DRYING BEHAVIOUR AND WATER TRANSPORT MECHANISMS DURING EVAPORATION OF AN AGRICULTURAL SOIL

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Collaboration between 3 groups

- Gembloux Agro Bio Tech: Soil science/hydraulics
- Engineering faculty: geomechanics
- Engineering faculty: chemical engineering

Same types of phenomena but
- Different points of view
- Different applications
- Different terminology
Application comes from soil science

- Climate change and global warming
  - Intensive evaporation of moisture from agricultural land during dry seasons
  - Effects on soil hydro-mechanical behavior e.g., shrinkage, cracking, conductivity hydraulic, etc.

Bordia, Gembloux (April 2018)
Goals

- Characterizing the evaporation process of an agricultural soil under high temperature conditions
- Investigating the moisture transport mechanisms between the soil surface and the atmosphere
  - Experimentally
  - Numerically
Characteristics of the studied soil

- **Soil type**: Cutanic Luvisol
- **Soil texture**: silt loam (70-80 %), clay (18-22 %), sand (5 -10 %), organic matter (C, N)
- **Soil sample preparation**:
  - Disturbed soils were taken from the Bordia field, between 0-10 cm depth
  - Dried at 40 °C for 1 week
  - Crushed and sieved at 2 mm size
  - Compacted in core rings of 8 cm diameter, 5 cm height
  - Soil sample is saturated after 2 nights
Evaporation tests in a Hyprop device

- Camera
- Temperature sensor
- Tensio Top
- Tensio Bottom
- Pressure sensors
- Soil sample
- Sampling ring
- Thermistor
- Sensor unit
- Balance
Experimental results

- A long experiment …
Experimental results
Experimental results

- Soil temperature evolution with time (e.g., from Test 3)
Coupled thermo-hygro-mechanical model

- LAGAMINE finite element code (developed at Liège)
- Mechanical model
  - Bishop’s effective stress :
    \[ \sigma'_{ij} = \sigma_{ij} - p_g \delta_{ij} + S_e (p_g - p_w) \delta_{ij} \]
    Where \( p_g, p_w \) are resp. gas and water pressure
  - Nonlinear elastic model :
    \[ \sigma'_{ij} = D_{ijkl}^e \varepsilon_{ij} \]
    Where \( D_{ijkl}^e \) is a function of suction
Coupled thermo-hygro-mechanical model

- Hydraulic model
  - **Water retention curve** (Dual porosity model, Durner, 1994)

\[
S_e(h) = w_1 [1 + (\alpha_1|h|)^{-n_1}]^{m_1} + w_2 [1 + (\alpha_2|h|)^{-n_2}]^{m_2}
\]

Where

- \( h \): water tension
- \( w_1, w_2 \): weighing factors
- \( \alpha_1, \alpha_2 \): inverse of the air entry pressure
- \( m_1, n_1, m_2, n_2 \): model’s parameters

- **Hydraulic conductivity** (Mualem, 1976 adapted)
Coupled thermo-hygro-mechanical model

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Coupled thermo-hygro-mechanical model

- Mixed convective/radiative boundary conditions
Coupled thermo-hygro-mechanical model

- Axisymmetric geometric configuration

\[
\begin{align*}
p_{w0} &= 0.1 \text{ MPa} \\
p_{g0} &= 0.1 \text{ MPa} \\
T_0 &= 28 \degree C
\end{align*}
\]
Coupled thermo-hygro-mechanical model

- Mesh: 20 x 50
- Convective transfer coefficients
  - \( \alpha = 0.0048 \,[m/s] \)
  - \( \beta = 84.8 \,[W/m^2/K] \)
- Simulation time: 120 h
- Boundary conditions
  - Environment \( RH = 27.1 \% \)
  - Water pressure \( P_c = -185 \, MPa \)
  - Air temperature \( T_a \)
Numerical results

- Good agreement between experiments and modeling, including for shrinkage

![Evaporation rate with time](chart1.png)

![Soil surface temperature](chart2.png)
Numerical results

- Moisture is always mainly removed through Darcian advective flow during evaporation process.
- The evaporation front moves towards the bottom of the sample.

Flux of water and vapour flow at soil surface.

![Graph showing flux of water and vapour flow over time](image)
Conclusions

- Under the experimental conditions, four periods of evaporation were identified;
- Good numerical results using the THM model;
- Moisture transport mainly governed by Darcian advective flow;
- And now?
  - Impact of agricultural practices on water transport, cracks;
  - Impact of type of soil;
  - Impact of dessication cracking or wetting/drying cycles;
  - Identify an appropriate tillage method and management practices to improve the soil structure and the water retention capacity of the soil.
Thank you