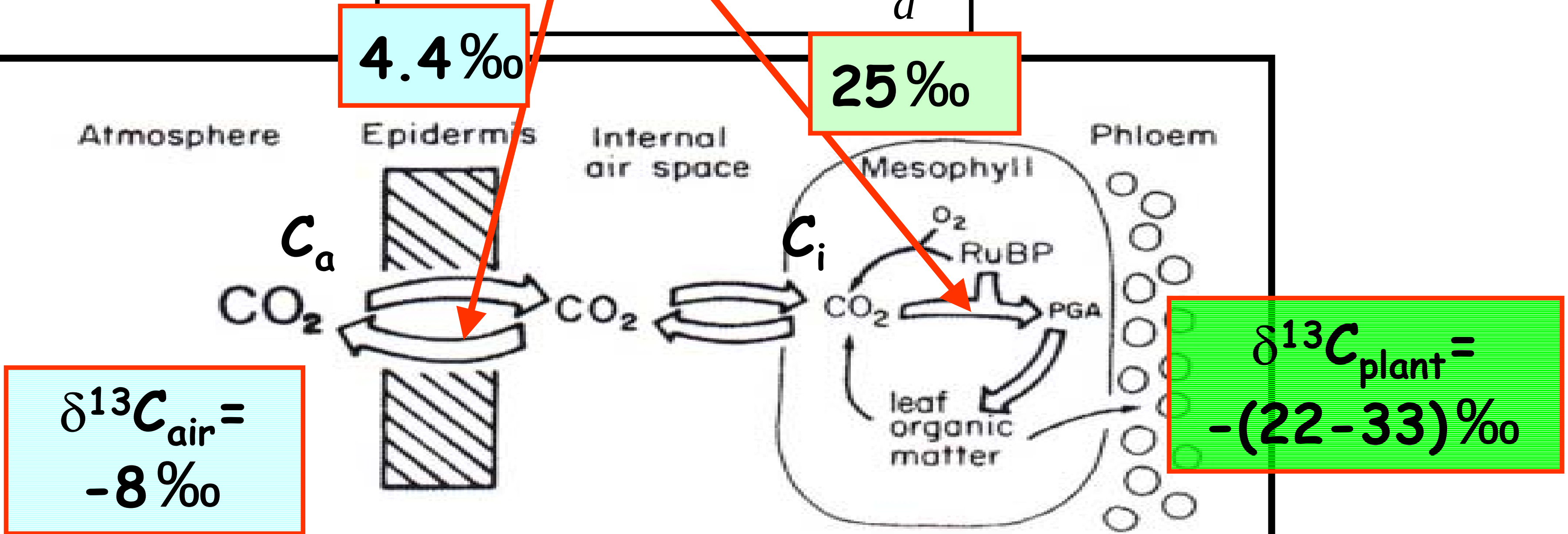


Figure 2. Important steps in CO_2 fixation during C_3 photosynthesis. Sizes of arrows indicate the relative fluxes through the various steps (including the reverse steps) according to the best models available. Sizes of symbols reflect relative concentrations of CO_2 at various stages.

In C_4 plants diffusion is major component; $\delta^{13}C_{plant}$=-(12-15)‰

Resolving the fate of elevated Carbon dioxide

- Understanding the future distribution of fixed atmospheric carbon in the terrestrial biosphere is a major goal.
- Carbon fixed can be transferred into numerous ecosystem pools.
- Is the carbon being transferred into long-term-lived pools, or will C cycle merely be accelerated, resulting in no long-term net increase in store C?

