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:
(Choat et al. 2012 Nature)

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

MOTIVATIONS: THE EXPERIMENTAL SITE OF PUECHABON

✔ Mediterranean climate

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

✔ Long term records (1998→)
  ➢ 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)

\( \Psi \sim -1 \text{ MPa} \)

Lempereur et al. in prep

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

Relative Stem Growth

Ψ ~-1 MPa

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)
MOTIVATIONS: SEASONAL PATTERN OF GROWTH & C FLUXES

Relative Stem Growth

Gross Photosynthesis (gC m⁻² day)

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

Relative Stem Growth

C Source

C Sink

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

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

Day of year

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

Davi et al., 2005; Dufrêne et al., 2005

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

THE MODEL CASTANEA

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

THE MODEL CASTANEA
Photosynthesis → Maintenance Respiration = Carbon available for growth
ALLOCATEION IN CASTANEA & HYPOTHESIS TESTING

Photosynthesis \[\rightarrow\] Maintenance Respiration \[\rightarrow\] Carbon available for growth

- Leaves
- Repro.
- Above and below ground Woody tissue
- 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)

Tree diagram:
- Leaves
- Repro.
- Above and below ground Woody tissue
- Fine Roots
- Storage (NSC)
Photosynthesis

Maintenance
Respiration

Carbon available for growth

ALLOCATION IN CASTANEA & HYPOTHESIS TESTING

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)
ALLOCATION IN CASTANEA & HYPOTHESIS TESTING

H1: Source Limitation

Growth depends on available carbon only
**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

**H1:** Sink-Storage

Growth is Limited by water potential \(\rightarrow\) Available Carbon is allocated to Storage
ALLOCATION IN CASTANEA & HYPOTHESIS TESTING

**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

**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

\[ \sim -1 \text{ MPa} \]
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)
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 m$^2$ year$^{-1}$)
RESULTS: STORAGE & FINE ROOT/LEAF BIOMASS

Challenges:

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

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

Challenge:

1. Fine root/leaf is far from published value (~0.6, Lopez et al. 1998 Plant & Soil)

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NEW HYPOTHESIS

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

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

\(\Psi_{\text{predawn}}\) at Puechabon

Limousin et al. 2010 Tree Phys
NEW HYPOTHESIS

FineRoot
Leaf

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

NEW MODEL

Sink-FineRoots

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

NEW MODEL
Storage in the sapwood at the Puechabon site

Rodriguez-Calcerrada et al. submitted
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