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Atmosphere-Biosphere Interactions and C Isotopes

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CNR-IRET

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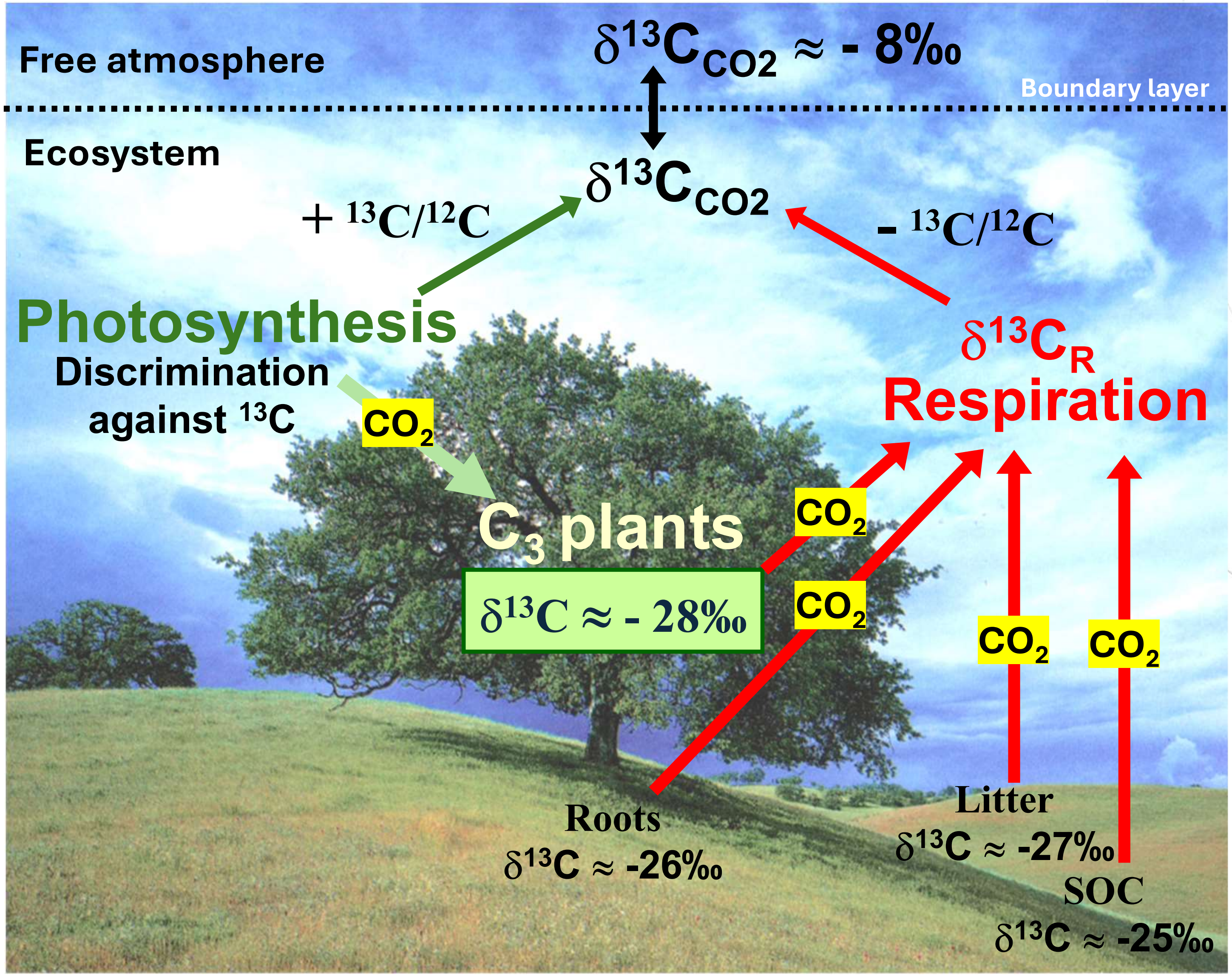
Italiadomani

AIMS

- To analyse the **relationships between carbon fluxes and the isotopic composition** of the main **autotrophic and heterotrophic components of the ecosystem**

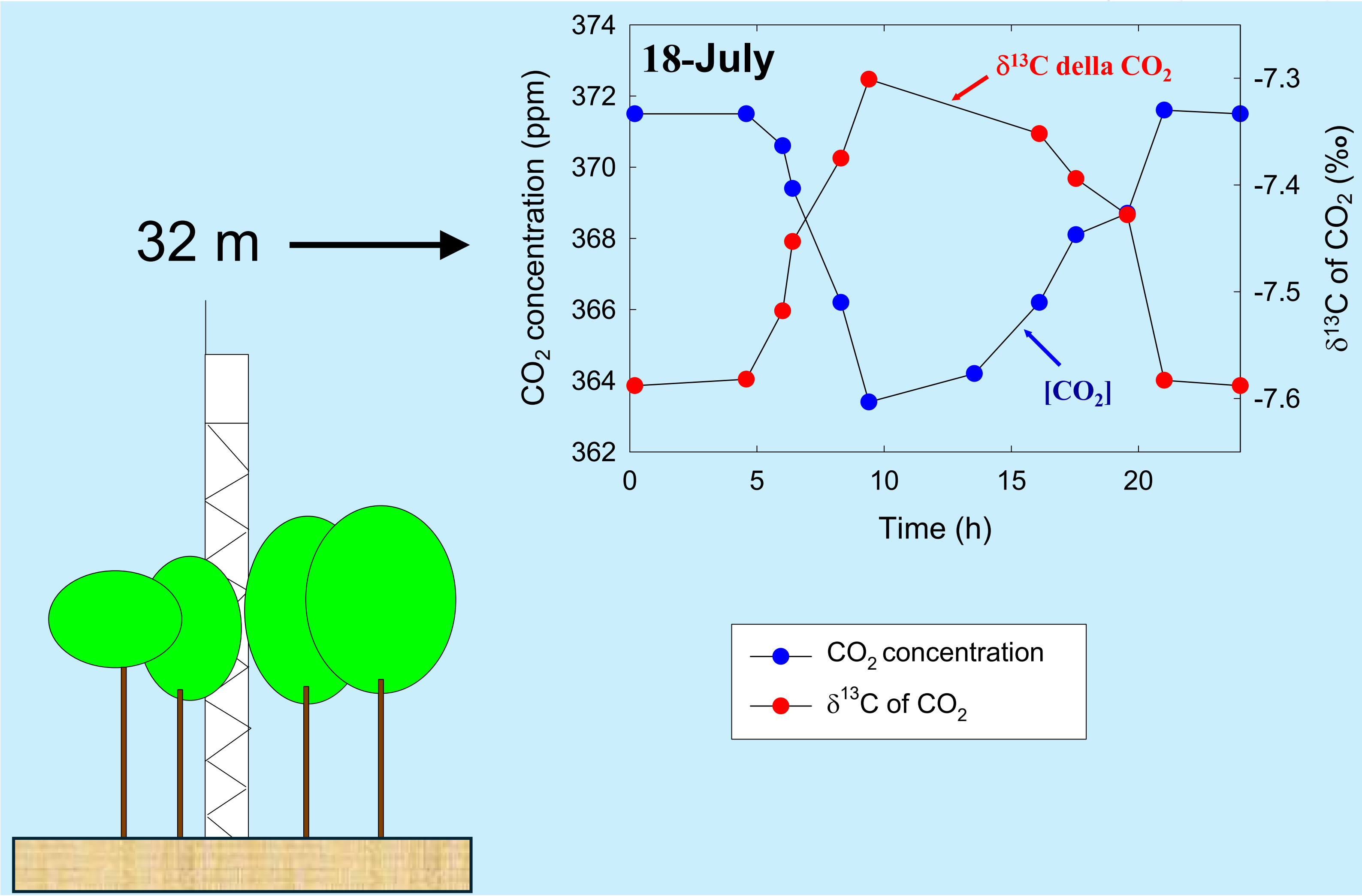
- To assess: 1) how environmental factors, anthropic disturbances and land-use changes influence **carbon fluxes**, **source-sink relationships** and **water-use efficiency** in different types of ecosystems; 2) the potential of **C isotopes to infer information on such ecological processes**



- $\delta^{13}C$ of atmospheric CO_2 in an ecosystem is determined by the **net balance** between the **photosynthetic** and **respiratory** fluxes

- Through isotopic analysis it is possible to carry out a qualitative-quantitative study of the ecosystem's carbon balance and its components

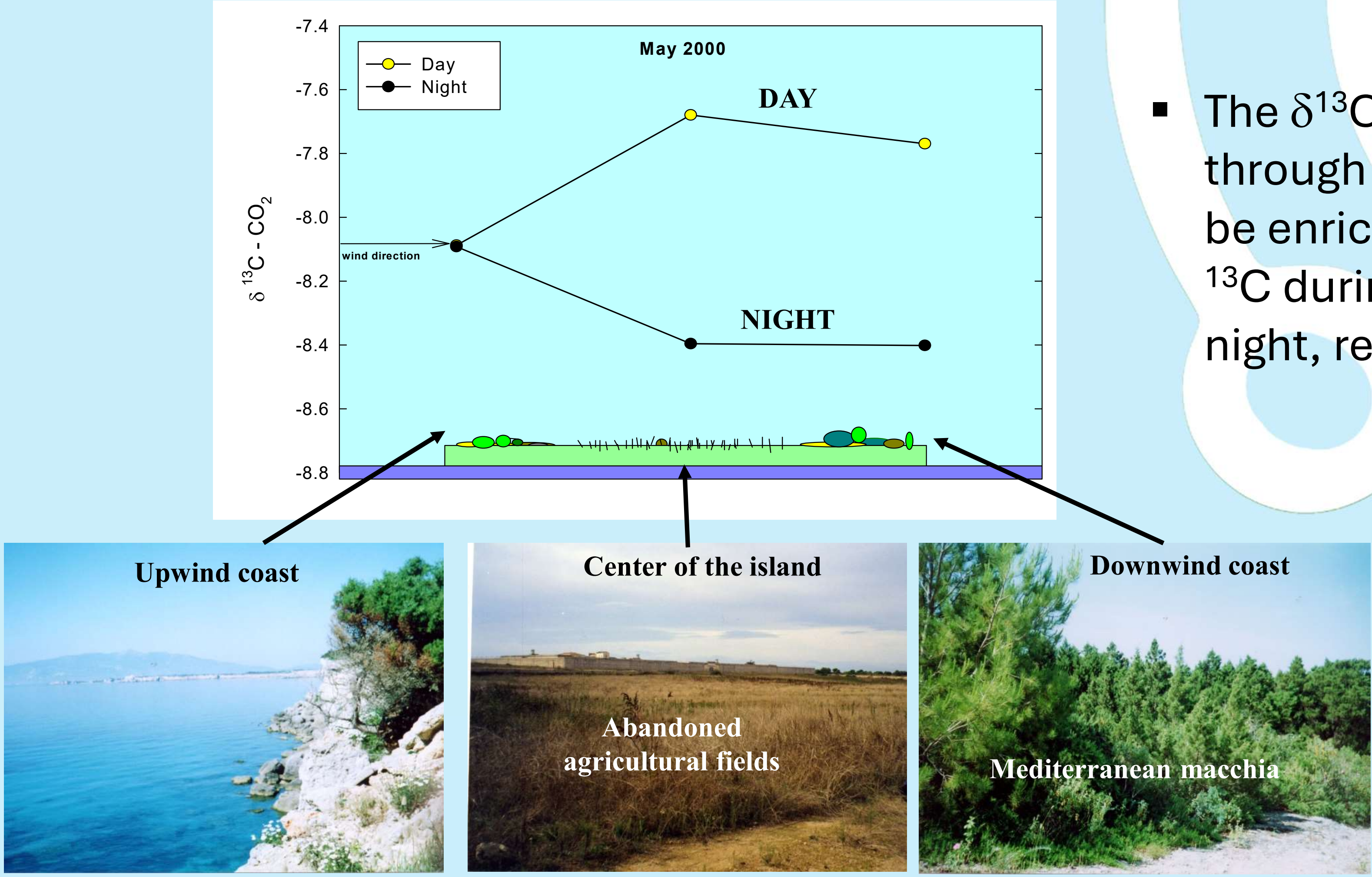
Daily variation of CO_2 concentration and δ13C in a beech forest



- CO_2 concentration and δ^{13}C above the forest canopy show a mirror-like daily pattern

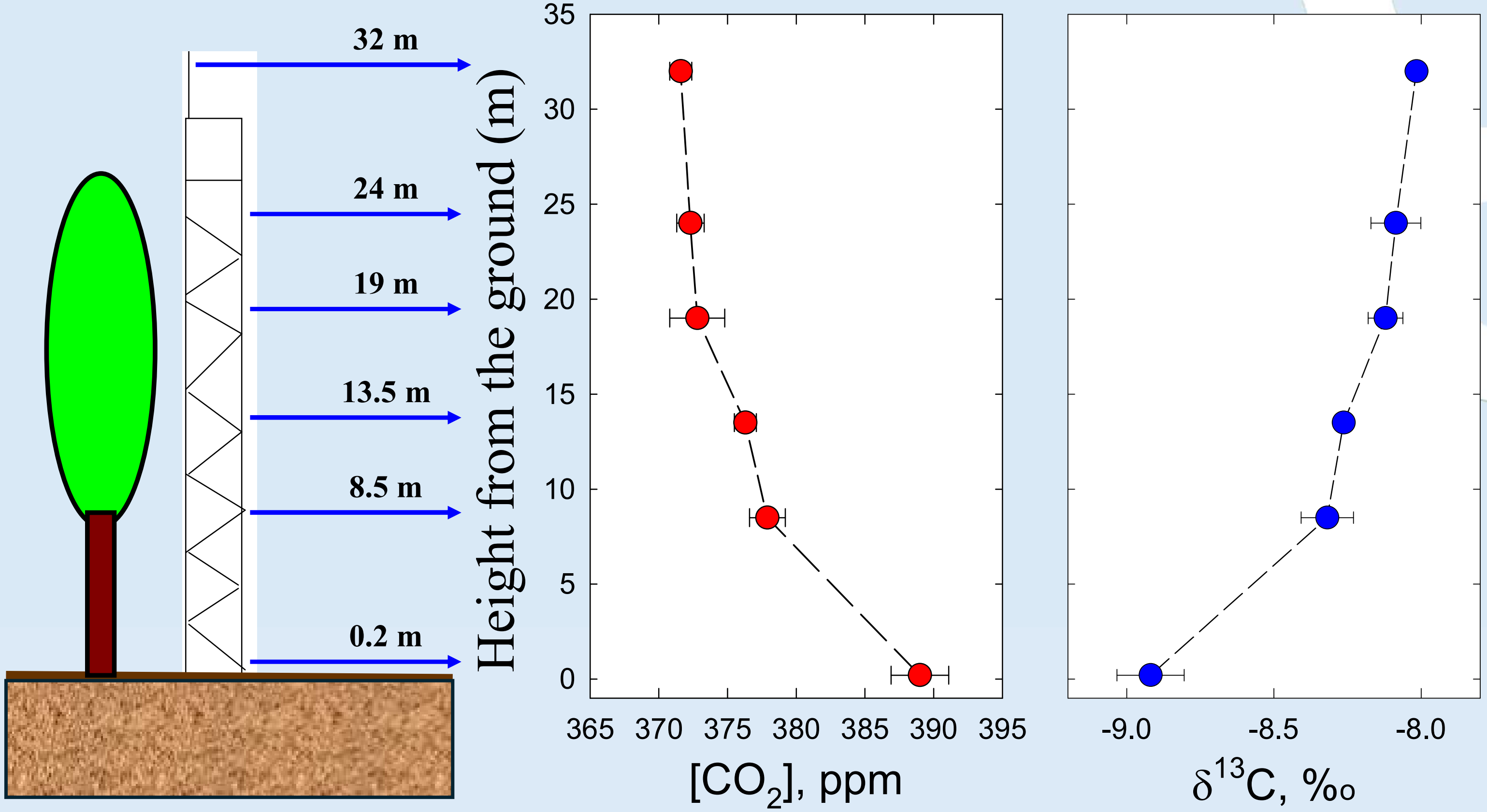
- The CO_2 concentration decreases during the daytime hours, progressively enriching in the **heavier isotope ^{13}C**
- The opposite trends occur during the night

$\delta^{13}C$ of CO_2 sampled upwind, center and downwind of Pianosa Island

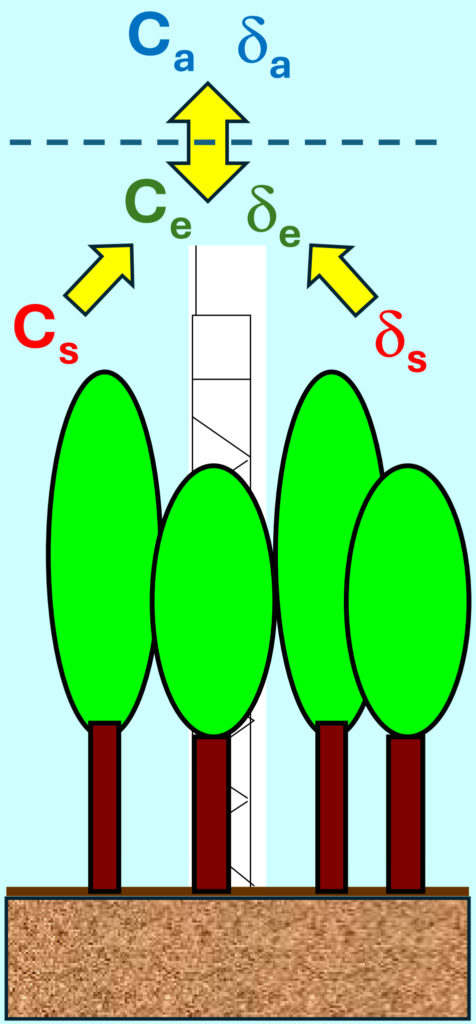


- The $\delta^{13}C$ of CO_2 passing through the island tends to be enriched and diluted in ^{13}C during the day and the night, respectively

Vertical night profile of CO_2 concentration and $\delta^{13}C$ in a beech forest



- During the night, a vertical profile of CO_2 concentration and $\delta^{13}C$ is observed, with a decrease in $[CO_2]$ associated with an increase in $\delta^{13}C$ from the ground to above the forest canopy



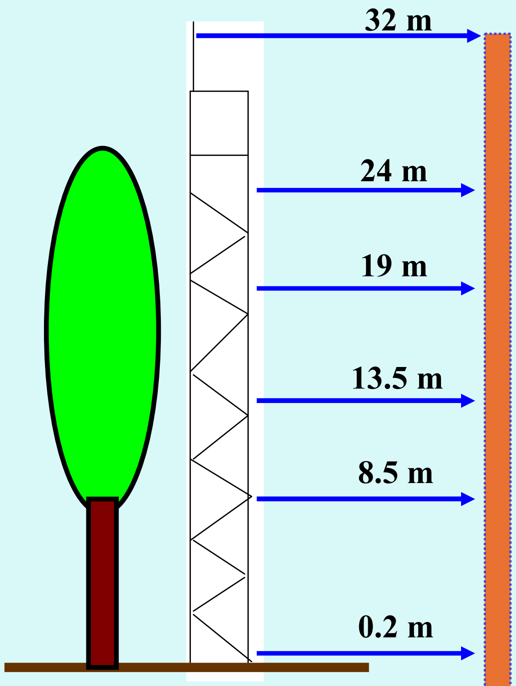
The concentration and isotopic composition (δ) of CO_2 within the **boundary layer of an ecosystem** (C_e and δ_e) are determined by concentration and δ of **atmospheric CO_2** (C_a and δ_a) and of that **released by the ecosystem** (C_s and δ_s)

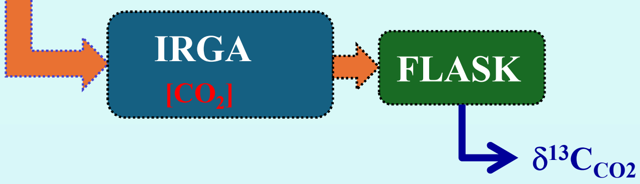
$$\begin{cases} C_e = C_a + C_s & \text{mass balance equation} \\ C_e\delta_e = C_a\delta_a + C_s\delta_s & \text{Isotope mass balance equation} \end{cases}$$

