

Effects of Attenuation and Dispersion Factors on Tebuthiuron Leaching Simulation

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Abstract

Differences on response of mathematical models on herbicide leaching in the environment can occur due to the models and their limitations, mainly when using soil lysimeters. Tebuthiuron is a herbicide used in sugarcane crop and is applied in the recharge area of the Guarany aquifer in Brazil, one of the largest in the world. This study was conducted to compare the leaching potential of the herbicide within lysimeters using sandy soils of the Espirado watershed in the recharge area from the region of Ribeirão Preto, SP, Brazil. The traditional Attenuation Factor (AF) model was used at various soil layers, adding a Dispersion Factor (DF) to the model. The fitness of the model was good for the total amount of tebuthiuron leached, but not for the rate of leaching. The model overestimated the level of herbicide leaching at 100 days after application, but the final concentration leached with the water was as predicted by the model.

Key Words: Agriculture, Ground Water, Nonpoint Source Pollution, Solute Transport, Water Quality.

Introduction

The region of Ribeirão Preto city, São Paulo, Brazil, is an important sugar cane producing area where high volume of pesticide is used. It is also a recharge area of the Guarany Aquifer the main ground water source in South America and one of the biggest of the world.

The diffuse rural pollution of a pesticide can be a significant source of water contamination. In a recent research Matallo *et al.* (2003), studied the risk of ground water contamination of the Espirado watershed, located in the recharge area, with the herbicide tebuthiuron and concluded that although there was a potential risk, the herbicide would not reach the water table. Matallo *et al.* (2004), also concluded with studies with lysimeters that the AF model ("Attenuation Factor"), fitted best to sandy soils of the region and that this was due, among other factors, to the dispersion and/or convection attributed to the soil columns.

In order to further understand the process, this work was conducted with mini lysimeters to evaluate the effect of

adding into the AF model the dispersion factor to improve the fitness of the model.

Material and methods

The properties of the sandy soil chosen for this study, Typic Quartzipsamment were determined in a previous study conducted by Matallo *et al.* (2003) (Table 1). Data of depths below 50 cm down to the saturate zone of the aquifer were based on the average values found in literature. Water recharge index was calculated based on the

Table 1. Typic Quartzipsamment soil properties of the recharge area of Guarany Aquifer at the Espirado watershed in Ribeirão Preto, SP, Brazil.

Soil properties	Depths range(cm)		
	0-12	12-22	22-50
Field Capacity (%)	20.13	18.41	18.06
Density (g/cm ³)	1.20	1.07	1.26
Organic carbon (%)	0.24	0.15	0.02

difference of rain and evapotranspiration of the Espirado Watershed area.

The sorption coefficient (K_d) values at the different depths were determined as 0.4; 0.2; and 0.1 mL/g, at of 0-12, 12-22, and 22-50 cm depths. The leaching potential of the herbicide in lysimeter was evaluated by the multi-layered AF model. AF, is defined as a fraction of the pesticide applied to the soil surface that leaches to a determined depth (Rao et al. 1985). It is fitted in the following equation:

$$(1) \quad AF = \exp(-tr \times k)$$

where tr is the duration of leaching and k is the first order constant of degradation of the herbicide in the soil. K is dependent on the half-life ($t_{1/2}$) of the herbicide and can be expressed by the following equation:

$$(2) \quad k = \frac{0.693}{t_{1/2}}$$

The travel duration or leaching time (tr) can be expressed by the following equation:

$$(3) \quad tr = \left(\frac{L \times FC}{q} \times RF \right)$$

where L is the depth of the water table or aquifer, FC is field capacity, and q is the net water recharge index.

The Retardation Factor (RF) of the herbicide leaching was obtained by the following equation:

$$(4) \quad RF = 1 + \frac{(BD \times OC \times K_{oc})}{FC}$$

where BD is soil density, OC is organic carbon, K_{oc} is the sorption coefficient of the herbicide and (K_d) is sorption coefficient adjusted to the organic carbon content of the soil.

The Dispersion Factor was obtained according to the following equation developed by Ogata (1970):

$$(5) \quad fd = \frac{1}{2} \left[\operatorname{erfc} \left(\frac{L - v \cdot t}{2\sqrt{D \cdot t}} \right) + \exp \left(\frac{v \cdot L}{D} \right) \cdot \operatorname{erfc} \left(\frac{L + v \cdot t}{2\sqrt{D \cdot t}} \right) \right]$$

where, erfc represents the complementary error function, L is the length of the lysimeter in meters, v is the average speed of water in the soil (m s^{-1}), t is the time of the herbicide application, and D is the longitudinal dispersion coefficient ($\text{m}^2 \text{s}^{-1}$).

