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Experimental monitoring and numerical study of pesticide (carbofuran) transfer in an agricultural soil at a field site

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ABSTRACT

We studied the transport of a pesticide at field scale, namely carbofuran molecule, which is known for its high mobility, especially in sandy soils with high hydraulic conductivity and low organic matter. To add to our knowledge of the future of this high-mobility molecule in this type of soils, we developed a mechanistic numerical model allowing the simulation of hydric and solute transfers (bromide and carbofuran) in the soil. We carried out this study in an agricultural plot in the region of Mnasra in Morocco. Confrontation of the measured and simulated values allowed the calibration of the parameters of hydric transfer and carbofuran. The developed model accurately reproduces the measured values. Despite a weak irrigation and precipitation regime, carbofuran was practically leached beyond the root zone. Prospective simulations show that under a more important irrigation regime, carbofuran reaches a 100-cm depth, whereas it does not exceed 60 cm under a deficit regime.

1. Introduction

Groundwater reserves are important exploitable water resources. Unfortunately, the intensive agriculture practised today requires the use of fertilizers and pesticides in large quantities and, sometimes, in an uncontrolled way, and significantly reduces the quality of groundwater (Ibnoussina et al., 2006; Laftouhi et al., 2003; Saâdi et al., 1999; Teijón et al., 2010; Worral and Kolpin, 2004).

To control the potential contamination of groundwater by pesticides, it is essential to understand the transport process involved (Kodešová et al., 2011). The approaches used include a field study conducted in natural agro-pedo-climatic conditions (Candela and Mariñô, 2004; Rekolainen et al., 2000), and a simulation using mathematical models (Beven, 2012).

Russo et al. (1994) studied the effects of variations of the soil water content on pesticides leaching in agricultural unsaturated zones. Kuntz and Grathwohl (2009) studied the simulation of pollutant flow and transport of two reactive compounds, i.e., lindane and phenanthrene, in a column of the unsaturated zone. They were interested in the validity of the hypothesis of a continuous stream percolation in the deterministic models, from local to larger scales.

Our study is focused on the modelling of transport of carbofuran, which is a broad-spectrum insecticide–nematicide that belongs to the carbamates chemical family. Carbofuran gives rise to harmful effects on human health and environment. Several previous studies showed that the mobility of carbofuran in a sandy soil was lower in organic matter, and presents an environmental problem, such as high potential leaching (Dahchour, 1995; Krishna and Philip, 2008). According to its mobility index

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(GUS = 3.75, Gustafson, 1989), this pesticide is leached easily after a heavy rainfall or a repetitive irrigation (Dahchour, 1995; El Mrabet, 2002). However, results of soil column suggest that there are real possibilities for carbofuran to reach relatively deep aquifers (Moreal and Van bladel, 1983).

To understand the mechanisms of this substance transport in sandy soils, and to study its impact on groundwater contamination, we carried out an experimental study of the water movement and the transport of both carbofuran and an anionic tracer flow (KBr) (Hmimou et al., 2011), on the bare soil of an experimental plot in the Mnasra region (Morocco). Particular attention was paid to the unsaturated soil, the location of the main flow and the transport process. On the other hand, to better evaluate the risk of groundwater contamination by carbofuran, we used a mechanistic mathematical model developed by the Interdisciplinary Laboratory Environment and Natural Resources (LIRNE) and validated on experimental data collected from the study site. It should be noted that the degradation products of carbofuran were not traced.

The developed model can reproduce the fate of carbofuran in the unsaturated zone, depending on the irrigation system used. Such simulations need an advanced hydrodynamic characterization of the soil. Hence, we carried out negative charge infiltration experiments at several locations in the experimental station (Perroux and White, 1988; Tamoh and Maslouhi, 2004).

