Variations of immobile water content and first-order mass exchange coefficient in three soil profiles

Y. Coquet†(1), L. Alletto(2), P. Vachier(1), (1) UMR INRA/INAPG Environnement et Grandes Cultures, Grignon; (2)ESA Purpan, Toulouse
†corresponding author: coquet@grignon.inra.fr, Y. Coquet - UMR EGC - BP 01 - 78850 Thiverval-Grignon - France

1 - Context

The largest French aquifer, the Beauce limestone of the Parisian Basin, underlies a region of intensive cereal agriculture. This groundwater reservoir is contaminated by various agricultural pesticides. Such contaminations cannot be explained by the pesticide fate models commonly used for risk assessment (e.g. PZRM). Facing this difficulty, one has to reconsider the description of the various processes implemented in these pesticide fate models. Among these processes, transport could be more complex than a simple convection-dispersion approach.

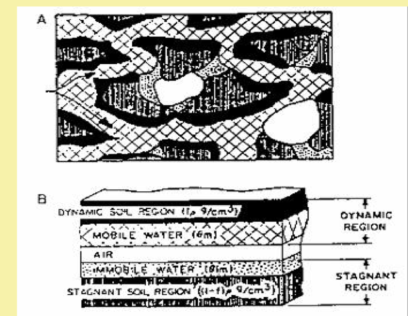
2 - Objectives

Among the various mechanisms explaining preferential transport of solutes in soils, the "mobile/immobile water" (MIM) concept considers a partitioning of the water-filled soil porosity into a mobile region where the solutes are transported by convection- dispersion and an immobile region that exchanges solute with the mobile region by molecular diffusion only. We checked the relevance of the MIM concept to Beauce soils and explored its relation to the soil pedological organization (horizonation).

The "mobile/immobile water" (MIM) concept

$$\theta_m \frac{\partial c_m}{\partial t} + \theta_{im} \frac{\partial c_{im}}{\partial t} = \theta_m D \frac{\partial^2 c_m}{\partial z^2} - q \frac{\partial c_m}{\partial z}$$

$$\theta_{im} \frac{\partial c_{im}}{\partial t} = \alpha (c_m - c_{im})$$



(van Genuchten et Wierenga, 1976)

θ_m, mobile water content; c_m, concentration in the mobile region
θ_{im}, immobile water content; c_{im}, concentration in the immobile region
D, dispersion coefficient; q, water flux density in the mobile region
α, mass exchange coefficient between the mobile and the immobile regions

3 - Materials and Methods

The immobile water fraction (θ_{im}/θ) and the mass exchange coefficient (α) have been measured in three different soil profiles (Luvisols, Cambisol) of a heterogeneous agricultural field. The field had been ploughed to 28 cm in Sep 2003 and a 7 cm-deep seedbed prepared for sowing winter wheat in Nov 2003. Excavations were dug to describe and sample the soil profiles (Table 1). The surface horizon corresponded to the 28 cm-thick ploughed layer (LA1, LA2, LA3). In profiles 1 and 3, BT1 and BT3 were clay-enriched illuvial horizons and had similar characteristics. In profile 3, B3 corresponded to a heavy red clay horizon. Horizons C1, C2 and C3 corresponded to the weathered limestone.
We used tension infiltrometers (Jaynes et al., 1995) to successively infiltrate at -0.1 kPa matric potential solutions of bromide and fluorobenzoates under steady state water flow. Resident concentrations (C) of the various anions in the 1 cm-thick layer below the infiltration surface were measured and θ_{im}/θ and α calculated from the regression of $\ln(1-C/C_0)$ vs. time, where C_0 is the input concentration. Two to four replicates per depth have been done.

Table 1. Characteristics of surface (LA1, LA2, LA3) and subsurface soil horizons (BT1,C1, C2, B3, C3) of the three profiles.