The Average Speed (v) of water movement in the soil (m s^{-1}) was calculated by:

$$(6) \quad v = \frac{K}{n} \cdot \frac{dh}{dl}$$

where K represents hydraulic conductivity (m.s^{-1}), and n is the effective soil porosity and dH/dl is the hydraulic coefficient.

The Longitudinal Dispersion Coefficient (D), ($\text{m}^2 \cdot \text{s}^{-1}$), can be expressed by:

$$(7) \quad D = \alpha \cdot v + D^*$$

Where α is the dynamic dispersivity (m) and D^* is the molecular diffusion ($\text{m}^2 \text{s}^{-1}$).

Results and Discussion

The model fitted well to the total amount of leaching (Table 2) but even with adjustments was not able to explain the initial amounts leached. The model also did not explain a peak of leaching at 100 days after application of the herbicide (Figure 1), which was not confirmed by the measured data set. On the other hand, the model fitted well at the end of the dispersion curve 150 days after application (Figure 1).

Table 2: Predicted by the AF model and observed amount (μg) of tebuthiuron leaching.

Predicted	Observed
703.9	799.6
¹ Average of 2 samples	

The elution curve reflects the combined effects of diffusion and hydrodynamic dispersion of a solute through soil (Biggar and Nielsen, 1962). In this way, the differences of the models and experimental data of leaching could be due to the sorption of the herbicide in the macropores allowing its

detection in the first days of the experiment.

In this process, the water and solute fraction moving through macropores would be retained for a longer period and, since the solutes keep moving through macropores the amount of the herbicide leached would vary, explaining the peaks of the measured data at 150 days after application (Figure 1).

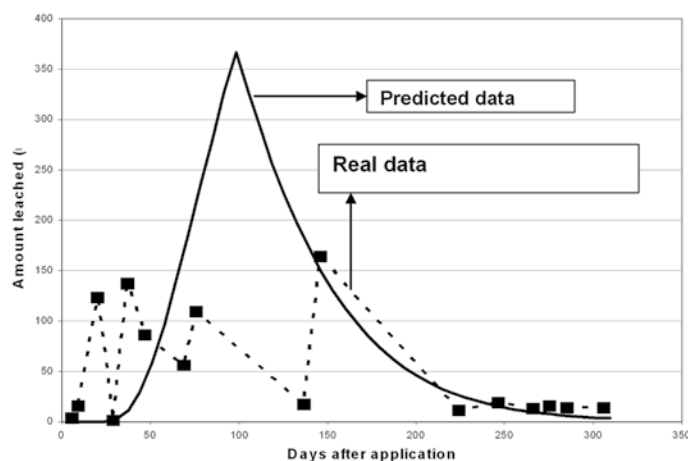


Figure 1. Tebuthiuron elution in the soil.

On the other hand, tebuthiuron retention in micropores can not be ignored, being a process similar to the adsorption not being retained by physical or chemical bounds and its leaching would be retarded explaining the differences observed and predicted of the experiment and also explaining the adjustment of the model AF at the end of the experiment at 150 days. This hydrodynamic behavior was described by Romero *et al* (2001) using the model PESTLA to describe the movement of racemics and enantiomers herbicides such as mecoprop and dichlorprop in sandy loam soils with high levels of calcium.

It is also important to consider the normal degradation process which occurs during the leaching period and could also explain the initial behavior of the herbicide. According to Matallo *et al.* (2003), the degradation of the herbicide is better fitted in a bi-exponential equation in the upper layer of the soil (0–12 cm), meaning that the degradation is initially rapid ($t_{1/2} = 1.3$ days) then followed by a much slower process ($t_{1/2} = 1,386$ days). Because of this, we have used

for the equation just half of the rate of the herbicide and by doing so a higher half-life. This was done because if there is no rain after the application, the herbicide would stay at the soil surface where would quickly degrade to half of the rate followed by a slower degradation. Also, in case of higher moisture followed by rain, the herbicide would leach more rapidly to deeper layers, where the degradation is slower.

Conclusion

The AF model predicted well the total amount of the herbicide leached in Typic Quartzipsamment soil but even with the inclusion of the dispersion factor to the model it did not fit well during the first 150 days after the herbicide application and adjusted better at the end of the period. This behavior could be due to the dispersion and diffusion of the herbicide in the micropores associated with the differential movement of water through soil pores.

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