Dynamic Carbon allocation

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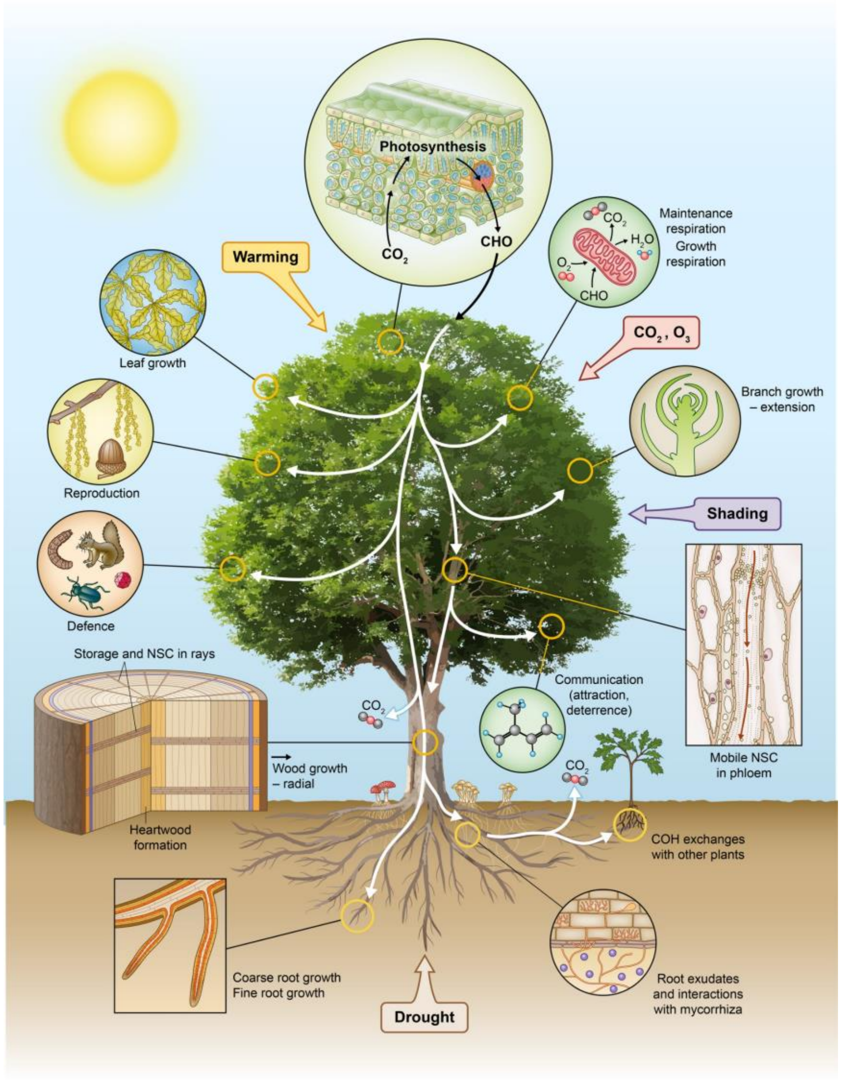
Where does the Carbon go?



Carbon allocation controls the partitioning of carbon fixed in photosynthesis between respiration and biomass production, between short- and long-lived tissues, and between above- and below-ground tissues.

Which organs and processes carbon is allocated to determines the longevity of carbon in the terrestrial biosphere, the interactions between carbon water and nutrient cycles, and numerous other biotic interactions.

Hartmann *et al*., (2020) New Phytologist

How does JULES currently model Carbon allocation?

Joint UK Land Environment Simulator

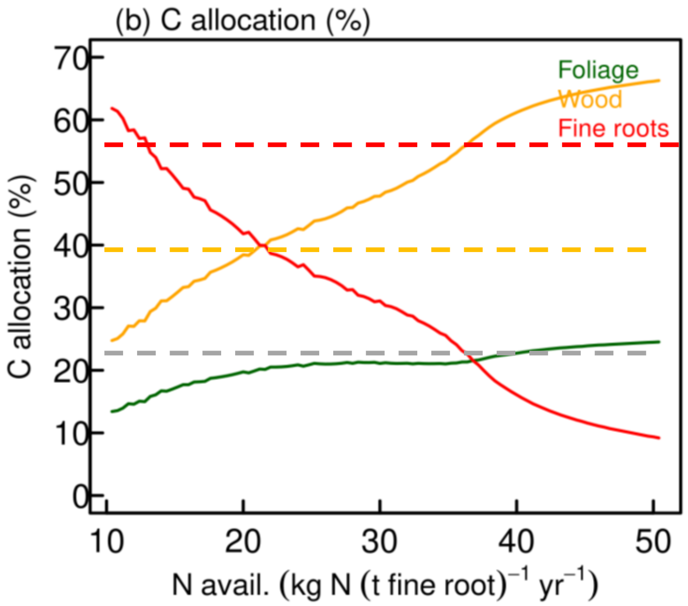
- JULES models carbon allocation to leaf, root and wood pools using allometric equations to relate the vegetation C density to the seasonal maximum LAI:

$\mathcal{L} = \sigma_{\mathrm{l}} L_{\mathrm{b}}$ Leaf carbon pool

$\mathcal{R} = \mathcal{L}$ Root carbon pool

$\mathcal{W} = a_{\mathrm{wl}} L_{\mathrm{b}}^{b_{\mathrm{wl}}}$ Wood carbon pool

Clark *et al*., (2011) GMD

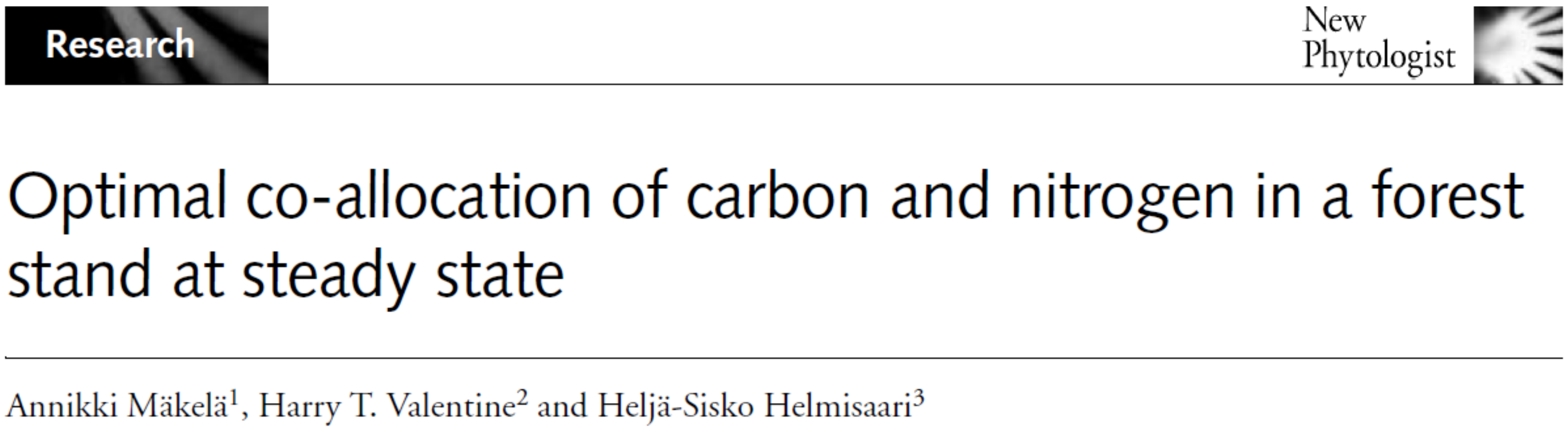


- The proportion of allocation to each pool is invariant, and does not respond to changes in the environment such as changing nutrient status.

A new Carbon allocation model for JULES based on optimisation theory

- Optimisation models are concerned with the outcomes of plant mechanisms rather than the mechanisms themselves – helpful for problems such as C allocation where the mechanisms are not fully understood.

- We are using the **Makela *et al*., (2008)** model:



Research

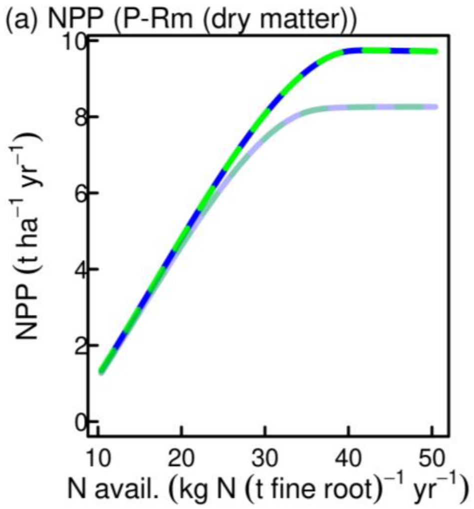
New Phytologist

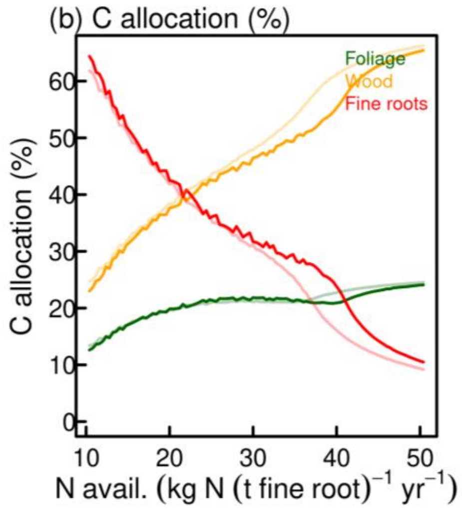
Optimal co-allocation of carbon and nitrogen in a forest stand at steady state

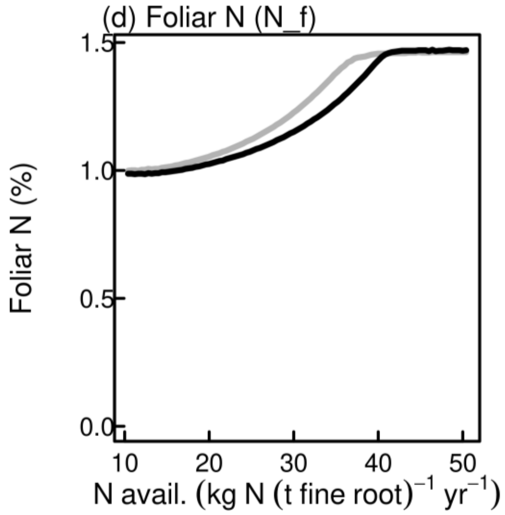
Annikki Mäkelä[1], Harry T. Valentine[2] and Heljä-Sisko Helmisaari[3]

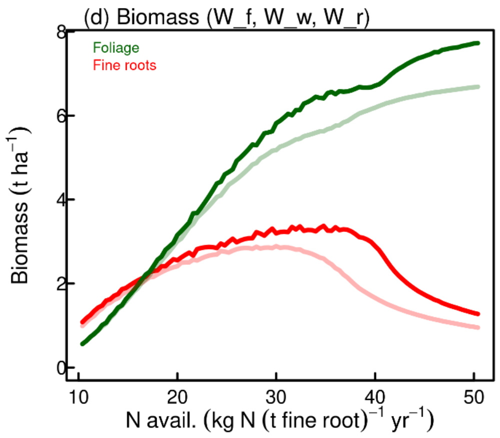
- Maximises NPP with respect to stand-level C and N availability. It describes the balance between C gains (photosynthesis) and C costs (maintenance respiration, fine-root construction) resulting from increased N availability, and how that balance shifts when resource availability changes.

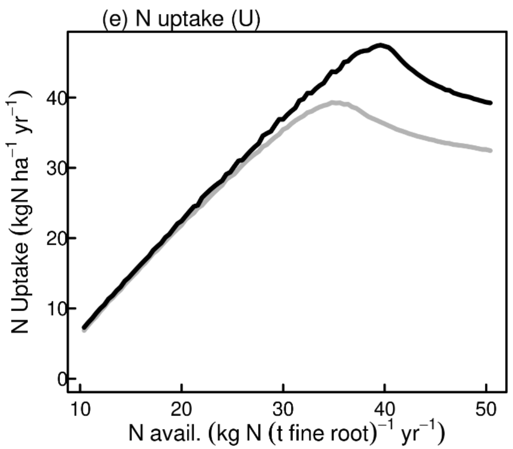
Incorporating the mechanistic Farquhar photosynthesis model: Response to increasing N availability