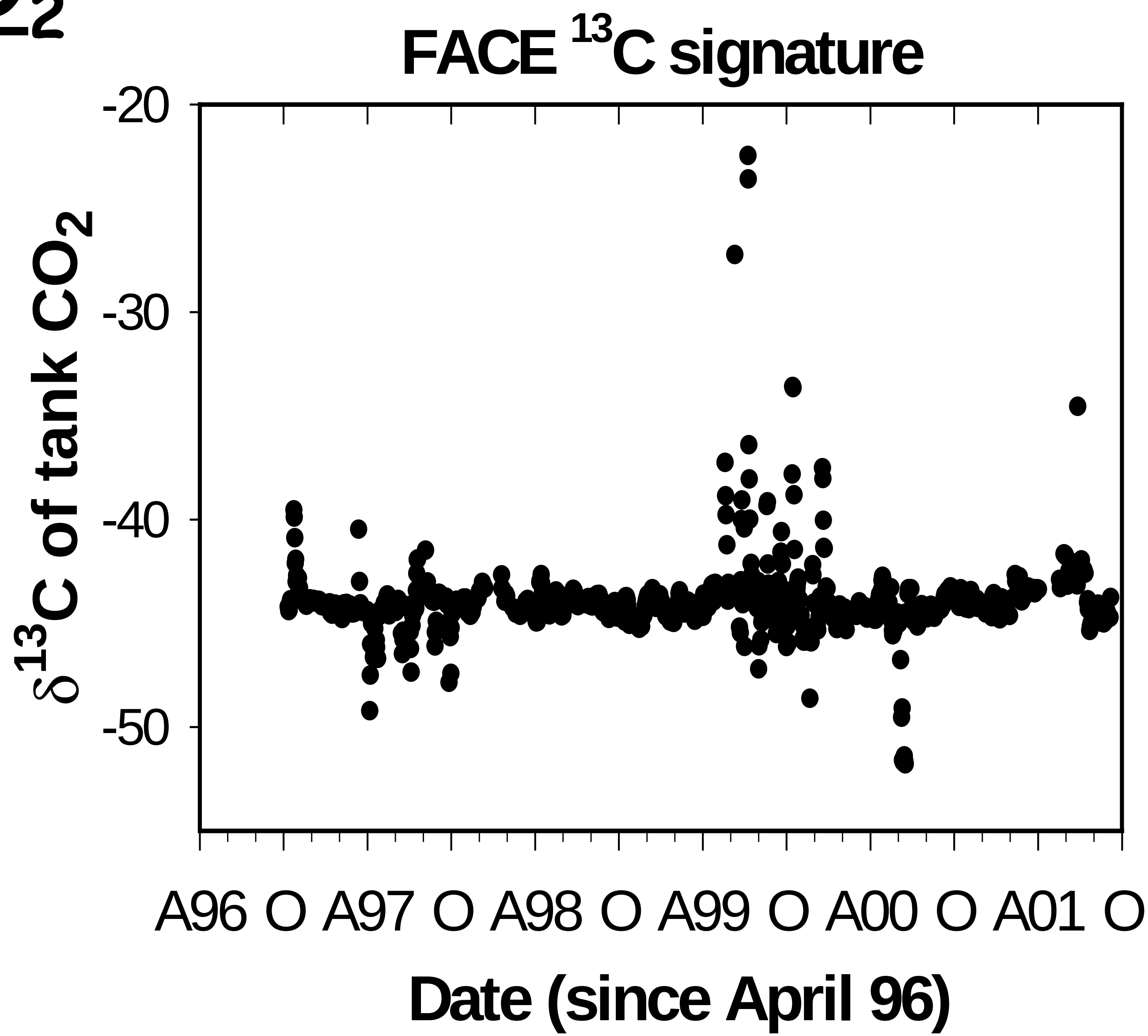
The FACE studies

Loblolly pine forest

Sweetgum forest


VEGETATION SECTOR
SOIL SECTOR

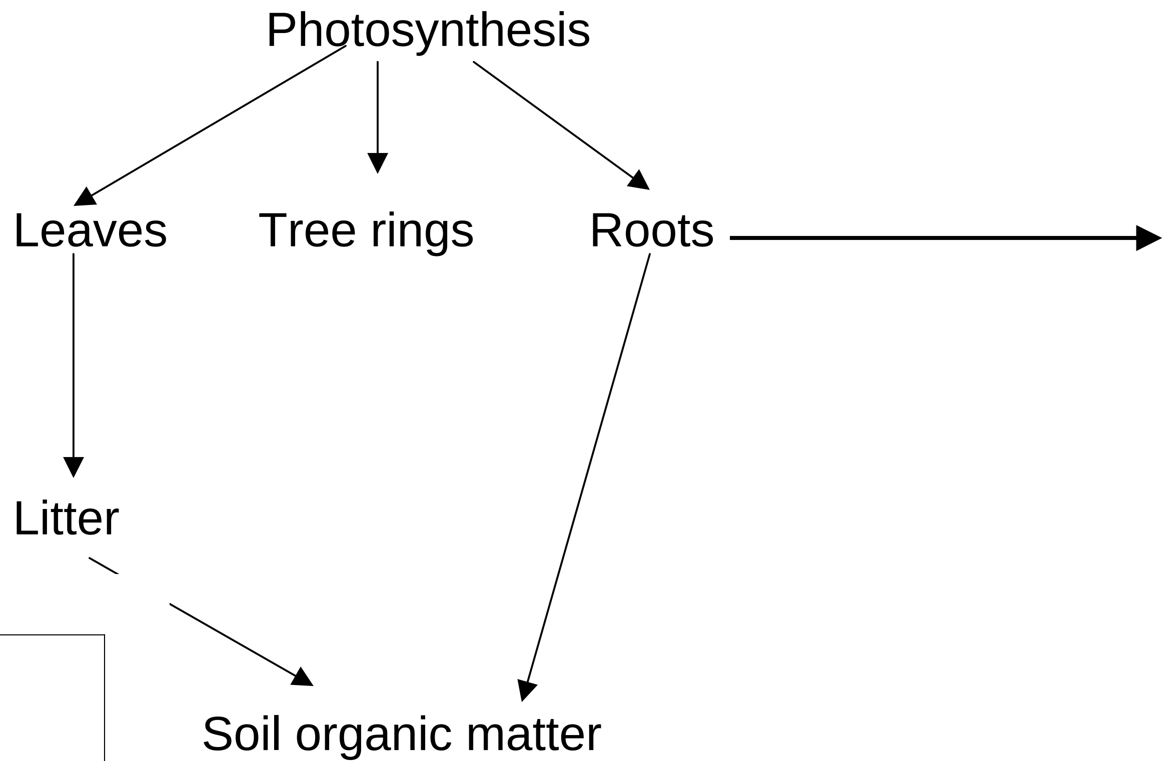
Isotope Composition of Source CO_2

