Preferential flow in surface and subsurface soils of the recharge area of a groundwater aquifer

Lionel Alletto, Yves Coquet, Pierre Vachier, Christophe Labat

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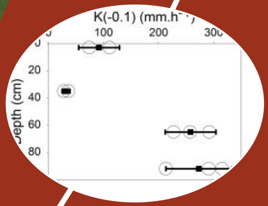
Outline

Preferential flow in soils : the Mobile-Immobile Model

Context of the study

Materials and Methods



Results and Discussion

Conclusion

Part I

Preferential flow in soils : the Mobile-Immobile Model

Preferential transport: water short-circuiting a fraction of porosity thus increasing the downward flux rate of solutes

2 models of preferential transport:

- *via* the macroporosity (root channels, earthworms holes, cracks…) in water content is near or at saturation …

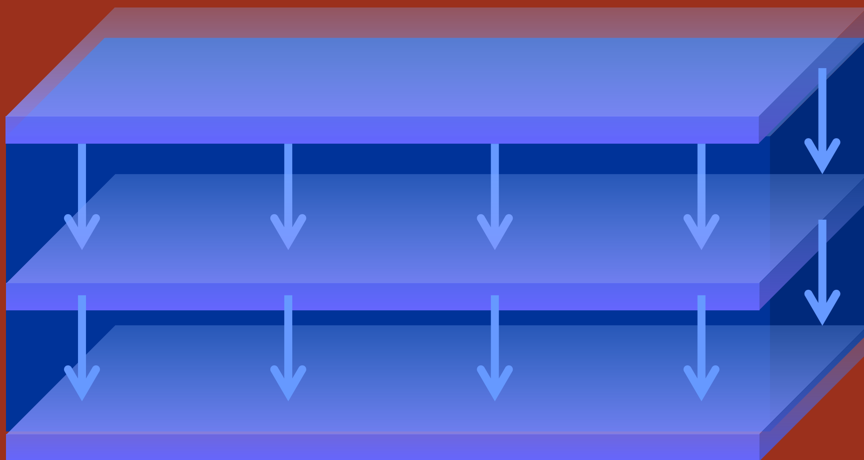
- *via* the mesoporosity, the microporosity acting as a source-sink for solutes (by diffusion): Mobile-Immobile Model (MIM)

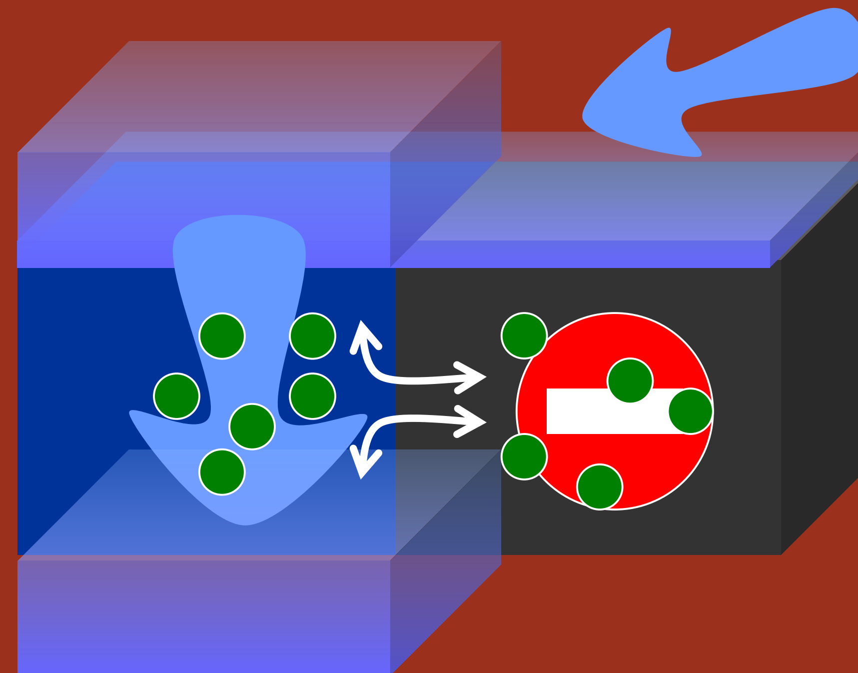
All the porosity is active:

(Coats & Smith, 1964 ; van Genuchten & Wierenga, 1976, 1977)

1 $$\theta = \theta_m$$

2 $$\theta = \theta_m + \theta_{im}$$





$$V_{w1} = \frac{J_w}{\theta_m} = V_w = \frac{J_w}{\theta}$$

$$V_{w2} = \frac{J_w}{\theta_m} > V_w = \frac{J_w}{\theta}$$

α

$$\theta_{im}\frac{\partial C_{im}}{\partial t} = \alpha(C_m - C_{im})$$

Part II

Context of the study

!

