What drives carbon allocation to stem and fine roots in a mature coppice of Quercus ilex in the Mediterranean?
A data model analysis
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WHAT DRIVEs CARBON ALLOCATION TO STEM AND FINE ROOTS IN A Quercus ilex FOREST?

A DATA-MODEL ANALYSIS

MARTIN-STPAUL NK.; LEMPEREUR M., DELPIERRE N., OURCIVAL JM, DAVI H., FRANCOIS C., LEADLEY P., DUFRENE E. & RAMBAL S.
Recent climate change:

- Increase drought prone area world wide
  (Dai 2012 Nature Climate Change)

Increase vulnerability of forests:
  (Choat et al. 2012 Nature)
- Decrease productivity
  (Ciais et al. 2005 Nature)
- Increase mortality
  (Allen et al. 2010 FEM; Carnicer et al. 2012 PNAS)

Dryer climate in the future!

Anticipating the future of forests:

- Improving process based models
- Finding out the most influential processes that drives growth & C allocation

Summer rainfall anomaly (%)

MOTIVATIONS: THE EXPERIMENTAL SITE OF PUECHABON

- Mediterranean climate

- Evergreen *Quercus ilex* (~65 years old)

  - Fluxes: ecosystem (*Eddy Covariance, litterfall*); tree (*sap flow*); organ (*Chamber*)
  - C stocks: forest inventory, litter fall
  - Phenology, growth, cavitation curves, storage

Puechabon experimental site
http://puechabon.cefe.cnrs.fr/
MOTIVATIONS: SEASONAL PATTERN OF GROWTH & C FLUXES

Relative Stem Growth

Ψ ~ -1 MPa

Gross Photosynthesis (gC m⁻² day)

Lempereur et al in prep

Plant Ψₚredawn

Day of year

Day of year

Plant Ψₚredawn
MOTIVATIONS: SEASONAL PATTERN OF GROWTH & C FLUXES

Relative Stem Growth

ψ ~ -1 MPa

Lempereur et al in prep

IS GROWTH LIMITED
BY THE SOURCE? due to the decrease in carbon availability
BY THE SINK? Due to the decrease in the water potential

Gross Photosynthesis (gC m⁻² day)

Day of year
**MOTIVATIONS: SEASONAL PATTERN OF GROWTH & C FLUXES**

- **Relative Stem Growth**

- **Gross Photosynthesis (gC m$^{-2}$ day)**

- **NEE (gC m$^{-2}$ j$^{-1}$)**

- **C Source**

- **C Sink**

![Graph showing seasonal pattern of growth and C fluxes](image-url)
MOTIVATIONS: SEASONAL PATTERN OF GROWTH & C FLUXES

Where the C sequestered during the summer period is allocated to?

Relative Stem Growth

Gross Photosynthesis (gC m\(^{-2}\) day)

NEE (gC m\(^{-2}\) j\(^{-1}\))
THE MODEL CASTANEA

2D Stand-scale model
Half Hourly time step
Average Tree (Monospecific)
Water budget
Carbon Budget
Carbon allocation

Davi et al., 2005; Dufrêne et al., 2005 Ecological Modelling
Photosynthesis → Maintenance Respiration = Carbon available for growth
ALLOCATION IN CASTANEA & HYPOTHESIS TESTING

Photosynthesis → Maintenance Respiration → Carbon available for growth

Storage (NSC)

Leaves

Above and below ground Woody tissue

Repro.

Fine Roots

Storage (NSC)
ALLOCATION IN CASTANEA & HYPOTHESIS TESTING

Photosynthesis

Maintenance Respiration

Carbon available for growth

Data assimilation (MCMC)
Eddy Covariance, sapflow

Extensive calibration
(Rodriguez-Calcerrada et al 2012)
(Rodriguez-Calcerrada et al sub)

Leaves

Above and below ground Woody tissue

Repro.