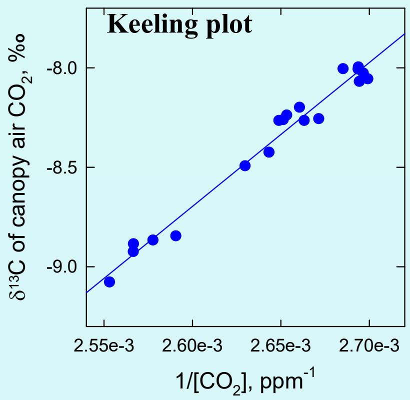
Combining the above equations, we obtain the linear relationship between δ_e and $1/C_e$ (**Keeling plot**)

$$\delta_e = C_a(\delta_a - \delta_s)\,1/C_e + \delta_s$$

Nocturnal Keeling Plot in a beech forest

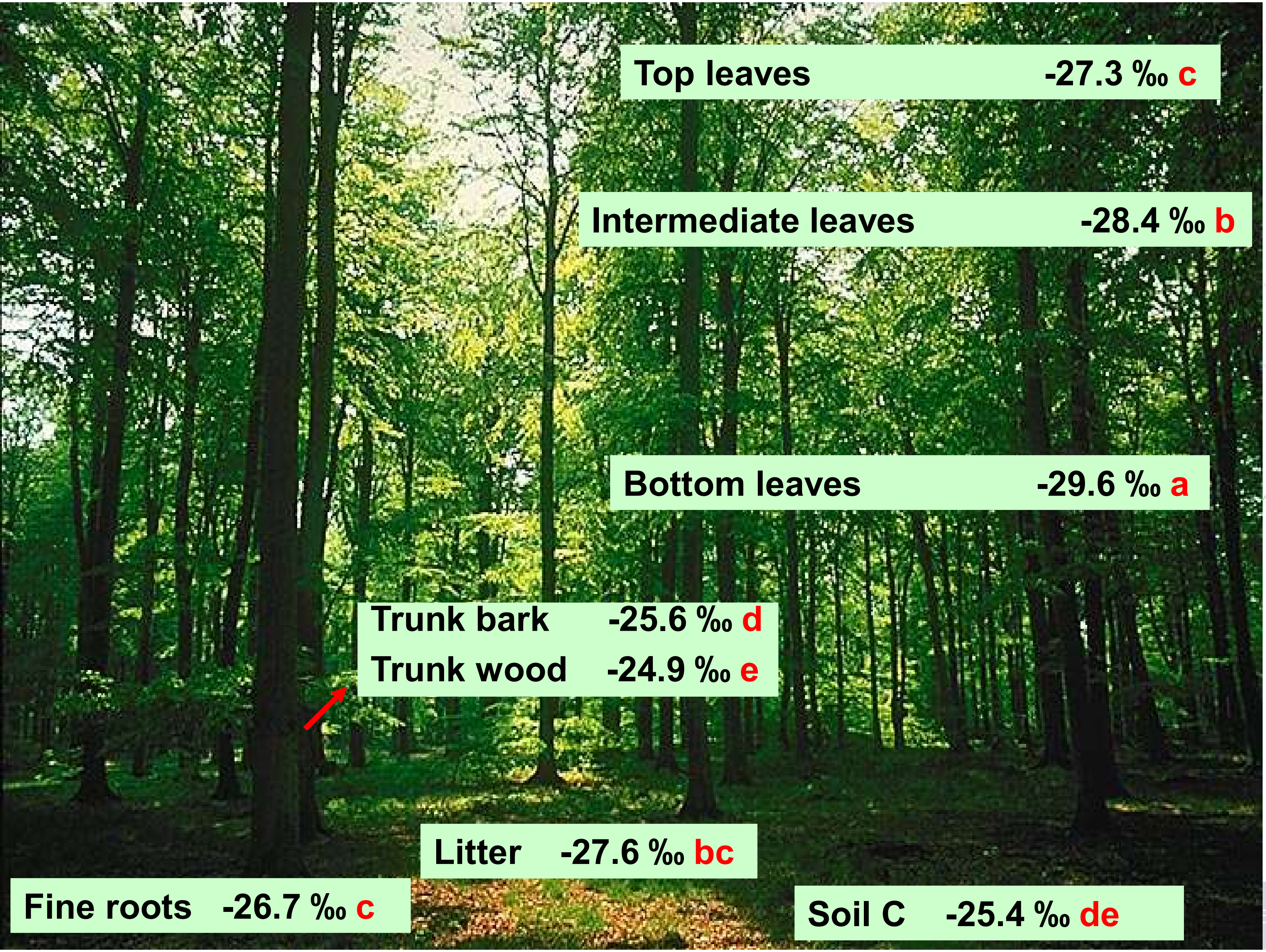






Nocturnal Keeling plot: The y-intercept (δ_s) gives an estimate of the **isotope composition** of the **ecosystem respiratory C source** ($\delta^{13}C_R$)

$$\delta_e = C_a(\delta_a - \delta_s)\ 1/C_e + \delta_s$$



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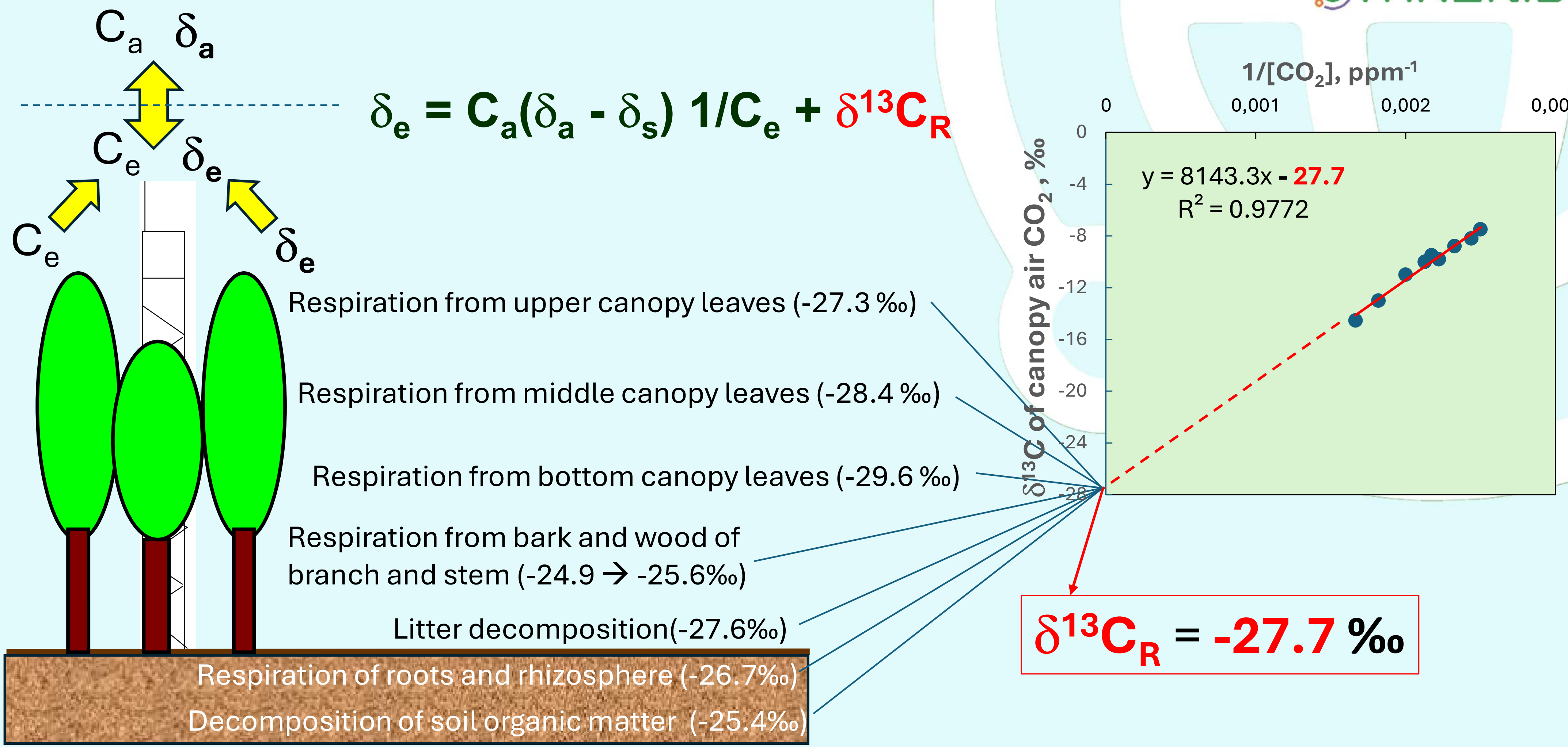
The above- and below-ground ecosystem components of a beech forest show different $\delta^{13}C$

$$\delta_e = C_a(\delta_a - \delta_s)\,1/C_e + \delta^{13}C_R$$



$\delta^{13}C_R$ = -27.7 ‰

What is the reason for the differences in isotopic composition of the C pools and fluxes in the soil-plant-atmosphere continuum?

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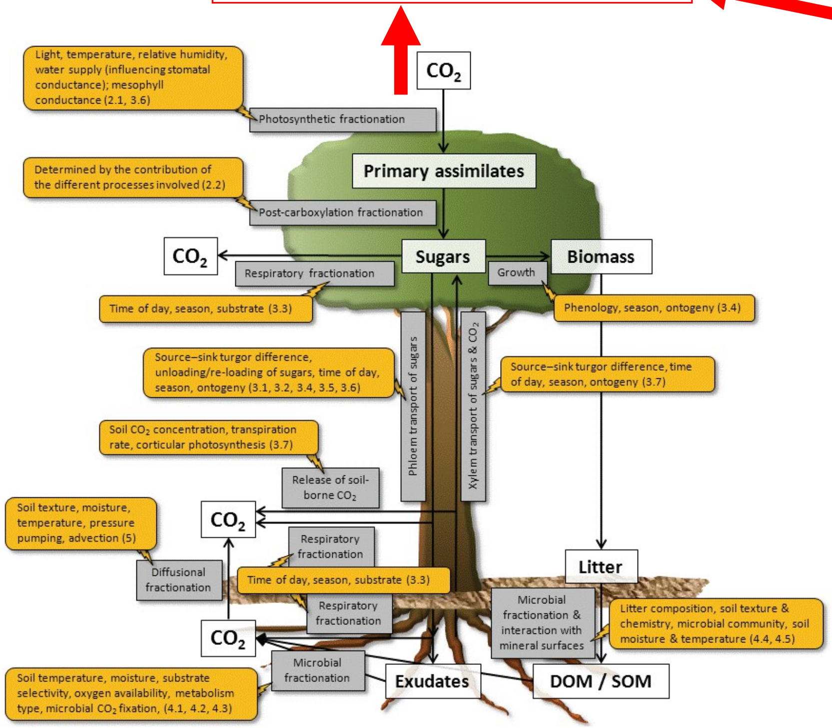
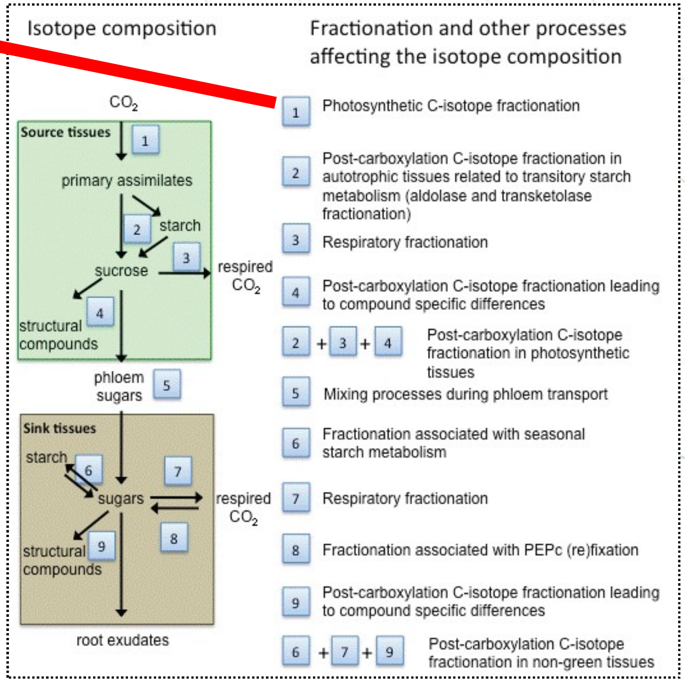
$$\Delta = a + (b - a)\frac{C_i}{C_a} - d$$

a is the fractionation during CO_2 diffusion in still air
b is the net fractionation during carboxylation in C_3 plants (i.e. mostly Rubisco)
d accounts for further fractionations during respiration, photorespiration and liquid phase diffusion.



Source tissue (e.g. leaf)

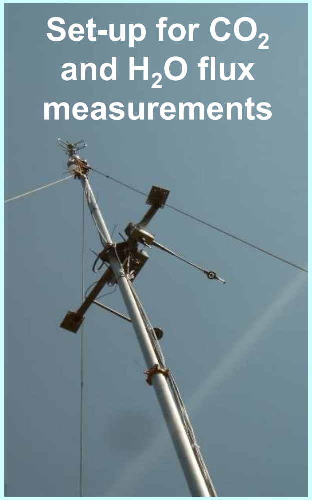
Sink tissue (e.g. roots)

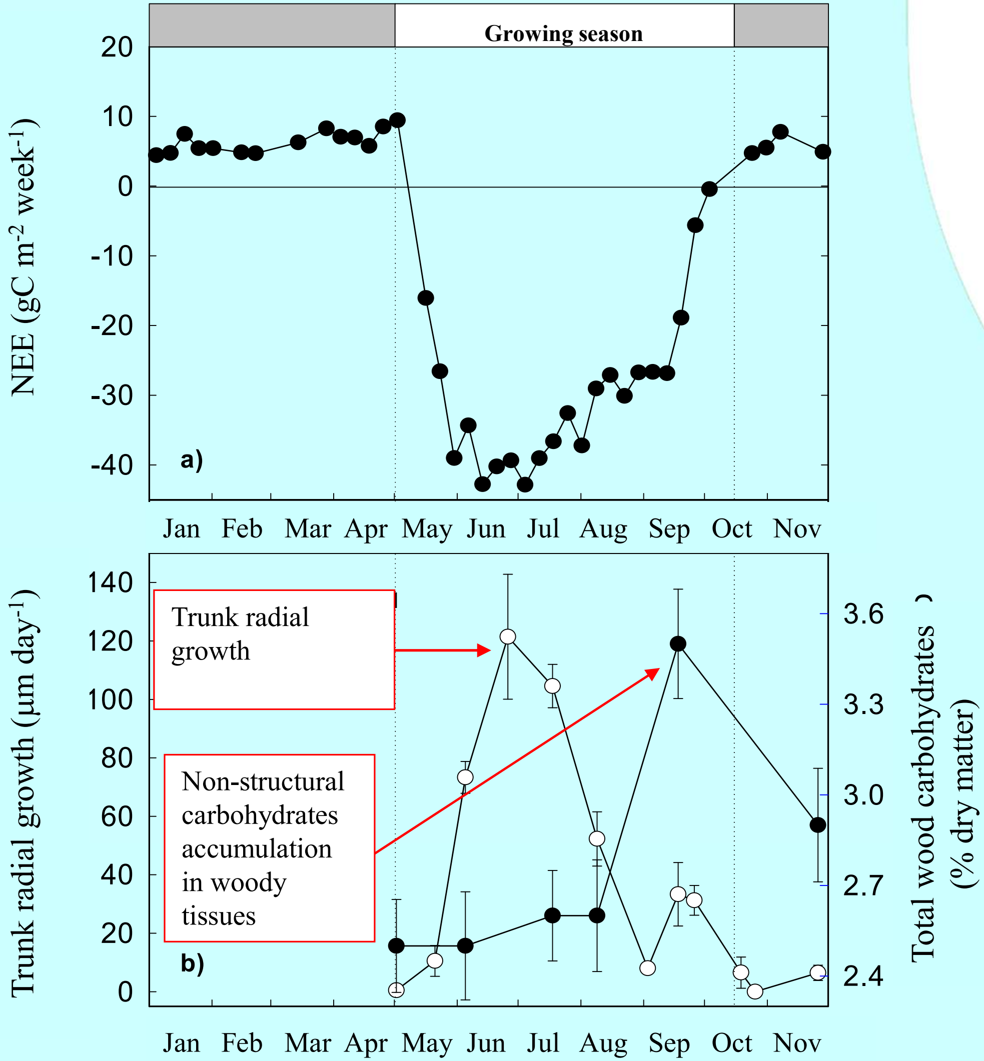


The main fractionation step by **Rubisco** activity and all **downstream fractionation steps** (collectively addressed as **post-carboxylation fractionation**) affect the C isotope composition of **source** and **sink** tissues

Overview of processes and factors determining the isotope signature of C pools and fluxes in space and time in the soil-plant-atmosphere continuum (from Bruggemann et al., 2011)

Seasonal variation of net ecosystem CO_2 exchange (NEE), trunk radial growth and non-structural carbohydrates

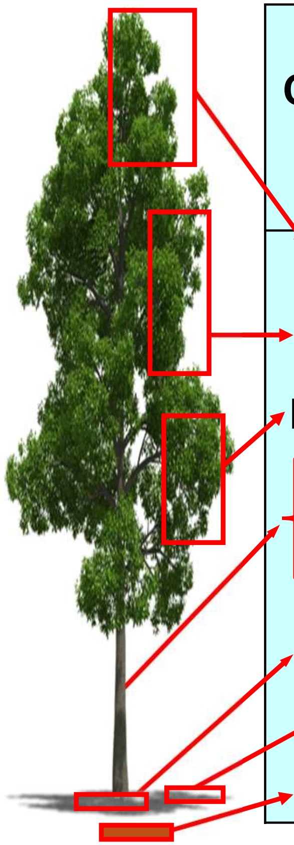




Seasonal net C sink of this beech forest was mostly distributed between **plant growth** (May-July) and **non-structural carbohydrate accumulation** in woody parenchymatic cells (August-September)

Storage carbohydrates represent a consistent C sink during the late summer-autumn period

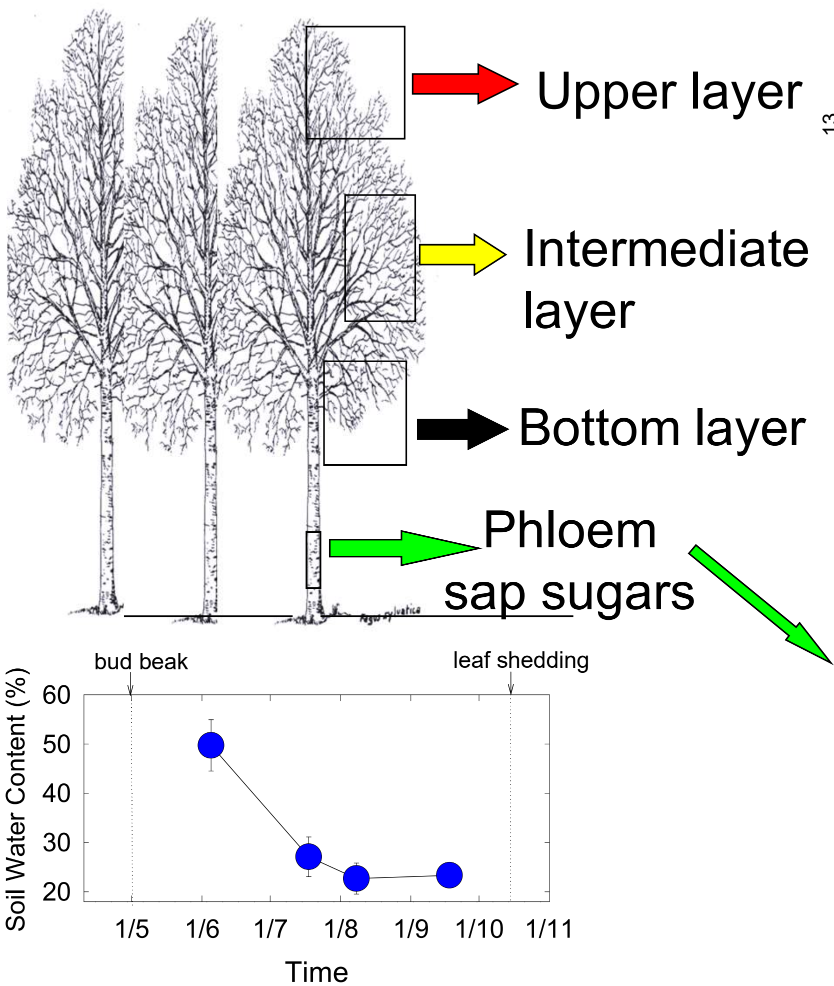
Seasonal variation of $\delta^{13}C$ of dry matter in different ecosystem components

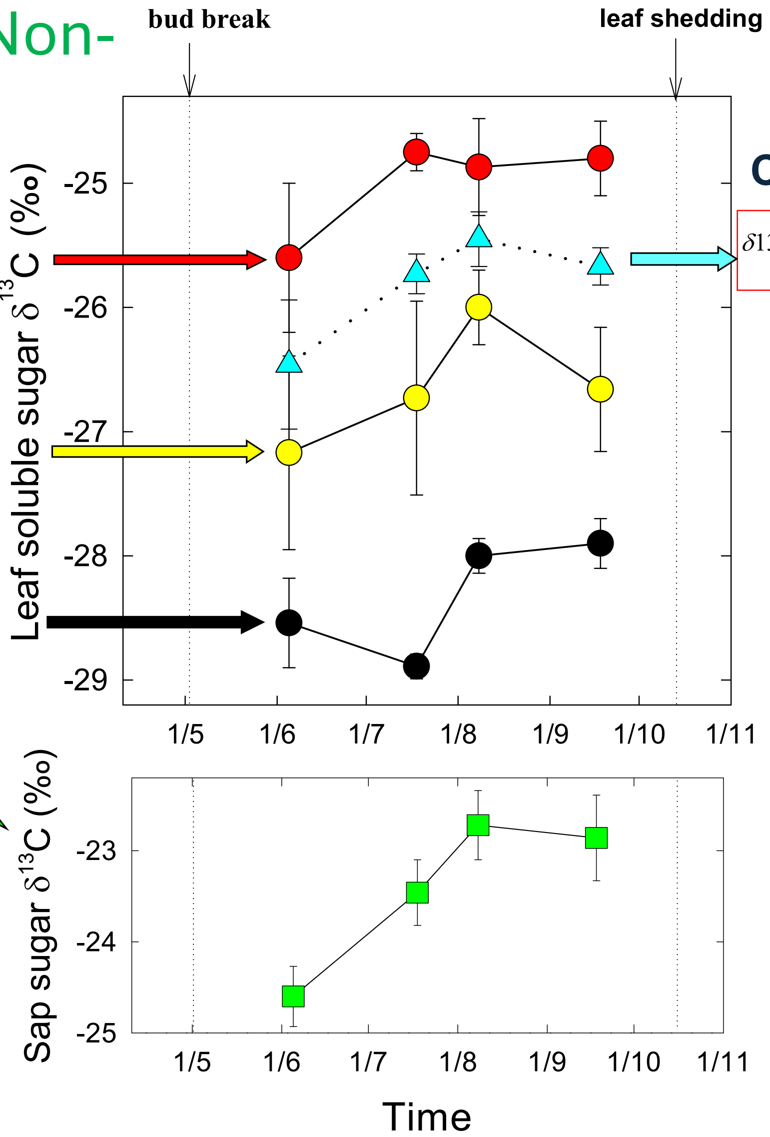


Ecosystem Components	Carbon Isotope Composition (‰)				
	5 June	18 July	8 Aug	18 Sept	26 Nov
Leaf (24 m)	-27.3 a	-27.0 a	-27.4 a	-27.2 a	n.d.
Leaf (19 m)	-28.4 a	-28.4 a	-28.7 a	-28.9 a	n.d.
Leaf (13.5m)	-29.6 a	-29.9 a	-30.0 a	-30.2 a	n.d.
Trunk bark	-25.6 a	-25.5 a	-25.6 a	-25.5 a	-25.6 a
Trunk wood	-24.9 a	-25.0 a	-24.9 a	-24.5 a	-24.7 a
Fine roots	-26.7 ab	-27.1 a	-26.0 bc	-26.2 bc	-25.7 c
Litter	-27.6 a	-27.7 a	-27.5 a	-27.4 a	-27.3 a
Soil Carbon	-25.4 a	-25.5 a	-25.1 a	-25.5 a	-25.2 a

$\delta^{13}C$ in dry matter of different ecosystem components shows little seasonal variability

