Incorporating plant plasticity in agroforestry simulation models
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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

2nd World Congress of Agroforestry, 23 – 28 August 2009, Nairobi Kenya
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
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 ressource
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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
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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

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Virtual vectors of branches

Plot radiative conditions

Tree light availability

Growth of virtual branches

Depends on the stem growth

Depends on individual light availability
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II. 2 Simulation

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

\textbf{CWsimulated} = 10.1m  \textbf{CWsimulated} = 13.4m

\textbf{CWreal} = 11.2m  \textbf{CWreal} = 14.2m

Reconstruction of the differential deformations between the orientations

A high plasticity of poplar crown

\{Crown flexibility = 0.8 \hspace{1cm} (range [0-1])\}

\{Crown sensitivity = 1.5 \hspace{1cm} (range [0-2])\}
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 (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 depends 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: $\delta = 0.0015, \phi = 0.5, R^*_0 = 0.5$
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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

2000 2010 2012
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III. 3 Results: Opportunistic root system: effect on fine root distribution

Under crop

Under tree line

Graphs showing root proportion vs. depth (m) with blind root growth and opportunistic root growth indicated.
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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%

### Total growth (Kg C)

- blind root growth
- opportunistic root growth

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***

```
<table>
<thead>
<tr>
<th>Year</th>
<th>&quot;rigid&quot; tree</th>
<th>plastic tree</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>0.55</td>
<td>0.50</td>
</tr>
<tr>
<td>2010</td>
<td>0.50</td>
<td>0.46</td>
</tr>
<tr>
<td>2020</td>
<td>0.45</td>
<td>0.42</td>
</tr>
<tr>
<td>2030</td>
<td>0.40</td>
<td>0.35</td>
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</tbody>
</table>
```

**Above ground C fraction**

```
<table>
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<tr>
<th>Year</th>
<th>above ground C fraction</th>
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</thead>
<tbody>
<tr>
<td>2000</td>
<td>0.3</td>
</tr>
<tr>
<td>2010</td>
<td>0.4</td>
</tr>
<tr>
<td>2020</td>
<td>0.5</td>
</tr>
<tr>
<td>2030</td>
<td>0.6</td>
</tr>
</tbody>
</table>
```

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

**Total growth (Kg C)**

```
<table>
<thead>
<tr>
<th>Year</th>
<th>Cumulated net photosynthesis (Kg C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>0</td>
</tr>
<tr>
<td>2010</td>
<td>50</td>
</tr>
<tr>
<td>2020</td>
<td>100</td>
</tr>
<tr>
<td>2030</td>
<td>150</td>
</tr>
</tbody>
</table>
```
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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Contact :
Christian Dupraz
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