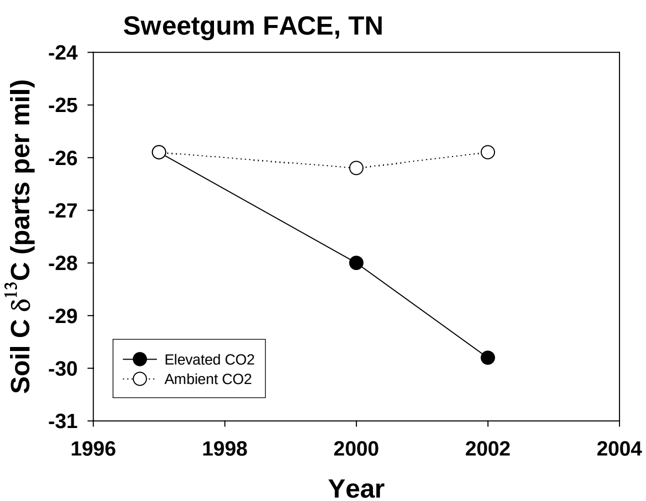


Ecosystem C transfer through various pools

Leaf $\delta^{13}C$ ‰		
Site	Elevated CO_2	Ambient CO_2
Duke	-39.5	-28.3
Corvallis	-35.2	-29.0
Minnesota	-35.1	-27.2
Wisconsin	-38.9	.27.3
ORNL	-39.0	-26.2