Seasonal variation of $\delta^{13}C$ of Non-Structural Carbohydrates





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Canopy-weighted mean value

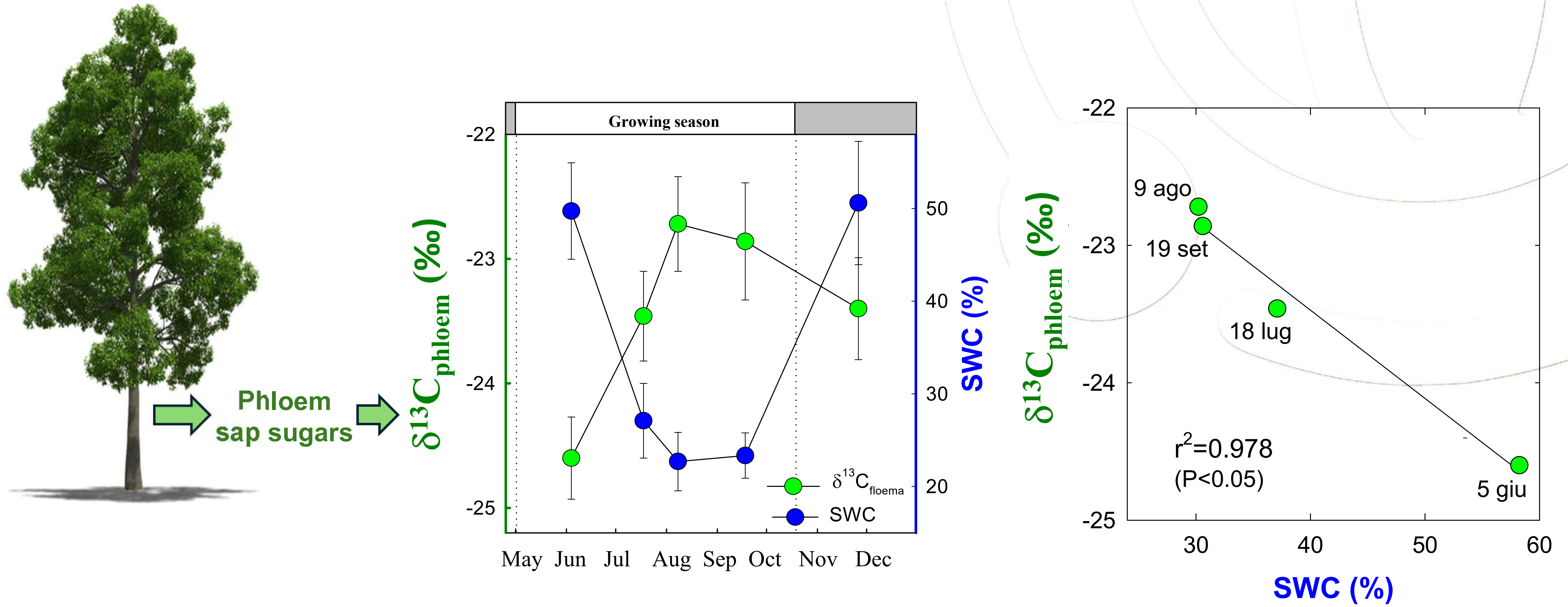
$$\delta 13C_{canopy} = \frac{\delta 13C_1 x LAI_1 x S_1 + \delta 13C_2 x LAI_2 x S_2 + \delta 13C_3 x LAI_3 x S_3}{\sum_1^3 LAI_i x S_i}$$

Seasonal variations in $\delta^{13}C$ of leaf and phloem sap sugars

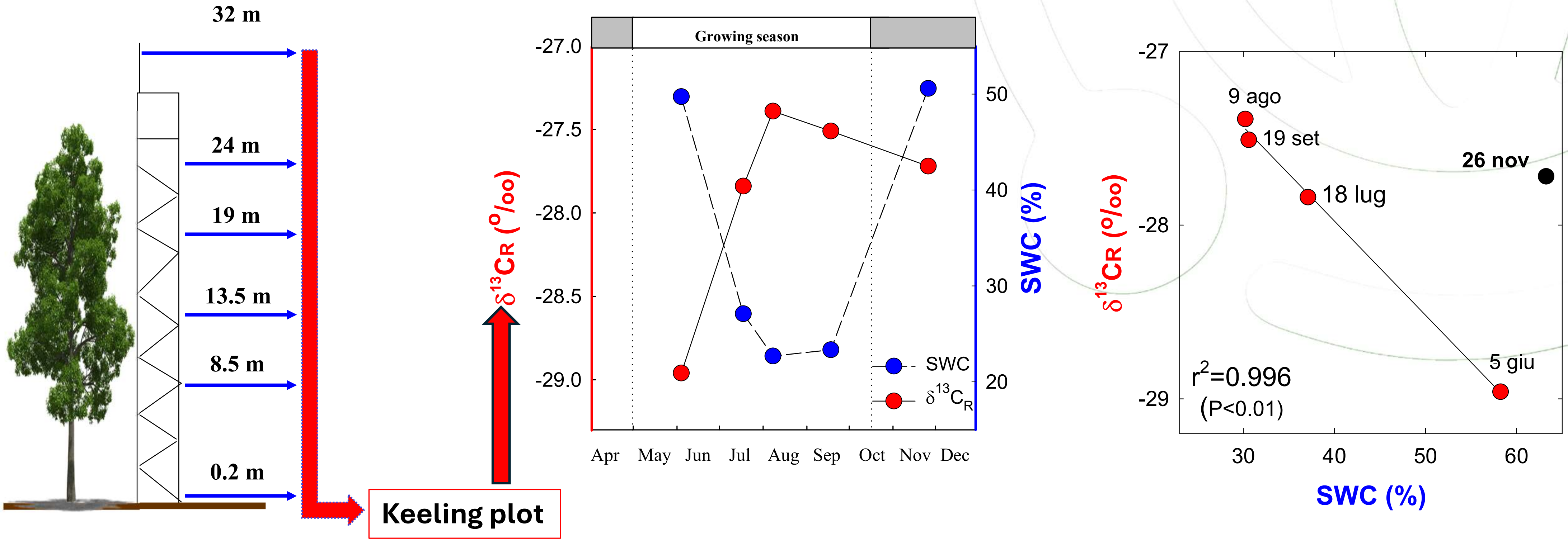
The $\delta^{13}C$ of soluble sugars in leaves and sap phloem shows a seasonal variation dependent on soil water availability

Scartazza et al. (2004)

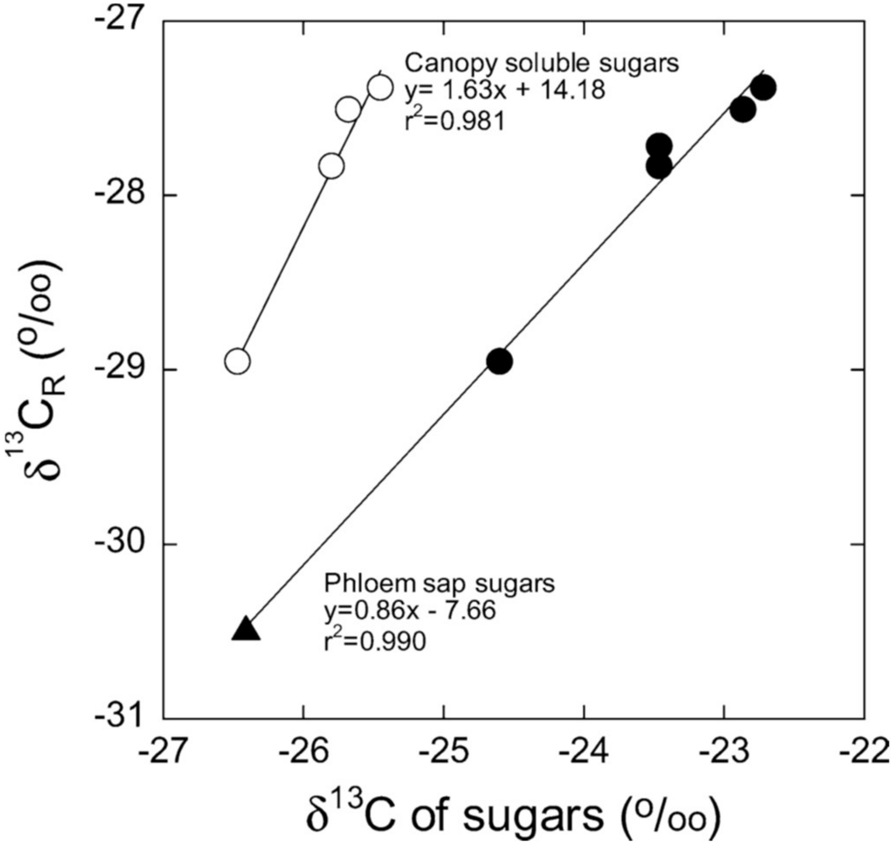
Seasonal Variation of Soil Water Content (SWC) and $\delta^{13}C$ of phloem sap sugars ($\delta^{13}C_{phloem}$)



Seasonal Variation of Soil Water Content (SWC) and $\delta^{13}C$ of ecosystem respired CO_2 ($\delta^{13}C_R$) determined by nocturnal Keeling plots

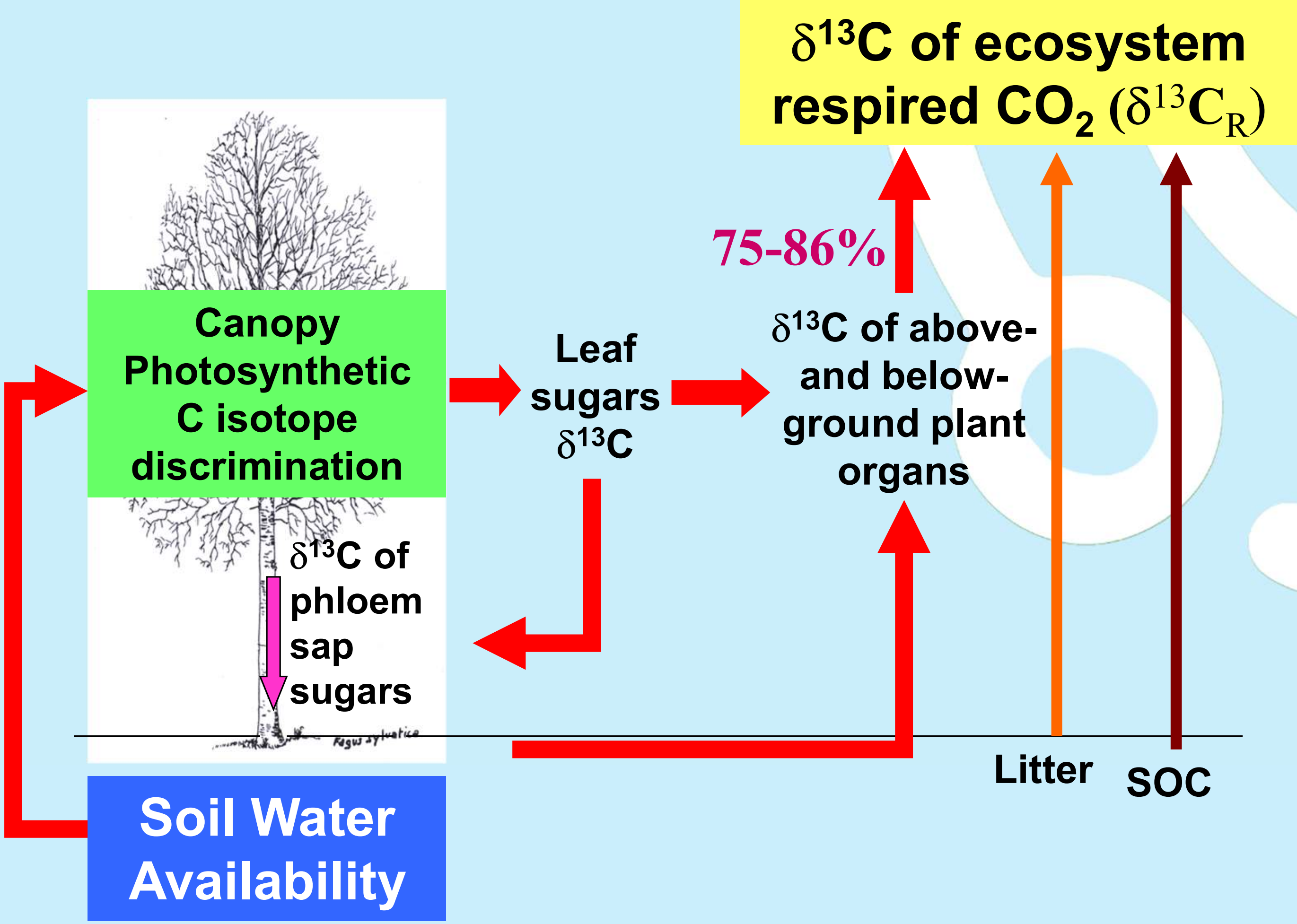


Relationship between $\delta^{13}C$ of leaf and phloem sugars and ecosystem respired CO_2 in the Collelongo beech forest

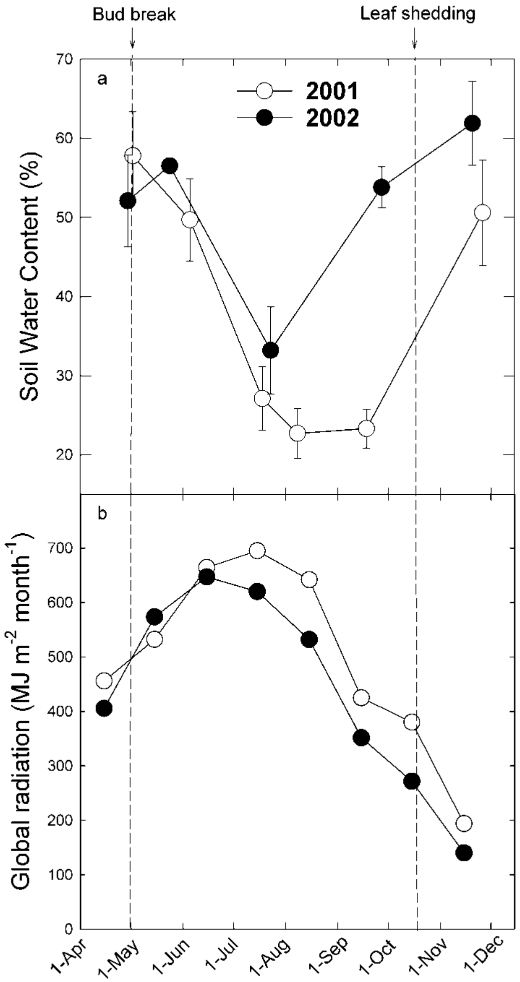


The **$\delta^{13}C$ of ecosystem respired CO_2** ($\delta^{13}C_R$) were linearly related to increases in **phloem sugar $\delta^{13}C$** and **leaf sugar $\delta^{13}C$**, indicating that **a major proportion of ecosystem respired CO_2 was derived from recent assimilates**

Scartazza et al. (2004)

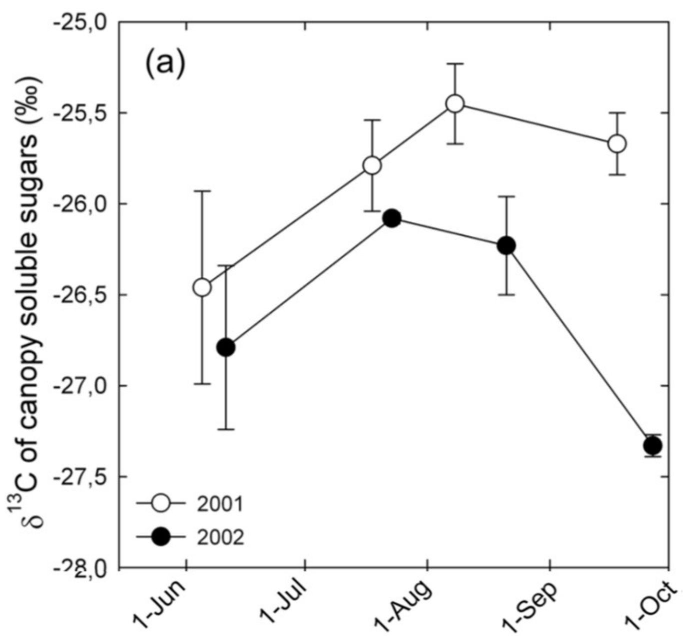

δ13C of ecosystem respired CO2 (δ13CR)
75-86%
Canopy Photosynthetic C isotope discrimination
Leaf sugars δ13C
δ13C of above- and below-ground plant organs
δ13C of phloem sap sugars
Fagus sylvatica
Litter
SOC
Soil Water Availability

Interannual variation of $\delta^{13}C$ of the beech canopy



Seasonal variations of the **canopy-weighted mean value of leaf sugar $\delta^{13}C$ ($\delta^{13}C_{canopy}$)**

$$\delta 13C_{canopy} = \frac{\delta 13C_1 x LAI_1 x S_1 + \delta 13C_2 x LAI_2 x S_2 + \delta 13C_3 x LAI_3 x S_3}{\sum_1^3 LAI_i x S_i}$$

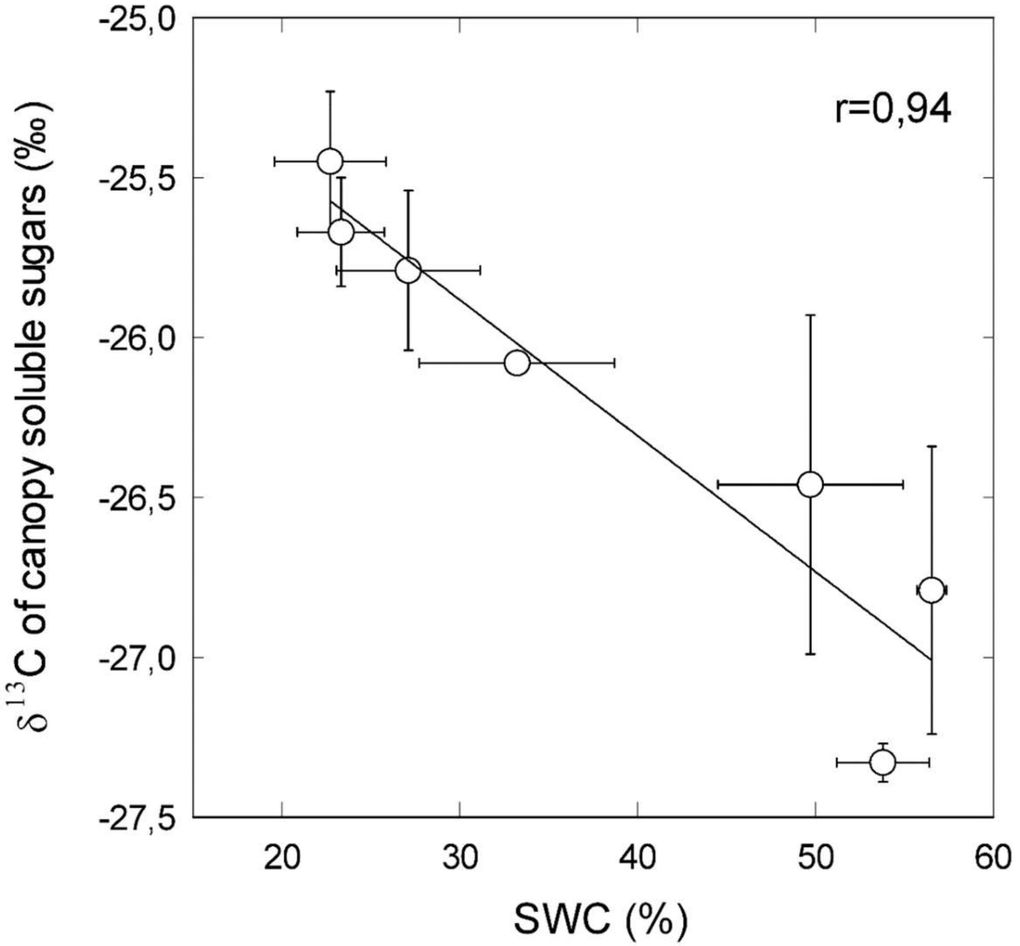


Based on C discrimination model, **higher $\delta^{13}C$ values** in leaf carbohydrates during August-September 2001 compared with 2002, indicate **lower intercellular to atmospheric CO_2 partial pressure ratio** in canopy leaves

Decrease in C isotope discrimination and **increase in Water-Use Efficiency**

Scartazza et al. (2013)

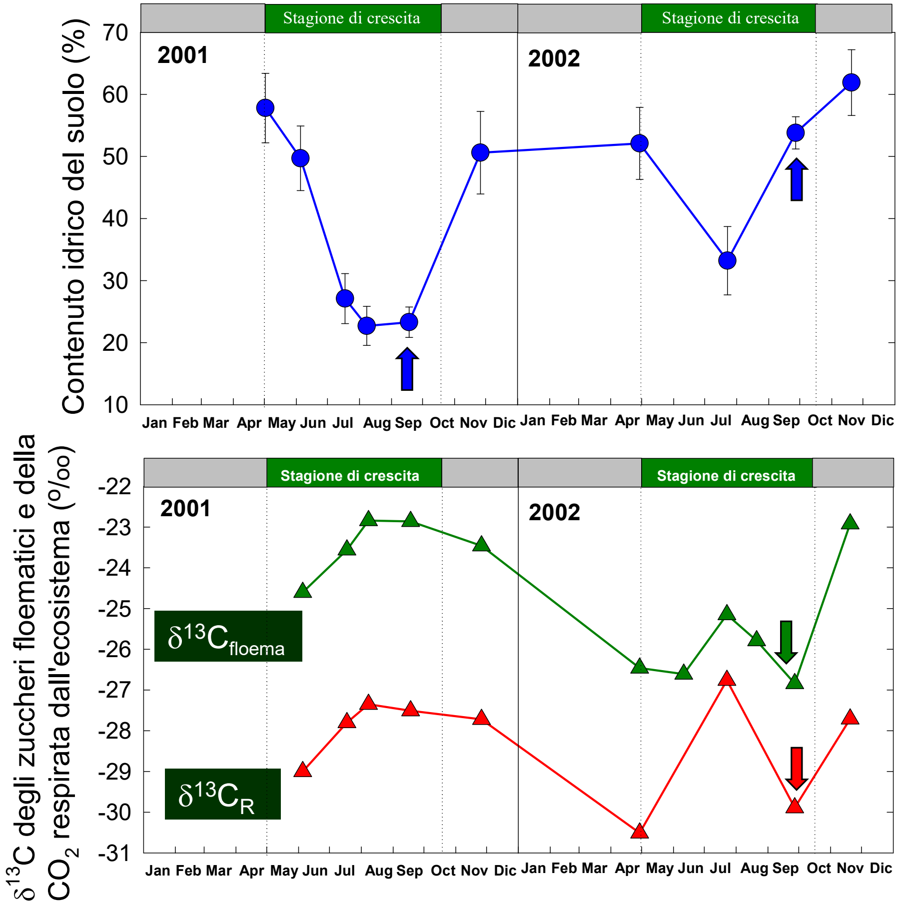
Relationship between Soil Water Content (SWC) and $\delta^{13}C$ of canopy-weighted mean value of leaf soluble sugars



