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Impact of tillage on solute transport in a loamy soil from leaching experiments

A. Besson [a,b,*], M. Javaux [a], C.L. Bielders [a], M. Vanclooster [a]

[a] Earth and Life Institute, Environmental Sciences, Université Catholique de Louvain, Croix du Sud 2, BP 2, B-1348 Louvain-la-Neuve, Belgium
[b] Soil Science Unit, INRA 2163 Avenue de la Pomme de Pin, CS 40001, Ardon, 45075 Orleans Cedex 2, France

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ABSTRACT

Soil tillage practices can affect water flow and solute transport processes dynamically in space and in time. However, the relationship between tillage practices and flow and transport in soils is not yet well understood. Within this paper, we analyze the short term impact of the conversion from conventional mouldboard ploughing (CT) to reduced disc harrowing (RT) on the solute transport process within a loamy soil. Solute breakthrough experiments at two flow rates were performed on 2 undisturbed lysimeter collected in a CT and RT field plot. Solute transport parameters were estimated using transfer function theory. Important differences in solute transport were observed between the RT and the CT treatments. The CT treatment exhibited a rapid, more homogeneous and less dispersive solute transport as compared to the RT treatment. These results are explained by the changes in soil structure due to tillage and compaction. The dominant transport was identified as being a stochastic-convective process in both lysimeters. The similarity of the mixing regime for the two soil columns can be explained by preferential solute trajectories activated within structural macropores as a result of the high flow rates applied. We show that the relationship between tillage practices and transport is complex, not only scale and time dependent but also influenced by the boundary conditions and tillage practices.

1. Introduction

Soil is a key component of terrestrial ecosystems where water runoff, infiltration, drainage and storage interact with chemical movement. Flow and transport in soil is complex, space and time scale dependent and subject to human influence. Soil tillage, for instance, has a major control on flow and transport. Indeed, the mechanical perturbation, aiming at developing desirable soil conditions for a seedbed and establishing specific surface configuration for planting, irrigation, drainage or harvesting operations, can have a considerable impact on the soil structure, and hence, on soil hydraulic functioning (Kepner et al., 1978). Tillage may consist of a wide range of practices, ranging from minimum and reduced tillage, say harrowing, and no-till practices for conservation systems in which a substantial part (at least 30%) of the soil remains covered by previous crop residues (Holland, 2004), to mouldboard ploughing as in traditional (or conventional) systems.

Different tillage practices can explain the differences observed in soil structure and, consequently, in water flow and chemical transport in the soil. Several authors underline the benefits of reduced tillage on hydraulic functioning. Plant water uptake, soil water storage, soil water infiltration and transmission are improved in many conservation systems, mainly as a consequence of the modification in soil physical and hydraulic properties (van Doren and Allmaras, 1978; Hatfield et al., 2001; Turner, 2004; De Vita et al., 2007; Moret and Arrúea, 2007; Casa and Lo Cascio, 2008; Strudley et al., 2008). Tracer studies also show that conservation tillage generally promotes more rapid leaching of non-reactive solutes (Gish et al., 1991; Shipitalo and Edwards, 1993; Shipitalo et al., 2000) and pesticides (Alletto et al., 2010 for an extensive review). Indeed, macropore flow dominates generally solute transport in conservative tilled soil as compared to conventionally tilled soil (Petersen et al., 2001; Vervoort et al., 2001; Kulli et al., 2003; Vogeler et al., 2006). Conventional tillage generally reduces solute transport by cutting functional macropores (Jarvis, 2007). As suggested by the studies of Vanclooster et al. (2005) and Javaux et al. (2006), cutting functional macropores by intense cultivation will also affect flow pathways, and general solute mixing regime at the scale of the soil profile.

Yet, the relationship between tillage and flow and transport is not unambiguous. Whereas the abovementioned studies and additional numerical studies suggest greater solute leaching under

Abbreviations: CT, conventional tillage; RT, reduced tillage; TDR, Time Domain Reflectometry; T1, T2, T3, TDR transects; z_m, mean soil depth; J_{w1}, steady state flow rate equal to 5 cm per day (cm d^{-1}); J_{w2}, steady state flow rate equal to 20 cm per day (cm d^{-1}); D_L, longitudinal dispersion coefficient; v, mean solute velocity; λ_L, longitudinal hydrodynamic dispersivity; C^{rt*}, time-normalized resident concentration; superscript "l", local parameters; superscript "m", depth averaged parameters; R, retardation factor; BTCs, breakthrough curves.

* Corresponding author at: Soil Science Unit, INRA 2163 Avenue de la Pomme de Pin, CS 40001, Ardon, 45075 Orleans Cedex 2, France. Tel.: +33 02 38 41 78 00; fax: +33 02 38 41 78 79.
E-mail address: Arlene.Besson@orleans.inra.fr (A. Besson).

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conservation tillage (Masse et al., 1996; Isensee and Sadeghi, 1997), other studies show significantly opposite findings with no effect of tillage and even increased flow and transport in conventionally tilled soils (Granovsky et al., 1993; Levanon et al., 1993; Clay et al., 1998).

