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Incorporating plant plasticity in agroforestry simulation models

Marie Ange Ngo Bieng, Rachmat Mulia C. Dupraz, M. Laurans, G. Talbot, G. Vincent, M. Van Noordwijk
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

$CW = 14.2m$

$CW = 11.2m$

*Experimental 13 years old poplar-wheat agroforest*
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
Incorporating plant plasticity in agroforestry simulation models

II. 1 The model: STReTCH (Vincent & Harja, 2007)
Shape transformation response of trees in crowded habitats

The yearly simulation loop
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

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Stand initial conditions

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

- **Flexibility:** range of possible deformation of the trees
- **Sensitivity:** reactivity to a light gradient
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II. 3 Results

Crown radius (m)

Orientation N->S  Crown radius / time  Orientation E->O

**CWsimulated** = 10.1m  **CWsimulated** = 13.4m

**CWreal** = 11.2m  **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 $ijk$:

$$p_{ijk} = \frac{\varepsilon_{ijk}^\alpha c_{ijk}^{-\beta}}{\sum_{i,j,k} \varepsilon_{ijk}^\alpha c_{ijk}^{-\beta}}$$

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

Coarse root system:
- topology: colonisation historic
- sections: Pipe-stem model

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

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:

\( \delta \) maximal daily variation of \( R^* \)

\( W_{\text{stress},t+1}^\phi \) water stress on day \( t+1 \)

\( \phi \) 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

Under crop

Under tree line

- Root proportion
  - depth (m)
  - blind root growth
  - opportunistic root growth
III. 3 Results: Opportunistic root system; effect on tree growth

Total growth (Kg C)

+ 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 $R^*$

Above ground C fraction

Total growth (Kg C)

+ 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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Lydie Dufour
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