Tertiary aquifer of the agricultural region of Beauce (France): contamination with several pesticides ($C > 0.1$ µg.L^{-1})

Objectives of the study

1- Diagnose the existence of preferential transport of the MIM type in a soil profile

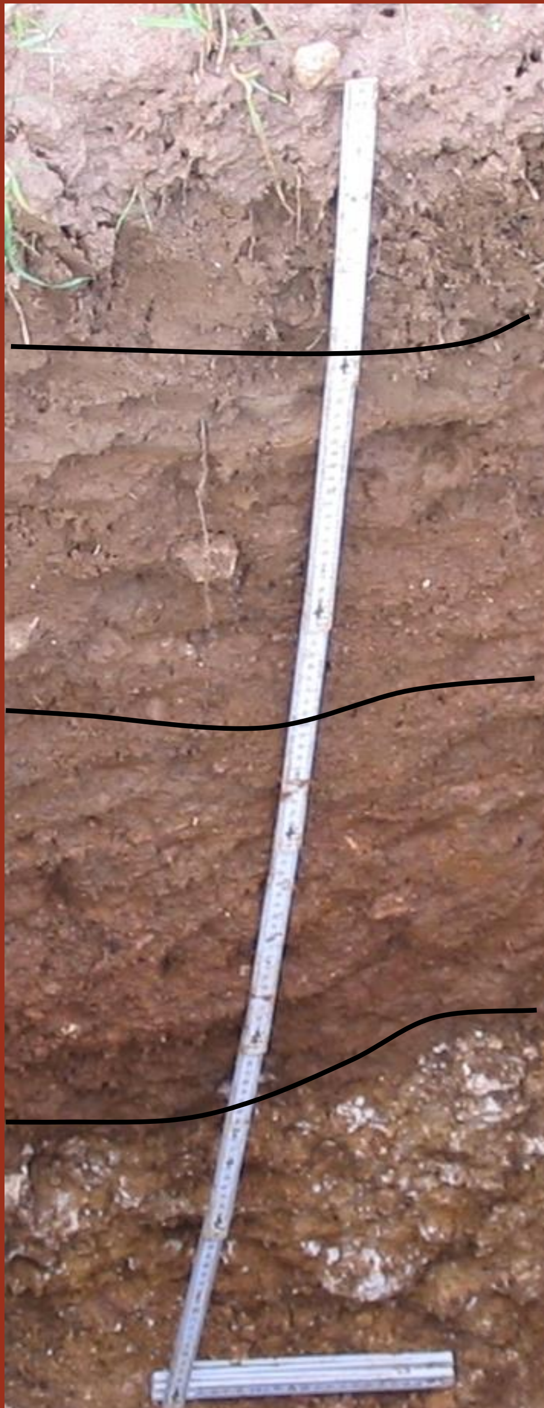
2- Estimate the (hydraulic conductivity) parameters of the MIM model: the immobile water fraction θ_{im}/θ and the mass exchange coefficient α of various materials from surface down to 1m-depth soil layers

Part III

Materials and Methods

The agricultural field site of Ouarville (Beauce)

- 25 ha
- ploughed in September 2003
- winter wheat sown in November 2003
- measurements : April-May 2004



0-27 cm A_p ploughed organo-mineral horizon

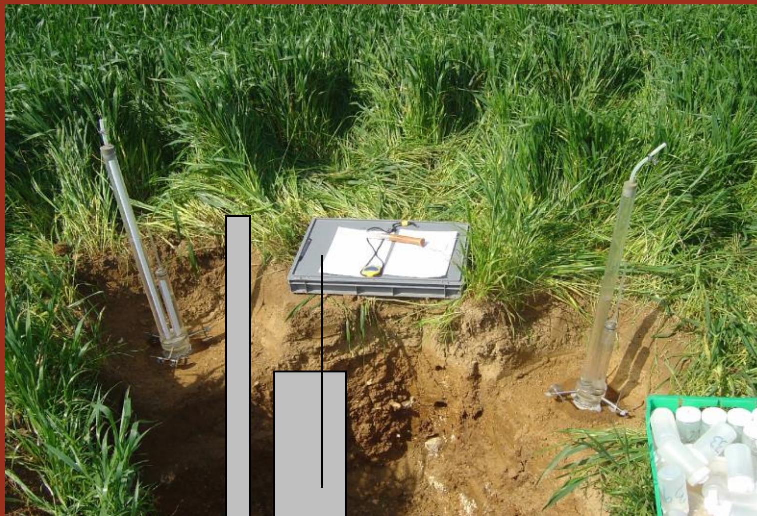
27-60 cm B_t clay-enriched illuvial horizon