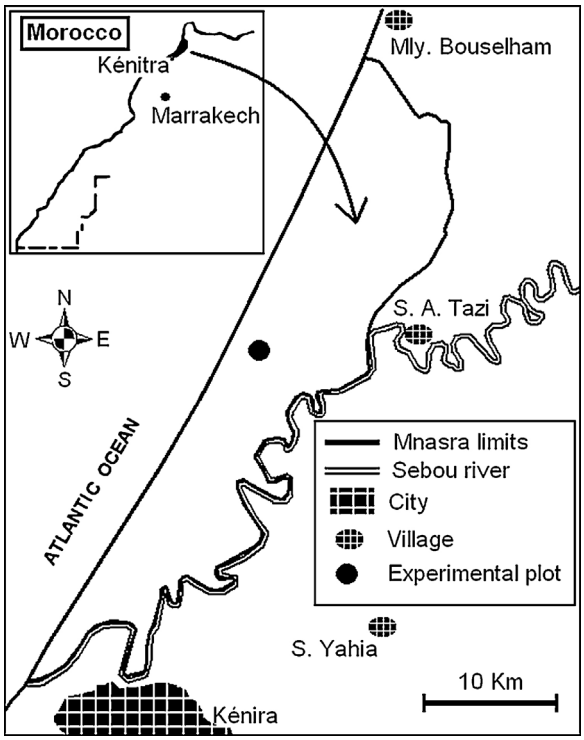

Fig. 1. The Mnasra region showing the studied site location.

2. Materials and methods

2.1. Study area

The study area is the experimental station (CDA 236) located in the Mnasra area, about 30 km north of the city of Kenitra, in northwestern Morocco (Fig. 1).

Mnasra region is a strip of land parallel to the Atlantic coast, of about 50,000 ha, located on the right bank of the Sebou River, 7 to 14 km wide and over about 50 km in length extending from the North of the Kenitra City. It is characterized by a diversity of crops, such as cereals, sugar beet, fodder and vegetables. The experimental site is equipped with a weather station that provided various data, such as rainfall and minimum and maximum temperatures (Fig. 1).

2.2. Description of experiments

The experiment was carried out on a 200-m^2 field with flat topography, subdivided into ten basic $4 \times 5 m^2$ plots. This study is focused on uncultivated plots on which are applied a Br and carbofuran flow tracer, and on an uncultivated and untreated control plot.

The site sandy soil was classified as an Alfisol, according to U S Soil Taxonomy (Soil Survey and Staff, 1999) and a sandy loam according to the USDA (USDA-SCS, 1975). Its physicochemical characteristics are presented in Table 1.

The tracer used is an anionic tracer (Br^-) form (KBr). It was applied with a dose of 61.77 g/m^2. The carbofuran $C_{12}H_{15}NO_3$ (2,3-dihydro-2,2-dimethylbenzofuran-7-yl-*N*-methyl carbamate) of the commercial product Furadan was applied with a dose of 4 g/m^2 based on active ingredient. Carbofuran has a solubility of 700 mg/L and a low vapor pressure, i.e., 3.41×10^{-6} mmHg at 25 °C. The half-life of carbofuran reaches values ranging from 25.7 to 107 days in soils with pH values and temperatures close to those of our experiments (El Mrabet, 2002). An injection mode was used in a slot corresponding to the injection of a constant concentration for a certain time. Spatial variability was considered by many measurement reiterations on average three times. The solutes were injected using a pulverizer, advancing at a constant speed while keeping the same nozzle flow rates to ensure a homogeneous application. The application of solutes was followed by a first irrigation during the monitoring period. The cumulative amounts of precipitation and irrigation were 62 mm and 160 mm, respectively. Irrigation was carried out with a sprinkler. Evapotranspiration was calculated on a daily basis from observed *in situ* data.

The spatio-temporal monitoring of physical and chemical parameters, such as humidity, temperature, bromide and pesticide concentrations in the soil was conducted for 90 days.

Table 1
Physicochemical characteristics of the soil.

Depth (cm)	pH	Organic matter (%)	Clay (%)	Loam (%)	Sand (%)	Bulk density (g·cm^{-3})
0–20	7.04	1.41	10.00	7.45	82.75	1.55
20–40	6.97	0.62	9.65	7.95	82.36	1.76
40–60	7.59	0.58	9.20	8.60	82.40	1.69