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)

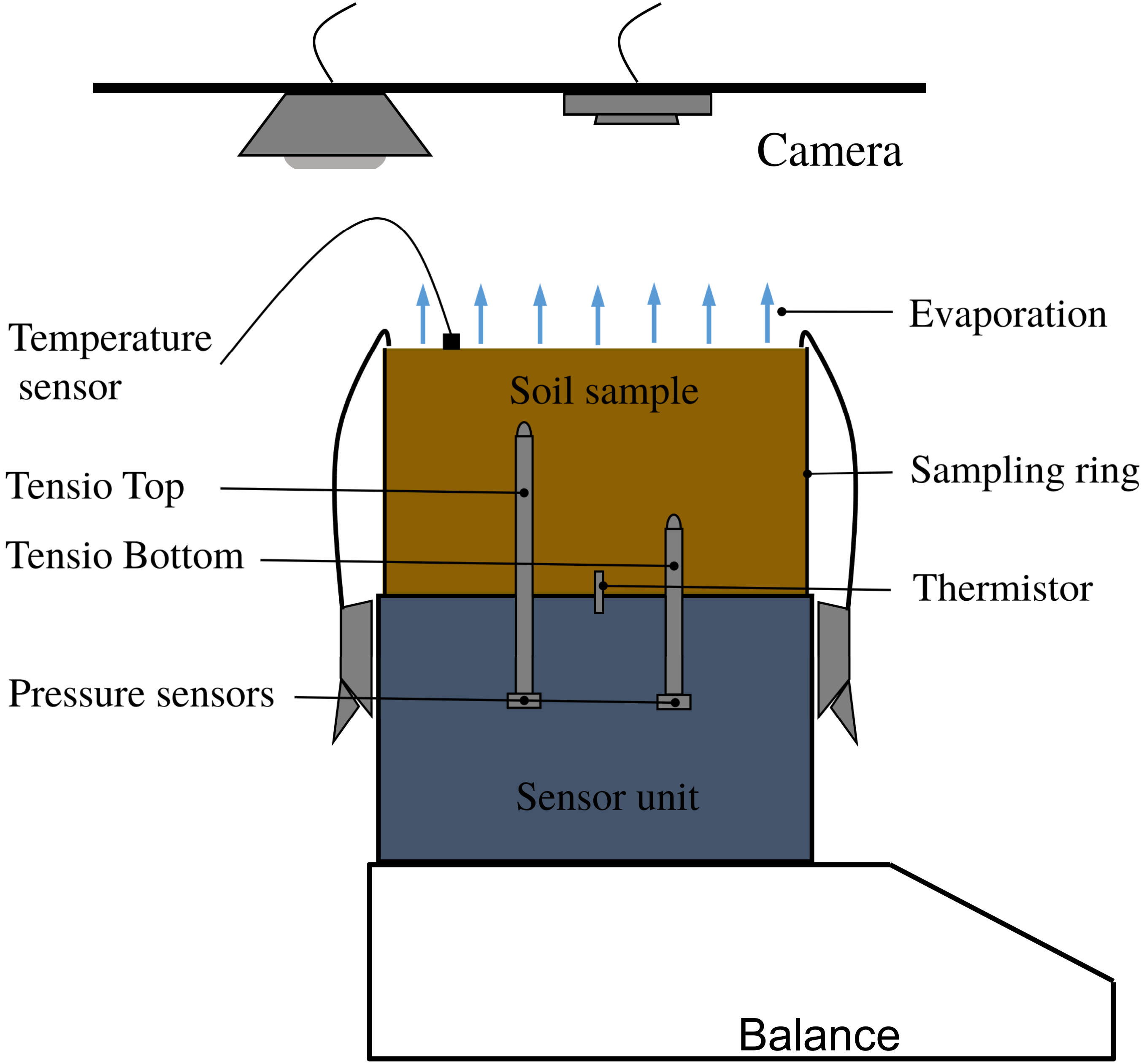
Goals

- 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

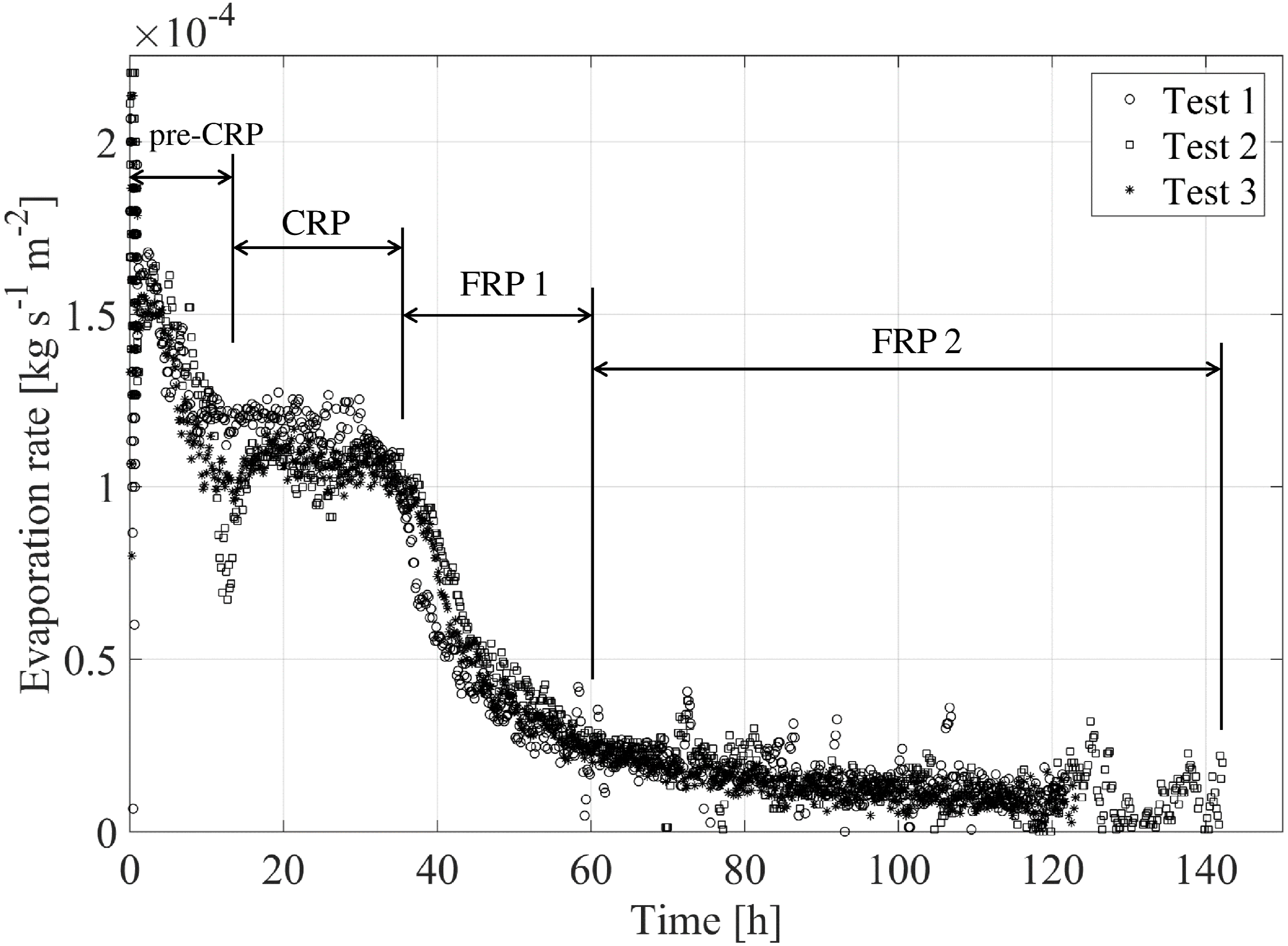
- **Soil type:** Cutanic Luvisol
- **Soil texture:** silt loam (70-80 %), clay (18-22 %), sand (5 -10 %), organic matter (C, N)
- **Soil sample preparation:**
  - Disturbed soils were taken from the Bordia field, between 0-10 cm depth
  - Dried at 40 °C for 1 week
  - Crushed and sieved at 2 mm size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