60-88 cm B heavy (red) clay horizon

88+ cm C weathered limestone

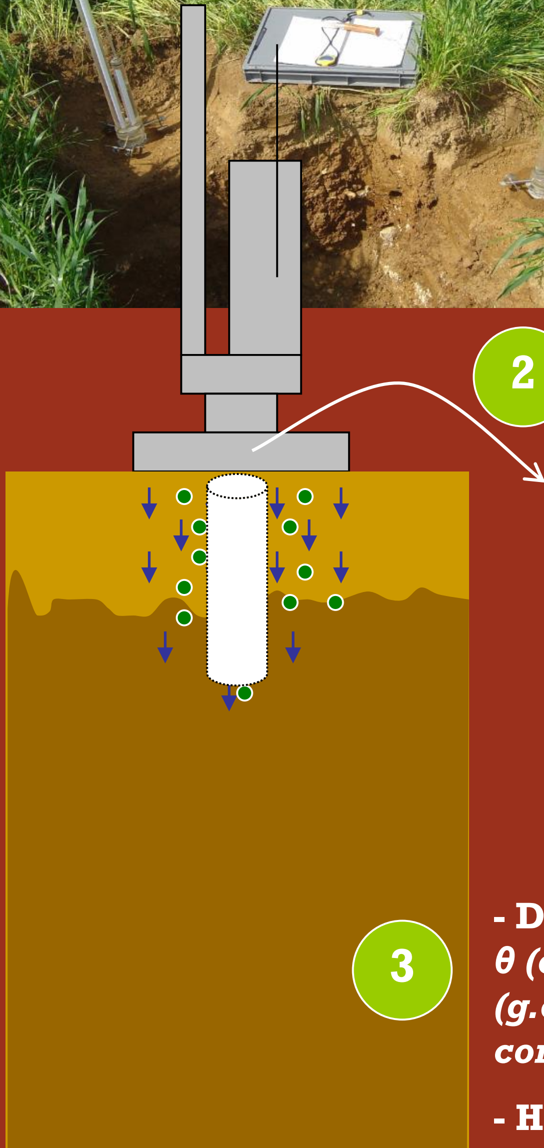
Layer	Depth	pH	Clay	Silt	Sand	OC	$CaCO_3$
				$g.kg^{-1}$			
A_p	3	5.93	223	701	75	11.1	1.34
B_t	35	6.55	352	607	41	6.0	<1
B	65	7.70	565	306	124	5.2	4.66
C	92	8.44	339	57	16	3.5	564

⇨ Orthic luvisol (FAO, 1998)

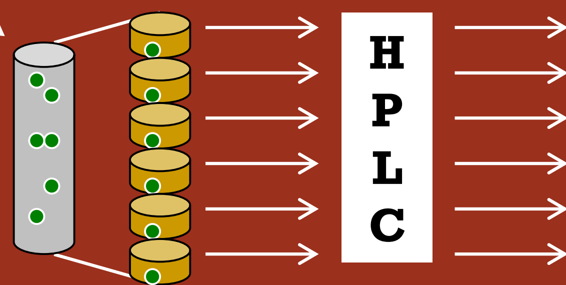


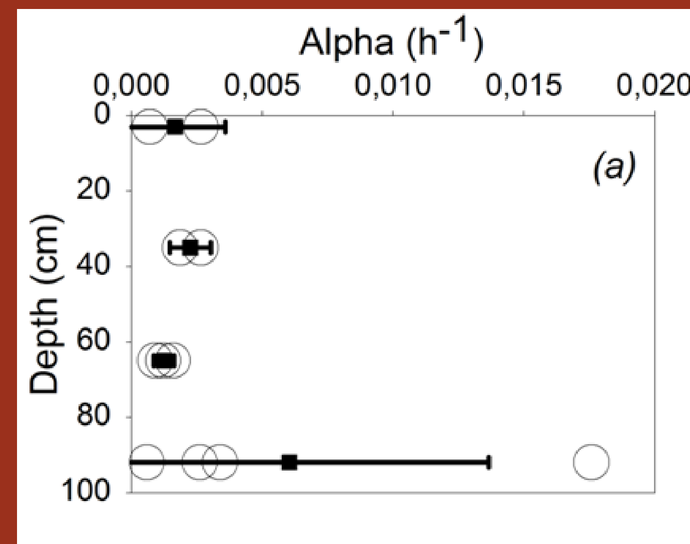
1 **Infiltration of water and 4 sequential infiltrations with tracers (Ø = 8 cm)**

matric potential -0.1 kPa



2 **Soil sampling : each 1 cm down to 10 cm**





3 **- Determination of water content *θ ($cm^3.cm^{-3}$)* , bulk density ρ_b *($g.cm^{-3}$) and the hydraulic conductivity, K(-0.1 kPa) ($mm.h^{-1}$)***

- HPLC analysis

4 **- Determination of immobile water content θ_{im}/θ, and the mass exchange coefficient α**

Assumptions of the model (Jaynes et al., 1995)

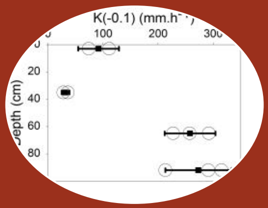
- Initial tracers concentrations = 0
- $C_m = C_0$ (no effect of the hydrodynamic dispersion in the mobile domain in the sampling volume)

Under these assumptions:

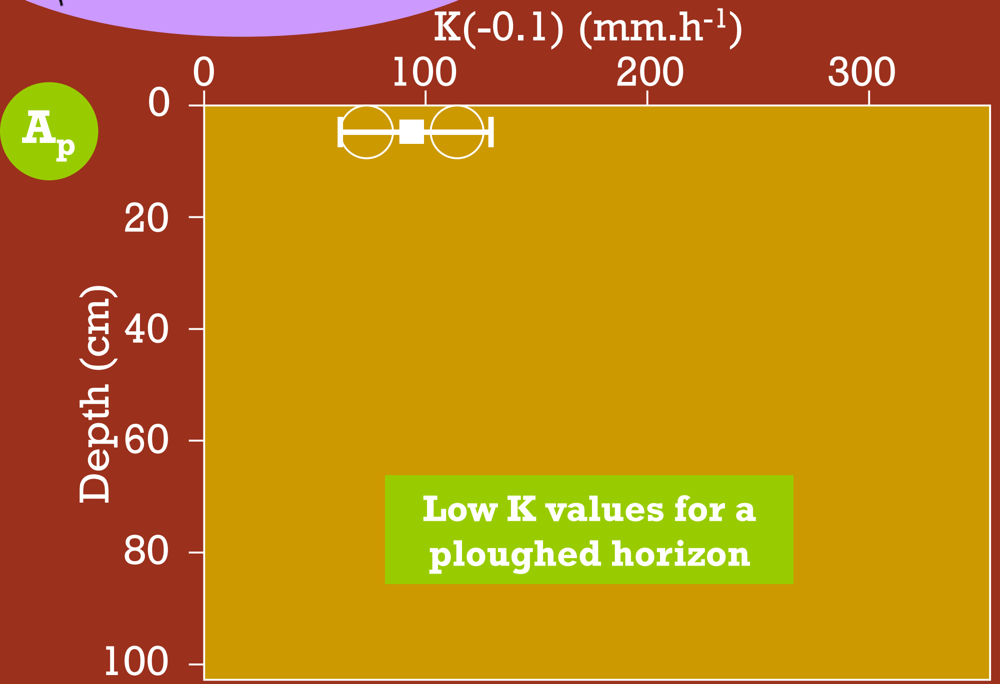
⇨ $\theta C = \theta_m C_m + \theta_{im} C_{im}$

⇨ $\ln(1 - C/C_0) = - \alpha t/\theta_{im} + \ln(\theta_{im}/\theta)$

Part IV

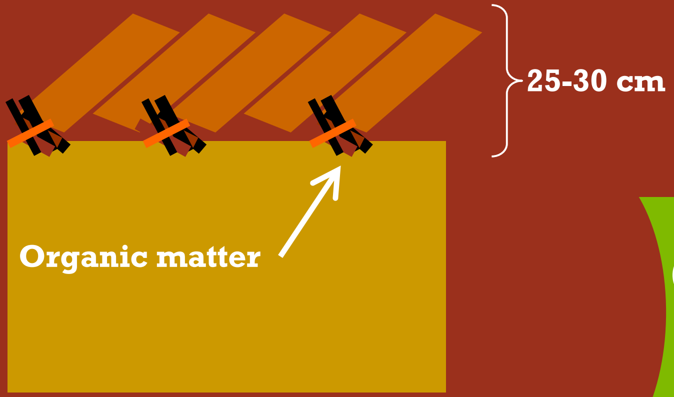


Results and Discussion



Rotary harrow tillage = homogenisation of the upper part of this horizon

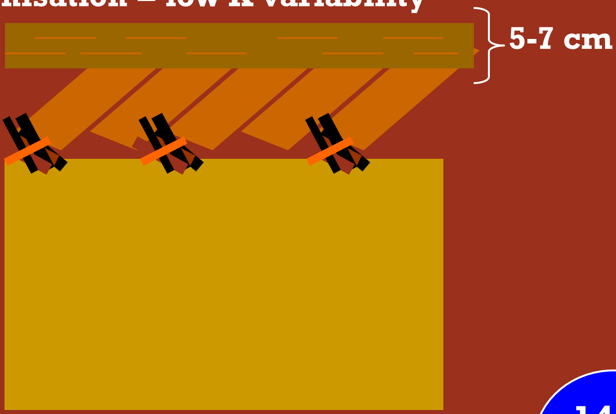
Ploughing: high hydraulic conductivity with a high variability (Coutadeur et al., 2002)