Differences in climate, in soil type, in physico-chemical soil properties, in soil historical management, in crop type residues, in experimental design and in space–time variation of initial soil conditions, can overwhelm tillage effects (Logsdon et al., 1993; Logsdon and Jaynes, 1996; Alletto et al., 2010). In addition the impact of tillage depends on intrinsic soil properties, on tillage characteristics such as tillage type, depth and speed and the level of exerted mechanical stress. In most experimental studies, the impact of two extreme tillage systems, *i.e.* conventional versus conservative, on flow and transport has been analyzed. Few studies analyze the impact of the mechanical stress applied to soils, *i.e.* for instance primary tillage (mouldboard ploughing) versus secondary tillage (harrowing), on flow and transport, notwithstanding tillage implements, and then the tillage intensity, have been reported to have an important impact on flow and transport (Jarvis, 2007).

Given the above mentioned debate, more detailed studies on the impact of tillage on flow and transport, in particular the mechanisms responsible for the control of tillage on flow and transport, are needed. Such studies will allow elucidate the benefits of conversion tillage on soil functioning as compared to conventional tillage.

The objective of this study was to compare the impact of conventional mouldboard tillage (CT), and reduced tillage (RT), consisting of harrowing without prior ploughing, on the solute transport process within a loamy soil. Our study focused on the short-term effects of tillage on the solute transport process, *i.e.* the comparison of the effect of changes in level of mechanical stress (CT and RT) on solute transport after one single reduced tillage operation (RT) following a long term CT. From laboratory controlled transport experiments on undisturbed soil lysimeters collected in field plots subject to a long term CT treatment, effective solute transport parameters were estimated. The variability of transport properties in terms of tillage practice was analyzed at local and depth averaged scale for two different flow rates.

Table 1
Soil texture of the A and Bt horizons of Eutric Luvisol.

	Depth (m)	Clay (g kg^{-1})	Silt (g kg^{-1})	Sand (g kg^{-1})
A horizon	0–0.3	156	657	187
Bt horizon	0.3–1	250	489	261

2. Materials and methods

2.1. Column sampling and soil characteristics

The experimental study was performed in the laboratory on two, 0.5 m^3 undisturbed lysimeters (0.8 m diameter × 1 m height) sampled in a Eutric Luvisol (FAO, 2006) in Louvain-la-Neuve, Belgium. The soil sampling technique was described by Vanclooster et al. (1995). The soil profile encompasses (1) a loamy A horizon, susceptible to structure deterioration when tilled, given the high silt content (about 66%) and (2) an argic Bt horizon with a higher clay content (about 25%). Under field conditions, the soil is a well drained loamy soil. Soil texture is summarized in Table 1.

The two soil columns were sampled in April 2007 on bare soil from the same field, which had been previously cultivated with a silage maize crop under conventional tillage. One day prior to sampling, part of the field was subjected to conventional tillage (CT), *i.e.* conventional mouldboard ploughing (0–30 cm) followed by disc harrowing (0–10 cm). Maize stalks were incorporated into the topsoil during tillage. The other part of the field was subjected to superficial and reduced tillage (RT) consisting only in disc harrowing (0–10 cm). One column (CT) was sampled from the conventionally tilled part and another column (RT) from the superficially tilled part.

A visual description of soil structure was realized on two soil pits dug in the CT and RT parts, as shown schematically in Fig. 1. The top 10 cm of the soil had a fine, porous and rather uniform structure for CT soil but encompassed a mix of porous zones and dense clods for the RT topsoil. In the lower part of the loamy A horizon (15–30 cm depth), undecomposed organic residues, many earth-worm holes and roots, dense clods (0.1–30 dm^3) or aggregates tightly packed were encountered for both tillage systems with a 5-cm thick plough pan identified at about −35 cm depth. However, the no-tilled horizon of RT soil presented less organic residue and was more strongly consolidated. To complete

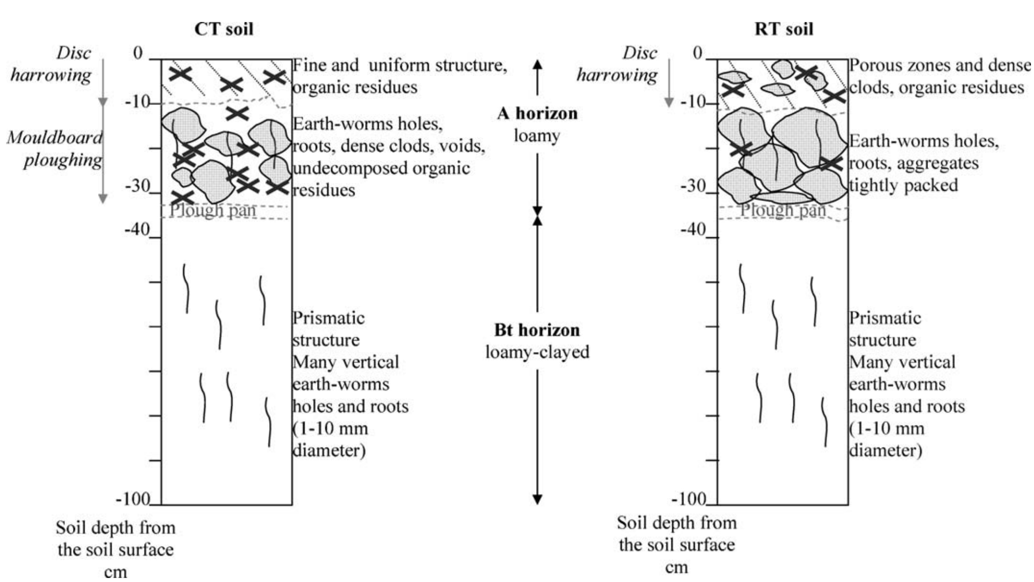

Fig. 1. Soil structure as schematized from *in situ* visual descriptions.