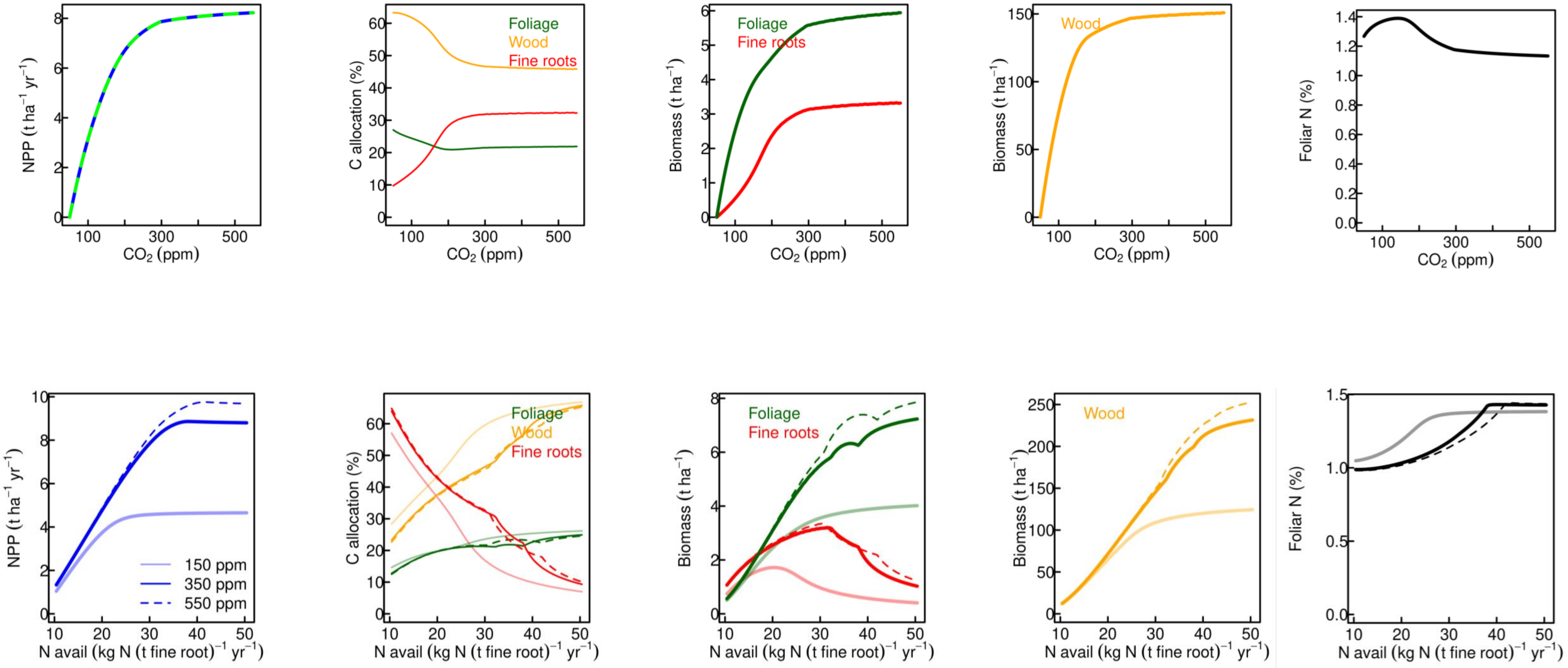




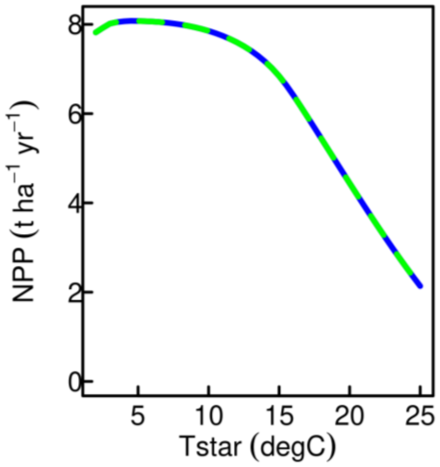


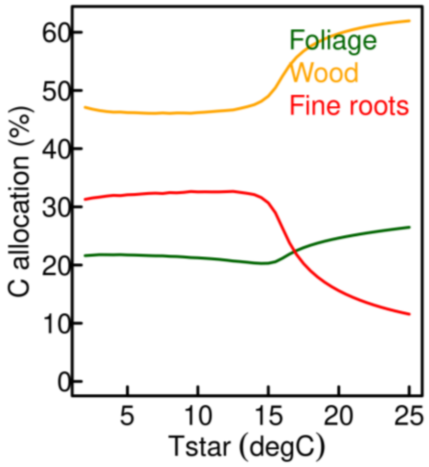


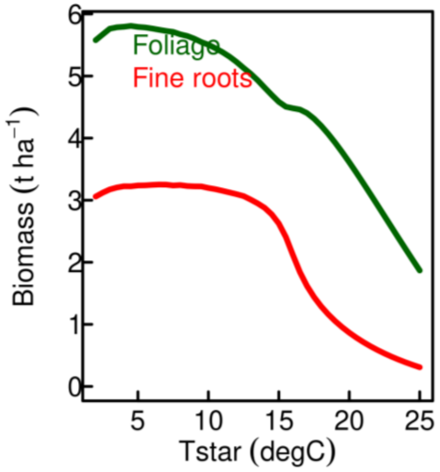
Sensitivity to increasing CO₂ concentration