- The different isotopic signature in canopy sugars may be explained by **partial stomatal closure** induced by **decreasing SWC** during relatively dry periods, leading to an **increase in WUE**
- Consistent with this hypothesis a highly significant relationship was found between **$\delta^{13}C$ of leaf canopy sugars and SWC** for both the yeras

Scartazza et al. (2013)

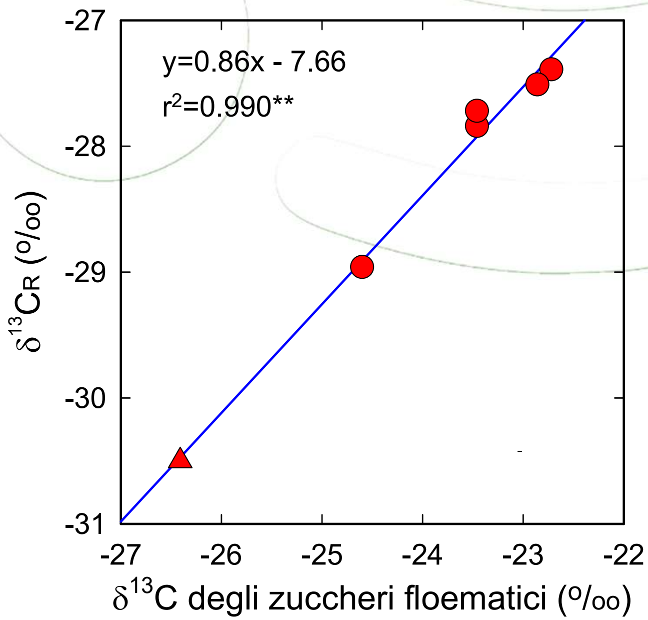
Seasonal and interannual variation of SWC, $\delta^{13}C$ of phloem sap sugars and ecosystem respiration



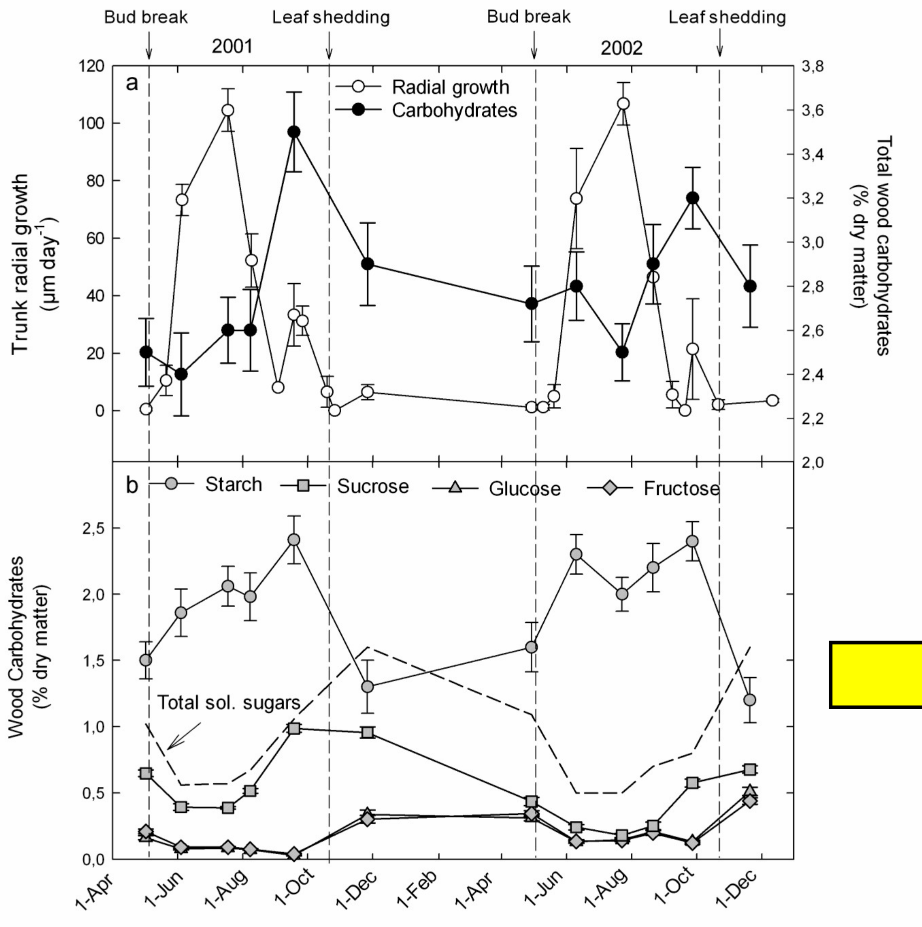
Interannual variation in **SWC**

Interannual variation in **$\delta^{13}C_{phloem}$** **$\delta^{13}C_R$**

Relationships between $\delta^{13}C$ of phloem sugars (**$\delta^{13}C_{phloem}$**), $\delta^{13}C$ of ecosystem-respired CO_2 (**$\delta^{13}C_R$**) and soil water content (**SWC**)



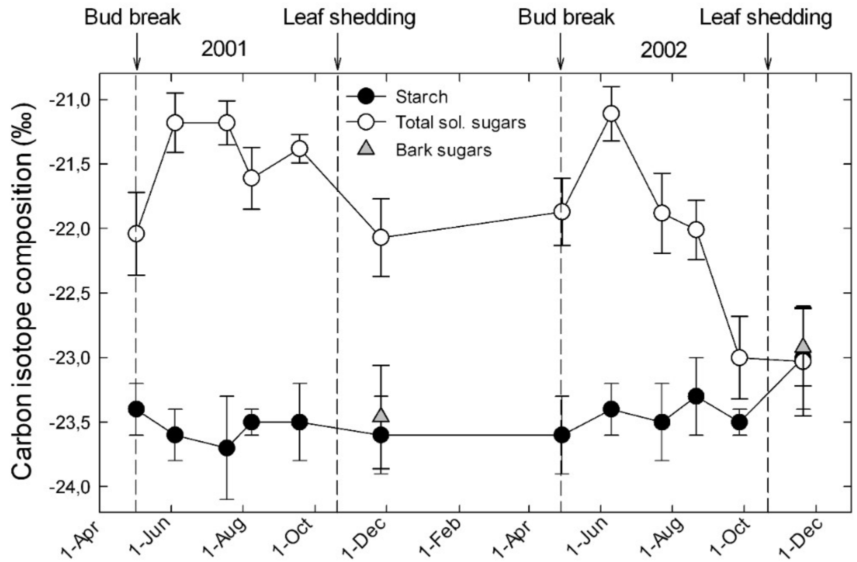
Seasonal and inter-annual variations of starch and soluble sugars in trunk woody tissues



Despite rilevant climatic differences, **trunk radial growth and carbohydrate accumulation in woody tissues showed similar trends**

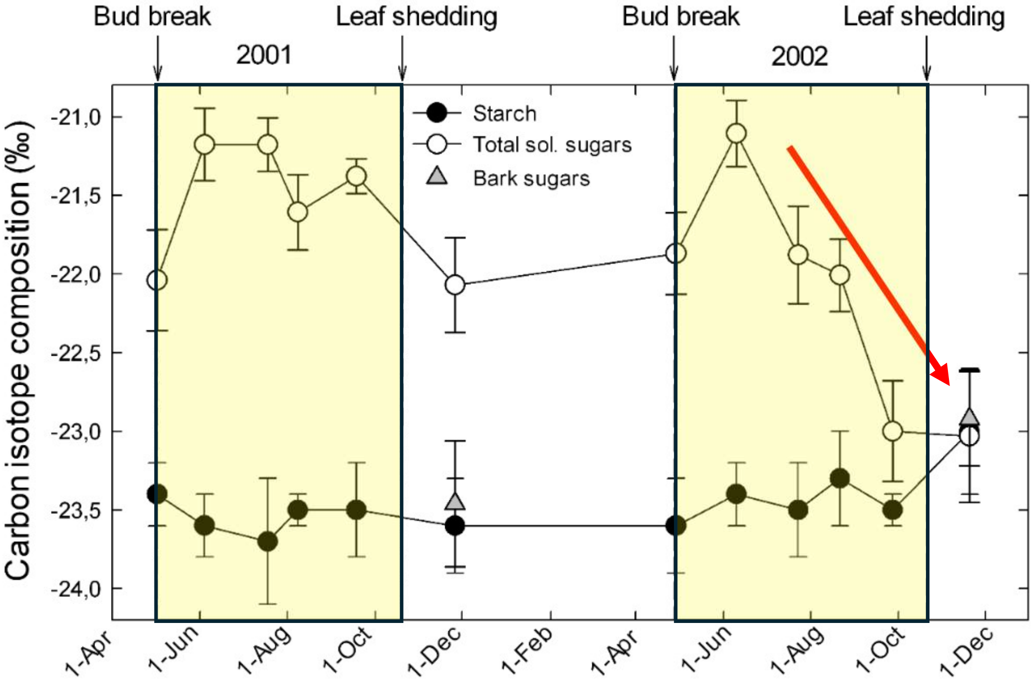
Inter-conversion between starch and wood soluble sugars:

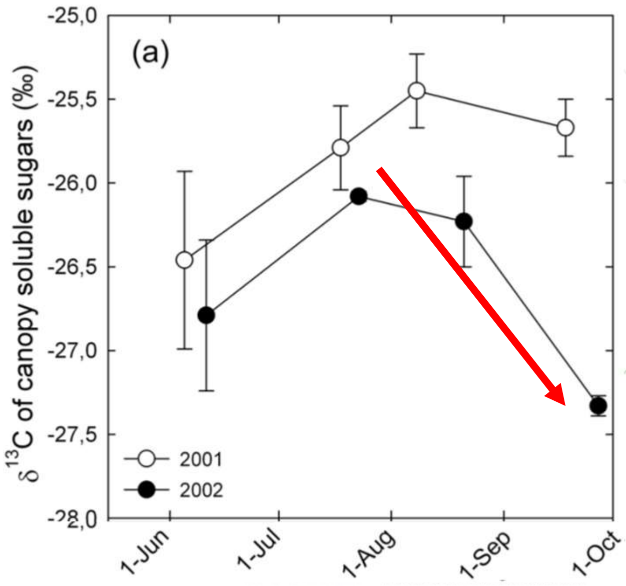
- **high level of soluble sugars** associated with **low starch content** at **bud break** and **after leaf shedding**
- **increase of starch from May to September-October** associated with **decrease of total soluble sugars**



Scartazza et al. (2013)

Seasonal and inter-annual variations in $\delta^{13}C$ of starch and soluble sugars in trunk woody tissues





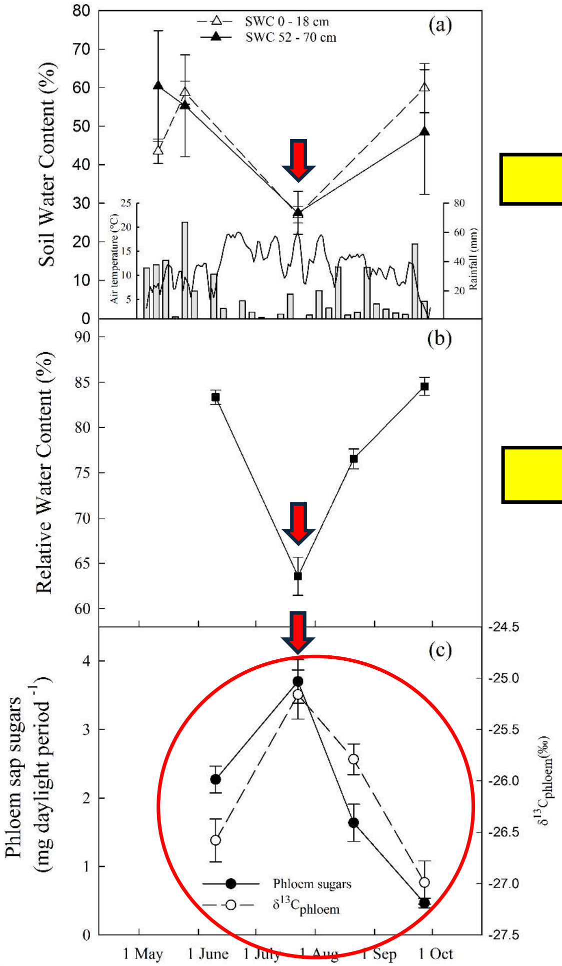
Wood starch $\delta^{13}C$ showed only slight interannual and seasonal variations

Conversely, $\delta^{13}C$ of wood soluble sugars showed wide seasonal and interannual variations, with a strong ^{13}C depletion (about 2‰) from June to September 2002, associated with the decrease in $\delta^{13}C$ of leaf canopy sugars

Wood carbohydrates were strongly ^{13}C enriched compared with leaf sugars throughout the growing season, due to possible **post-carboxylation C isotope fractionation processes leading to differences in $\delta^{13}C$ between source and sink tissues**

Scartazza et al. (2013)

Using C isotopes to follow the transport of photosynthates through the leaf-to-root system



Soil Water Content (**SWC**)

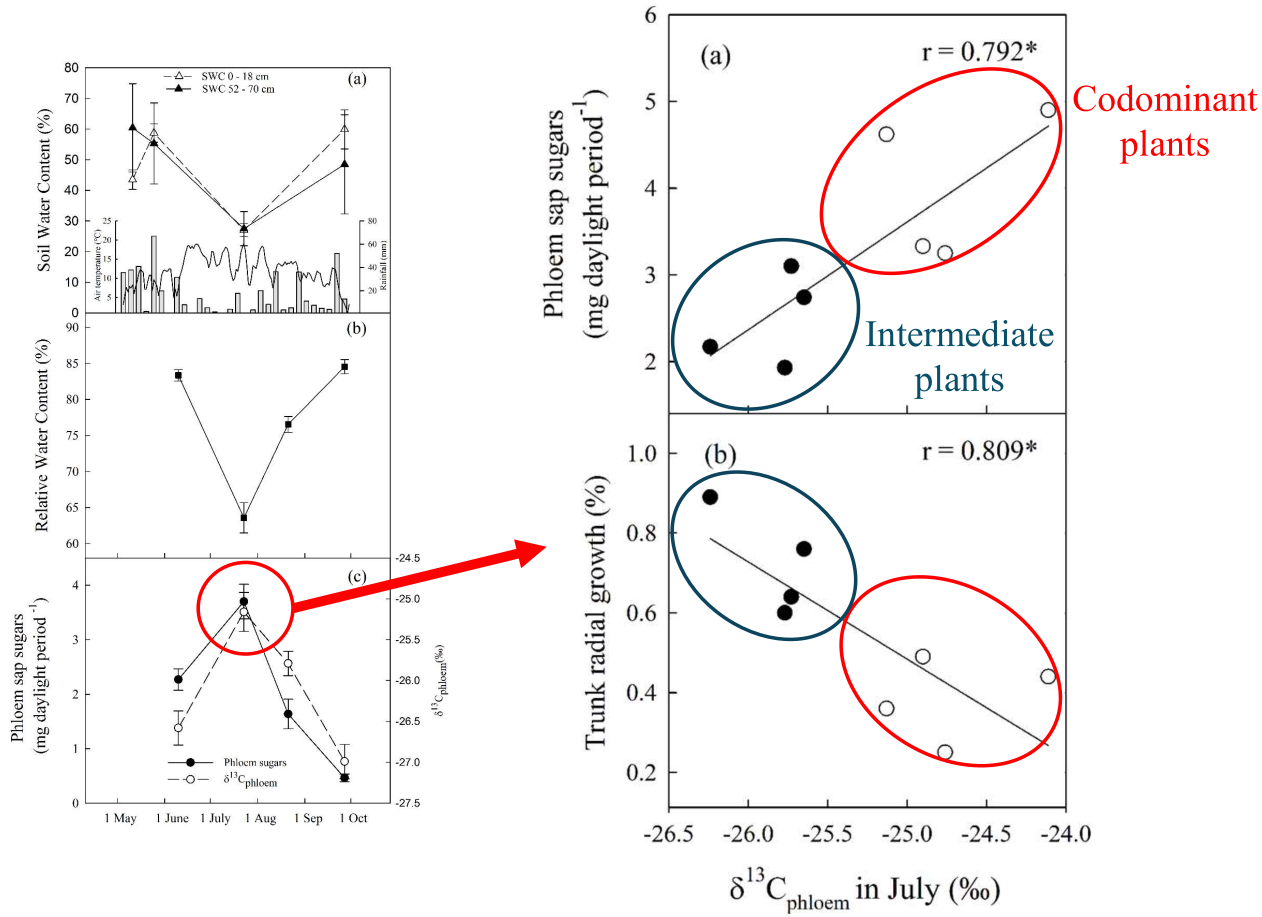
Relative Water Content (**RWC**)

Amount and δ^{13}C of phloem sap sugars ($\delta^{13}\mathbf{C}_{\mathbf{phloem}}$)

We observed a quite **parallel seasonal trend between δ^{13}C and the amount of phloem sap sugars**, with a seasonal peak in July for both of them, associated with a seasonal minimum of both **SWC** and **RWC**

Scartazza et al. (2015)

Sap sugar concentration and $\delta^{13}C$



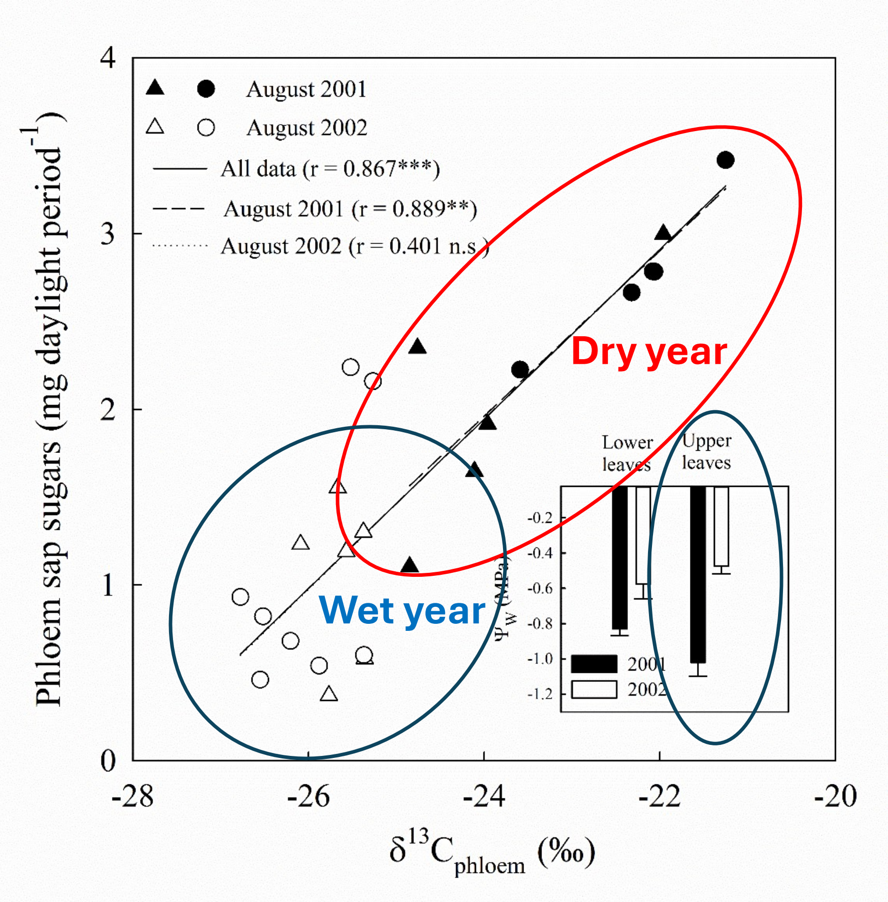
During July a significant inter-plant relationship between $\delta^{13}C$ and the amount of phloem sap sugars was detected depending on the social class

Plants showing a **higher ^{13}C enrichment of phloem sap sugars** (Codominant plants) were characterized also by a **higher amount of sap sugars** and a lower radial growth increment than the Intermediate plants

Possible sink limitation

Scartazza et al. (2015)

Sap sugar concentration and $\delta^{13}C$

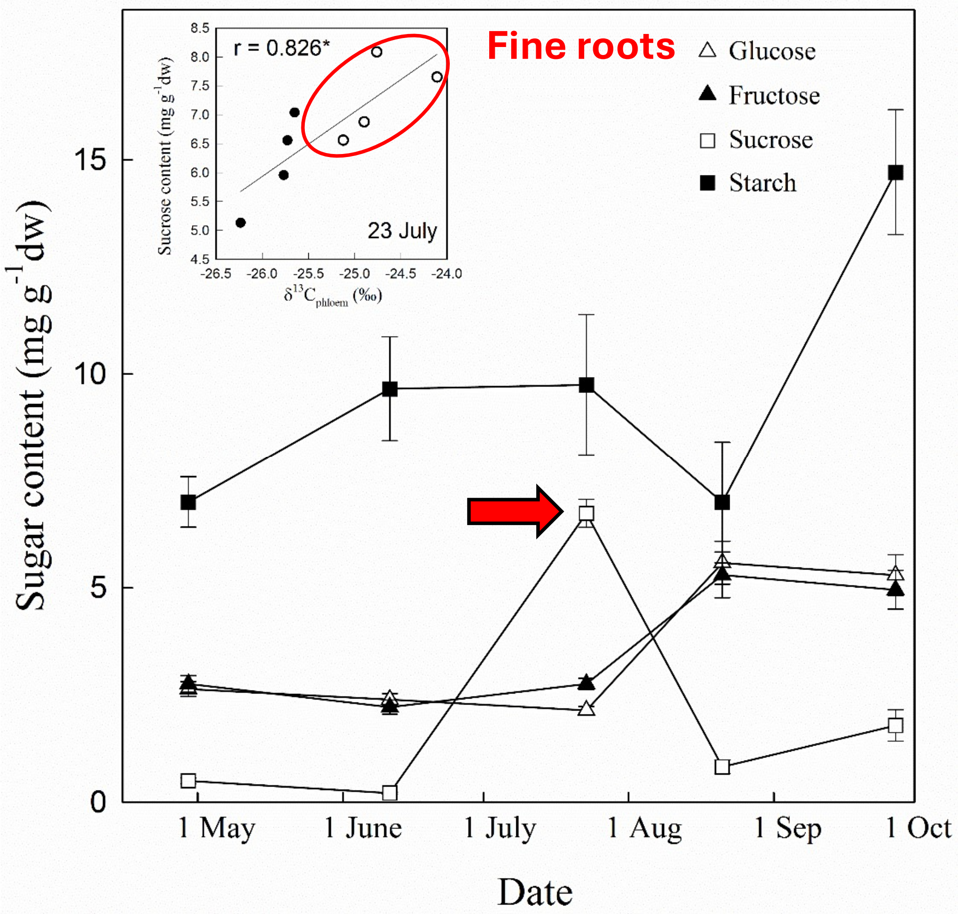


Between different years, **higher values of both $\delta^{13}C$ and the amount of phloem sap sugars** were recorded concurrently with **lower plant water potential** (August 2001 vs August 2002)