Evaporation tests in a Hyprop device

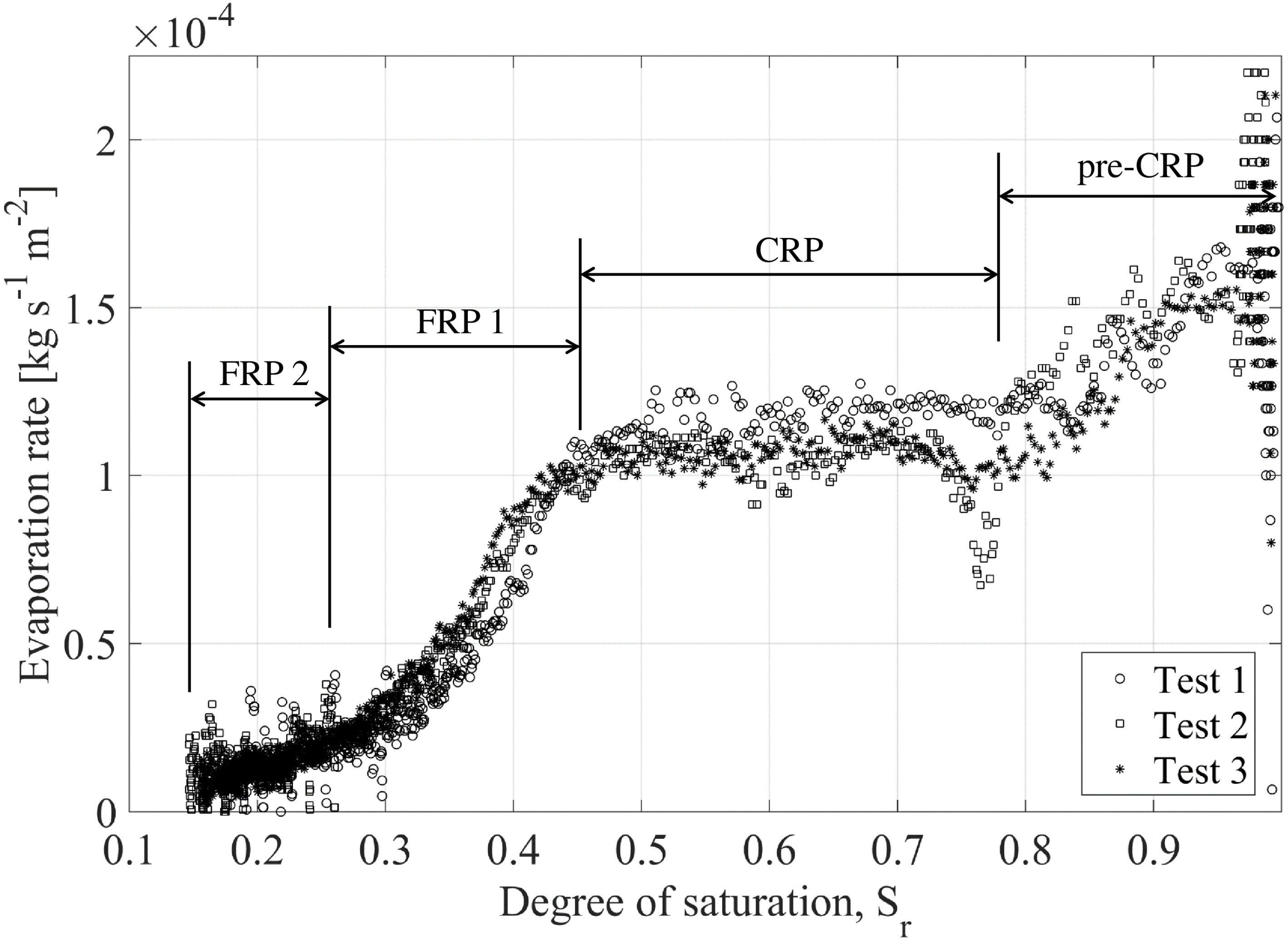


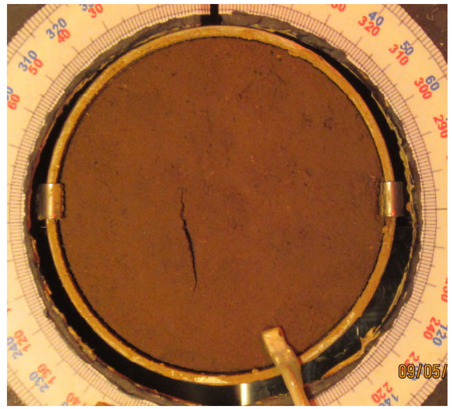
Experimental results

- **A long experiment …**



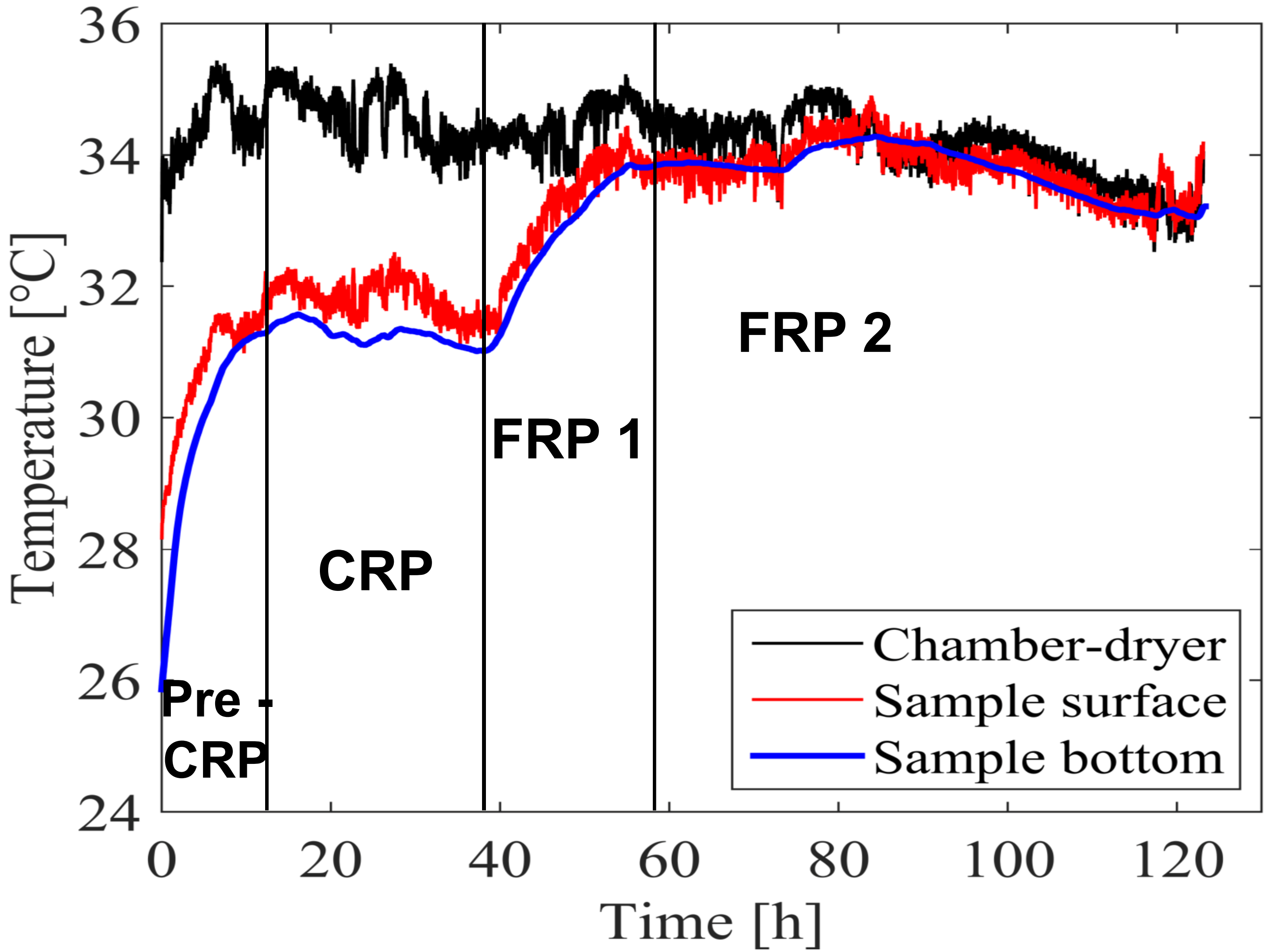
Experimental results





