Pedosphere **26**(5): 687–698, 2016
doi:10.1016/S1002-0160(15)60077-7
ISSN 1002-0160/CN 32-1315/P

Published by Elsevier B.V. and Science Press

PEDOSPHERE

www.elsevier.com/locate/pedosphere

Sorption and Leaching Potential of Isoproturon and Atrazine in Low Organic Carbon Soil of Pakistan Under a Wheat-Maize Rotation

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(Received April 14, 2015; revised June 15, 2016)

ABSTRACT

Pesticide leaching is a great threat in low organic carbon soils when subjected to improper irrigation scheduling. Limited data are available on the sorption and leaching potential of pesticides in agricultural soils of Pakistan with low soil organic carbon (SOC). Lysimeter and field studies were conducted with and without manure application at two irrigation levels in a wheat-fallow-maize rotation in Faisalabad, Punjab, Pakistan. Isoproturon was applied to wheat 55 d after sowing at 1 kg active ingredient (a.i.) ha^{-1}, while atrazine was sprayed on maize 30 d after sowing at 0.774 kg a.i. ha^{-1}. Soil was sampled from three depths (0–35, 35–70, and 70–110 cm) for the field study and four depths (0–35, 35–70, 70–115, and 115–160 cm) for the lysimeter study, 280 and 65 d after application of isoproturon and atrazine, respectively. The soil-water partition coefficients (K_d) of isoproturon and atrazine ranged from 0.3 to 1.2 and 0.4 to 1.5 L kg^{-1}, respectively, and increased linearly with increase in SOC contents. The organic carbon-normalized soil-water partition coefficient (K_{oc}) of isoproturon and atrazine averaged 246.1 and 184.9 L kg^{-1}, respectively, being higher with low spiking concentration. Isoproturon residues measured 280 d after application ranged from 2.1% to 3.6% of the applied mass in the lysimeter study and from 1.5% to 3.1% under field conditions. Atrazine residues 65 d after application ranged from only 0.62% to 0.78% and from 0.88% to 0.82% in the lysimeter and field studies, respectively. The lowest levels of residues for both pesticides were observed with frequent irrigation applied to manure-amended soil. A pesticide leaching risk screening tool, the ground water ubiquity score (GUS), indicated that in the absence of manure under both irrigation levels, isoproturon has a leaching potential (GUS = 2.8), while with the application of manure it has a very low leaching risk. Atrazine GUS ranged from 1.7 to 1.9, indicating a very low risk of leaching.

Key Words: concentration dependent sorption, irrigation, manure, leaching risk assessment, pesticide

Citation: Tahir M, Hassan A U, Maqbool S, Barber B, Koskinen W C, Peng X H, Mulla D J. 2016. Sorption and leaching potential of isoproturon and atrazine in low organic carbon soil of Pakistan under a wheat-maize rotation. *Pedosphere*. **26**(5): 687–698.

INTRODUCTION

For several decades, pesticide residues have been detected in the atmosphere, surface and ground water, soil, and food. The contamination of water bodies has been a major concern since it affects the drinking water quality, non-target organisms, and crop safety. Herbicides, which are agrochemicals used to control weeds during crop growth, represent important pesticides in terms of quantity applied annually (Maly *et al.*, 2005). For practical use, it is necessary that herbicides have limited persistence. They should neither remain in the soil, nor leach into ground water or other water resources. Water quality data indicate that herbicides are the most frequently detected group of pesticides in surface and ground water (Carter, 2000). In response to the increased detection of the contaminants, European Parliament and Council (2000, 2006) has imposed an upper limit of 0.1 μg L^{-1} for concentrations of individual pesticides and 0.5 μg L^{-1} for total pesticides in drinking water.

Isoproturon (3-(4-isopropylphenyl)-1, 1-dimethylurea) is used in Pakistan for pre- or post-emergence weed control in cotton and cereals such as wheat. It is moderately persistent with a half-life, ranging from 1.4 to 100 d (Walker *et al.*, 2001; Alletto *et al.*, 2006; Rodriguez-Cruz *et al.*, 2006). Due to high water solubility (70 mg L^{-1}) and moderately persistent behavior, isoproturon frequently results in surface and ground water contamination (Eibisch *et al.*, 2015). The leac-

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hing potential of isoproturon has been addressed in numerous studies (Dorfler *et al.*, 2006), and now considered as one of the highest risk pesticides (van Alphen and Stoorvogel, 2002). Atrazine is widely used as a post-emergence herbicide in maize growing areas of Pakistan, especially to suppress the population of *Trianthema portulacastrum* along with many other grasses and broad leaf weeds. Atrazine has frequently been detected in ground water and surface water (Miller *et al.*, 2000) due to its high mobility and high persistent behavior (McMurray *et al.*, 2006), with a half-life of 1 to 12 months.