Rotary harrow tillage

Macroporosity destroyed = low K values

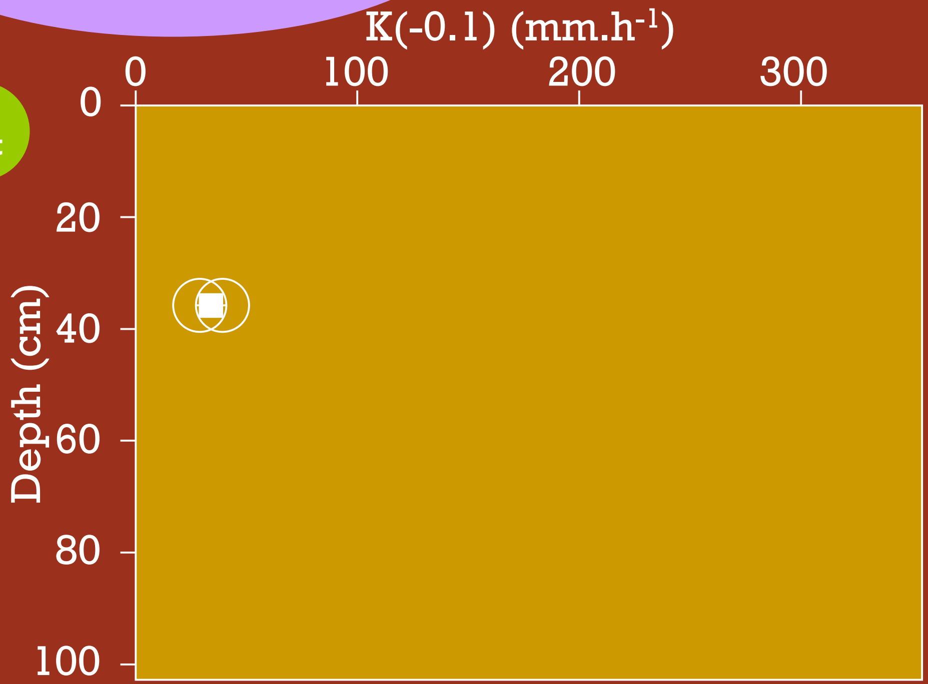
Homogenisation = low K variability



Legend

- ○ measured value
- ■ geometric mean value
- ⊢⊣ Error bar (95% confidence limit)

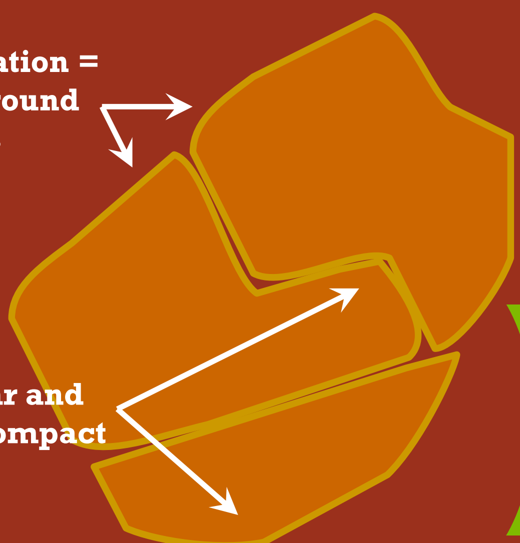
B_t



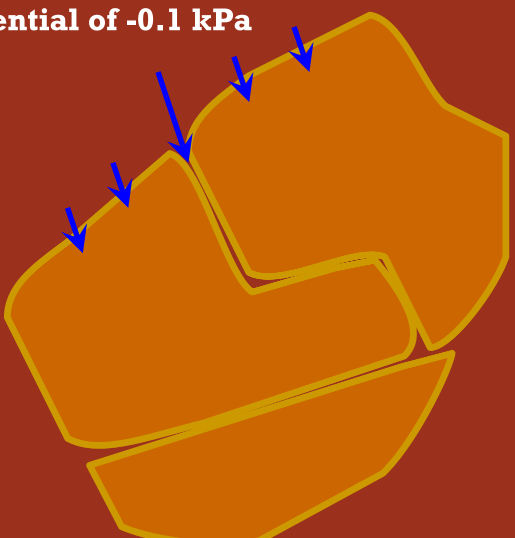
No-tillage + sub-angular structure + coatings (clay illuviation) = low hydraulic conductivity and low variability