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 :**

$$\sigma'_{ij} = D^e_{ijkl}\varepsilon_{ij}$$

Where D^e_{ijkl} 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

α_1, α_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

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

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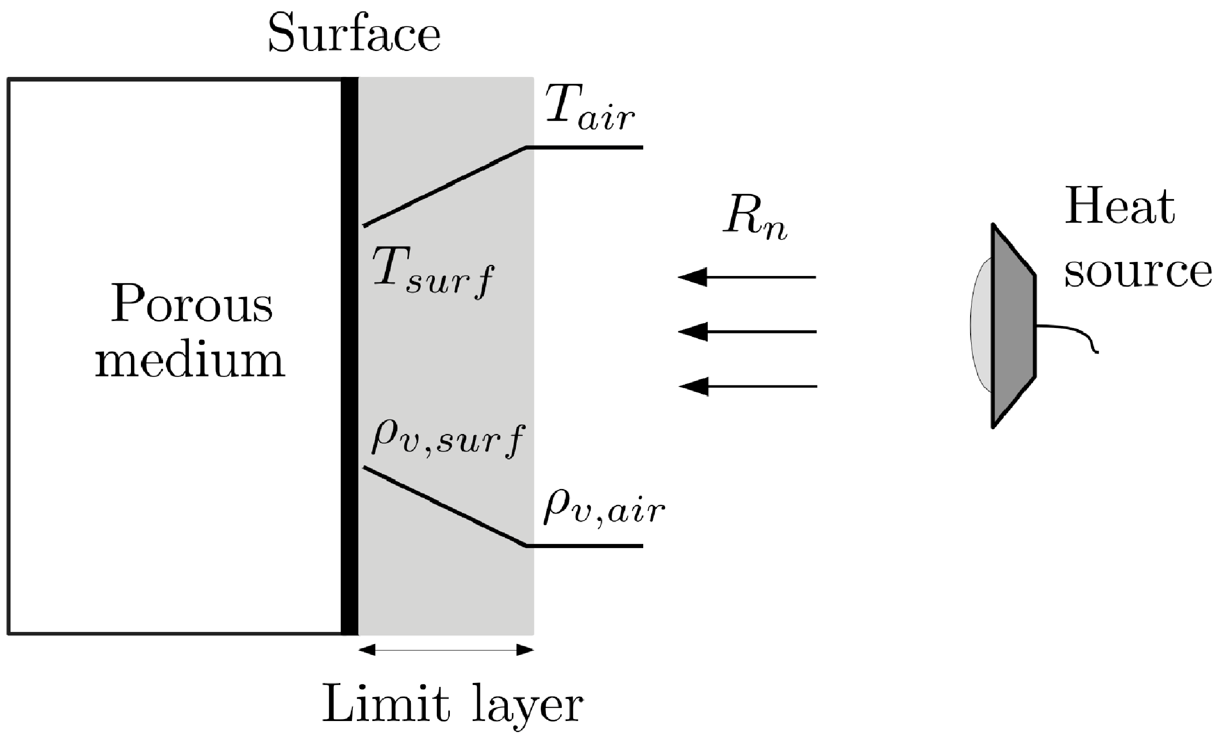
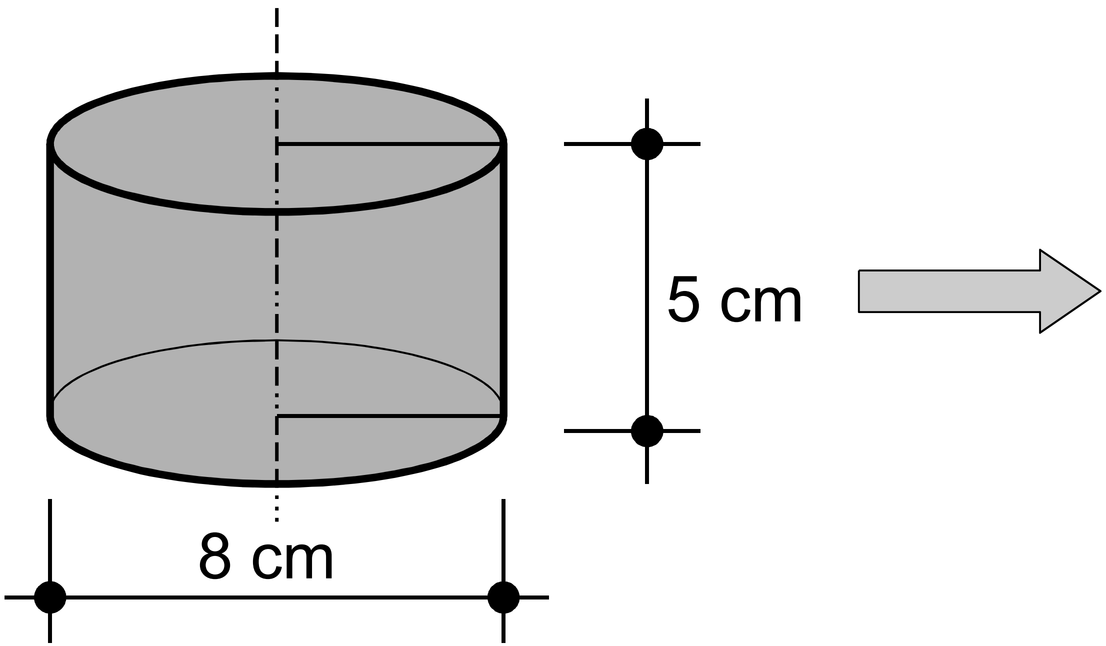
Coupled thermo-hygro-mechanical model