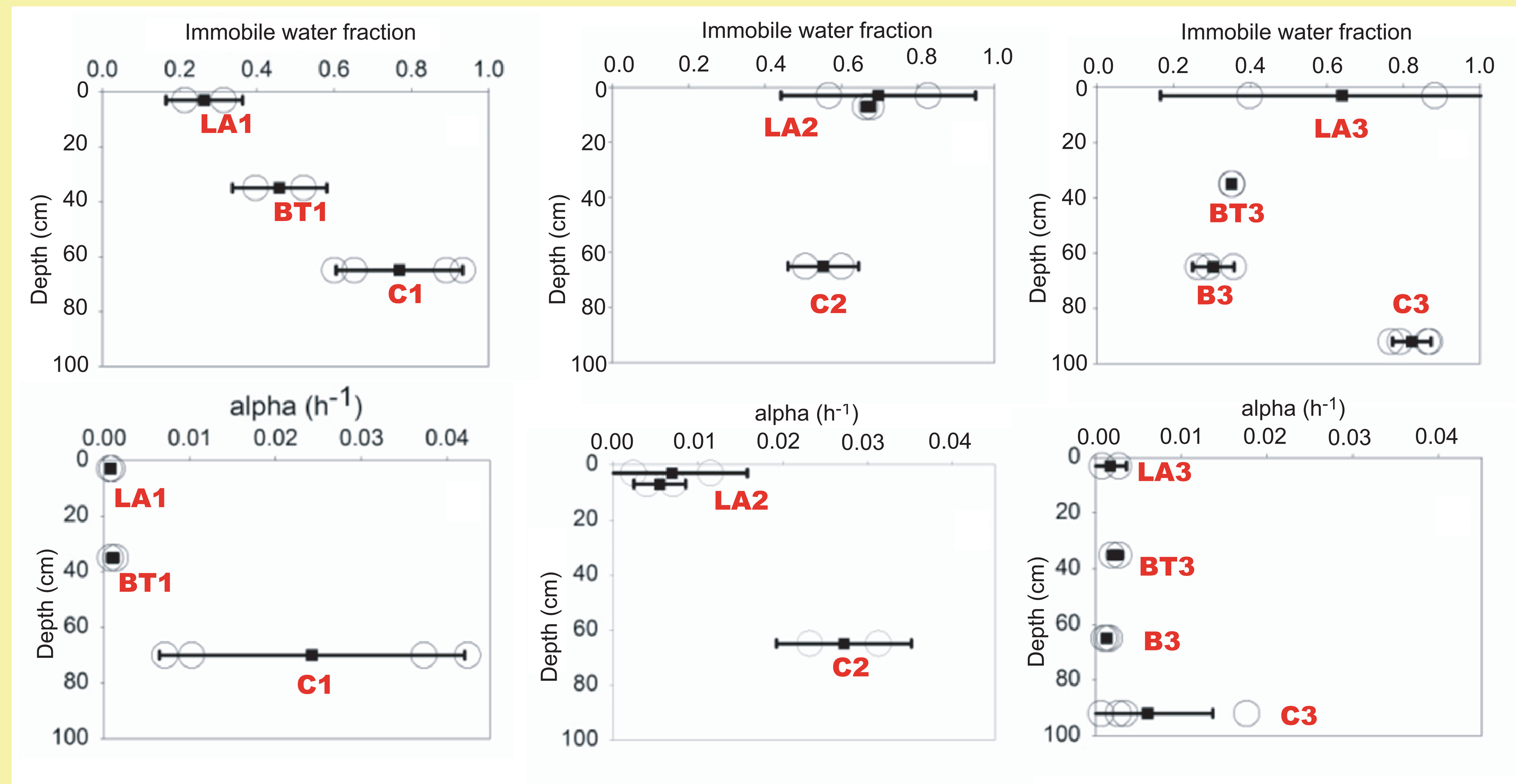
Profile	Horizon	Depth	pH	Clay (0 – 2 m)	Silt (2 – 50 m)	Sand (50 – 2000 m)	OC†	$CaCO_3$
		(m)				(g.kg^{-1})		
1	LA1	0 – 0.28	6.26	247	711	41	13.7	<1
	BT1	0.28 – 0.68	7.02	340	630	29	6.3	<1
	C1	0.68 - >1.20§	8.55	193	240	48	5.3	512
2	LA2	0 – 0.28	6.49	278	621	99	14.1	1.7
	C2	0.63 - >1.20§	8.56	201	82	36	3.1	670
3	LA3	0 – 0.30	5.93	223	701	75	11.1	1.3
	BT3	0.30 – 0.57	6.55	352	607	41	6.0	<1
	B3	0.57 – 0.88	7.70	565	306	124	5.2	4.7
	C3	0.88 - >1.20§	8.44	339	57	16	3.6	564

† OC, soil organic carbon content
§ Maximum depth of the excavation

4 - Results

The 3 soils have a θ_{im}/θ between 21 and 93 %. The variability of θ_{im}/θ was highest in the seedbed (surface of LA), and was related probably its aggregated structure. It was much less in ploughed layer (see measurement at 8-cm depth in LA2) θ_{im}/θ was high in the limestone (C) horizons (above 50 %).

