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A field study of the impact of different irrigation practices on herbicide leaching

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ABSTRACT

Agricultural practices, such as subsurface drainage, irrigation and tillage, may significantly affect pesticide leaching and, consequently, the risk of groundwater contamination. The aim of the present study was to investigate the impact of different irrigation systems on herbicide leaching to shallow groundwater through direct monitoring at the field scale in northern Italy over a 3-year period. Concentrations of the herbicide terbuthylazine (TBA) and its metabolite desethylterbuthylazine (DES) were monitored on 10 farms cropped with maize and irrigated by sprinkler, basin and border systems. Considering the results grouped according to the different irrigation systems, the mean TBA and DES concentrations was lower than the arbitrary non-health based legal limit of 0.1 μg/L using sprinkler and border systems, while it was 0.19 and 0.30 μg/L respectively for TBA and DES using basin systems.

However, since many factors other than the irrigation systems can contribute to pesticide leaching and in a field study it is impossible to discriminate between all the different variables, the concentrations of both compounds were simulated with and without irrigation using the model MACRO 5.1 in order to gain a deeper understanding of the role of irrigation on leaching. First, the groundwater table depth, which was measured daily in all fields, was used to calibrate the model and thus achieve a good soil hydrology calibration. To assess the performance of the model the root mean squared error (RMSE) was used. RMSE ranged from 0.2 to 0.5 m, showing that a satisfactory hydrology calibration was obtained. Afterward, the solutes were modelled and the results showed that under non-irrigated conditions, concentrations of both compounds would be very low. These findings validate the hypothesis that careful selection of agricultural practices, such as the type of irrigation, can reduce pesticide leaching.

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1. Introduction

Pesticide occurrence in groundwater is controlled by many factors such as the intensity of use, soil properties and pesticide properties (Barbash et al., 2001). In addition certain agricultural practices, such as tillage, the use of subsurface drains and irrigation, may appreciably contribute to pesticide leaching and subsequently to groundwater contamination (Gilliom et al., 2007). In this study, attention was focused on irrigation. An adequate water supply is critical for plant growth, and various methods can be used to supply water to plants. These different irrigation techniques influence water flow patterns in the soil (Bandaranayake et al., 1998) and solute movement.

The aim of this study was to investigate the impact of different irrigation systems on pesticide leaching to shallow groundwater by direct monitoring at the field scale over a 3-year period. Sprinkler, border and basin irrigation systems were considered. As water-quality monitoring shows that herbicides are the most frequently detected group of pesticides in ground and surface water (Carter, 2000), the herbicide terbuthylazine [N^2-*tert*-butyl-6-chloro-N^4-ethyl-1,3,5-triazine-2,4-diamine] (TBA) was chosen. TBA belongs to the triazine group of herbicides, which is amongst the most frequently used group for selective weed control in several crops (Barra Caracciolo et al., 2005). In Italy TBA uses are now limited to maize and sorghum according to the implementation of the Environmental Stewardship Programme as agreed by the TBA manufactures. The major dealkylation product of TBA is desethylterbuthylazine (DES) (Dousset et al., 1997). Dealkylated products are generally more persistent and water soluble, and therefore pose a risk of groundwater contamination (Guzzella et al., 2003). Thus DES concentrations were also monitored.

The focus of this study was to investigate the effect of irrigation on TBA and DES leaching to shallow groundwater in 10 farms located in the northern Italy selected to cover a range of different soil types and climatic conditions. Such field studies are helpful in order to better understand how agricultural practices affect pesticide leaching under real farm situations; however it is impossible to carry out these types of studies under identical conditions, so

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the effect of irrigation systems on pesticide leaching could be confounded by other factors. For this reason, the solute transport model MACRO 5.1 (Larsbo and Jarvis, 2003) was used to simulate TBA and DES leaching under both irrigated and non-irrigated conditions. Measured parameters (i.e. soil, climatic, pedological and hydrological data) were used to set a scenario for each farm. First, the model was run using real irrigation data. If a good fit between simulated and measured concentration is attained, it is possible to investigate the effect of irrigation on leaching by running the model without the input of water coming from irrigation. In this way, the effect of the irrigation system can be isolated and then it is possible to examine further the effect of differing irrigation systems on pesticide leaching under different situations.

2. Materials and methods

2.1. Study design

The 10 farms (Table 1) were located in the Po Valley of northern Italy (Fig. 1), which is an important agricultural area. The farms were cropped with maize and managed according to good agricultural practices. Two farms were irrigated by the basin system, two by border irrigation, one was not irrigated and the remaining farms were irrigated by sprinklers.