An increase of sap sugar concentration with decreasing plant water potential could **increase the osmotic potential in the phloem**, thereby maintaining turgor within sieve tubes **necessary for the transport of photosynthates towards sink organs**

Scartazza et al. (2015)

Sucrose transport to the root system



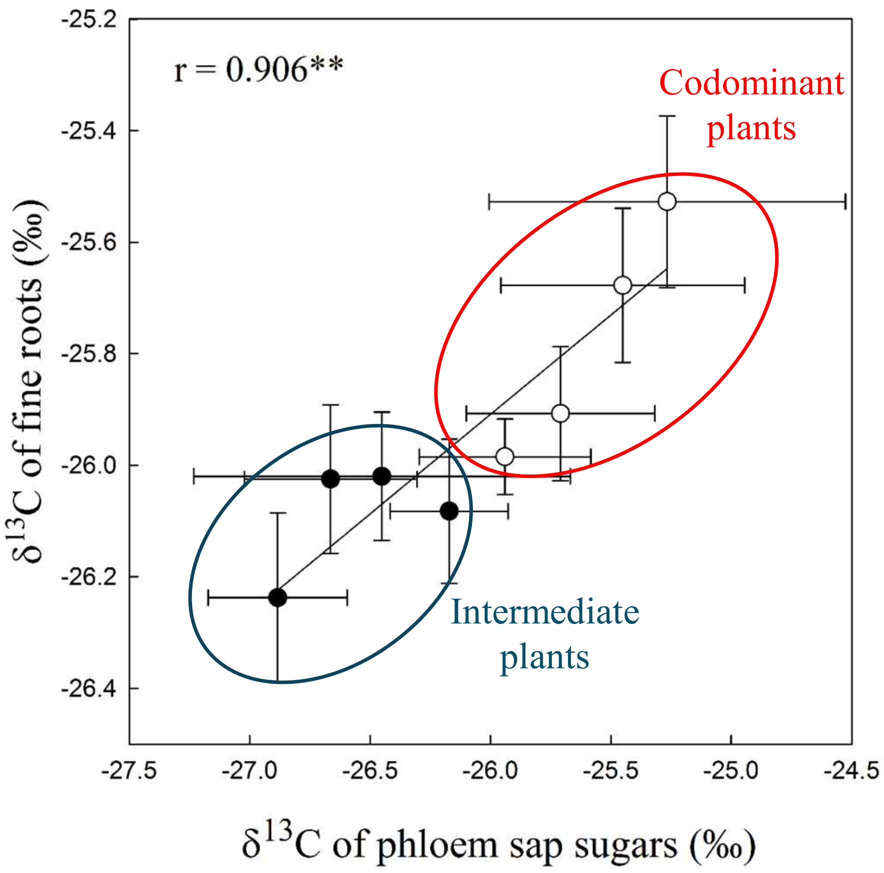
A seasonal peak of **sucrose** content in **fine roots** was observed during the relatively dry month of July

The amount of sucrose in fine roots varied among the analyzed trees and was **related to $\delta^{13}C_{phloem}$**

These results possibly indicate that phloem loading and transport of leaf sucrose was not impaired by mild drought and that this sugar was mainly transferred towards the fine roots in July, depending on social class and tree size

Scartazza et al. (2015)

Relationship between the mean seasonal value of δ13C of phloem sap sugars and the mean seasonal value of δ13C of fine roots in different plants of the Colellongo beech forest



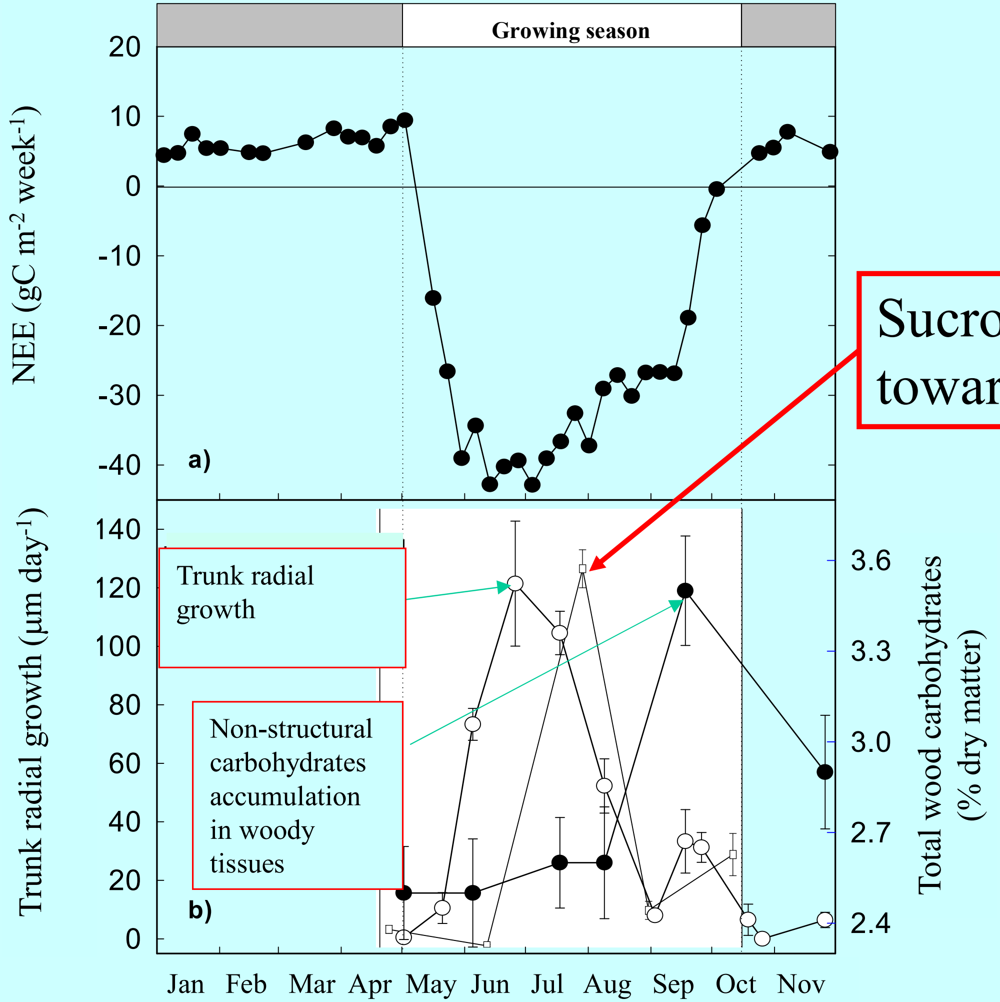
A positive relationship between $\delta^{13}C_{phloem}$ and $\delta^{13}C_{fine\ roots}$ was observed among intermediate and codominant trees

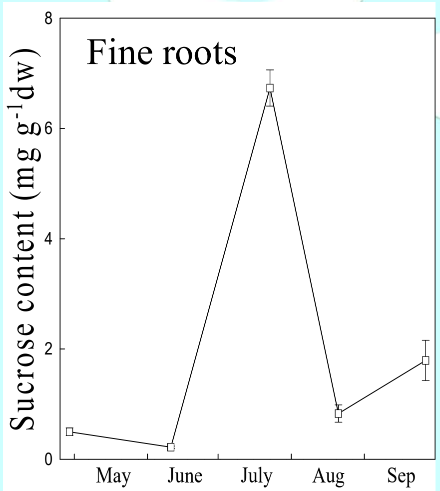
This suggests that: i) phloem sugars were in a large part allocated towards fine roots; ii) $\delta^{13}C_{fine\ roots}$ may represent a powerful proxy to detect inter-plant difference in Δ and **WUE** within this forest

Scartazza et al. (2015)

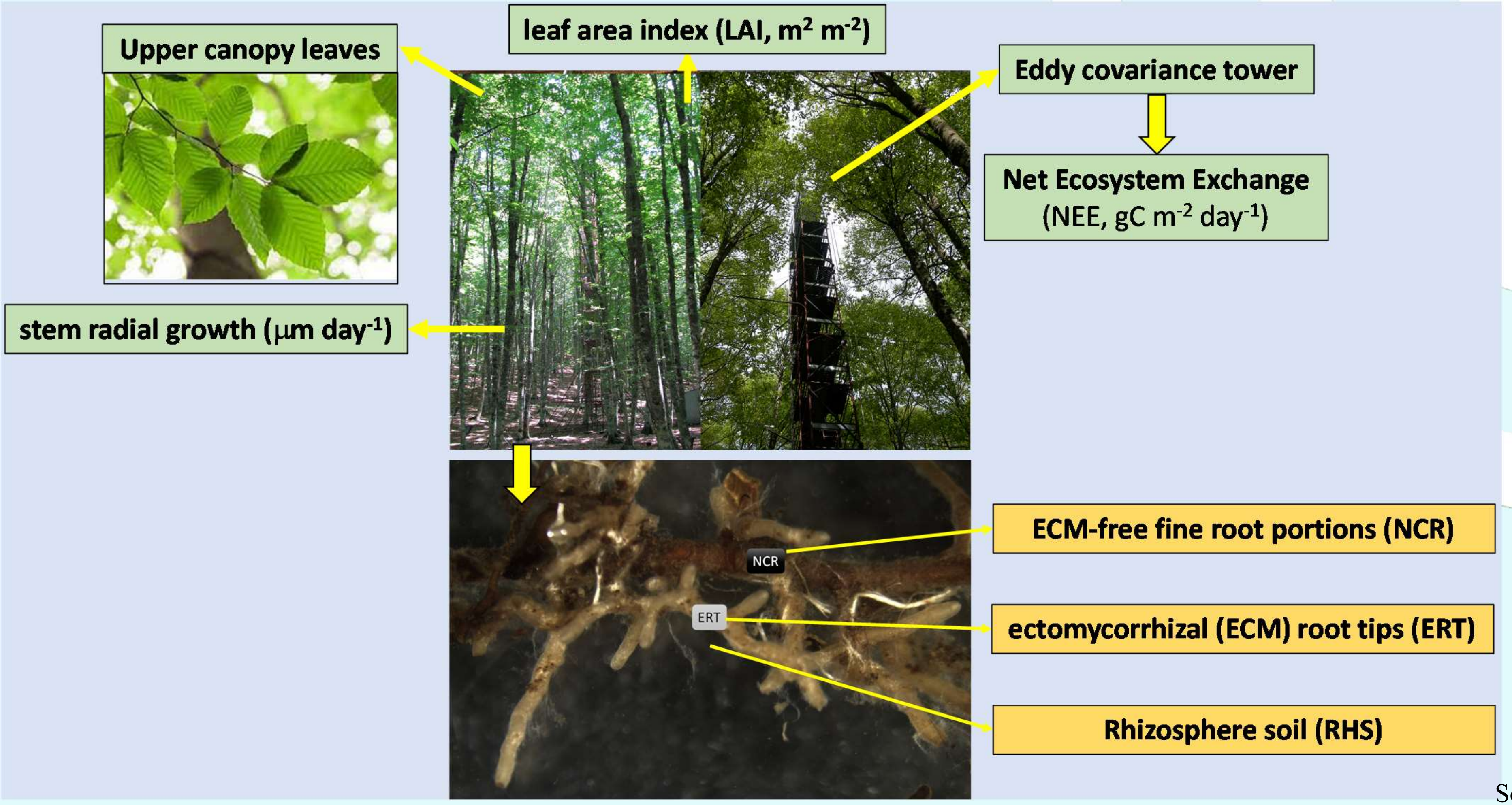
Scartazza et al., in press

Ecosystem C exchange and source-sink relationships





Carbon isotope fractionation between plant and mychorrizal fungi



Scartazza et al. (2023)

Seasonal variation of C uptake, stem growth, ectomychorrizal root tips and isotope composition of different soil-ECM-plant continuum

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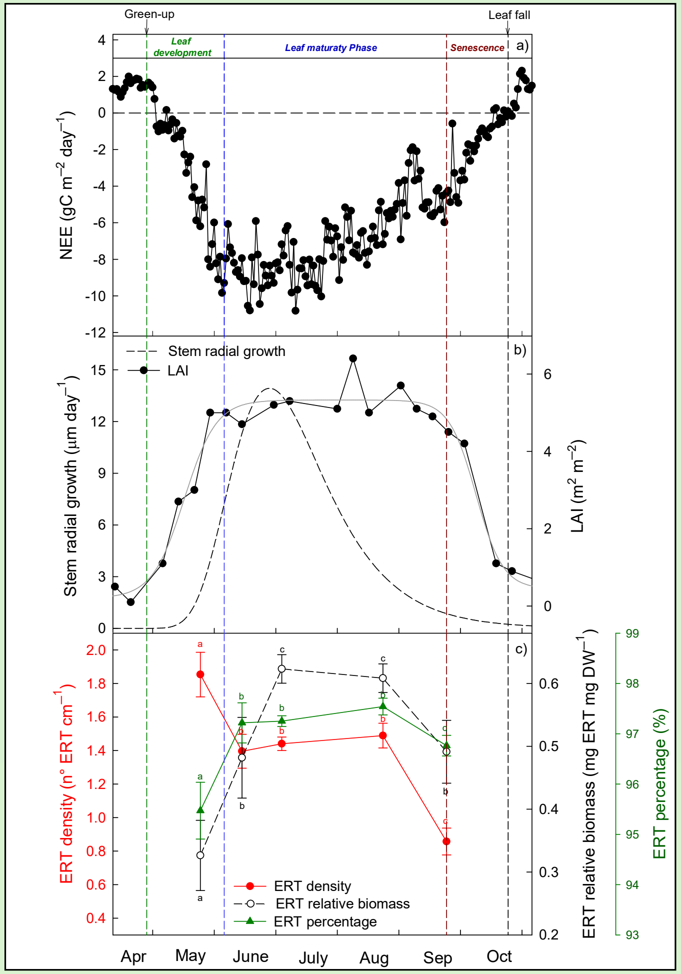

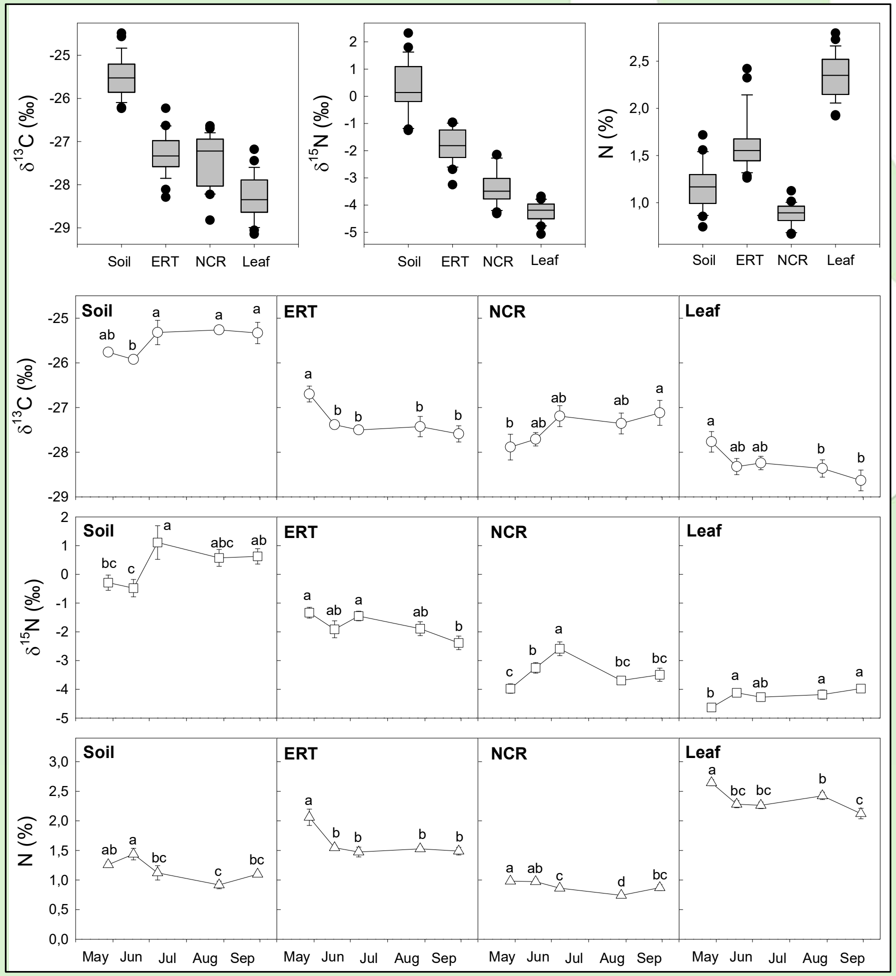

A synchronous seasonal pattern of ecosystem C uptake, stem radial growth and biomass accumulation in ectomycorrhizal root tips was recorded

$\delta^{13}C$, $\delta^{15}N$ and N varied depending on both the season and the plant-ECM-soil component analyzed

Scartazza et al. (2023)

Relationships between C and N isotope compositions of leaves and those of Ectomychorrizal Root Tips (ERT)

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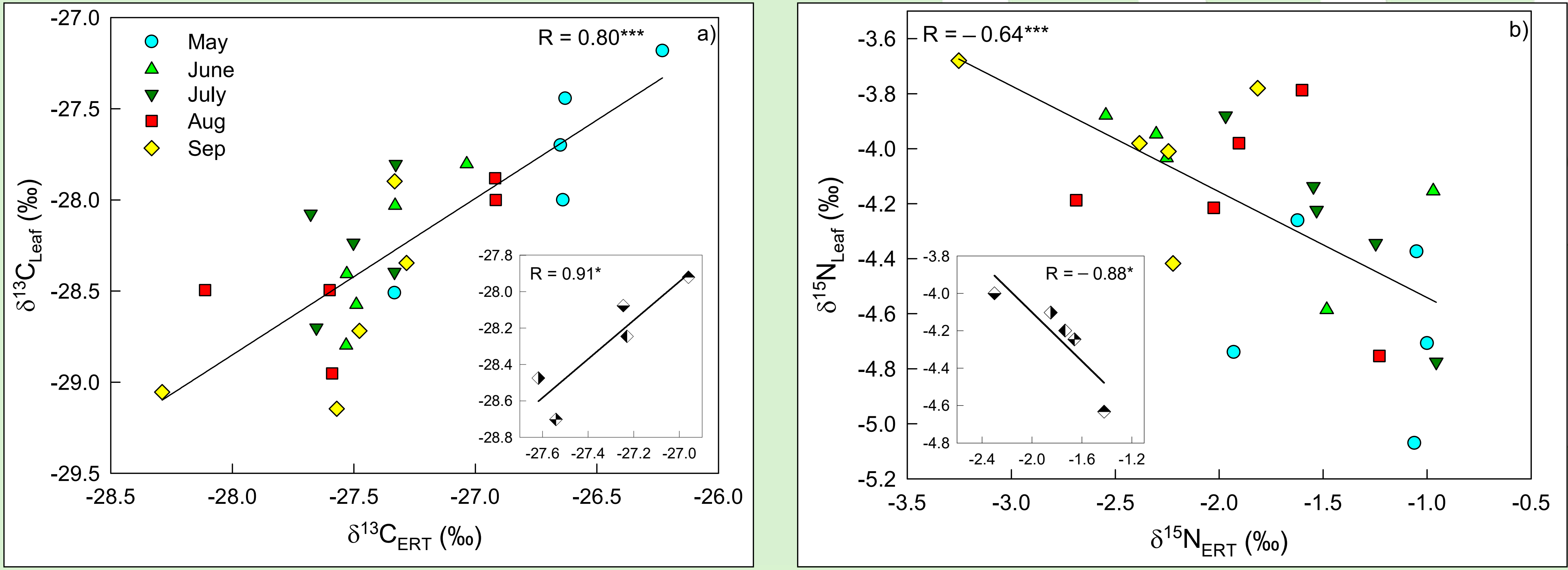
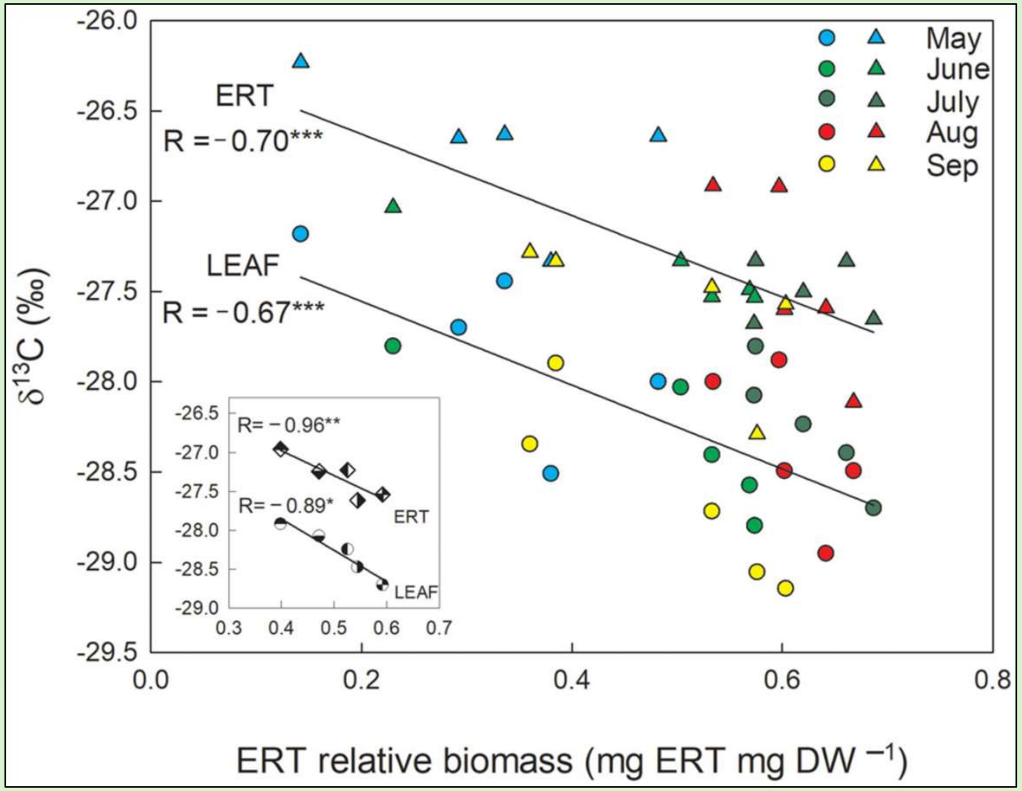