Clay illuviation = coatings around aggregates

Sub-angular and partially compact structure



Very limited water infiltration = low K at the matric potential of -0.1 kPa

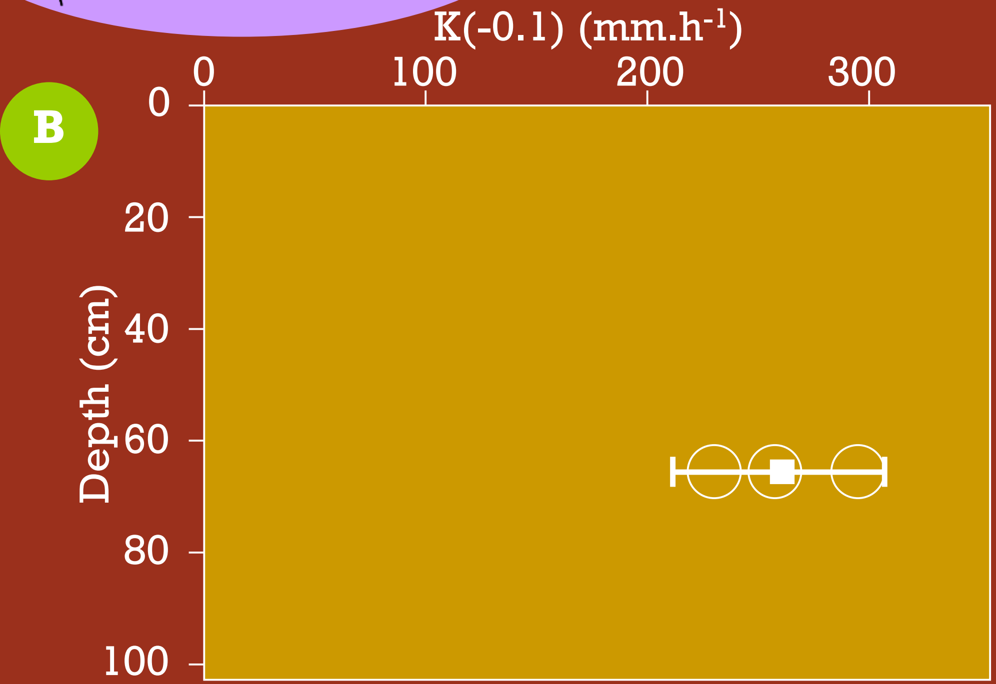


Legend

○ measured value

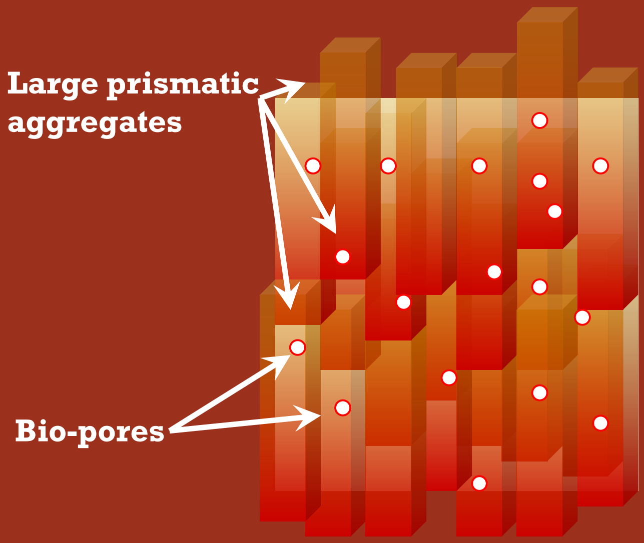
■ geometric mean value

⊢ Error bar (95% confidence limit)



Large aggregates with bio-porosity = water could easily run between them

→ **High hydraulic conductivity**

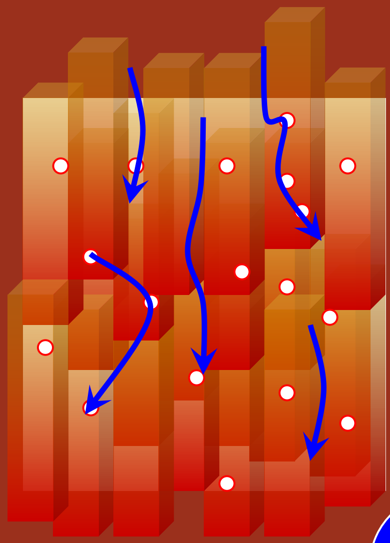


<u>Legend</u>

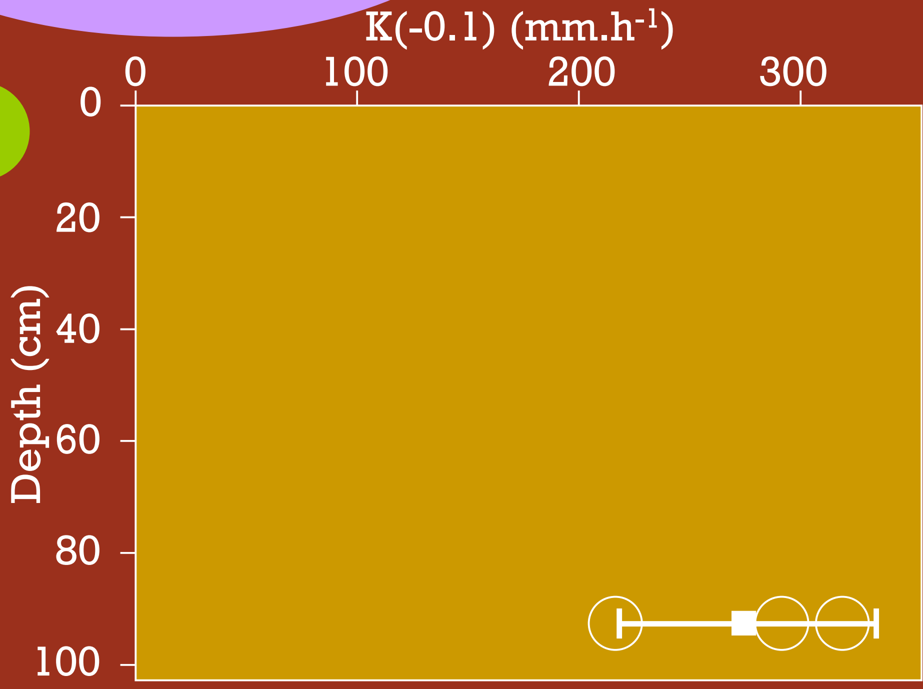
○ measured value

■ geometric mean value

├─┤ Error bar (95% confidence limit)



