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

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
MOTIVATIONS: SEASONAL PATTERN OF GROWTH & C FLUXES

Relative Stem Growth

\[ \Psi \sim -1 \text{ MPa} \]

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

Lempereur et al in prep

\(\Psi \sim -1 \text{ MPa}\)
MOTIVATIONS: SEASONAL PATTERN OF GROWTH & C FLUXES

Relative Stem Growth

$\psi \sim -1 \text{ MPa}$

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⁻¹)

NEE (gC m⁻² j⁻¹)

C Source

C Sink
MOTIVATIONS: SEASONAL PATTERN OF GROWTH & C FLUXES

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

Relative Stem Growth

C Source

C Sink

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

Day of year
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
Photosynthesis → Maintenance Respiration → Carbon available for growth

Storage (NSC)
Leaves
Repro.
Above and below ground Woody tissue
Fine Roots
Storage (NSC)
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
Repro.
Above and below ground Woody tissue
Fine Roots
Storage (NSC)
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)
Growth depends on available carbon only

H1: Source Limitation

Growth depends on available carbon only
Growth depends on available carbon only.

**H1:** Source Limitation

Growth is Limited by water potential $\rightarrow$ Available Carbon is allocated to Fine Roots

**H2:** Sink-FineRoots

**H1:** Sink-Storage

Growth is Limited by water potential $\rightarrow$ Available Carbon is allocated to Storage

Relative growth

GPP

$\sim$-1 MPa
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

**H3: Sink-Storage**
Growth is Limited by water potential → Available Carbon is allocated to Storage

**VALIDATION:**
Yearly wood increment (forest inventory + allometric relationship): 2000 → 2010
Temporal dynamic of Storage concentration
Temporal dynamic & Level of $\frac{\text{FineRoot}}{\text{Leaf}}$ biomass

$\sim -1 \text{ MPa}$
RESULTS: STEM GROWTH MEASURED vs. SIMULATED

**Source Limitation**

- \( R^2 = 0.4 \)
- Slope = 0.45

**H2: Sink-FineRoots**

- \( R^2 = 0.6 \)
- Slope = 0.8

**H3: Sink-Storage**

- \( R^2 = 0.6 \)
- Slope = 0.8

Annual growth simulated vs. Annual growth measured (gC m² year⁻¹)
RESULTS: STEM GROWTH MEASURED vs. SIMULATED

H2: Sink-FineRoots

H3: Sink-Storage

Source Limitation

Annual growth measured (gC m² year⁻¹)

<table>
<thead>
<tr>
<th>R²</th>
<th>Slope</th>
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<tr>
<td>0.4</td>
<td>0.45</td>
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<td>0.6</td>
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<td>0.6</td>
<td>0.8</td>
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BEST GUESSES
Initial Konfiguration: 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 $\Psi_{\text{plant}}$ (Growth: Lockhart 1965; Mortality: Anderegg et al., 2012)
NEW HYPOTHESIS

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

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

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

FineRoot  
Leaf

\[ \sim 0.6 \]
Lopez et al. 1998

NEW MODEL

Sink-FineRoots

Storage
NEW HYPOTHESIS

Rodriguez-Calcerrada et al. submitted

Storage in the sapwood at the Puechabon site

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

Storage vs. $\Psi$ (MPa)
SUMMARY

✓ 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