Carbon movement through stocks





Initial Conditions

CO_2= 360 ppm

Atmospheric CO_2
$\delta^{13}C$ = -8 ‰

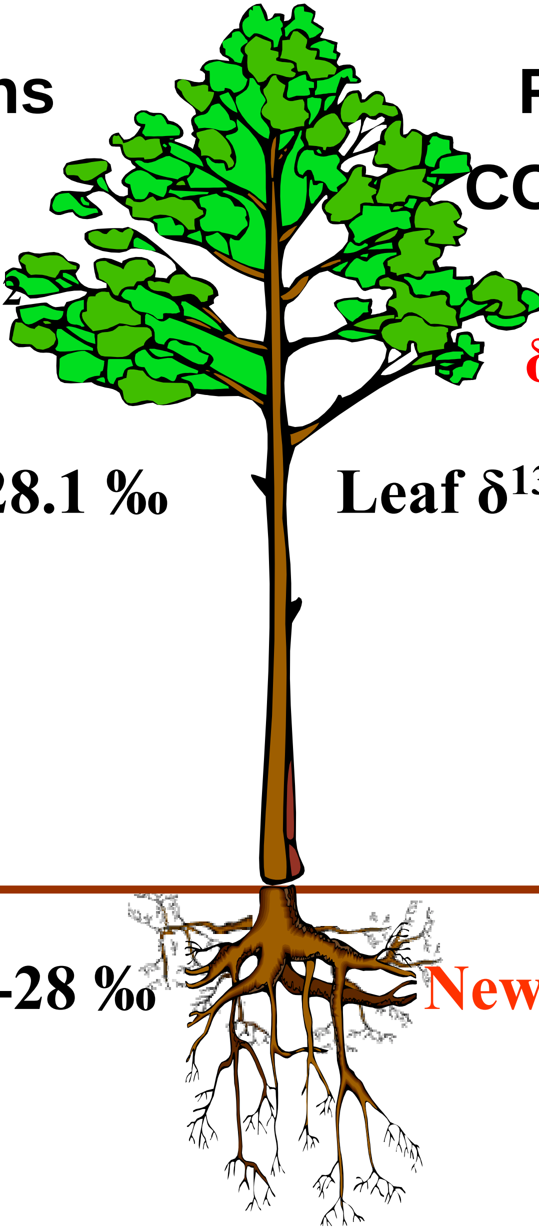
Leaf $\delta^{13}C$ = -28.1 ‰

FACE Conditions

CO_2= 360 + 150 ppm

Atmospheric CO_2
$\delta^{13}C$ = -18 to -21 ‰

Leaf $\delta^{13}C$ = -39.5 ‰



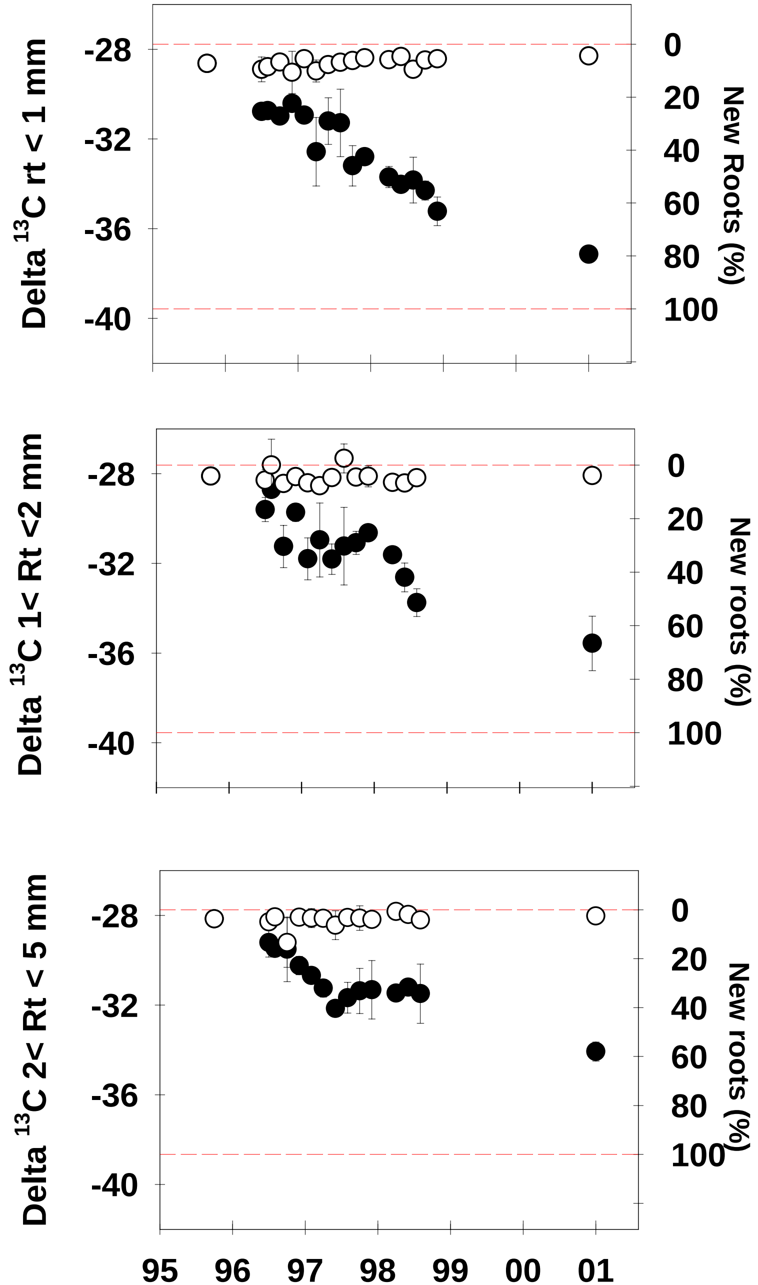
Root $\delta^{13}C$ = -28 ‰

New Root $\delta^{13}C$ = -39.5 ‰

Root C dynamics

% C from depleted CO_2 = $\{(\delta^{13}C_t - \delta^{13}Ca) / (\delta^{13}Ce - \delta^{13}Ca)\} \times 100$