The isotope composition of ERT showed a positive ($\delta^{13}C$) and negative ($\delta^{15}N$) correlation with that of leaves

Scartazza et al. (2023)

Relationships between Ectomycorrhizal Root Tips (ERT) biomass and $\delta^{13}C$ of both Leaf and ERT



The insert reports the relationships for the individual trees

The significant relationship between **leaf $\delta^{13}C$** and **ERT relative biomass** indicates:

- a **greater ERT development** in plants showing a **higher photosynthetic C isotope discrimination** (i.e., a lower $\delta^{13}C$ of photosynthetic products)

and/or

- a possible **feedback effect of root colonization on leaf photosynthesis and C isotope discrimination**

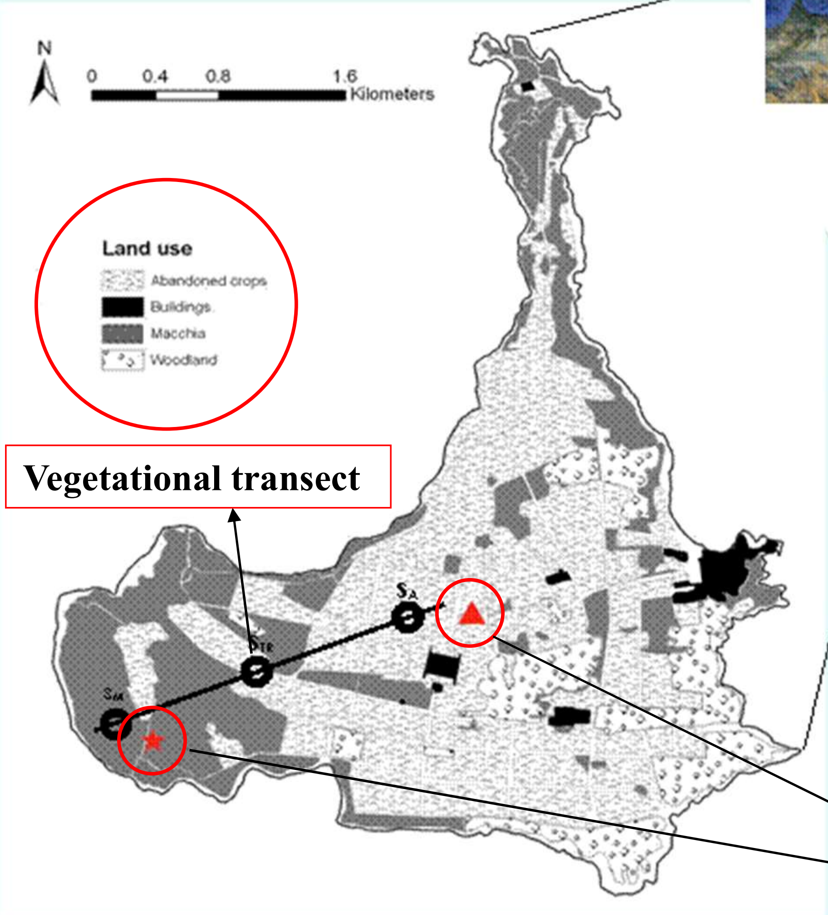
Scartazza et al. (2023)

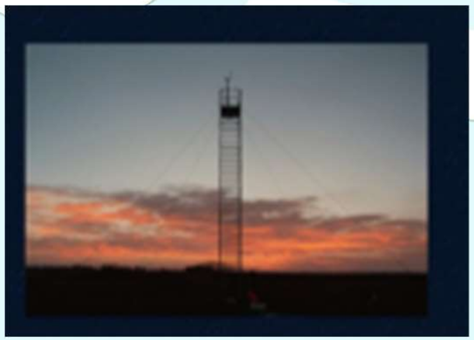
Carbon isotopes, land-use changes and water-use efficiency

PIANOSA ISLAND

Tuscan Archipelago National Park, Italy

Pianosa was a penal colony until the end of the 1990s, when the rural landscape was abandoned and the island entered in a slow and largely unmanaged process of re-naturalization





Scartazza et al. (2014)

Scartazza et al. (2014)

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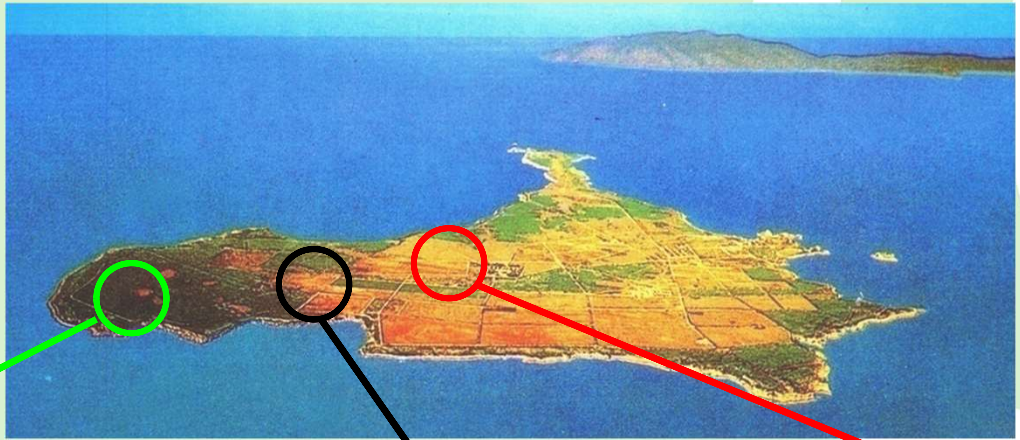
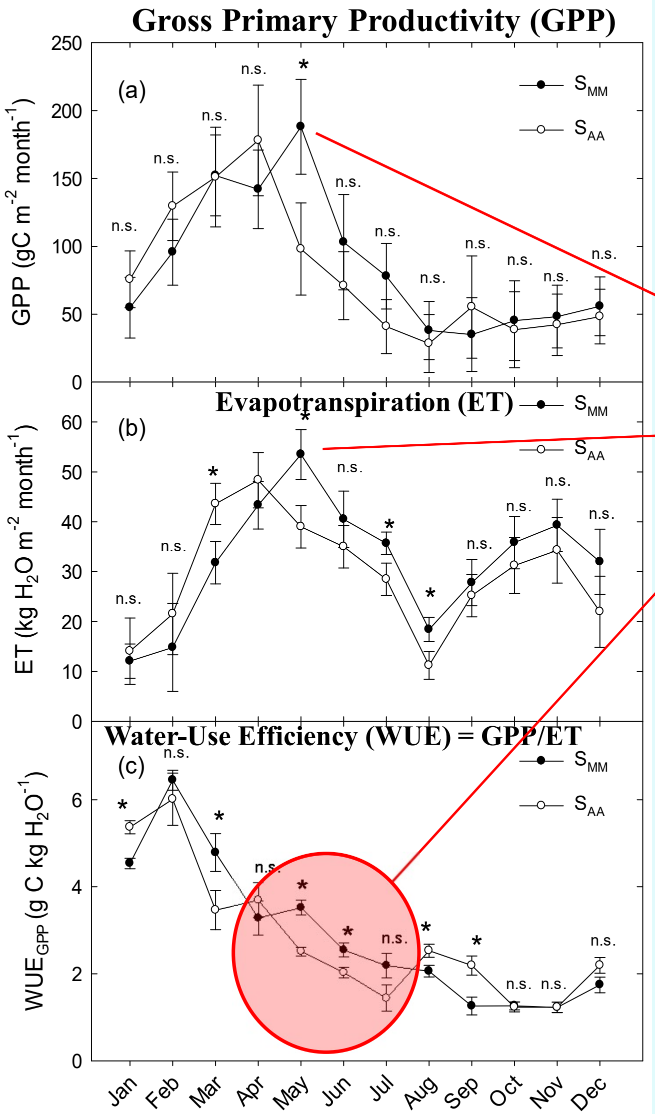


Mediterranean macchia

Transition site

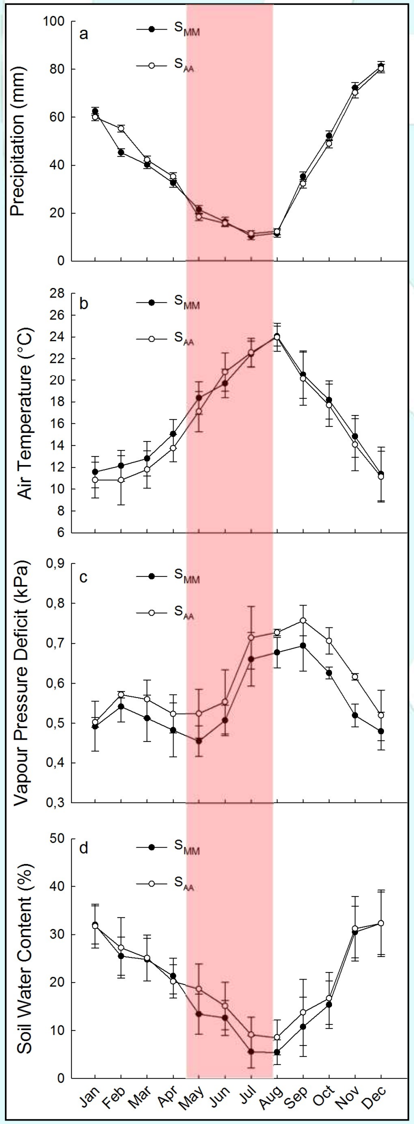
Abandoned agricultural site

Eddy-covariance data



Mediterranean Macchia Site (S_{MM})

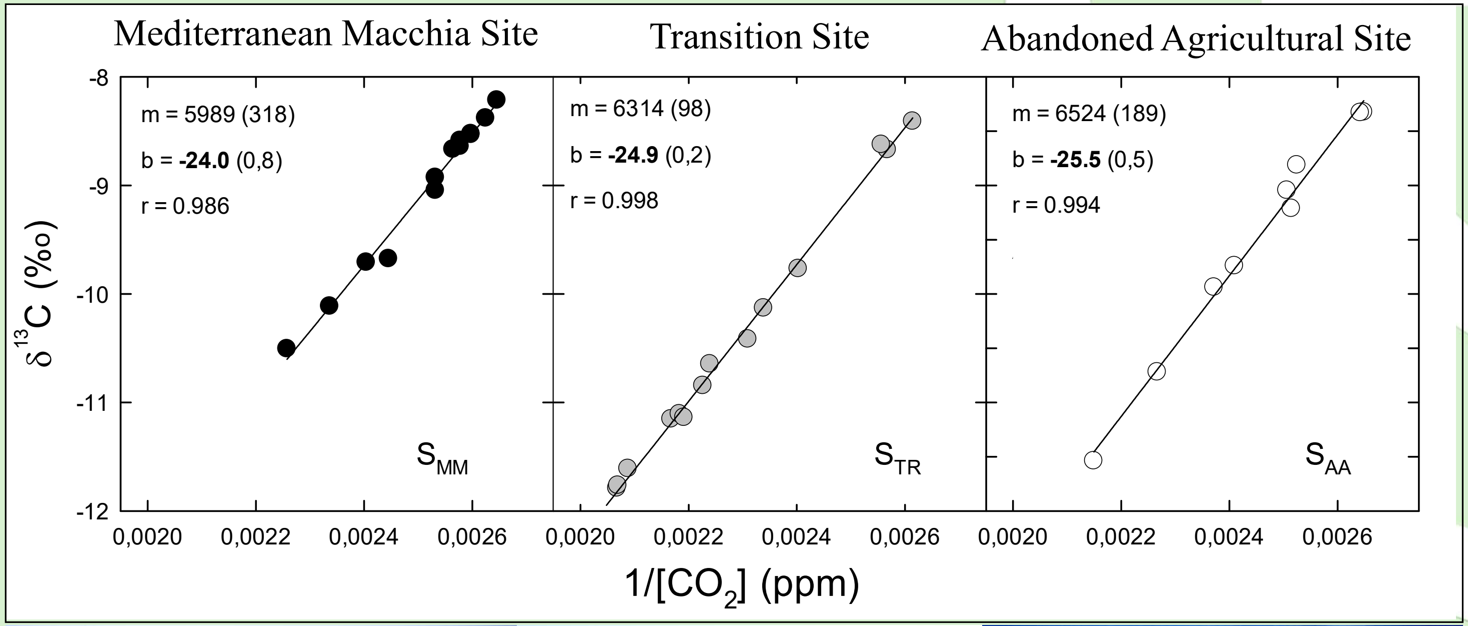
Abandoned Agricultural Site (S_{AA})

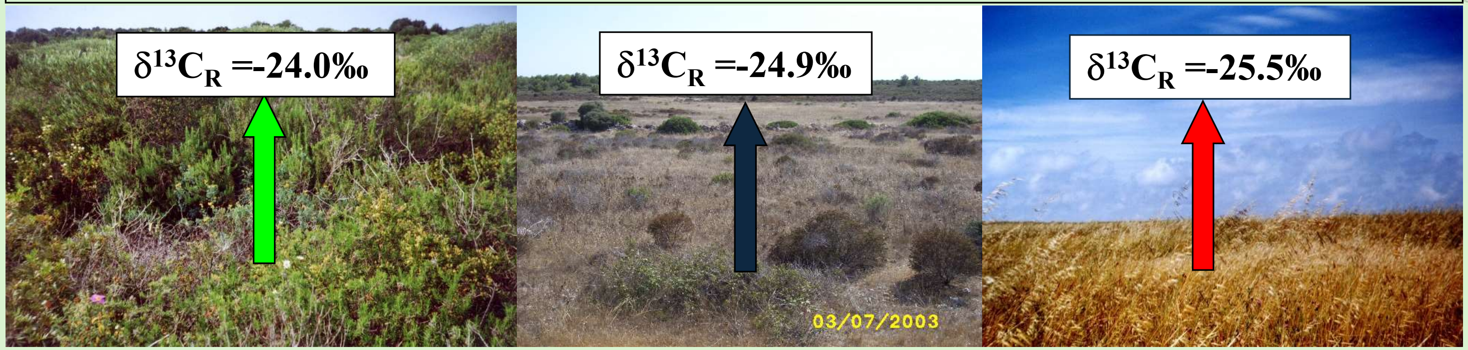


The Mediterranean macchia showed higher GPP, ET and WUE during spring-summer period compared to the abandoned agricultural field

Scartazza et al. (2014)

Nocturnal Keeling plots in different sites





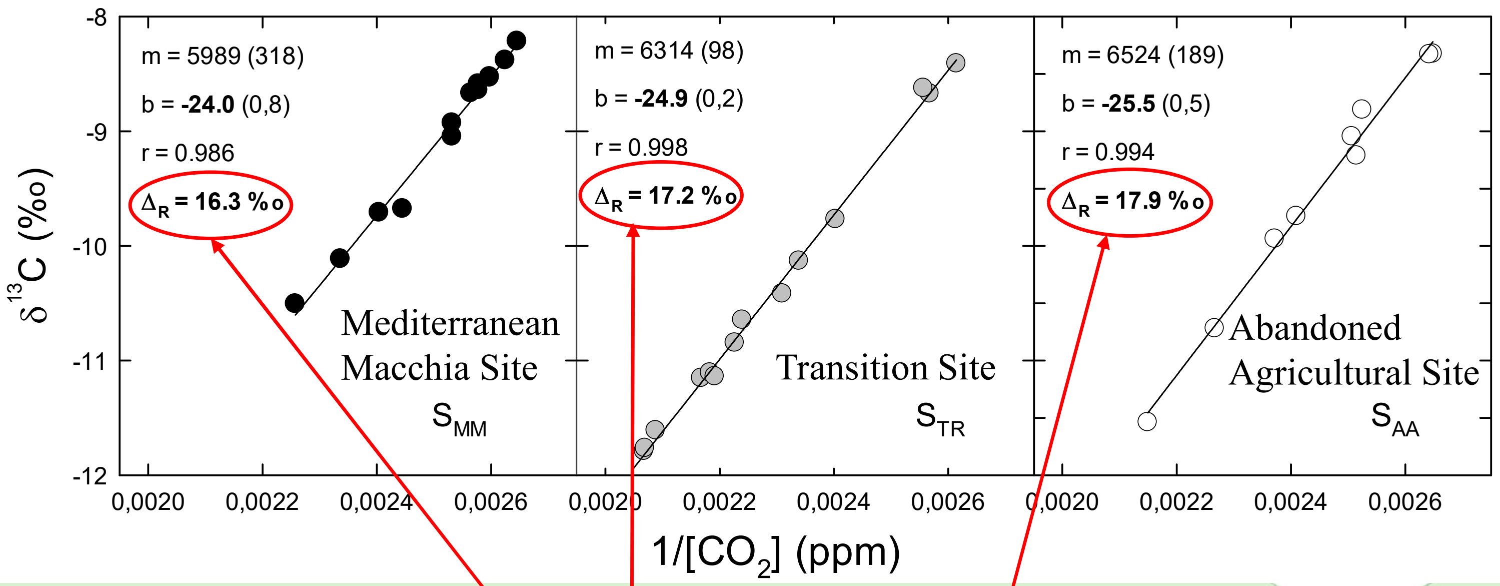
Scartazza et al. (2014)

Ecosystem C Isotope Discrimination (Δ_e)

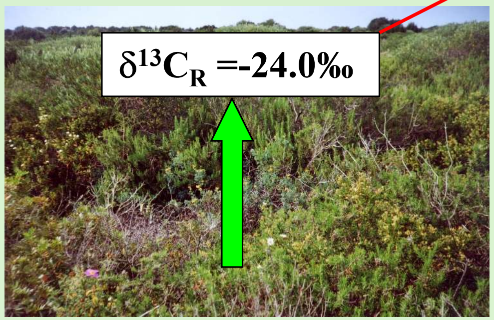
The **ecosystem C isotope discrimination** (Δ_e) is calculated as a function of the **$\delta^{13}C$ of ecosystem respired CO_2** ($\delta^{13}C_R$) determined by Keeling plot (Keeling 1958; 1951) and the **$\delta^{13}C$ of free troposphere CO_2** ($\delta^{13}C_{trop}$) through the following equation (Buchmann et al., 1998):

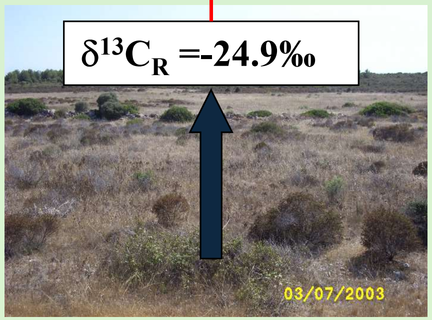
$$\Delta_e = (\delta^{13}C_{trop} - \delta^{13}C_R)/(1 + \delta^{13}C_R)$$

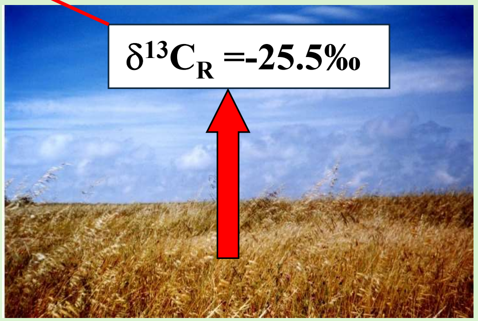
Ecosystem C Isotope Discrimination (Δ_{eco})



$$\Delta eco = \frac{\delta^{13}C_{trop} - \delta^{13}C_R}{1 + \delta^{13}C_R}$$







Scartazza et al. (2014)

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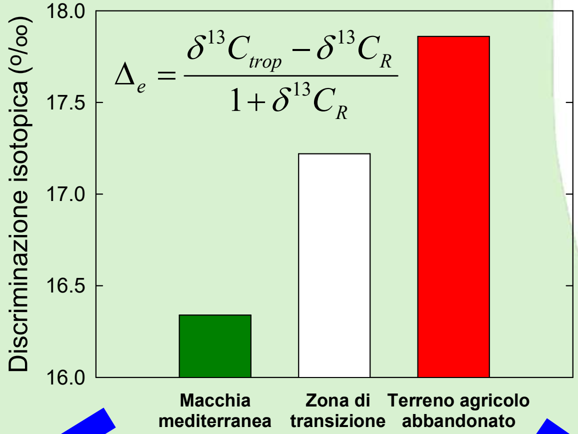
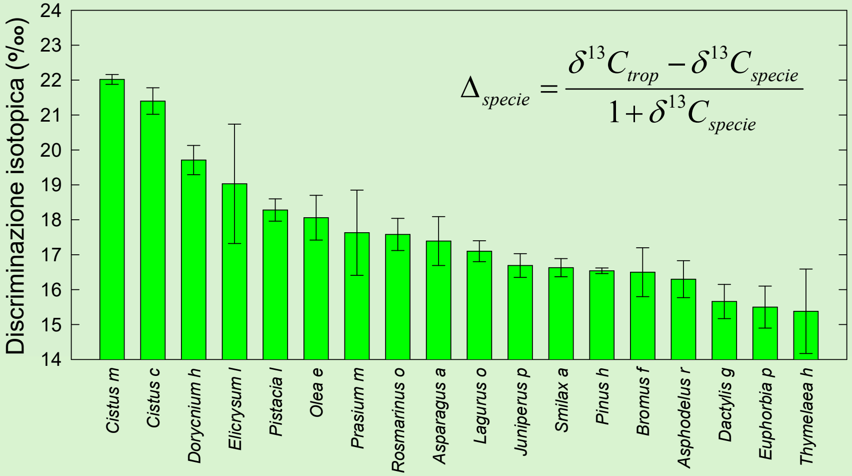
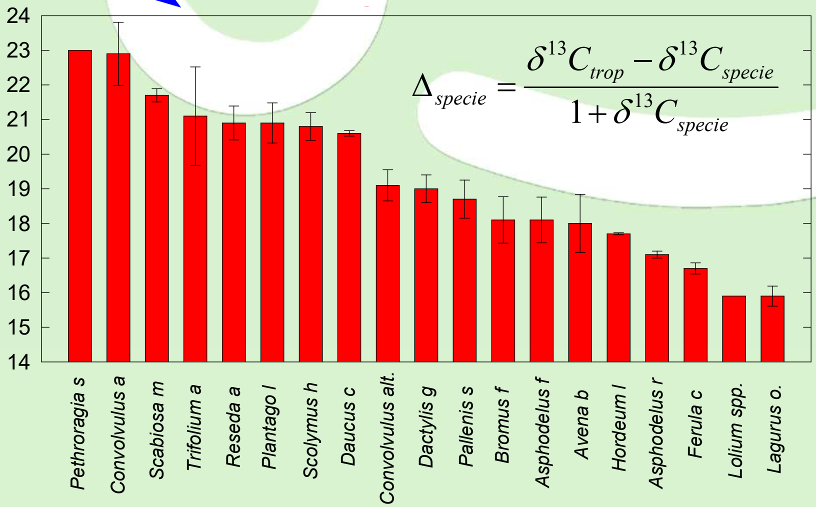