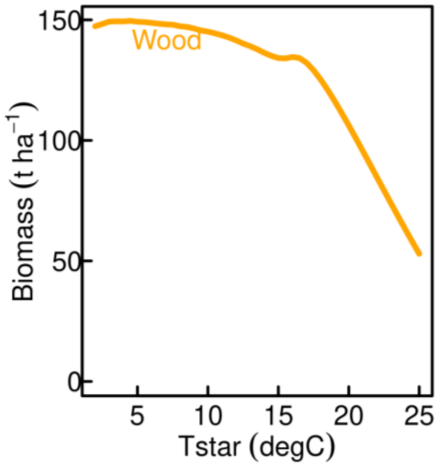


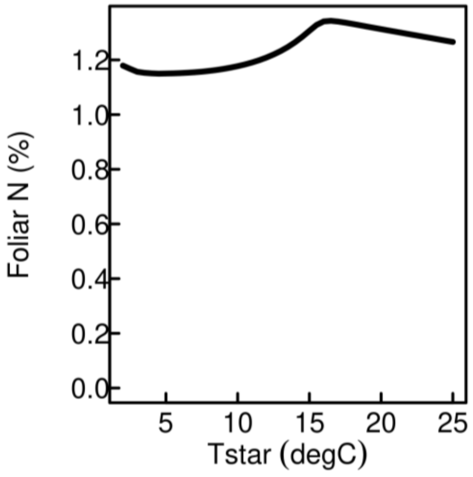
Sensitivity to increasing temperature

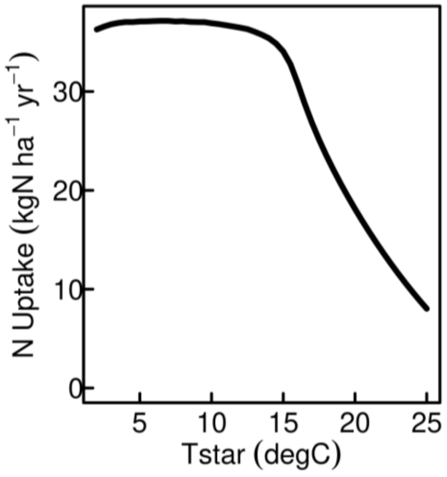




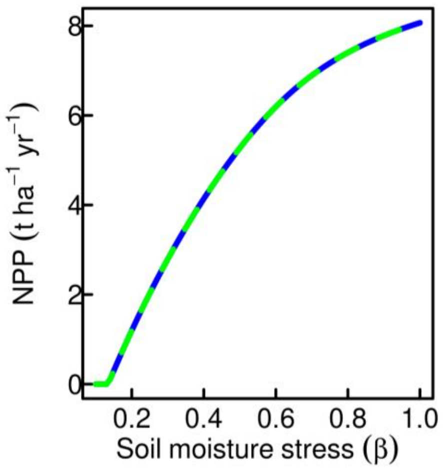


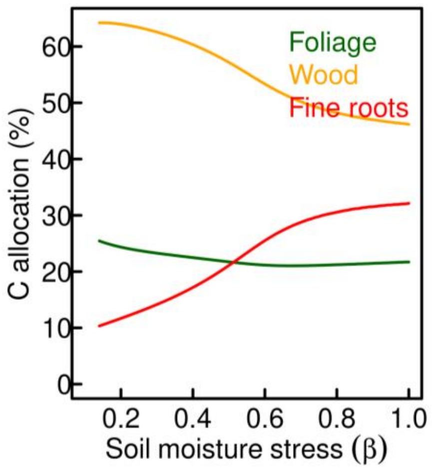


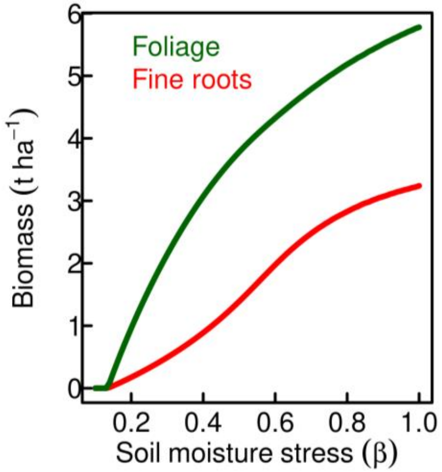


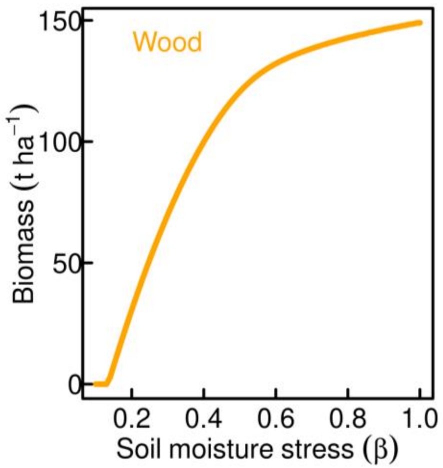


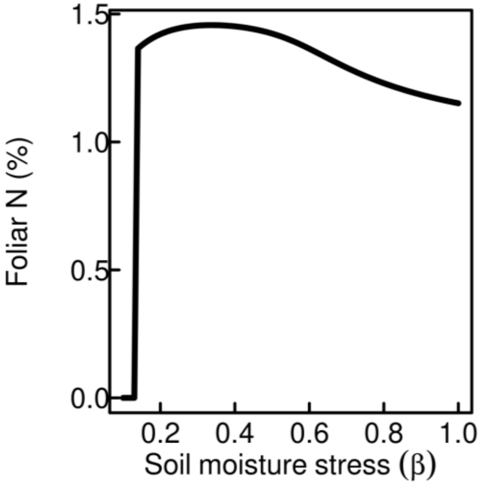
Sensitivity to increasing soil moisture

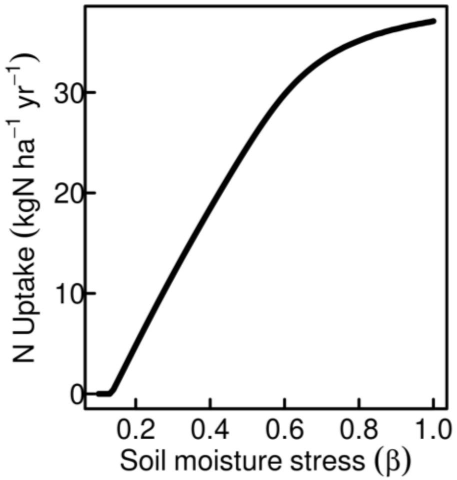












