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Simazine transport in undisturbed soils from a vineyard at the Casablanca valley, Chile

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ABSTRACT

Simazine is a soil-active herbicide that has been applied worldwide in agricultural soils, being the second most commonly detected herbicide in groundwater and surface waters. Although its use has been restricted in many countries of Europe, it is still applied in many locations around the world in orchards, vineyards and forestry. Therefore, it is important to study its fate and transport in the environment. This paper investigates simazine transport in undisturbed bare soils from a vineyard at the Casablanca valley, Chile. In the study site, shallow groundwater tables (<1.0 m depth) and high simazine levels (>15 μg L^{-1}) in the groundwater were observed and thus, there is potential for simazine to be transported further away through the saturated zone. The soils from the study site were characterized and the hydrodynamic transport parameters were determined. Column leaching experiments showed that the two-site chemical non-equilibrium model correctly represented simazine transport. It was found that 36.3% of the adsorption sites achieve instantaneous equilibrium and that the first-order kinetic rate of the non-equilibrium sites was 6.2×10^{-3} h^{-1}. Hydrus 2D was used to predict the transport of simazine in the study site under natural field conditions. Simulation results showed that simazine concentrations at depths shallower than 2.1 m are above the maximum contaminant level of 4 μg L^{-1} (defined by the U.S. Environmental Protection Agency). The timing of herbicide application was found to be important on simazine leaching and the main processes involved in simazine transport were degradation and adsorption, which accounted for 95.78 and 4.19% of the simulated mass of pesticide, respectively. A qualitative agreement in the timing and magnitude of simazine concentration was obtained between the simulations and the field data. Therefore, the model utilized in this investigation can be used to predict simazine transport and is a valuable tool to assess agricultural practices to minimize environmental impacts of simazine.

1. Introduction

The use of pesticides has been a common practice to improve agricultural productivity. However, their inappropriate use can have detrimental effects on human health and on the environment (Márquez et al., 2005; Chang et al., 2008). Soil and groundwater contamination by pesticides has been extensively documented around the world (Kolpin et al., 1998; Close et al., 1999; Lapworth et al., 2006). Simazine is the second most commonly detected pesticide in groundwater and surface waters in the United States, Europe, and Australia (Barbash et al., 2001; Wilson et al., 2011), as it has been widely used to control broadleaf weeds in agricultural and non-crop fields (Gunasekara et al., 2007). Even though its use has been restricted in many countries of Europe, simazine is still applied in many locations around the world, principally in orchards, vineyards and forestry production (Chang et al., 2008; Flores et al., 2009; Morgante et al., 2012). Therefore, it is important to study its fate and transport in the environment.

Pesticide transport in soils has been widely studied under field and laboratory conditions (Gamerdinger et al., 1991; Pang et al., 2000; Pot et al., 2011). These studies have shown that non-

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equilibrium processes must be included when studying pesticide transport. Chemical non-equilibrium models have given particularly good results for representing the transport of many organic and inorganic chemicals; in which sorption occurs mainly on organic carbon and have both rate limited and instantaneous sorption (Pot et al., 2011). However, there are few laboratory or field studies on triazine herbicides, other than atrazine, that investigated their degree of non-equilibrium. Gamerdinger et al. (1991) studied non-equilibrium sorption and degradation of atrazine, simazine and cyanazine in two soils (silty clay and silt loam) from New York. They found evidence that atrazine transport can be represented using non-equilibrium kinetic models. The non-equilibrium sorption of simazine and cyanazine was found to be similar than that of atrazine. Close et al. (1999) and Pang et al. (2000) studied pesticide transport of picloram, atrazine and simazine through two New Zealand soils. At depths shallower than 1.1 m, they monitored simazine levels that were higher than 4 μg L^{-1}, which is the simazine maximum contaminant level (MCL) defined by the U.S. Environmental Protection Agency (EPA). Mao and Ren (2004) also reported a chemical non-equilibrium behavior for atrazine in sandy soils. Chang et al. (2008) performed a comparative study of three different pesticide transport simulation models to determine the simazine's groundwater vulnerability in a citrus orchard located in the Rio Grande Valley.