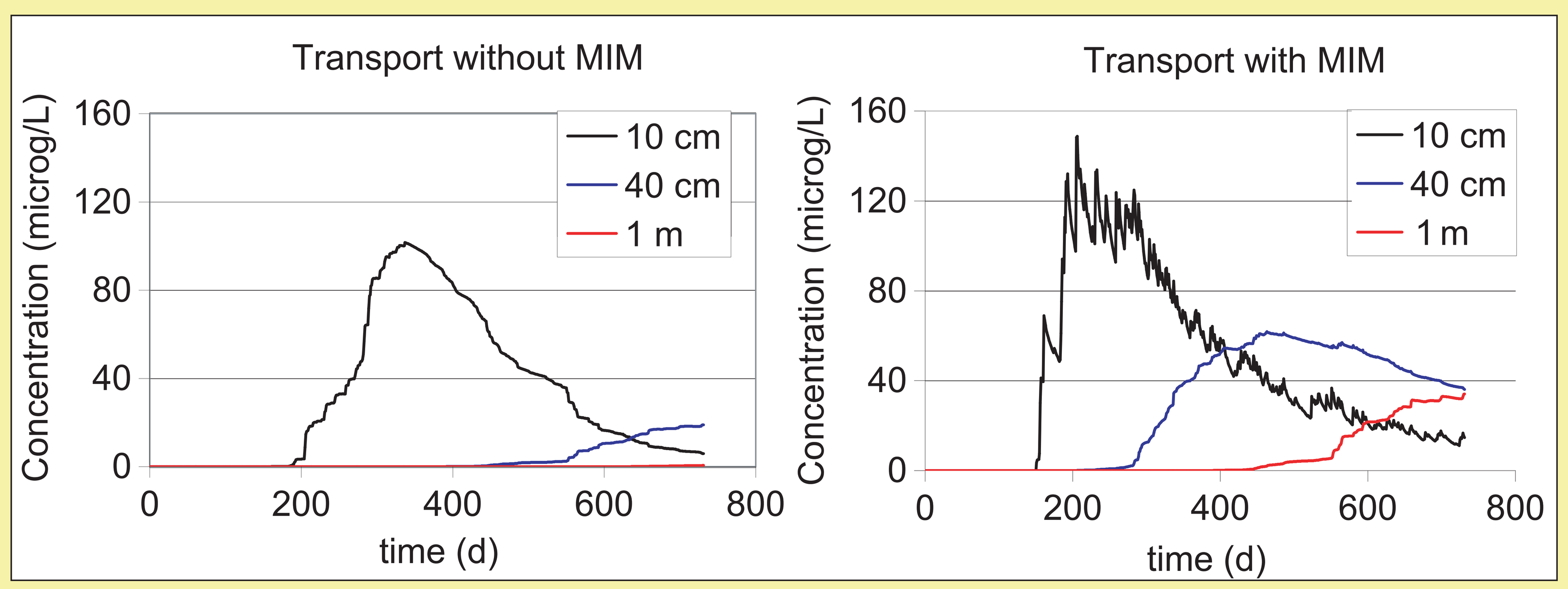
Exchange coefficient α was generally low (less than 0,012 h^{-1}, i.e. a characteristic time, ln2/α, larger than 2.4 d), except in limestone horizons were exchanges were faster. α was also more variable in the limestone horizons.



The existence of a high immobile water fraction in Beauce soils, combined to a low mass exchange coefficient with the mobile water, may be responsible for a fast migration rate of pesticides towards depth.

5 - Implication for modelling pesticide leaching

A first modelling test with HYDRUS-1D (Šimunek et al., 1999) shows a significant effect of the MIM process on leached isoproturon concentrations. This effect is highly dependent on the θ_{im}/θ value.



6 - Perspectives

The main issue, both theoretical and methological, for the operational use of the MIM concept is its applicability to transient water regimes. More research work, such as that of Köhne et al. (2004), is necessary to overcome this difficulty.

7 - References

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