BIFOR: A mature temperate deciduous forest under Free-Air CO_2 Enrichment (FACE)

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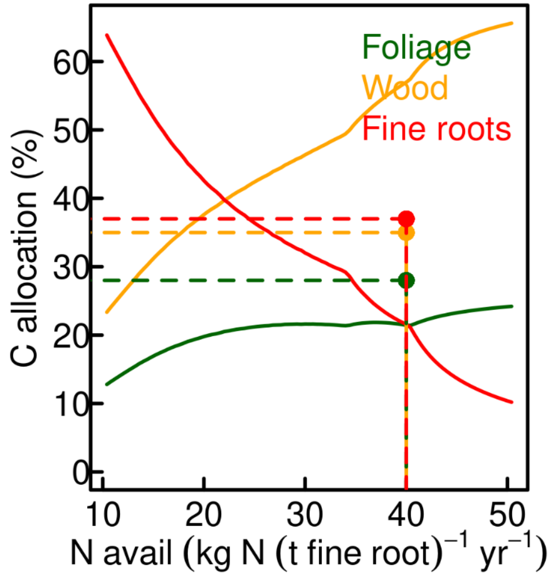
- 23% increase in photosynthesis in eCO_2 (Gardner et al., 2021)
- No change in leaf N is eCO_2 (Gardner *et al.*, 2021)
- No down-regulation of photosynthetic capacity in eCO_2 (Gardner *et al.*, 2021)
- 28% increase in basal area increment in eCO_2 (Norby *et al.*,)
- Increased allocation of carbon below-ground in root exudates in eCO_2 (Rumeaue *et al.*, 2023)

