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Modeling the effect of soil structure on water flow and isoproturon dynamics in an agricultural field receiving repeated urban waste compost application

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HIGHLIGHTS

- Impact of soil heterogeneity on water flow and isoproturon dynamics was evaluated.
- Soil heterogeneity was created by moldboard plowing and compost amendments.
- A long-term numerical modeling on field experiment was performed using HYDRUS-2D.
- HYDRUS-2D described accurately lysimeter outflows and IPU loss after calibration.
- Soil structures in tilled layer (Γ, Δ, IF) had a large influence on IPU distribution.

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ABSTRACT

Transport processes in soils are strongly affected by heterogeneity of soil hydraulic properties. Tillage practices and compost amendments can modify soil structure and create heterogeneity at the local scale within agricultural fields. The long-term field experiment QualiAgro (INRA–Veolia partnership 1998–2013) explores the impact of heterogeneity in soil structure created by tillage practices and compost application on transport processes. A modeling study was performed to evaluate how the presence of heterogeneity due to soil tillage and compost application affects water flow and pesticide dynamics in soil during a long-term period. The study was done on a plot receiving a co-compost of green wastes and sewage sludge (SGW) applied once every 2 years since 1998. The plot was cultivated with a biannual rotation of winter wheat–maize (except 1 year of barley) and a four-furrow moldboard plow was used for tillage. In each plot, wick lysimeter outflow and TDR probe data were collected at different depths from 2004, while tensiometer measurements were also conducted during 2007/2008. Isoproturon concentration was measured in lysimeter outflow since 2004. Detailed profile description was used to locate different soil structures in the profile, which was then implemented in the HYDRUS-2D model. Four zones were identified in the plowed layer: compacted clods with no visible macropores (Δ), non-compacted soil with visible macroporosity (Γ), interfurrows created by moldboard plowing containing crop residues and applied compost (IF), and the plow pan (PP) created by plowing repeatedly to the same depth. Isoproturon retention and degradation parameters were estimated from laboratory batch sorption and incubation experiments, respectively, for each structure independently. Water retention parameters were estimated from pressure plate laboratory measurements and hydraulic conductivity parameters were obtained from field tension infiltrometer experiments. Soil hydraulic properties were optimized on one calibration year (2007/08) using pressure head, water content and lysimeter outflow data, and then tested on the whole 2004/2010 period. Lysimeter outflow and water content dynamics in the soil profile were correctly described for the whole period (model efficiency coefficient: 0.99) after some correction of LAI estimates for wheat (2005/06) and barley (2006/07). Using laboratory-measured degradation rates and assuming degradation only in the liquid phase caused large overestimation of simulated isoproturon losses in lysimeter outflow. A proper order of magnitude of isoproturon losses was obtained after considering that degradation occurred in solid (sorbed) phase at a rate 75% of that in liquid phase. Isoproturon concentrations were found to be highly sensitive to degradation rates. Neither the laboratory-measured isoproturon fate parameters nor the

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independently-derived soil hydraulic parameters could describe the actual multiannual field dynamics of water and isoproturon without calibration. However, once calibrated on a limited period of time (9 months), HYDRUS-2D was able to simulate the whole 6-year time series with good accuracy.

1. Introduction

Water flow and contaminant transport in the vadoze zone can be strongly affected by soil structure heterogeneity. Soil structure can be defined as the arrangement of solid and void space that exists in a soil at a given time (Kay, 1990). Its heterogeneity can be caused by natural processes or by anthropogenic interventions like soil tillage, fertilization or compost application. Soil tillage has a very important influence on soil structure and thus on soil hydraulic properties. Tillage practices may include a wide range of agricultural operations, ranging from reduced tillage or no-till practices in conservation systems to moldboard plowing as in conventional systems. Soil tillage and management affect soil hydraulic properties with consequences for the storage and movement of water, nutrients and pollutants, and for crop growth (Strudley et al., 2008). It can cause changes in soil pore-size distribution and in saturated hydraulic conductivity (Coutadeur et al., 2002; Mubarak et al., 2009; Or et al., 2000; Xu and Mermoud, 2003) and hence influences water flow pathways and solute transport in soil. Conventional tillage generally reduces solute preferential transport by disrupting functional macropores (Jarvis, 2007), as suggested in the studies by Javaux et al. (2006) and Vanclooster et al. (2005). Tillage can generate heterogeneities within the soil profile, and may produce various compacted and non-compacted zones or clods (Manichon and Roger-Estrade, 1990). Compacted zones generally have a much lower hydraulic conductivity than non-compacted zones (Ankeny et al., 1990; Schneider et al., 2009) and may have a large influence on water flow and solute transport. Coquet et al. (2005a) performed a field experiment to explore the impact of soil structure heterogeneity created by agricultural operations (trafficking, plowing) on water flow and solute transport. Water and solute transport were mostly associated with non-compacted soil, while very little water or bromide penetrated compacted clods thus engaging preferential (funneled) flow patterns around them.