Knowledge of herbicide behavior in soil is of utmost importance for understanding its fate and movement in environment. The residue time and distribution of a pesticide in root zone and the vadose zone below are of main concern regarding its chances to enter the food chain or leach down to ground water. While various physico-chemical processes affect the fate of agrochemicals, adsorption is one of the most important processes affecting their movement, persistence, and degradation (Ertli *et al.*, 2004), and hence influences the leaching potential of pesticides. Sorption capacity of a pesticide to the soil solid phase is described by the soil-water partition coefficient (K_d). The ease of use and comparability of results for different chemicals have made K_d an approach state of the art in assessment and modelling of the fate of pesticides in the environment (Wauchope *et al.*, 2002). Isoproturon and atrazine sorption in agricultural topsoil has previously been described using either a linear isotherm (Vincent *et al.*, 2007) or the Freundlich isotherm (Mbuya *et al.*, 2001; Boivin *et al.*, 2005). In many cases, sorption of pesticides is represented by the organic carbon (OC) partition coefficient (K_oc), which is K_d divided by the fraction of OC (f_oc) in the soil. The value of K_oc is nearly constant for different soils or size fractions of a soil (De Wilde *et al.*, 2009). In general, compounds with higher K_oc values will be less mobile than those with lower values (Navarro *et al.*, 2009). Root zone soil water regime and resulting drainage below root zone are another important factor which influences the leaching behavior of the pesticides in soil. Frequent irrigation/heavy rainfall increases degradation rate and plant water uptake, but causes preferential flow (Dorfler *et al.*, 2006; Grundmann *et al.*, 2011) through the soil vadose zone.

Since organic matter is the main soil component contributing to the sorption of pesticides (Spark and Swift, 2002; El Bakouri *et al.*, 2009) and sorption is one of the main processes reducing the mobility of these chemicals in soils, the addition of exogenous organic matter to soil has been suggested as a promising method to reduce pesticide leaching (Si *et al.*, 2006, 2011; Singh, 2008). Thus, use of manure is one of the best practices for controlling pesticide leaching through soils with low organic matter (Worrall *et al.*, 2001). Decreased leaching of pesticides in manure-amended soils may be due not only to the presence of additional organic matter, but also to structural changes in the porosity induced by the higher soil organic carbon (SOC) content. Agricultural soils are low in SOC, and use of organic amendments in the form of manure or compost is a commonly recommended agricultural practice (Ferreras *et al.*, 2006). Most Pakistani soils have less than 10 mg g^{-1} SOC, which is not usually uniformly distributed through the soil profiles in cultivated soil, and organic matter content is highest at the surface and decreases with increasing soil depth (Tahir *et al.*, 2012). The influences of SOC on sorption of isoproturon and atrazine have also been described in many studies (Krutz *et al.*, 2003; Boivin *et al.*, 2005; Drori *et al.*, 2005; Larsbo *et al.*, 2013). Organic amendment in the form of manure also increase the soil water retention capacity (Tahir *et al.*, 2012) and the microorganism activities which lead to the increased biodegradation of pesticides (Vieuble'-Gonod *et al.*, 2009; El Sebaïa *et al.*, 2011).

Simulation models are frequently used to evaluate and predict the fate of pesticides under a wide range of environmental and management scenarios (Vanclooster *et al.*, 2000). Because quantitative predictions are both pesticide- and soil-specific, thus, site-specific experimental data are crucial inputs in order to obtain an accurate assessment of environmental risks. The shallow ground water pollution by pesticides has been also recognized in Pakistan (Tariq *et al.*, 2004). Few site-specific studies of isoproturon and atrazine sorption and mobility have been conducted in Pakistani soil, and sufficient data are lacking to develop reliable models. The present study was conducted to determine the effects of manure amendment at different flood irrigation levels on sorption and leaching behaviors of isoproturon and atrazine under lysimeter and field conditions in a Pakistani soil with a wheat-fallow-maize rotation.

MATERIALS AND METHODS

Lysimeter and field experimental procedures

Herbicides were applied to lysimeters and field trials in a wheat-fallow-maize rotation on the research farm located at the Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pun-