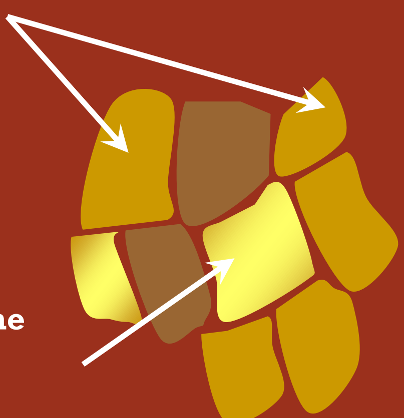
C



Weathered limestone : high hydraulic conductivity due to important fracturation and weathering processes

Small well-structured aggregates

Calcareous stone (with a variable fraction and distribution)



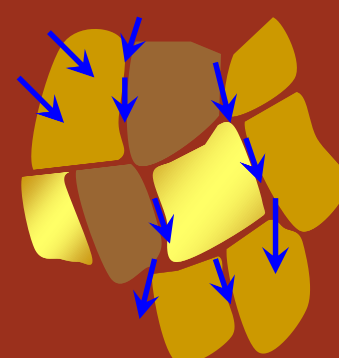
Legend

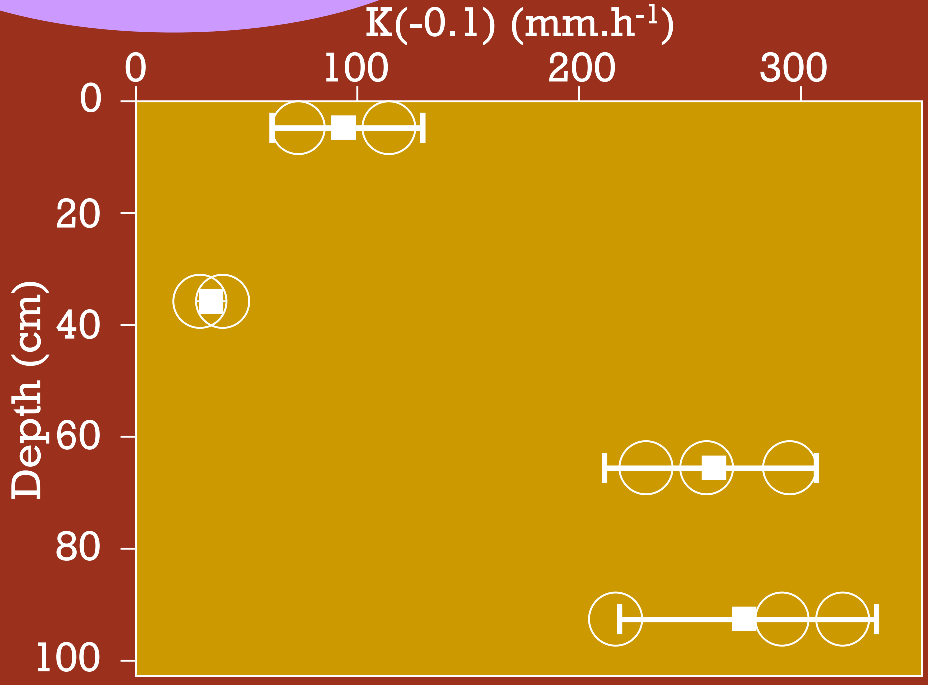
○ measured value

■ geometric mean value

⊢⊣ Error bar (95% confidence limit)

High hydraulic conductivity with a high variability due to a short-range heterogeneity of the limestone





Rotary harrow tillage = homogenisation of the upper part of this horizon

No-tillage + compact structure + coatings (clay illuviation) = low hydraulic conductivity and low variability

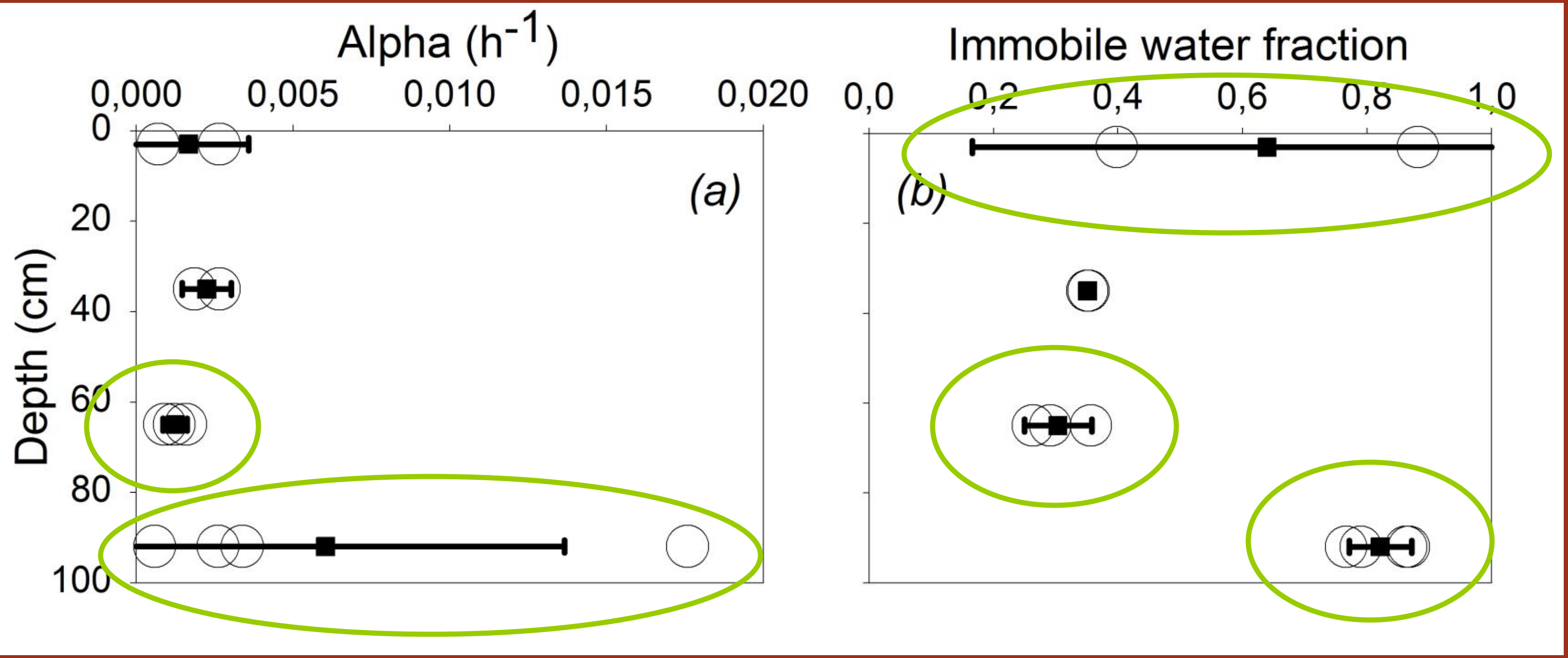
Large aggregates with bio-porosity = water could easily run

