Modeling 3D Spatially Distributed Water Fluxes in an Andisol under Banana Plants

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Humid tropical climate: 2.5 to 4.5 m water.year$^{-1}$ with intensities > 70 mm.h$^{-1}$

Main stemflow around the pseudo-stem

Stemflow x 10 to 35 the incident rainfall + throughfall

KNO$_3$ supply: massive and localized around the stem

(400 kg N/ha/y
800 kg K/ha/y)

Bassette and Bussière, 2004

Godefroy and Dormoy., 1988
Objectives

- Evaluate distributed subsurface water fluxes under banana plants and to use the collected data to evaluate and numerically simulate these distributed water fluxes using the HYDRUS software package.

- Hence, the study had several phases:
  
  - (i) laboratory experiments to obtain soil hydraulic parameters characterizing the unsaturated hydraulic conductivity function, $K(h)$, and the soil water retention curve, $\theta(h)$;
  
  - (ii) field experiments to measure surface water fluxes (stemflow and throughfall) and subsurface pressure heads and drainage fluxes;
  
  - (iii) numerical modeling using the HYDRUS model to predict distributed water fluxes and compare them to the in situ drainage measurements.
Material and methods

Schematic representation of the flow domain

- Faux-tronc du bananier
- Tensiomètres de surface
- Tensiomètres à 25 cm de profondeur
- Tensiomètres à 55 cm de profondeur
- Collerette
- Tuyaux
- Tôles
- Lysimètres
- Partiteur de stemflow

vers les bidons munis de capteurs de pression
Schematic representation of the flow domain

HYDRUS 3D model simulate Darcian water flow in a three-dimensional flow domain in the unsatured-saturated flow system

Richards Equation of water transfer

\[
\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x} \left[ K \left( \frac{\partial h}{\partial x} \right) \right] + \frac{\partial}{\partial y} \left[ K \left( \frac{\partial h}{\partial y} \right) \right] \frac{\partial}{\partial z} + \left[ K \left( \frac{\partial h}{\partial z} - 1 \right) \right] - S
\]

Water retention curve (Wind measurements)

\[
\theta(h) = \frac{\theta_s - \theta_r}{(1 + |\alpha h|^n)^m}
\]

Run-off, soil evaporation, plant nutrition

Hydraulic conductivity curve (Double ring Infiltrometers)

\[
K(h) = K_s S \left( 1 - \left( 1 - S e^{-m} \right)^m \right)^2
\]

Mualem - Van Genuchten (1980)
Material and methods

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Pressure Head \(-h\) [m], Min = -1.752, Max = -0.800

(c) Banana stem

(d) Seepage

(b) Free drainage

A horizon
B horizon

(b) Throughfall

Lysimeter 1
Lysimeter 2
Lysimeter 3

Seepage

Stemflow
## Results: Soil properties

### Physical properties of the Andisol

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Clay†</th>
<th>Bulk density</th>
<th>Organic C</th>
<th>Total porosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>58.6%</td>
<td>0.71 g cm⁻³</td>
<td>6.69%</td>
<td>0.673 m³ m⁻³</td>
</tr>
<tr>
<td>B</td>
<td>63.1%</td>
<td>0.49 g cm⁻³</td>
<td>3.73%</td>
<td>0.665 m³ m⁻³</td>
</tr>
</tbody>
</table>

### Effective soil hydraulic parameters

<table>
<thead>
<tr>
<th>Material</th>
<th>$\theta_r$</th>
<th>$\theta_s$</th>
<th>$\alpha$</th>
<th>n</th>
<th>$K_s$</th>
<th>l</th>
</tr>
</thead>
<tbody>
<tr>
<td>A horizon</td>
<td>0.13</td>
<td>0.75</td>
<td>19.0</td>
<td>1.07</td>
<td>3</td>
<td>0.5</td>
</tr>
<tr>
<td>B horizon</td>
<td>0.11</td>
<td>0.75</td>
<td>23.3</td>
<td>1.05</td>
<td>1.06</td>
<td>0.5</td>
</tr>
<tr>
<td>Wick</td>
<td>0</td>
<td>0.63</td>
<td>0.06</td>
<td>3.61</td>
<td>280</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Mean pressure heads measured with tensiometers

-3.5  -3  -2.5  -2  -1.5  -1  -0.5  0

0  20  40  60  80  100  120  140  160

Time, d

Pressure Head, m

0  50  100  150

Rainfall, mm

-3.5  -3  -2.5  -2  -1.5  -1  -0.5  0

0  20  40  60  80  100  120  140  160

Time, d

Pressure Head, m

0  50  100  150

Rainfall, mm

Simulating period

-3  -2  -1  0  1  2

-3.5  -3  -2.5  -2  -1.5  -1  -0.5  0

0  20  40  60  80  100  120  140  160

Time, d

Pressure Head, m

Rainfall  6 cm - Observed  25 cm - Observed  55 cm - Observed
Modeling 3D Spatially Distributed Water Fluxes

Results
Measured and simulated cumulative fluxes from four lysimeters
Conclusion

- Using **experimental** and calculated drained volumes, as well as soil pressure head data, we attributed **drainage fluxes under the banana stem** or immediately downstream from the stem almost exclusively to **the stemflow**.

- **Simulations** showed that under heavy fluxes, such as those due to stemflow, the wicks reproduced the actual field drainage reasonably well. Under smaller surface fluxes (e.g., throughfall), measured water fluxes with lysimeters were, on average, 50% underestimated compared with simulated water fluxes without lysimeters.

- The spatially distributed water fluxes under the banana plant also considerably influence **solute transport**. Our results, *i.e.*, a concentrated water flow around the plant stem, bring into question the common practice of applying fertilizers and pesticides at the foot of the plant.
Wick lysimeters

Material and methods