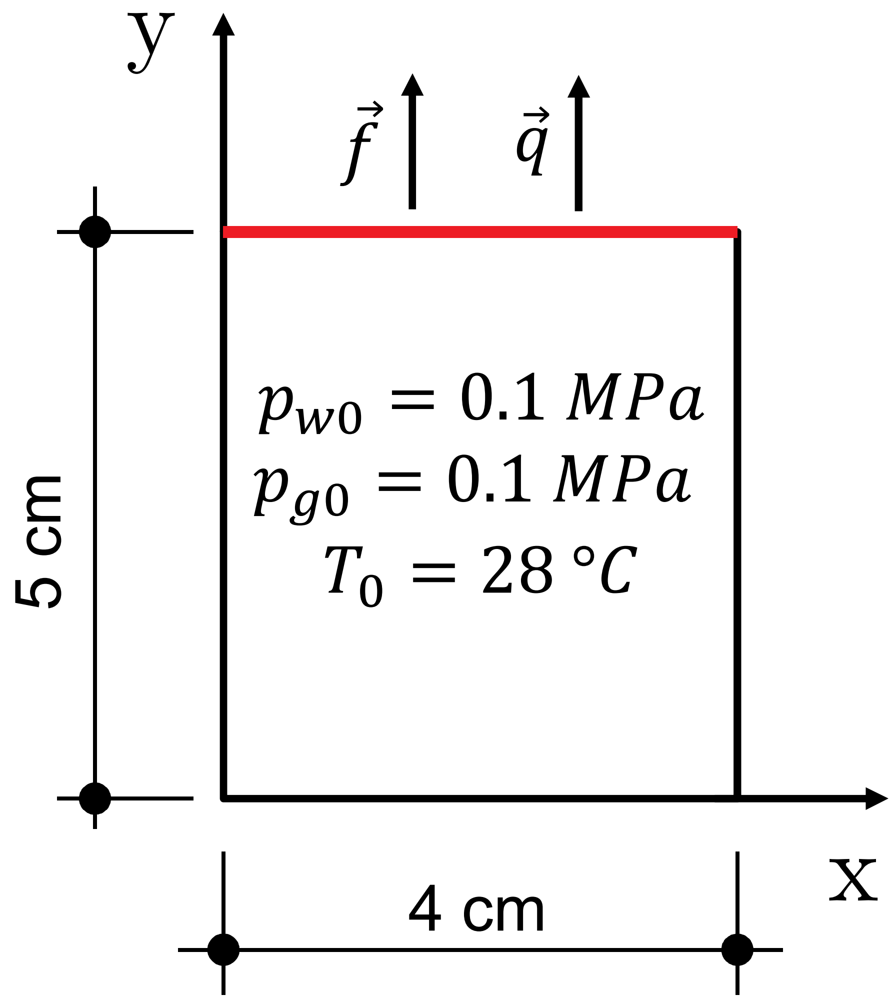
- Mixed convective/radiative boundary conditions