On each farm, a field approximately 10 ha in size was monitored. Before starting the monitoring, each field was assessed for the absence of surface-water bodies, the uniform direction of groundwater flux, slope (which should not exceed 5%), and the absence of cracking soil, perched groundwater and tile drainage. The groundwater depth was shallow, but varied amongst the 10 fields (Table 1).

Three piezometers were installed in each field, placed at the edge of the field in the direction of down-gradient groundwater flow in order to maximize interception of shallow groundwater flow leaving the field. The piezometers were made of PVC pipes, with a rubber plug inserted at the base to prevent backflow and a cast-iron manhole cover above each piezometer. A layer of bentonite pellets was placed outside and inside the manhole cover to act as a hydraulic insulating agent, thereby minimizing potential contamination from the percolation of preferential fluxes.

Meteorological data (Table 2) were collected on each farm from a digital remote-controlled station, which recorded minimum and maximum temperature, precipitation and groundwater level on an hourly basis. On farms Ba1 and Ba2, the measurements came from the regional meteorological station closest to the farms, provided by the regional agency for the protection of the environment (ARPA Lombardia).

2.2. Irrigation practices and field management

Irrigation is a common practice in the Po Valley in order to ensure maize production. Only in some areas in the Friuli region it is possible to obtain satisfactory yields without irrigation. The type of irrigation system depends upon the crop, landscape and local customs. The most recent Italian agricultural census (ISTAT, 2000) showed that sprinkler and border systems are the most common irrigation systems. Basin irrigation is widely used in the North of Italy for rice crop and then for the crops in rotation with rice, such as maize.

Information on irrigation practices (Table 1), such as the number of applications and the volume of water applied, was provided by the farmers.

All the fields were cropped with maize for the entire study period. TBA was applied pre-emergence annually as the formulation BoleroTZ® (Monsanto, containing 214 g ai/L) and was applied at 4 L/ha. Spray-bar calibration was performed prior to each application, and each piezometer was protected with a plastic film during application in order to avoid any direct contamination.

2.3. Water sampling and analysis

Groundwater was sampled by applying low negative pressure. The depth of the piezometer screen is reported in Table 1. Each piezometer was purged prior to sampling in order to remove standing water. The sample volume (approximately 1 L) was collected in glass bottles, being stored immediately in a portable freezer and then transferred to a refrigerator at 4 °C prior to analysis. Samples were collected every 2 months from April 2005 to December 2007. The water table depth within each piezometer was measured at each sampling event. Less than 1 month elapsed between sample collection and analysis.

Water samples were analysed measuring both TBA and DES concentrations according to the SPE–GC–MS method presented in Pichon (2000). The analytes were identified through: (i) comparison between the retention time of the samples and the analytical standards (purity > 99%), (ii) comparison of the mass spectra of the samples and the analytical standards, and (iii) comparison of the mass spectrum in the NIST library with that of the samples. Quantification was performed in single-ion monitoring mode. Concentrations of each analyte were calculated using an external calibration curve, the limit of quantification in the water samples being 5 ng/L.

2.4. Evaluation of the hydraulic transit times beneath the fields

In order to assess the hydraulic transit times beneath each field, the horizontal movement of water was estimated using "Darcy's Law":

$$q = K \times i$$

where K is the hydraulic conductivity (m/s) and i is the hydraulic gradient, which is equal to the hydraulic head difference (H) between two points in the soil divided by the distance between those points (L) (m). Furthermore, the q value was divided by the porosity in order to take into account that only the interstitial spaces in the soil are able to conduct water.

Based on estimated K values from the literature (Bear, 1972) and measured hydraulic heads and K values calculated using the pedotransfer function (PTF) proposed by Wösten et al. (1999) and site-specific data, lateral groundwater flow velocities were estimated using Darcy's law to vary between 0.3 and 98.3 m/in 2 months, and so the sampling frequency (2 months) was considered to be adequate (Table 3).

2.5. Model description

MACRO (version 5.1) is a comprehensive mechanistic one-dimensional non-steady state model of water flow and solute transport in structured or macroporous soils (Larsbo and Jarvis, 2003). This model was chosen because such soils are typical in the Po Valley.

The model accounts for macropore flow, with the soil porosity divided into two flow domains (macropores and micropores) each characterized by a flow rate and solute concentration, with the boundary between them defined by a fixed water potential associated with a saturated matrix water content and hydraulic conductivity (Stenemo and Jarvis, 2007). Each domain has its own pressure head and solute concentration. Richards' equation and the convection–dispersion equation are used to model soil water flow and solute transport in the soil micropores, while in the macropores

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