Fine Roots

Storage (NSC)
ALLOCATION IN CASTANEA & HYPOTHESIS TESTING

Photosynthesis

Maintenance
Respiration

Carbon available
for growth

Data assimilation (MCMC)
Eddy Covariance, sapflow

Extensive calibration
(Rodriguez-Calcerrada et al 2012)
(Rodriguez-Calcerrada et al sub)

Prescribed
(in situ measurements
litterfall & phenology)

Simulated
by testing 3 different
hypothesis

Leaves
Repro.
Above and below ground
Woody tissue
Fine Roots
Storage (NSC)
H1: Source Limitation

Growth depends on available carbon only
ALLOCATION IN CASTANEA & HYPOTHESIS TESTING

**H1:** Source Limitation
Growth depends on available carbon only

**H2:** Sink-FineRoots
Growth is Limited by water potential → Available Carbon is allocated to Fine Roots

**H1:** Sink-Storage
Growth is Limited by water potential → Available Carbon is allocated to Storage

Relative growth

GPP

~ -1 MPa
**H1:** Source Limitation
Growth depends on available carbon only

**H2:** Sink-Fine Roots
Growth is Limited by water potential \(\rightarrow\) Available Carbon is allocated to Fine Roots

**H3:** Sink-Storage
Growth is Limited by water potential \(\rightarrow\) Available Carbon is allocated to Storage

**VALIDATION:**
Yearly wood increment (forest inventory + allometric relationship): 2000 \(\rightarrow\) 2010
Temporal dynamic of Storage concentration
Temporal dynamic & Level of \(\frac{\text{FineRoot}}{\text{Leaf}}\) biomass
RESULTS: STEM GROWTH MEASURED vs. SIMULATED

\[ R^2 = 0.4 \]
\[ \text{Slope} = 0.45 \]

\[ R^2 = 0.6 \]
\[ \text{Slope} = 0.8 \]

\[ R^2 = 0.6 \]
\[ \text{Slope} = 0.8 \]

**Source Limitation**

**H2:** Sink-FineRoots

**H3:** Sink-Storage
RESULTS: STEM GROWTH MEASURED vs. SIMULATED

Source Limitation

H2: Sink-FineRoots

H3: Sink-Storage

Annual growth simulated

R²=0.4
Slope=0.45

R²=0.6
Slope=0.8

R²=0.6
Slope=0.8

Annual growth measured (gC m² year⁻¹)
RESUL TS: STORAGE & FINE ROOT/LEAF BIOMASS

**H2:** Sink-FineRoots

**H3:** Sink-Storage

Challenge:

- Fine Root Leaf is far from published value (~0.6, Lopez et al. 1998 Plant & Soil)

- Fine roots are sensitive to $\Psi_{\text{plant}}$ (Growth: Lockhart 1965; Mortality: Anderegg et al., 2012)
RESULTS: STORAGE & FINE ROOT/LEAF BIOMASS

Challenge:

- *Fine Root* / *Leaf* is far from published value (~0.6, Lopez *et al.* 1998 *Plant & Soil*)

- Fine roots are sensitive to *Ψ*<sub>plant</sub> (*Growth*: Lockhart 1965; *Mortality*: Anderegg *et al.*, 2012)
**NEW HYPOTHESIS**

\[
\text{Fine root mortality} = \frac{1}{1 + \exp(0.77 \times \Psi_{\text{predawn}} + 2.4)}
\]

\[
\text{Fine root growth} = f(\text{Storage}, \text{FRootTh})
\]

\text{if } (\Psi_{\text{dawn}} < -1 \text{MPa}) \{ \text{All growth} = 0 ; \text{Storage}=1 \}
**NEW HYPOTHESIS**

- **FineRoot**
  - Leaf

- Storage

~0.6

Lopez et al. 1998

**NEW MODEL**

![Sink-FineRoots](image)

![Storage](image)
NEW HYPOTHESIS

Storage in the sapwood at the Puechabon site

Soluble sugars (%) vs. \( \Psi_{pd} \) (MPa)

Rodriguez-Calcerrada et al. submitted
✓ Stem growth is likely not C-limited and can be accurately model assuming a direct effect of water potential

✓ The carbon sequestered during the drought period might be used for fine root production or reconstruction

✓ A model accounting for fine roots mortality and reconstruction was consistent with the observations of increasing storage concentration during the seasonal drought
SUMMARY & CONCLUSION

✓ Stem growth is likely not C-limited and can be accurately model assuming a direct effect of water potential

✓ The carbon sequestered during the drought period might be used for fine root production or reconstruction

✓ A model accounting for fine roots mortality and reconstruction was consistent with the observations of increasing storage concentration during the seasonal drought

✓ The process simulated by the improved model are believed to be involved in tree vulnerability to drought (McDowell et al. 2011 Trends. Ecol. Evolution)

✓ This model might be a step in assessing tree’ outcomes under climate changes
Thank you for your attention