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)

Dryer climate in the future!

Increase vulnerability of forests:

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

Anticipating the future of forests:

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

CONTEXT

MOTIVATIONS: THE EXPERIMENTAL SITE OF PUECHABON

Puechabon experimental site
http://puechabon.cefe.cnrs.fr/

- 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

Gross Photosynthesis (gC m⁻² day)

$\Psi \sim -1$ MPa

Lempereur et al in prep

Plant $\Psi_{\text{predawn}}$
MOTIVATIONS: SEASONAL PATTERN OF GROWTH & C FLUXES

**IS GROWTH LIMITED**

BY THE SOURCE? due to the decrease in carbon availability

BY THE SINK? Due to the decrease in the water potential

---

Relative Stem Growth

Gross Photosynthesis (gC m⁻² day)

Day of year

Plant Ψ

Ψ ~-1 MPa

Lempereur et al in prep

Gross Photosynthesis (gC m⁻² day)
MOTIVATIONS: SEASONAL PATTERN OF GROWTH & C FLUXES

Relative Stem Growth

Gross Photosynthesis (gC m⁻² day⁻¹)

C Source

C Sink

Day of year

0 100 200 300

0.0 0.2 0.4 0.6 0.8 1.0

NEE (gC m⁻² j⁻¹)

0 1 2

-2 -1 0 1
MOTIVATIONS: SEASONAL PATTERN OF GROWTH & C FLUXES

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

Gross Photosynthesis (gC m\(^{-2}\) day)
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)
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)
ALLOCATION IN CASTANEA & HYPOTHESIS TESTING

**Photosynthesis**

Data assimilation (MCMC)
Eddy Covariance, sapflow

**Maintenance Respiration**

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

**Carbon available for growth**

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
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

\( \sim -1 \, \text{MPa} \)
**ALLOCATION IN CASTANEA & HYPOTHESIS TESTING**

**Growth** depends on available carbon only

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

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

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

**H2:** Sink-**FineRoots**
- 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**
RESULTS: STEM GROWTH MEASURED vs. SIMULATED

*Source Limitation*

*H2: Sink-FineRoots*

*H3: Sink-Storage*

\[
\text{Annual growth simulated} \quad \text{Annual growth measured (gC m}^2\text{ year}^{-1})
\]

- **H2:**
  - $R^2 = 0.6$
  - Slope $= 0.8$

- **H3:**
  - $R^2 = 0.6$
  - Slope $= 0.8$

- **Source Limitation:**
  - $R^2 = 0.4$
  - Slope $= 0.45$
RESULTS: STEM GROWTH MEASURED vs. SIMULATED

**Source Limitation**

**H2:** Sink-FineRoots

**H3:** Sink-Storage

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

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

Annual growth measured (gC m\(^2\) year\(^{-1}\))

**BEST GUESSES**
**RESULTS: 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)

*Graph showing changes in storage concentration and fine roots/leaves concentration over years.*

*Published value of 0.6 from Lopez et al. 1998.*
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**

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

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

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

FineRoot

Leaf

Sink - FineRoots

NEW MODEL

\( \sim 0.6 \)

Lopez et al. 1998

Storage


0.0 0.5 1.0 1.5 2.0 2.5


0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7
Storage in the sapwood at the Puechabon site

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