	Amb CO_2	**Elev CO_2**
NPP Allocation (%)*		
Wood (+coarse roots)	35.00	38.00
Leaves (+reproduction)	28.00	29.00
Fine roots (+exudation)	37.00	33.00
Leaf N (%)$^+$		
	2.61	2.65
Foliage:fine roots ratio*		
	0.77	0.88
V_{cmax}25 (umol m^{-2} s^{-1})$^+$		
	61.64	59.74
J_{max}25 (umol m^{-2} s^{-1})$^+$		
	115.38	119.82
LMA (kg m^{-2})$^+$		
	0.089	0.088

* Data from Richard Norby for oaks in 2021
\+ Data from Anna Gardner for oaks in 2019



Thank you

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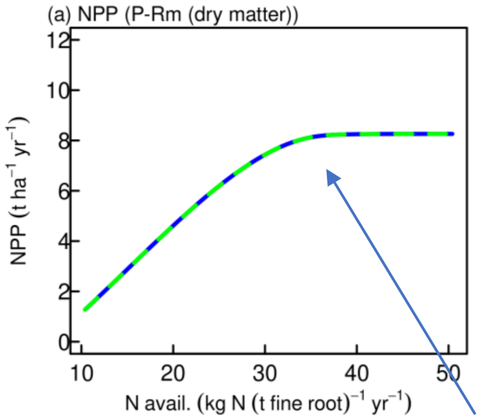
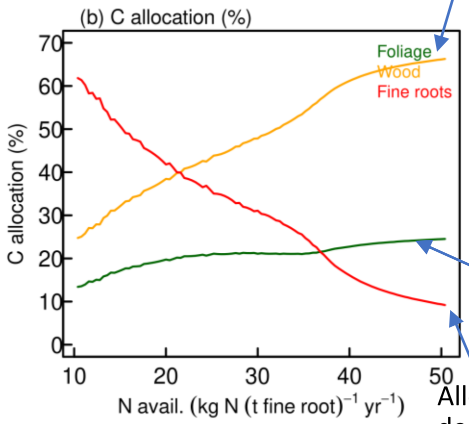
Mean annual Met. conditions at FI-Hyy	
Temperature (^{o}C)	5.74
Shortwave radiation (W m^{-2})	134.61
N availability (kg N (t fine root)$^{-1}$ yr^{-1})	30
CO$_2$ (ppm)	397
Specific humidity (kg kg^{-1})	0.0049
Soil moisture stress (β)	1
Latitude (^{o}N)	61.85
Longitude (^{o}E)	24.3

Reproducing the Makela model for Pine


(a) NPP (P-Rm (dry matter))

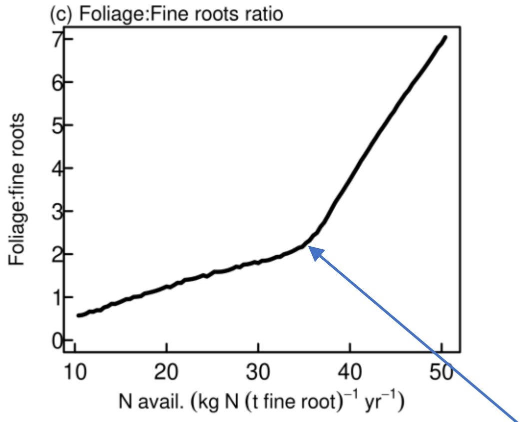

(b) C allocation (%)

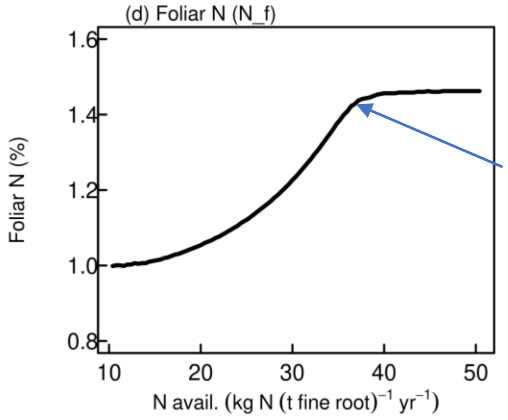
Allocation to wood increases with increasing N availability – allocation to wood also increases with increasing GPP. Higher productivity leads to taller trees that require more allocation to wood than shorter trees

Allocation to foliage remains relatively constant. But productivity increases because of increasing foliar N

Allocation to fine-roots decreases with increasing N availability – smaller fine-root density needed to supply the required canopy N.

NPP (and GPP) increase with increasing N avail., then saturates when light becomes limiting.