In-growth Root mass	δ^{13}Ca	δ^{13}Ce
<1 mm	-27.6	-39.6
1-2mm	-27.6	-39.5
>2 mm	-27.9	-38.7



Incorporation of ^{13}C Tracer

short-term
non-steady-state

Observed $\delta^{13}C$ =

pool size change

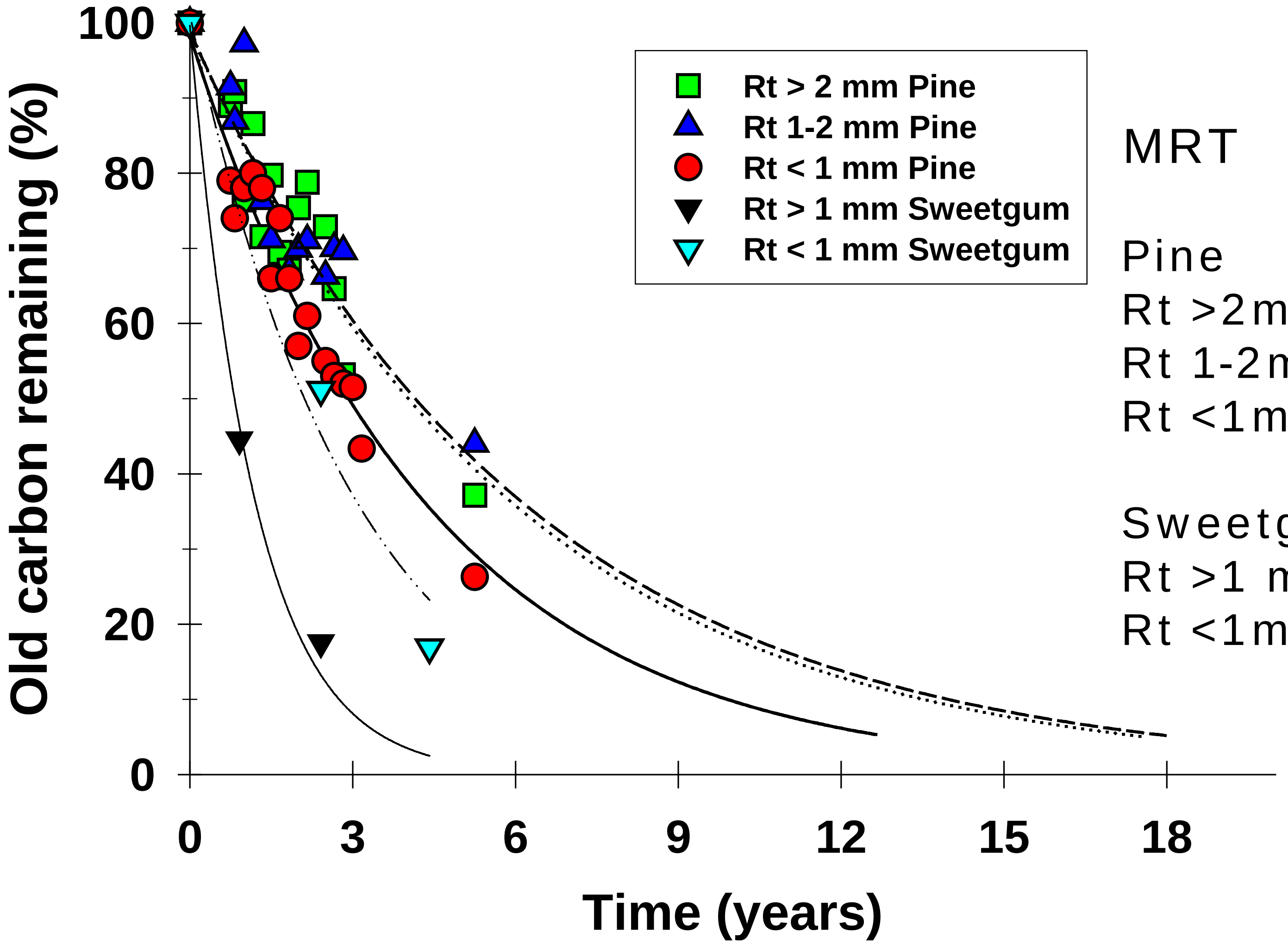
&

pool replacement

C turnover, MRT

$F(t) = e^{-kt}$; **MRT**=-1/k (years)