In addition to soil tillage, application of organic amendments into soil can alter soil structure and thus can have an effect on water flow and solute dynamics. Compost amendment to soil increases soil organic matter content and has an effect on pesticide sorption and degradation (De Wilde et al., 2008; Guo et al., 1993; Kodešová et al., 2011). Organic matter increases macroporosity and infiltration rates, but can lead to a decrease of hydraulic conductivity at low pressure head (Gupta et al., 1977). Schneider et al. (2009) performed a study on the effect of urban waste compost incorporation on near saturated hydraulic conductivity. They found that the large variability of soil hydraulic conductivity within the tilled layer was predominantly controlled by tillage practices rather than by compost amendments. Pot et al. (2011) quantified the effects of tillage practice and repeated compost application on isoproturon transport in a tilled layer using column leaching experiments. While hydraulic conductivity measurements showed that tillage practice had a major effect compared to compost application, column leaching experiments showed no statistically significant effect of either tillage practice or compost addition.

Numerical models have been used to explain water flow and pesticide behavior in soil (Dousset et al., 2007; Kodešová et al., 2005; Pot et al., 2005). Gärdenäs et al. (2006) compared four conceptually different preferential flow and/or transport approaches for their ability to simulate drainage and pesticide leaching to tile drains. Model predictions were compared against drainage and MCPA concentration measurements made in a tile-drained field in southern Sweden. The authors concluded that two-dimensional models are suitable tools for studying pesticide leaching from tile-drained fields with large spatial variability in soil properties. Coquet et al. (2005b) used the numerical model HYDRUS-2D to successfully reproduce water flow and bromide transport in a soil profile that contained compacted and non-compacted soil zones. After minor adjustments of the van Genuchten soil hydraulic parameters α and K_s, the model reproduced water and bromide dynamics quite well. The work presented here goes one step further using the same approach but on the long term (6 years) to model water and isoproturon dynamics in a heterogeneous soil profile.

Isoproturon [3-(4-isopropylphenyl)-1,1-dimethylurea] is frequently used to control weeds in cereal crops and is one of the most detected herbicides in surface and ground waters, especially in France (SOeS, 2012). For this reason, isoproturon dynamics in soil has been largely studied in laboratory and field experiments. Dousset et al. (2007) performed displacement experiments of isoproturon in disturbed and undisturbed soil columns of a silty loam soil under similar rainfall intensities. Köhne et al. (2006) studied the physical and chemical non-equilibrium processes governing isoproturon transport under variably saturated flow conditions in undisturbed soil columns. Pot et al. (2005) also performed displacement experiments with isoproturon on two undisturbed grassed filter strip soil cores under unsaturated steady state conditions. Column leaching experiments are very useful for studying the coupling between pesticide transport, sorption and degradation processes, but they can hardly be multiplied in large number or performed at a large scale, so it is difficult to account for the spatial heterogeneity of the tilled layer at the plot scale with such a technique. One way to account for the spatial heterogeneity of the tilled layer is to use two- or three-dimensional transport models which allow accounting explicitly for the spatial distribution of the different soil structures encountered in the tilled layer at the plot scale. Meanwhile, pesticide modeling allows combining complex processes such as water flow, solute transport, heat transport, pesticide sorption, transformation and degradation, volatilization, crop uptake or surface runoff.

In this paper, we attempted to model a long-term field experiment, which was carried out on an agricultural field receiving repeated urban waste compost applications. Wick lysimeters were used to quantify water flow and isoproturon leaching. The main objective of this work was to evaluate how the presence of different soil structures in the tilled layer (due to soil tillage and compost application) affects water flow and isoproturon dynamics during a multiannual (6 years) time period. In this paper, we explicitly account for soil heterogeneity created by tillage and compost addition using a two-dimensional model for describing water flow and isoproturon transport in soil.

2. Materials and methods

2.1. Field experiment

The experimental field site was located at Feucherolles (Yvelines, France) in the western part of the Parisian Basin. The soil was a silt loam Albeluvisol (WRB), and contained on average 19% clay, 75% silt, and 6% sand in the plowed layer. The soil profile was composed of five horizons: a tilled loamy LA horizon (0–28 cm), an eluviated silt loam E horizon (38–50 cm), an illuviated silty clay loam BT horizon (50–90 cm), a transition silty clay loam BT/IC horizon (90–145 cm), and a silty loam structureless decarbonated loess IC horizon (145–200 cm). A field experiment was designed to evaluate the effects of urban waste compost application to soil since 1998. The field has been cultivated with a biannual rotation of winter wheat (*Triticum* spp.) and maize (*Zea mays* L.) (Fig. 1), except in 2006/07 when barley (*Hordeum vulgare* L.) was grown due to corn rootworm (*Diabrotica virgifera*