(c) Foliage:Fine roots ratio


(d) Foliar N (N_f)

Foliar N increases with increasing N avail., but plateaus at the level of N avail. that corresponds to the turning point in the foliage:fine-root ratio.
NPP and GPP have saturated because of limited light availability, so it not optimal to invest further N in leaves.

The foliage:fine-root ratio increases moderately with increasing N avail, to the point at which fine-root density starts to decrease with increasing N availability compared to foliage density.

…..and with elevated CO2

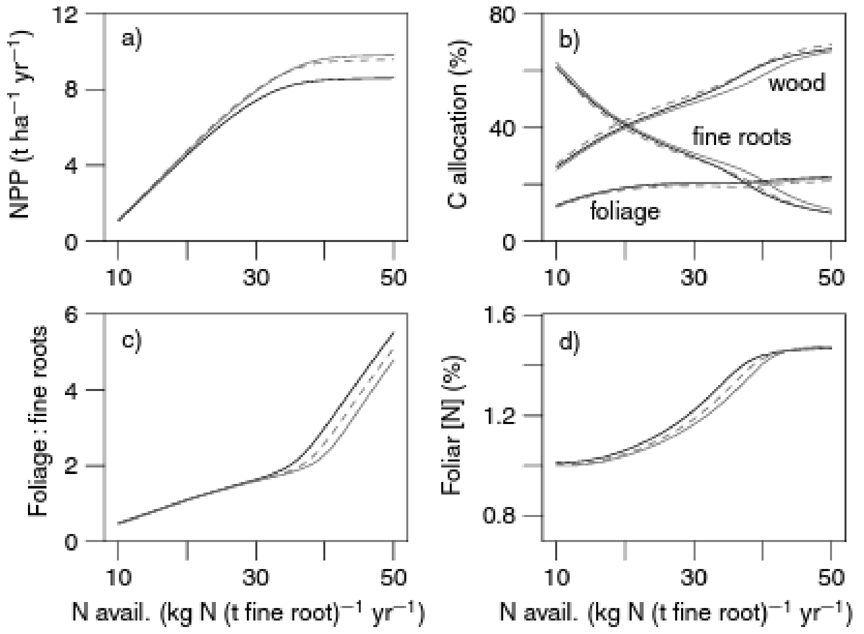


Fig. S3 Optimal model solutions with the standard parameter set in Table 1 (black), a 10% increase in σ_{fM0}, the nitrogen-saturated specific rate of photosynthesis (gray), and a 10% increase in both σ_{fM0} and c_{H}, the ratio of average pipe length to foliar N concentration (gray dash).

Can the model reproduce observations from BiFOR?

			From Makela et al., (2008) Table 1		Ambient CO2	Elevated CO2
Parameter		Units *Dry weight (DW)	Pine	Spruce	Oak	Oak
K_r	Amount of roots capturing 50% of available N	kg ha-1	2000	2000	2000(?)	2000(?)
K_f	Amount of foliage capturing 50% of max C gain	kg ha-1	2500	8000	8000(?)	8000(?)
T_f	Mean lifetime of foliage	yr	3.3	8	0.51	0.51
T_r	Mean lifetime of fine roots				1.32*	1.15*
T_s	Mean lifetime of sapwood	yr	40	33.3	2	2
Y_g	Growth efficiency	kg DW kg-1 C	1.54	1.54	1.54(?)	1.54(?)
r_m	Specific rate of maintenance respiration	kg-1 C (kg N)-1 yr-1	16	16	94.61	94.61 (?)
σ_{fM0}	N-saturated specific rate of photosynthesis	kg C (kg foliage*)-1 yr-1	8	4	45.53	62.54
n_r	Ratio of fine-root N to foliage N	-	1	1	0.67 (1.0)	0.67 (1.0)
n_w	Ratio of sapwood N to foliage N	-	0.07	0.07	0.1	0.1
f_i,i=f,r,w	Proportion N recycled	-	0.3	0.3	0.386 (?)	0.428 (?)
a_w	Sapwood weight per unit foliage and pipe length	m-1	0.8	0.4	0.65 (?)	0.65 (?)
C_H	Steady-state' pipe length coefficient	m kg-1 N kg DW	2800	3400	1350	1350
N_0	Concentration of nonphotosynthetic (structural) N	kg N (kg foliage*)-1	0.009	0.008	0.008 (?)	0.008 (?)
N_{ref}	Concentration of photosynthetic N	kg N (kg foliage*)-1	0.002	0.002	0.002 (?)	0.002 (?)