Mediterranean macchia

-WUE

+Δ



Abandoned Agricultural Site

Life forms	Species	Family	Sub-forms	Site
Phanerophyta (P)	*Juniperus phoenicea* L.	*Cupressaceae*	P caesp	S_{MM}
	Olea europea L. var. *sylvestris* Brot.	*Oleaceae*	P caesp	S_{MM}
	Pinus halepensis Mill.	*Pinaceae*	P scap	S_{MM}
	Pistacia lentiscus L.	*Anacardiaceae*	P caesp	S_{MM} – S_{TR}
	Rubus ulmifolius Schott	*Rosaceae*	P lian	S_{TR}
	Smilax aspera L.	*Liliaceae*	P lian	S_{MM}
Nano-phanerophyta (NP)	*Cistus creticus* L. subsp. *eriocephalus* (Viv.) Greuter & Burdet	*Cistaceae*	NP	S_{MM}
	Cistus monspeliensis L.	*Cistaceae*	NP	S_{MM} – S_{TR}
	Rosmarinus officinalis L.	*Labiatae*	NP	S_{MM}
	Thymelaea hirsuta (L.) Endl.	*Thymeleaceae*	NP	S_{MM}
Chamaephyta (Ch)	*Dorycnium hirsutum* (L.) Ser.	*Leguminosae*	Ch suffr	S_{MM}
	Euphorbia pinea L.	*Euphorbiaceae*	Ch suffr	S_{MM} – S_{AA} – S_{TR}
	Helichrysum litoreum Guss.	*Compositae*	Ch suffr	S_{MM}
	Prasium majus L.	*Labiatae*	Ch suffr	S_{MM}
Geophyta (G)	*Asphodelus ramosus* L.	*Liliaceae*	G rhiz	S_{MM} – S_{AA} – S_{TR}
	Convolvulus arvensis L.	*Convolvulaceae*	G rhiz	S_{AA}
Hemicryptophyta (Hc)	*Asphodelus fistulosus* L.	*Liliaceae*	Hc scap	S_{AA}
	Bituminaria bituminosa (L.) C. H. Stirt	*Leguminosae*	Hc scap	S_{TR}
	Brachipodium plukenetii (All.) P. Beauv.	*Gramineae*	Hc caesp	S_{TR}
	Convolvulus althaeoides L.	*Convolvulaceae*	Hc scand	S_{AA}– S_{TR}
	Dactylis glomerata L.	*Gramineae*	Hc caesp	S_{MM} – S_{AA} – S_{TR}
	Daucus carota L.	*Umbelliferae*	Hc bienn	S_{AA} – S_{TR}
	Lolium multiflorum Lam.	*Gramineae*	Hc scap	S_{AA}
	Onopordum Illyricum L.	*Compositae*	Hc bienn	S_{TR}
	Petrorhagia saxifraga (L.) Link	*Caryophyllaceae*	Hc caesp	S_{AA}
	Plantago lanceolata L.	*Plantaginaceae*	Hc ros	S_{AA} – S_{TR}
	Scabiosa maritima L.	*Dipsacaceae*	Hc bienn	S_{AA} – S_{TR}
	Scolymus hispanicus L.	*Compositae*	Hc bienn	S_{AA} – S_{TR}
	Thapsia garganica L.	*Umbelliferae*	Hc scap	S_{TR}
Therophyta (Th)	*Avena barbata* Pott.ex Link	*Gramineae*	Th scap	S_{AA} – S_{TR}
	Bromus fasciculatus Presl	*Gramineae*	Th scap	S_{MM} – S_{AA} – S_{TR}
	Hordeum leporinum Link	*Gramineae*	Th scap	S_{AA}
	Lagurus ovatus L.	*Gramineae*	Th scap	S_{MM} – S_{AA} – S_{TR}
	Pallenis spinosa (L.) Cass.	*Compositae*	Th scap	S_{AA}
	Reseda alba L.	*Resedaceae*	Th scap	S_{AA}
	Trifolium angustifolium L.	*Leguminosae*	Th scap	S_{AA}

Raunkiaer life form classification system based on location of the perennating bud.

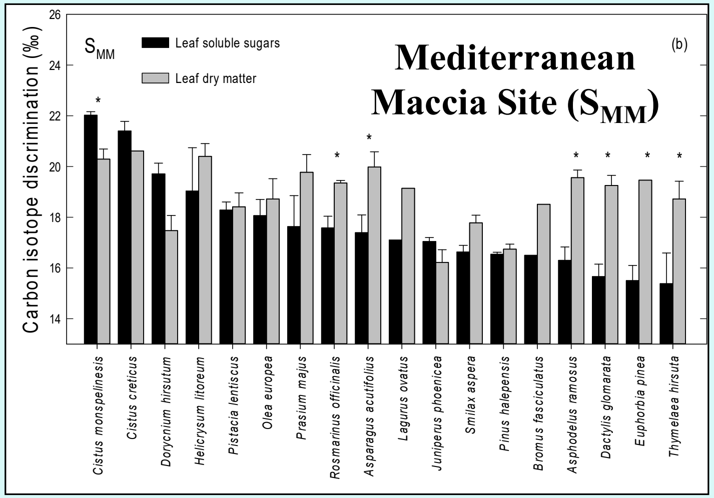
Life form	Location of perennating tissue	Plant types
Phanerophyte	*>0.5 m*	Trees and tall shrubs
Chamaephyte	0 - 0.5 m	Small shrubs and herbs
Hemicryptophyte	Soil surface	Prostrate shrubs or herbaceous plants that dieback each year
Cryptophyte	In the soil	Rhizomatous grasses or bulb forming herbs
Therophyte	Seed	Annuals

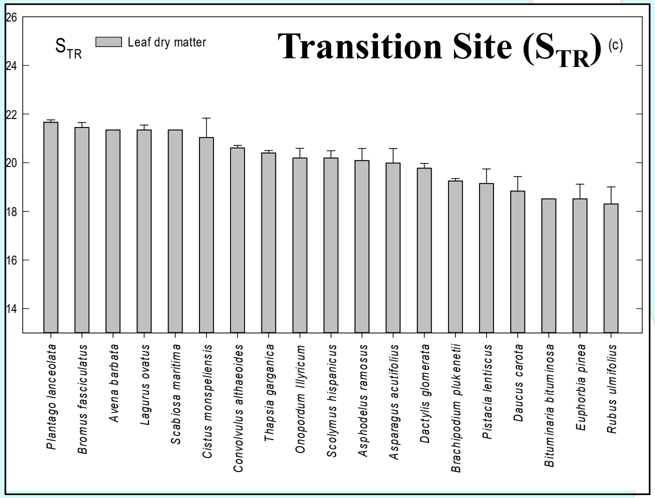
The abandoned agricultural site (S_{AA}) is colonized mainly by herbaceous annual species (Therophytes) which complete their vegetative cycle before the onset of the harsh summer conditions

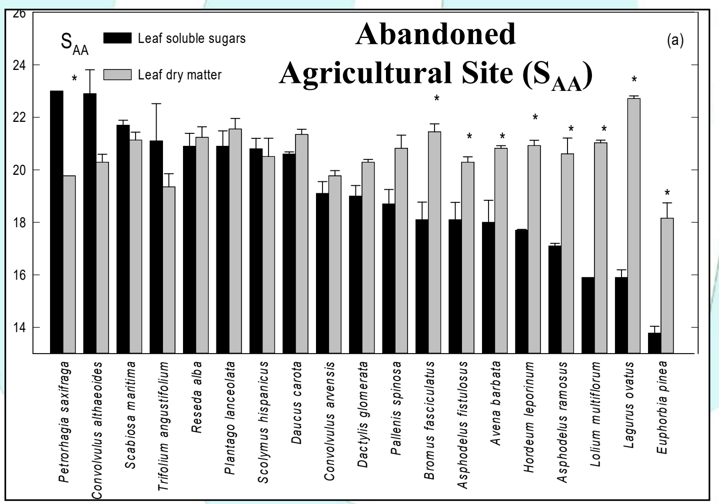
The Mediterranean macchia site (S_{MM}) is dominated by woody perennial species (Phanerophyta, Nano-phanerophyta and Chamaephyta)

The Transition site (S_{TR}) showed a progressive increase of the herbaceous and woody perennial species and a decrease of the annual herbaceous species (Therophytes)

Scartazza et al. (2014)







	Species abundance (%)			Δ_{dm} (‰) – Leaf Dry Matter -			Δ_{ss} (‰) – Leaf Soluble Sugars-	
Life forms	S_{MM}	S_{AA}	S_{TR}	S_{MM}	S_{AA}	S_{TR}	S_{MM}	S_{AA}
Phanerophyta	27.8	0	10.5	17.6 ± 0.3 (h)	-	18.7 ± 0.5 (fg)	17.3 ± 0.2 (bc)	-
Nano-phanerophyta	22.2	0	5.3	19.8 ± 0.3 (c-e)	-	21.0 ± 0.8 (a-d)	19.5 ± 0.9 (ab)	-
Chamaephyta	22.2	5.3	5.3	19.4 ± 0.5 (e-g)	18.2 ± 0.3 (gh)	18.0 ± 0.3 (gh)	18.4 ± 0.8 (bc)	13.8 ± 0.6 (d)*
Geophyta	11.1	10.5	10.5	19.8 ± 0.3 (c-f)	20.2 ± 0.4 (c-e)	20.3 ± 0.4 (b-e)	16.9 ± 0.4 (bc)*	18.1 ± 0.5 (bc)*
Hemicryptophyta	5.6	47.4	52.6	19.2 ± 0.4 (e-g)	20.7 ± 0.2 (a-d)	20.0 ± 0.2 (c-e)	15.7 ± 0.5 (cd)*	20.5 ± 0.4 (a)
Therophyta	11.1	36.8	15.8	18.8 ± 0.3 (e-h)	21.1 ± 0.2 (ab)	21.4 ± 0.1 (a)	16.8 ± 0.3 (b-d)*	18.6 ± 0.5 (b)*
Weighted-mean Δ value (Δ_{eco}, ‰)				19.0 ‰	20.7 ‰	20.1 ‰	17.8 ‰	19.2 ‰

$$\Delta_{eco} = (\Delta_{P} P + \Delta_{NP} NP + \Delta_{Ch} Ch + \Delta_{G} G + \Delta_{Hc} Hc + \Delta_{Th} Th)/(P + NP + Ch + G + Hc + Th)$$

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WUE of May determined by Eddy Covariance technique →

Ecosystem-integrated values of Δ

$C_i/C_a = (\Delta - a)/(b - a)$

WUE estimated from isotopic methods

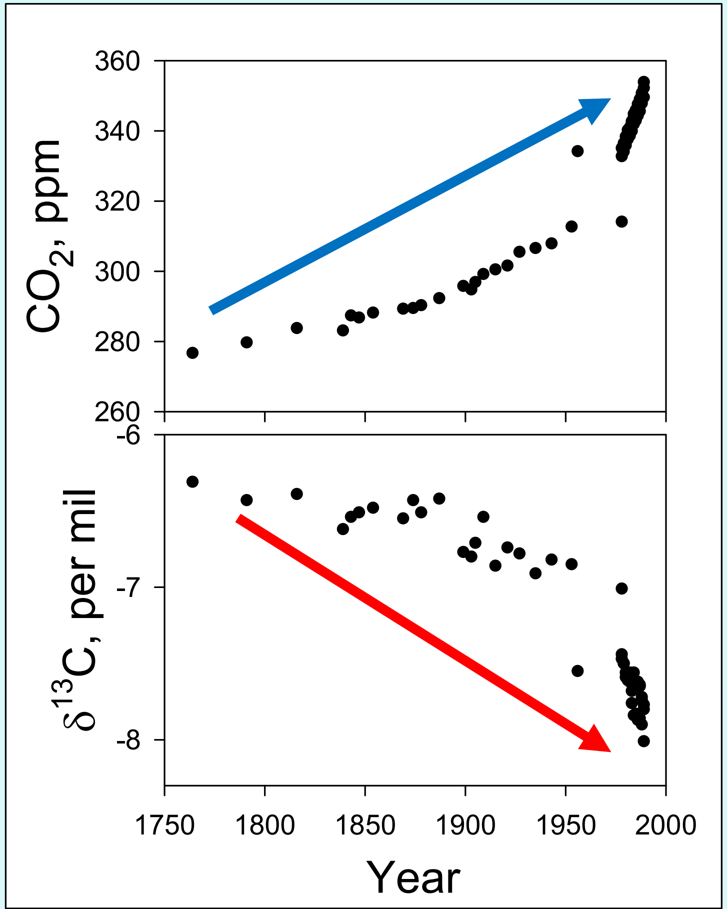
$\mathbf{WUE} = C_a(1 - C_i/C_a)/1.6\mathrm{VPD}$

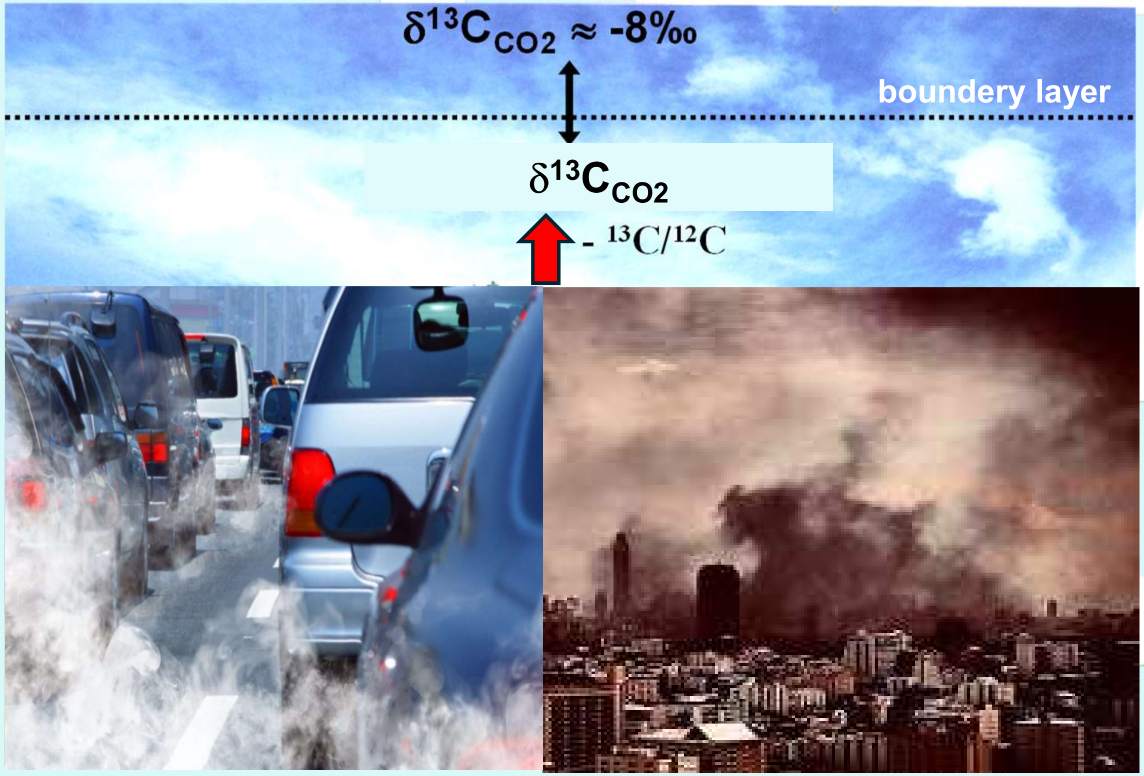
	ECOSYSTEM TYPE		
	S_{MM}	S_{TR}	S_{AA}
EC-WUE (May) - mmol mol^{-1}	5.5 ± 0.3		3.8 ± 0.4
Δ_R (from ecosystem respiration)	16.3 ‰	17.2 ‰	17.9 ‰
Δ_{eco} (from leaf dry matter)	19.0 ‰	20.1 ‰	20.7 ‰
Δ_{eco} (from leaf soluble sugars)	17.8 ‰	-	19.2 ‰
C_i/C_a (ecosystem respiration)	0.527	0.566	0.597
C_i/C_a (leaf dry matter)	0.646	0.695	0.721
C_i/C_a (leaf soluble sugars)	0.593	-	0.655
Iso-WUE$_R$ (ecosystem repiration)	6.3	5.4	4.7
Iso-WUE$_{dm}$ (leaf dry matter)	4.7	3.8	3.3
Iso-WUE$_{ss}$ (leaf soluble sugars)	5.4	-	4.1

Scartazza et al. (2014)

Carbon isotopes in urban environment

Time course of atmospheric CO_2 concentration and $\delta^{13}C$





- δ^{13}**C** of atmospheric CO_2 **decreases with increasing anthropogenic CO_2 emissions**
- In urban environments, a **decrease in δ^{13}C** has been observed in **tissues of plants grown near fossil fuel CO_2 sources**

Carbon isotopes in urban environment

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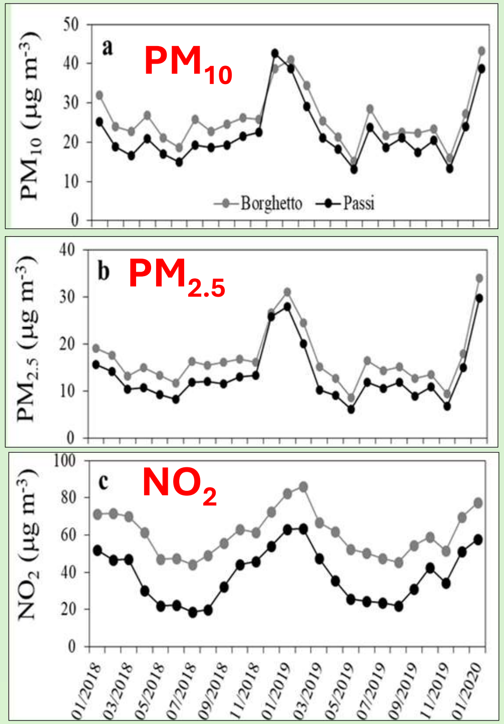
Urban-periurban transect (Pisa)

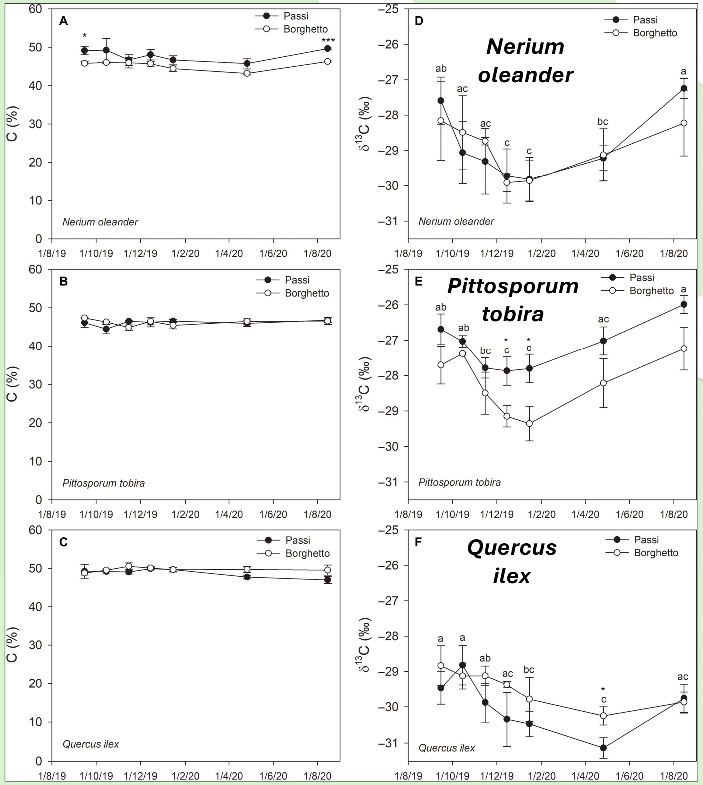
Passi (periurban)

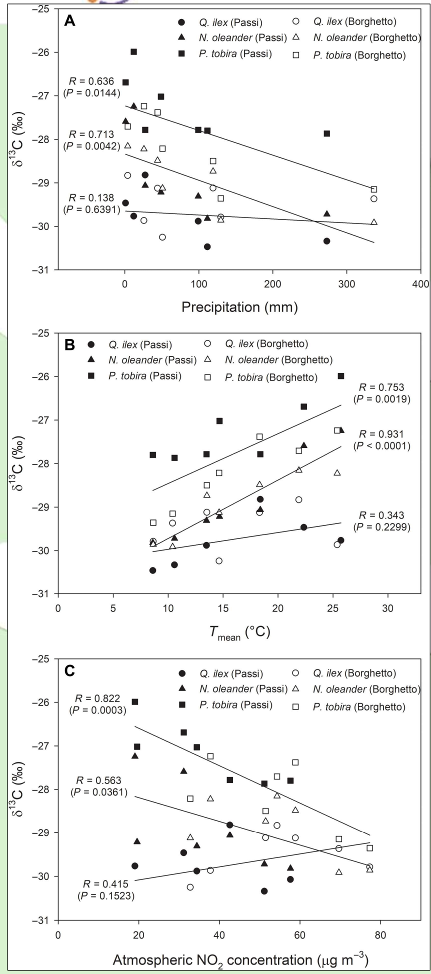
Borghetto (urban)

Air quality (Data: ARPAT)