Coupled thermo-hygro-mechanical model

- Axisymmetric geometric configuration





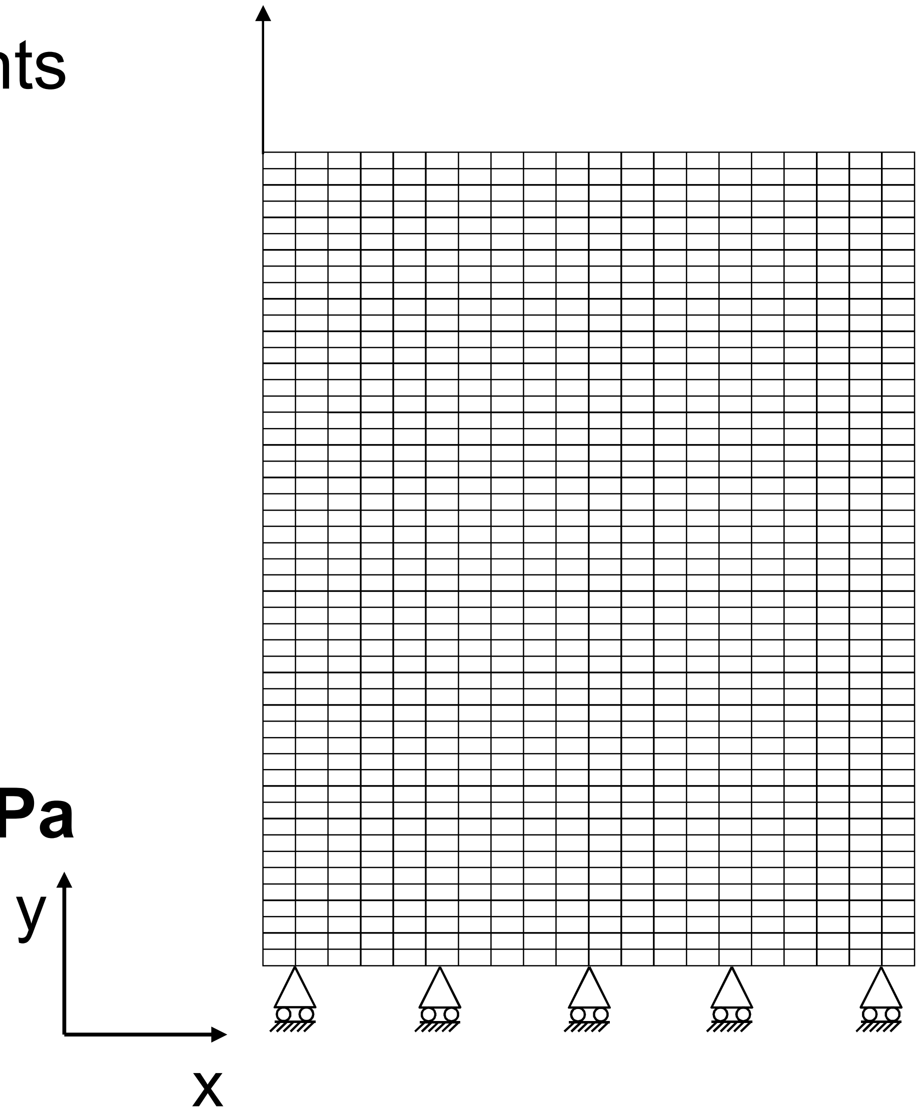
Coupled thermo-hygro-mechanical model

- 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 %**

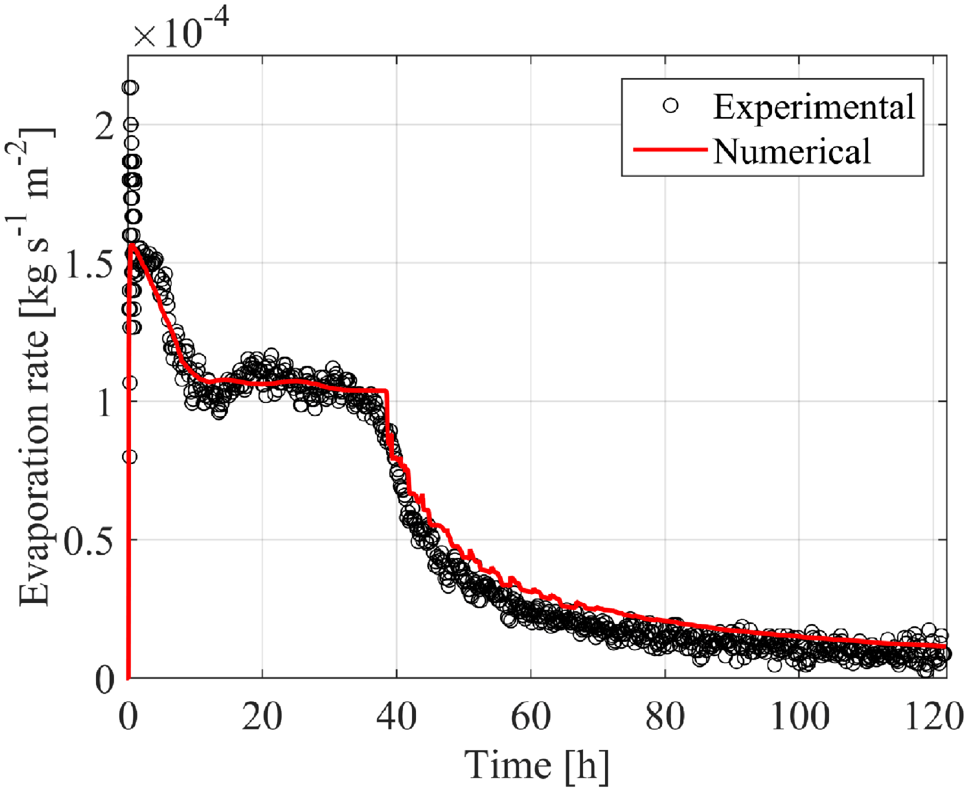
⟺ Water pressure $\mathbf{P_c}$ **= -185 MPa**

