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Incorporating plant plasticity in agroforestry simulation models

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Incorporating plant plasticity in agroforestry simulation models

I. Evidence of plasticity in Poplar / Walnut – wheat agroforest systems

II. Simulating crown plasticity

III. Simulating root plasticity

IV. Conclusion
I. Evidence of plasticity in temperate agroforest systems
I. Evidence of plasticity in Poplar – wheat agroforest systems

**Crown plasticity**
- A higher stretching in east-ouest than in north – south in orientation

**consequences:**
- Productivity of the system because of light availability

Experimental 13 years old poplar-wheat agroforest

\[ CW = 14.2 \text{m} \]

\[ CW = 11.2 \text{m} \]

CW = Crown Width
I. Evidence of plasticity in poplar/walnut – wheat agroforest systems

Roots plasticity
- fine root distribution is modified by association with a winter crop

Interest in agroforestry
- spatial complementarity for water resource
Objectives

- Reconstruction by modelling crown / root plasticity

- Exploration of the sensibility of the systems to the plasticity of trees by comparing simulations with or without plasticity
II. Simulating crown plasticity
II. 1 The model: STReTCH (Vincent & Harja, 2007)
Shape transformation response of trees in crowded habitats

A combination of 5 modules: growth, mortality, regeneration, light availability, crown deformation.
II. 1 The model: STReTCH (Vincent & Harja, 2007)
Shape transformation response of trees in crowded habitats

- Depends on the stem growth
- Depends on individual light availability
- Virtual vectors of branches

Plot radiative conditions

Tree light availability

Growth of virtual branches
II. 2 Simulation

**Plasticity parameters** (Vincent & Harja, 2007)

Flexibility: range of possible deformation of the trees

Sensitivity: reactivity to a light gradient
II. 3 Results

Crown radius (m)

Orientation N->S
CWsimulated = 10.1m
CWreal = 11.2m

Orientation E->O
CWsimulated = 13.4m
CWreal = 14.2m

Reconstruction of the differential deformations between the orientations

A high plasticity of poplar crown

\[
\begin{align*}
\text{Crown flexibility} &= 0.8 \quad \text{(range [0-1])} \\
\text{Crown sensitivity} &= 1.5 \quad \text{(range [0-2])}
\end{align*}
\]
III. Simulating roots plasticity
III. 1 The model: Hi-sAFe, an overview

- Tree growth (individual based model)
- Crop growth (Stics (brisson et al 2009))
- 3D modelling of competition:
  - light (ray-tracing)
  - water (matrix flux potential)
  - (and soon: Nitrogen)
III. 1 The model: Modelling root plasticity with a cellular automata

Allocation to voxel $ijk$:

$$p_{ijk} = \frac{\varepsilon^{\alpha}_{ijk} c^{-\beta}_{ijk}}{\sum_{i,j,k} \varepsilon^{\alpha}_{ijk} c^{-\beta}_{ijk}}$$

- $p_{ijk}$: allocated proportion
- $\varepsilon_{ijk}$: water uptake efficiency (L.m$^{-1}$)
- $c_{ijk}$: fine root cost (Kg.m$^{-1}$)
- $\alpha$: opportunism coefficient
- $\beta$: economic coefficient

Neighbours colonisation:

- triggered by thresholds on fine roots investment in the voxel
- thresholds depend on:
  - neighbour and father voxel positions
  - voxel shape and dimension
  - architectural parameters

Coarse root system:

- topology: colonisation historic
- sections: Pipe-stem model

Constraints on fine root growth

FR/CR allocation
III. 1 The model: Modeling plasticity in above/below-ground allocation

- Definition of a target shoot/root ratio:

\[ R^* = \frac{C_{\text{leaf}}}{C_{\text{leaf}} + C_{\text{fineroots}}} \]

- Daily allocation tends to reach \( R^* \)

- Allocation toward woody compartments depends on:
  - allometric relationships between stem, branches and foliage
  - functional constraints between coarse roots and fine roots

\[ R_{t+1}^* = R_t^* - \delta W_{\text{stress}}^\phi \]

- \( R^* \) decreases when water stress occurs:

\[ R_{t+1}^* = R_t^* - \delta \]

- \( R^* \) upper drifts in absence of water stress:

\[ \delta \quad \text{maximal daily variation of } R^* \]
\[ W_{\text{stress},t+1} \quad \text{water stress on day } t+1 \]
\[ \phi \quad \text{sensitivity to water stress} \]
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III. 2 Simulation experiments

Hybrid walnut / durum wheat
No water table
Non limitant nitrogen
Climate from Montpellier, France

Root plasticity:
« blind » root system: $\alpha = 0, \beta = 1$
opportunistic root system: $\alpha = 1, \beta = 1$

Above/below ground allocation:
Rigid tree: $\delta = 0, R^*_0 = 0.5$
plastic tree: $\delta = 0.0015, \phi = 0.5, R^*_0 = 0.5$
III. 3 Results: Opportunistic root system: effect on rooting pattern

« blind » root system: a half-sphere like growth

Opportunistic root system: a growth...
...first in depth... ... then along tree line... ... and finally under the crop
III. 3 Results: Opportunistic root system: effect on fine root distribution
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III. 3 Results: Opportunistic root system; effect on tree growth

+ 33% explained by:
- total PAR intercepted: +12%
- light use efficiency: +19%

**Above ground biomass**
+23%

**Below ground biomass**
+100%
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### III. 3 Results: Plasticity of carbon allocation; effect on tree growth

- **Evolution of R**:
  - [Graph showing the evolution of R* over time, comparing "rigid" and plastic trees.]

- **Above ground C fraction**:
  - [Graph showing the above ground C fraction over time, with two lines representing different conditions.]

- **Total growth (Kg C)**:
  - [Graph showing the cumulative net photosynthesis (Kg C) over time.]

+ 5% explained by:
  - total PAR intercepted: -11 %
  - light use efficiency: +17 %
IV. Conclusions
IV. Conclusions

Our models were able to simulate observed patterns of plasticity
- Crown plasticity: reconstruction of the observed difference between N-S and E-W orientation;
- Roots plasticity: higher fine root density below the layers exploited by crop roots

They were sensitive to the values of parameters governing plastic responses
- These parameters are difficult to parameterise because they have no simple biological meaning

Cf communication of Dupraz et al., session 23, Thursday morning
To be continued...
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II. 1 The model: STReTCH
Shape transformation response of trees in crowded habitats

Illustration of crown deformation

- a fixed vertical light gradient
- a fixed lateral anisotropic gradient