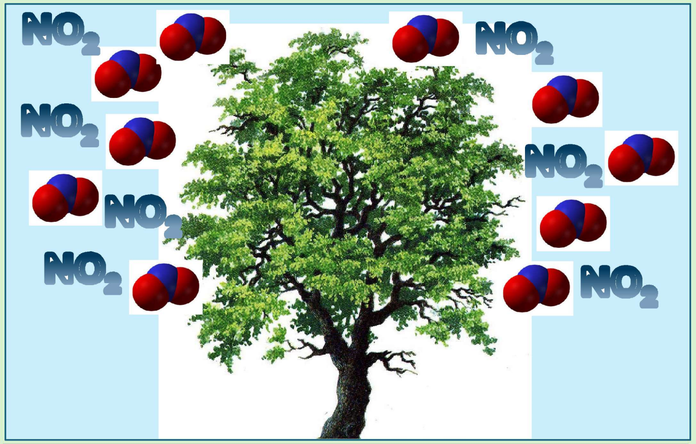
Leaf C concentration and $\delta^{13}C$



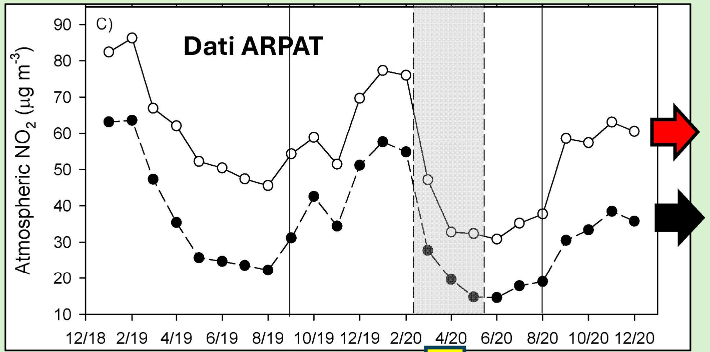


Scartazza et al. (2023)

Nitrogen isotopes in urban environment



Concentrazione atmosferica di NO_2



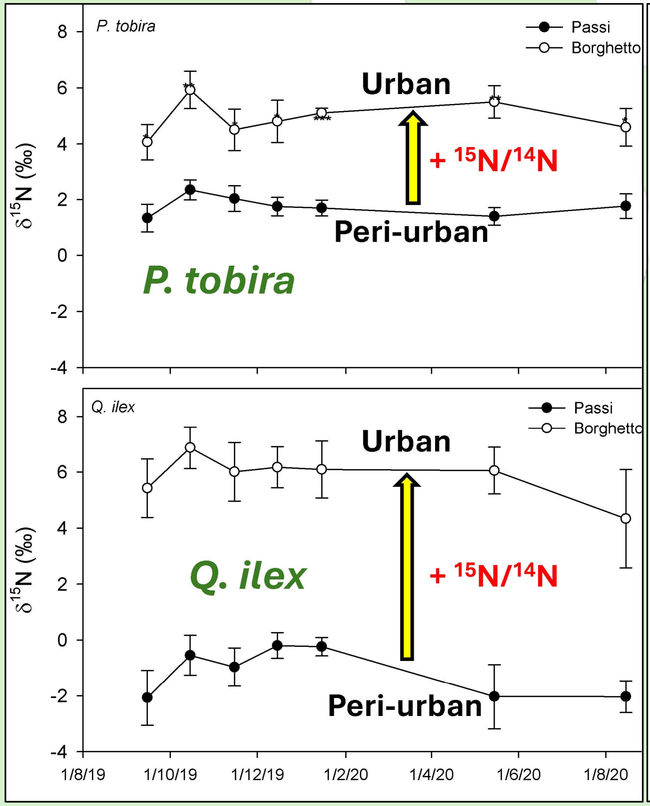
Lockdown

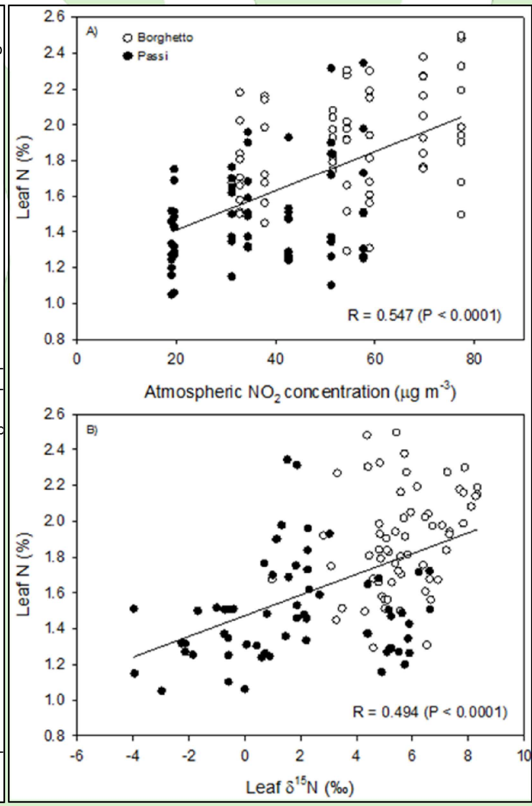
Borghetto (urban)

Passi (peri-urban)

^{14}N	^{15}N
14.00307	15.0001
99.63%	0.37%
Stable	Stable

$$\delta^{15}\text{N (per mil)} = \left[\frac{\left[\frac{^{15}\text{N}}{^{14}\text{N}}\right]_{\text{sample}}}{\left[\frac{^{15}\text{N}}{^{14}\text{N}}\right]_{\text{reference}}} - 1 \right] \times 1000$$





Scartazza et al. (2023)

Carbon isotopes in urban environment

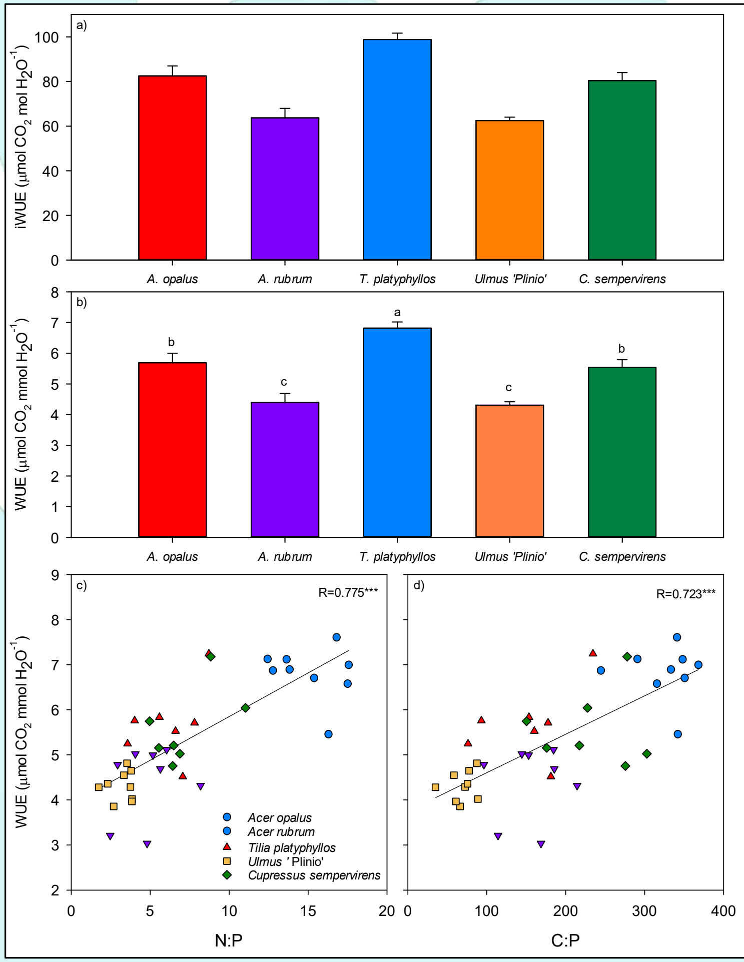
Species	δ_p (‰)
Acer opalus	-27.7 ± 0.4 b
Acer rubrum	-29.3 ± 0.4 c
Tilia platyphyllos	-26.3 ± 0.2 a
Ulmus Plinio	-29.4 ± 0.1 c
Cupressus sempervirens	-27.9 ± 0.4 b

$$\Delta = (\delta_a - \delta_p)/(1 + \delta_p)$$

$$C_i/C_a = (\Delta - a)/(b - a)$$

$$\textbf{iWUE} = A/g_s = C_a(1 - C_i/C_a)/1.6$$

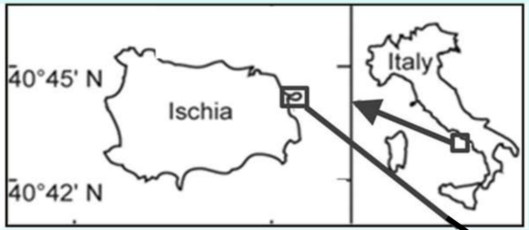
$$\textbf{WUE} = A/E = iWUE/VPD$$

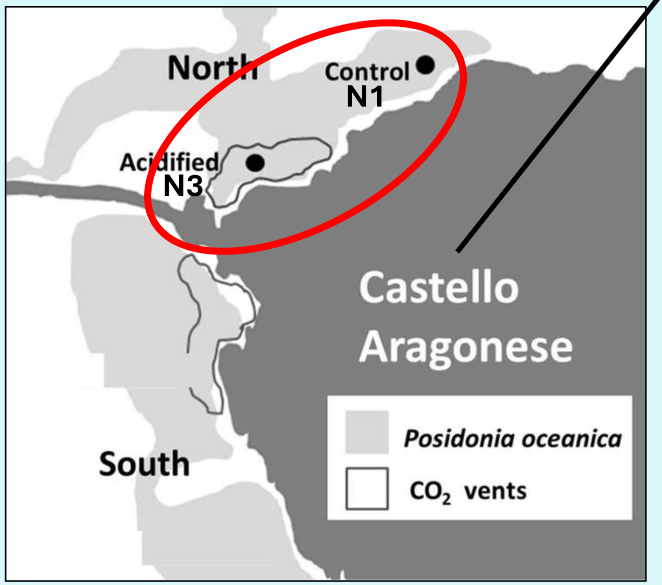


Scartazza et al. (2025)

Nutrient interaction in the soil-plant system affects C isotope discimination and water-use efficiency in an urban green infrastructure

Carbon isotopes in seagrassess meadows





Scartazza et al. (2017)

Effects of long-term exposure to naturally increased seawater CO_2 and reduced pH on **concentration and isotopic composition of structural and non-structural C compounds** in above- and below-ground organs of *P. oceanica* in a natural CO_2 vent system

The acidified station N3 fell below pH 8.00 (assumed as a threshold value for seawater acidification) during 55% of the sampling period 2011-2013

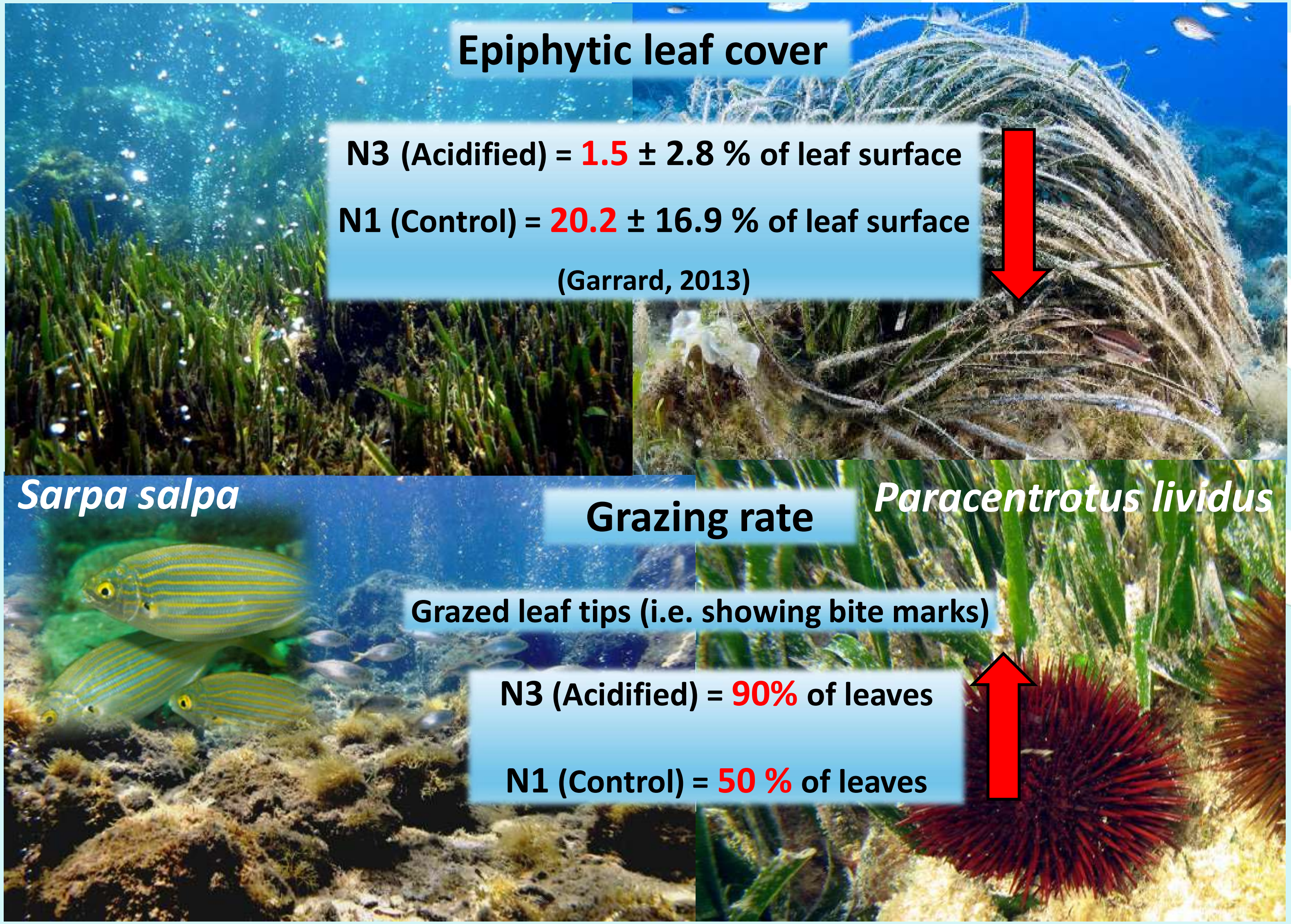
Station	pH_{NBS}	pCO_2 (µatm)
N1 (Control)	8.13 ± 0.05	509 ± 54
N3 (Acidified)	7.82 ± 0.31	2158 ± 2508

Epiphytic leaf cover

N3 (Acidified) = 1.5 ± 2.8 % of leaf surface

N1 (Control) = 20.2 ± 16.9 % of leaf surface

(Garrard, 2013)



Grazing rate

Grazed leaf tips (i.e. showing bite marks)

N3 (Acidified) = 90% of leaves

N1 (Control) = 50 % of leaves

CARBON METABOLITES

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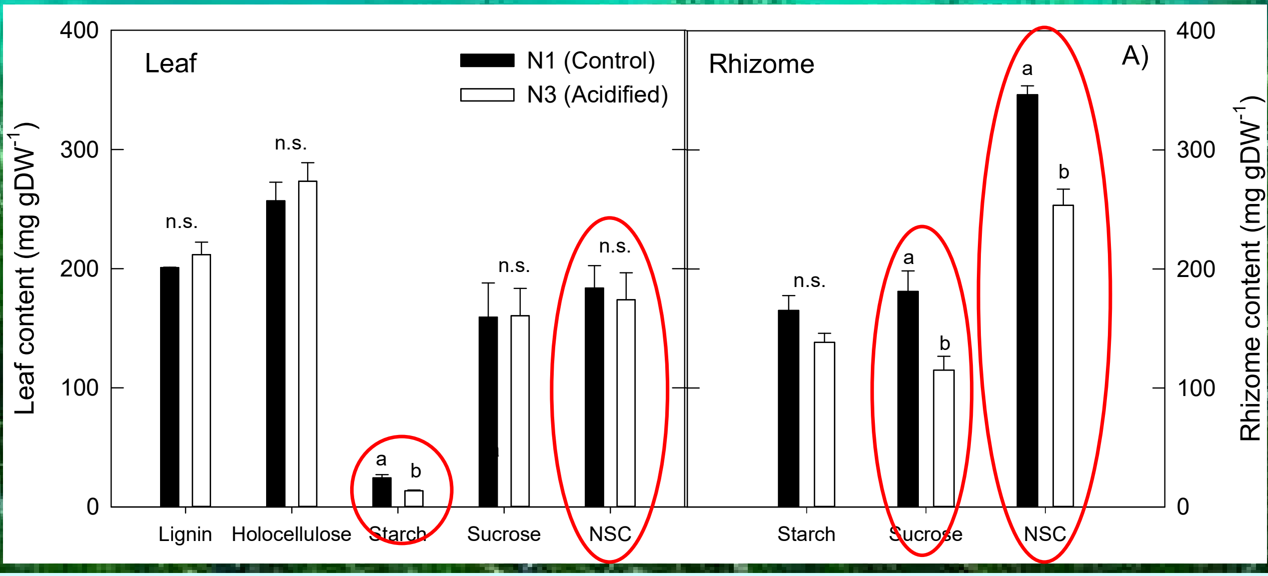
- Lignin (leaf)
- Holocellulose (leaf)
- Starch (leaf and rhizome)
- Sucrose (leaf and rhizome)
- Non Structural Carbohydrates (NSC)



The **decrease of NSC (mainly sucrose) in rhizomes of the acidified station** suggests the mobilization of this soluble carbohydrate reserve for:

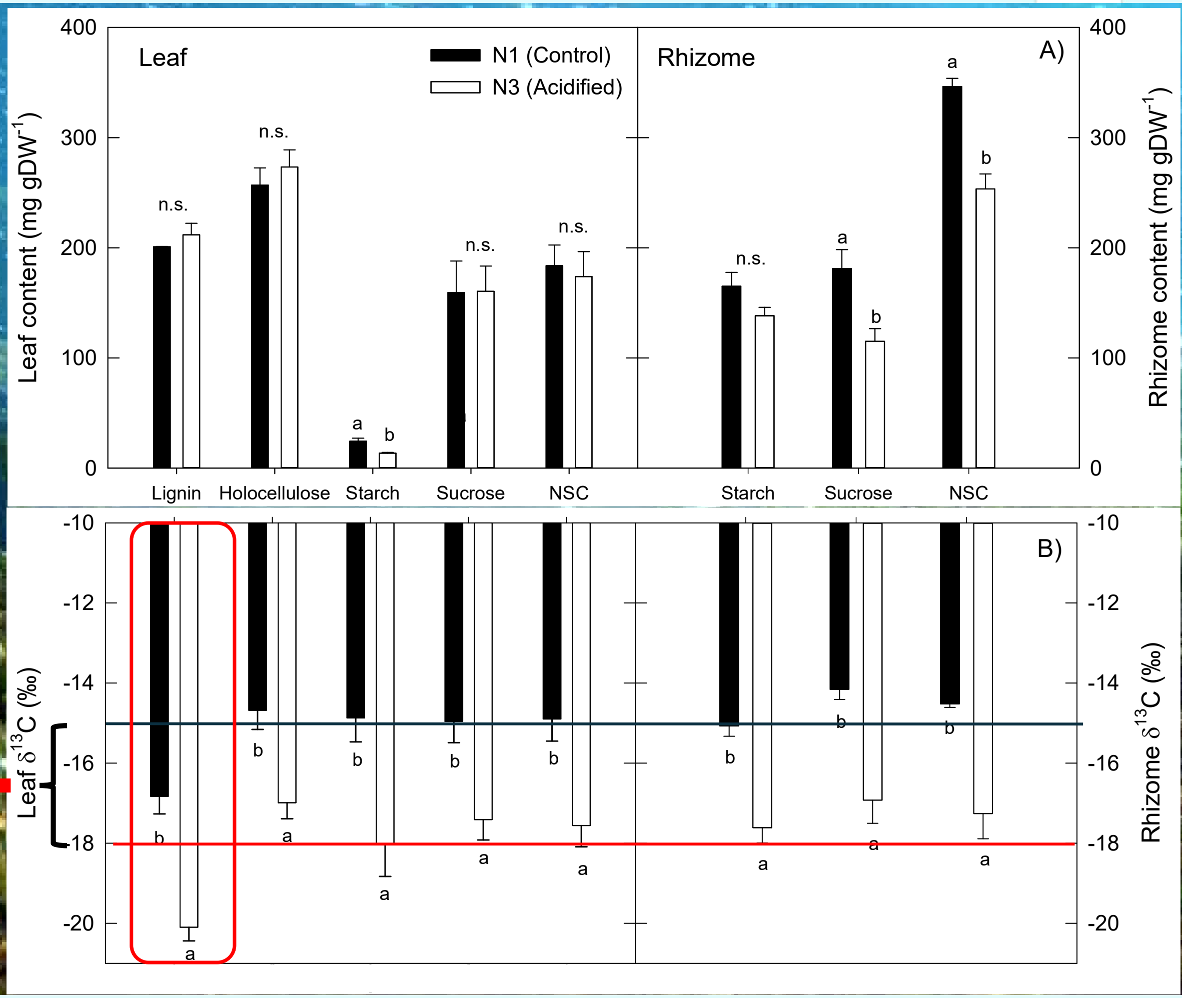
i) promoting a **greater production of shoots** as suggested by the **higher shoot density** of N3 than N1

ii) **replacing of leaf material** due to the **higher grazer-induced leaf loss** in N3 than N1

Shoots production and **replacement of leaf material** are dependent on the energy reserves and C skeletons stored as carbohydrates and on their mobilization and transport along common rhizomes

Scartazza et al. (2017)

δ¹³C OF CARBON METABOLITES



The consistent **¹³C-dilution** (more negative δ¹³C values) of several metabolites in above- and below-ground organs of *P. oceanica* in the acidified site could be due to:

- different δ¹³C values of the **photosynthetic C source (CO_2 and HCO_3^-)**
- **higher isotopic discrimination** due to an increased CO_2 diffusion at the carboxylation sites → isotopic effects during **C uptake** (diffusion/transport mechanisms) and **Rubisco carboxylation**

Scartazza et al. (2017)

CONCLUSIONS

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Carbon stable isotopes:

- serves **to trace the fate of C within an ecosystem** and to obtain insights on **C balance** and the **photosynthetic and respiratory fluxes**;
- are valuable **proxies of water-use efficiency and functional processes** from the plant to the whole ecosystem;
- are useful **indicators** of **ecosystem responses to climate change** and **anthropogenic perturbations**.

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THANKS!

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