Weathered limestone : high hydraulic conductivity due to important fracturation and weathering processes

Structure created by tillage and/or pedogenetic processes has impact on the hydraulic conductivity

MIM parameters

High variability of θ_{im}/θ : localization and size of the seedbed aggregates?



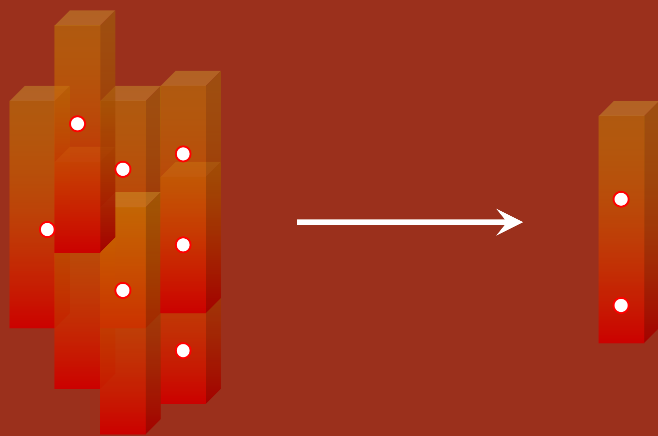
α min: 0.0006 h^{-1} max: 0.0176 h^{-1}

θ_{im}/θ min: 0.263 max: 0.882

→ MIM type of preferential transport is a characteristic of the Beauce soils

MIM parameters: Assumptions for B and C horizons

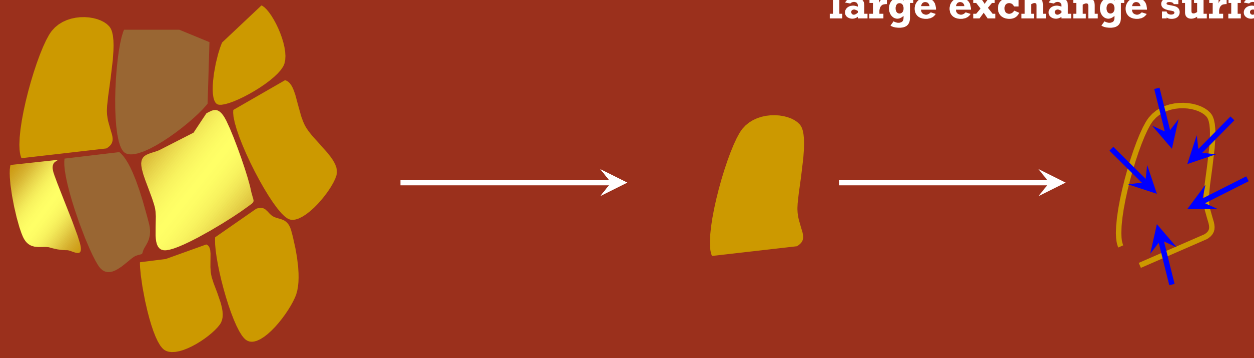
B horizon: large prismatic aggregates



limited exchange surfaces = low α values

C horizon: small well-structured aggregates

large exchange surfaces = high α values



Part V

Conclusion

Preferential flow of the MIM type seems to be a characteristics of the Beauce soils in surface and subsurface

Soil structure plays an important role on the hydraulic conductivity but also on the occurrence of MIM-type preferential flow

Management of soil structure, through tillage practices, appears to be a possible strategy for acting on water and solutes transfer in soil

Thank you.