Air temperature $\mathbf{T_a}$

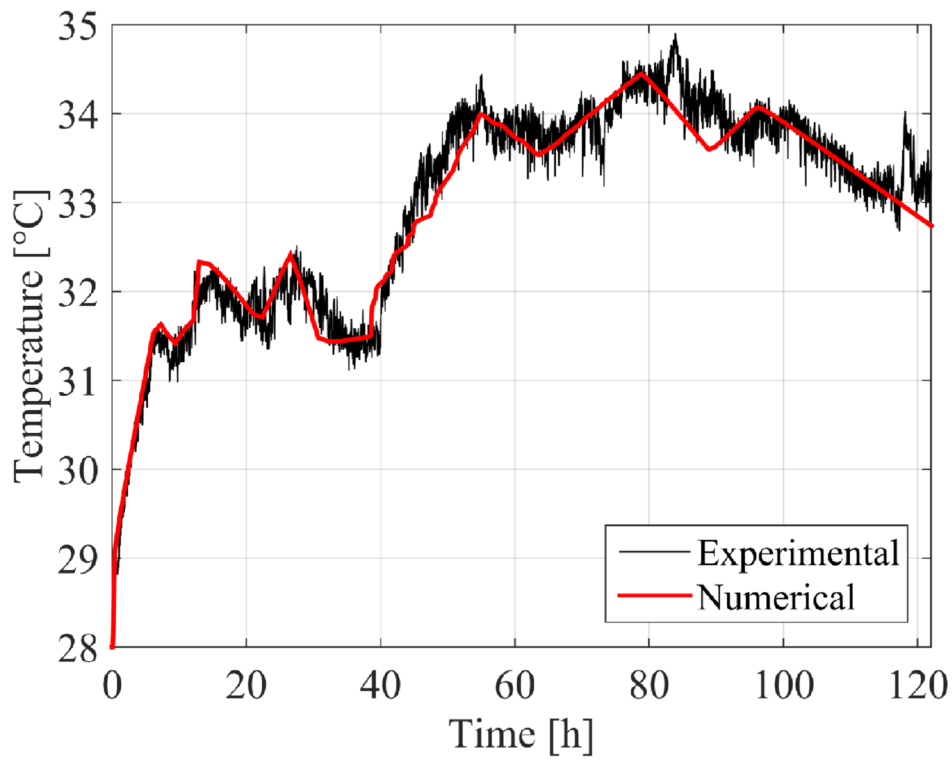


Numerical results

- Good agreement between experiments and modeling, including for shrinkage



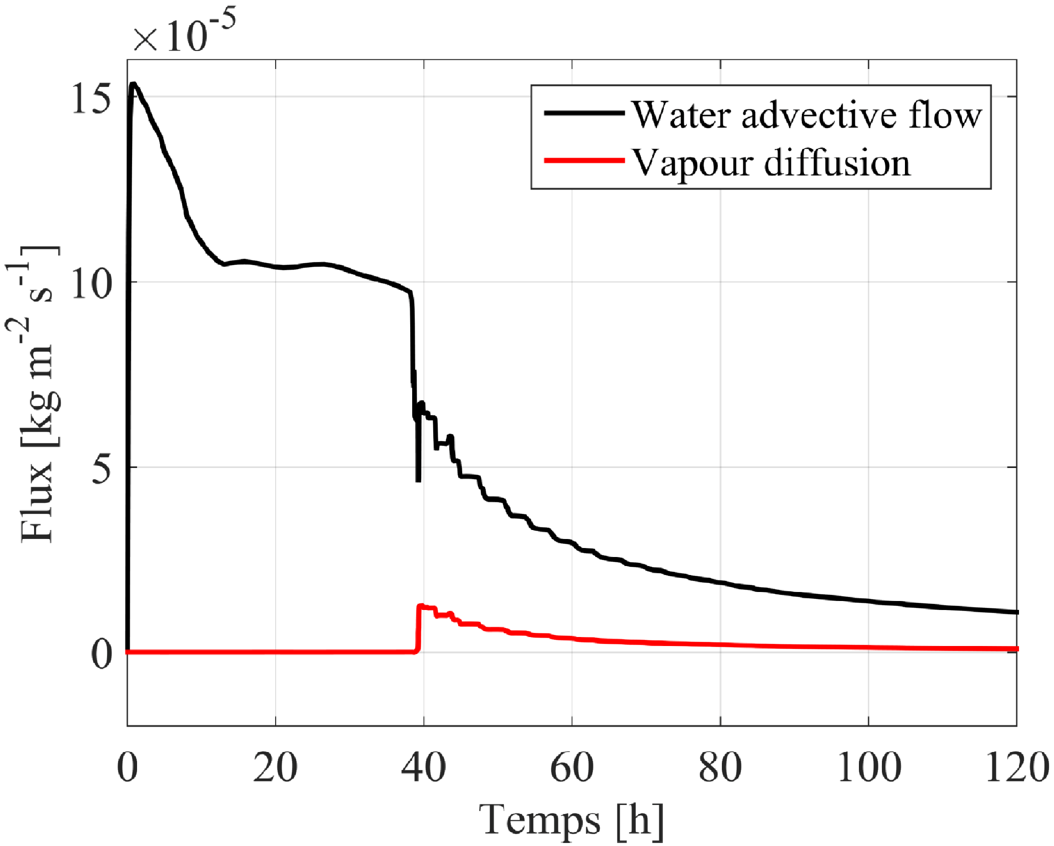
Evaporation rate with time



Soil surface temperature

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

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