Mean Residence time of root C



MRT

Pine

Rt >2mm	6.3y
Rt 1-2mm	5.7y
Rt <1mm	4.2y

Sweetgum

Rt >1 mm	3.0y
Rt <1mm	1.3y

MRT and C sequestration potential

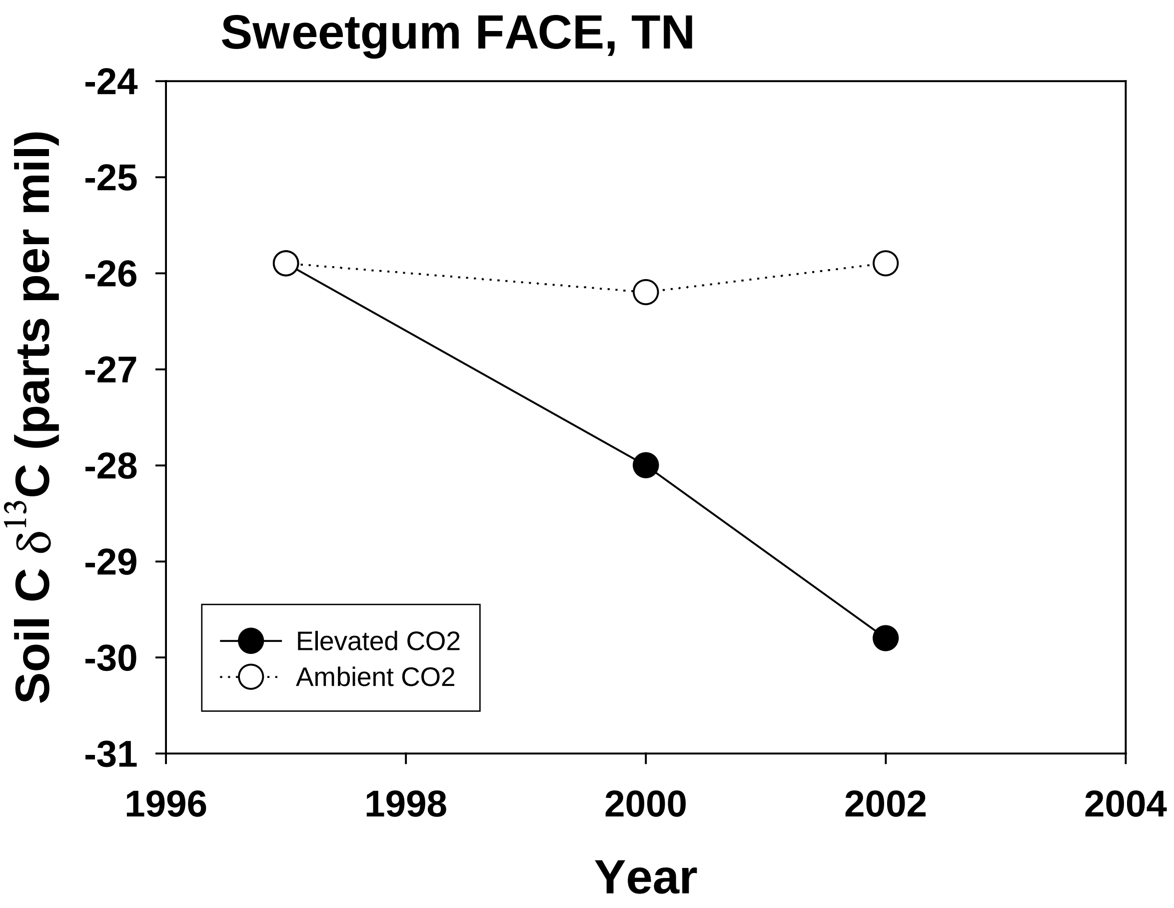
Pine forest

- 25% increase NPP
- 7% NPP directed to roots
- 4.2 y MRT Fine root population
- Approx. 50 gC m^{-2} y^{-1} from root inputs

Sweetgum forest

- 21% increase NPP
- 16% NPP directed to roots
- 1.2 y MRT Fine root population
- Approx. 150 gC m^{-2} y^{-1} from root inputs

Increases in soil C



Conclusions

Variations in C allocation to roots and root chemistry are important factors that control the rate of C accumulation in the soil.

The turnover rate of the fine root population is very important when predicting soil C accumulation. A better understanding of the dynamics of the root population is needed.

Soils with unsaturated capacities to protect inputs from rapid decomposition and large inputs contribute to store additional soil carbon under elevated CO_2.