Although simazine has been widely used in Chilean agricultural soils, mostly because of the pressure to produce high-quality food for consumers around the globe, only few studies have addressed groundwater contamination by pesticides in these soils. Its fate in this environment only has been studied in one vineyard located in the Casablanca Valley (Alister et al., 2005; Suárez et al., 2007; Kogan et al., 2007) and in one avocado plantation located in the Aconcagua Valley (Flores et al., 2009; Morgante et al., 2012). Most of these studies have used experimental data to determine the physicochemical properties of the pesticide and to evaluate leaching indexes to investigate the mobility of the pesticides through the soil. Since monitoring chemical concentrations in soils is typically very expensive, the use of mathematical models appears as a cost- and time-effective approach to assists decision makers in the prediction of groundwater contamination (Pang et al., 2000), and to design management strategies to minimize adverse impacts of chemicals on the environment (Chang et al., 2008). In Chile, only one study has addressed the challenge of developing mathematical tools to assist Chilean decision makers to predict groundwater contamination by pesticides (Suárez et al., 2007). In that study, simazine transport was investigated in unsaturated sandy soil columns collected in a vineyard from the Casablanca Valley, Chile. They determined that chemical non-equilibrium processes govern pesticide transport, and evaluated the transport of simazine under hypothetical field conditions. However, that investigation used disturbed soils to assess the "most risky" conditions for pesticide application, i.e., coarse soils and shallow groundwater tables. Therefore, even though it enabled to determine the main processes governing simazine transport, the soils used were not directly representative of the entire soil profile of the vineyard.

The aim of this work is to study the transport of simazine under natural conditions using undisturbed bare soils from the vineyard located in the Casablanca valley, Chile. It is important to note that although plant growth modifies soil moisture dynamics, e.g., due to root water uptake (Doussan et al., 2006) or due to soil compaction (Berli et al., 2008; Aravena et al., 2011), the investigation of these complex processes is out of the scope of this work. The specific objectives of this investigation are: (1) to explore how much simazine can reach the groundwater under natural field conditions; (2) to generate the required information to study simazine transport using mathematical models. In particular, to determine the representative soil hydraulic properties and the hydrodynamic parameters of the study site; (3) to investigate the main mechanism of simazine transport; and (4) to improve the previous model developed by Suárez et al. (2007), by studying groundwater flow and simazine transport in a two-dimensional representative transect of the soil profile from the vineyard subject to natural meteorological conditions. To achieve these objectives, groundwater levels and simazine concentration were monitored throughout a 2-year period in the study site. The spatial variability of the soil properties was investigated in undisturbed soil cores, and the hydrodynamic properties and the main mechanisms of simazine transport were determined in soil column leaching experiments. Finally, a numerical simulation of two-dimensional groundwater flow and simazine transport was performed in a representative transect within the study site. This simulation was utilized to investigate simazine transport under natural field conditions for a time-period of six years, and showed how valuable are these tools to assist decision makers in the prediction of groundwater contamination.

2. Materials and methods

2.1. Study site and field methods

The study site corresponded to a vineyard in the Casablanca Valley, Chile (33°16′ S; 71°23′ W). The field site is shown in Fig. 1 and in the Google Maps file that is available in the online version of this article. A field plot of approximately 75 × 200 m inside the study site was used in this investigation. Thirty two piezometers

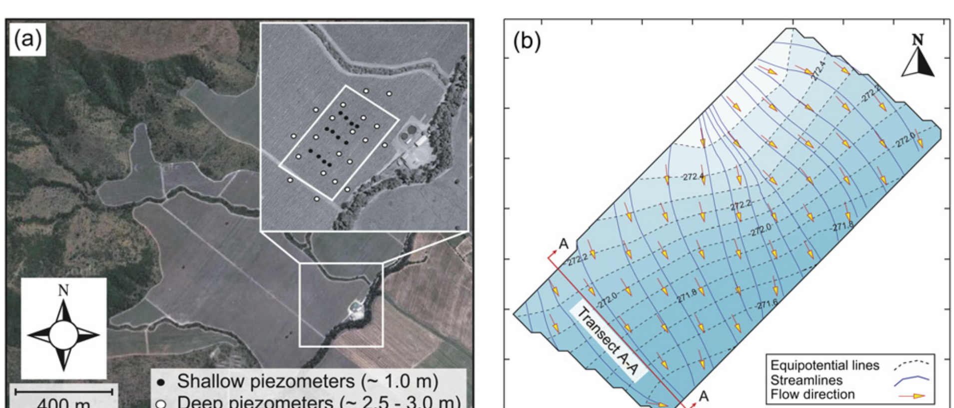

Fig. 1. (a) Location of the piezometers and of the field plot in the vineyard. (b) Groundwater streamlines in the field plot (September, 2003).