Mobility of atrazine in two types of soil in the state of Puebla

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Abstract

Surface and groundwater contamination by herbicides such as atrazine occurs by leaching through the soil profile. The objective of the study was to evaluate the mobility of atrazine in plots dedicated to maize cultivation, each with a different type of soil located in the municipalities of San Nicolás Buenos Aires (Regosol) and Los Reyes de Juárez (Calcisol), Puebla, Mexico. Displacement experiments were conducted on soil packed columns (8.5 cm in diameter and 30 cm in length). An aqueous concentration of 6.25 g L^{-1} of atrazine (Gesaprim®) was applied to each column. First, a pore volume of a soil restorative solution (without atrazine) was used and subsequently, 30 volumes of irrigation water pore containing atrazine were applied. The leachates and three depths of the soil columns (0-2 cm, 2-10 cm and 10-20 cm, respectively) were analyzed. Pearson's correlation results showed that organic material, texture and cation exchange capacity were the physicochemical characteristics of the soil that affect the mobility of atrazine. Atrazine had a delay coefficient of 1.08 in Regosol and 1.03 in Calcisol. The transport of the herbicide was nine times faster in the Regosol compared to Calcisol. Atrazine was retained in a greater amount in the first two centimeters of soil columns. The degraded mass percentage of atrazine was 94% for Regosol and 69% for Calcisol.

Keywords: atrazine mobility, Calcisol, corn crop, Regosol.

Introduction

Farmers protect their crops with agrochemicals such as herbicides to fight weeds (Carrero and Planes, 2008). They are organic substances, which can present one or more elements such as S, C, N, Cl, P and that when contact with the environment present transformations at the physical, chemical and biological level (Josep and Figueras, 1998). That is, they generate complex systems to study, due to adsorption and absorption phenomena in soils, in cultives, rhizosphere, interactions with microorganisms, small vertebrates and invertebrates.

For example, some elements are volatilized towards the troposphere, either by chemical or microbial degradation, whose metabolites are not necessarily innocuous to the biosphere (López-Geta *et al*., 1992). One of the most commonly used herbicides in Mexican agriculture is atrazine, $C_8H_{14}ClN_5$ (CAS: 1912-24-9, 6-chlorine-N-ethyl-N-isopropyl-1,3,5-triazine-2,4-diamine, which is characterized by act on a systemic level and being broad spectrum (Kim *et al*., 2011). It is used for the emerging control of broadleaf weeds and pasture, acts at root (rhizosphere) and accumulates in the leaves preventing the photosynthesis of plants (Marquez *et al*., 2009).

Farmers generally apply an atrazine concentration of 0.1- 4 kg ha^{-1} year^{-1}, in crops of sorghum maize, pineapple, sugar cane, wheat and various types of pastures (Fernández *et al*., 2001; Villada-Canela, 2006). When atrazine is used to increase yields in maize production, there is a negative impact on soil fertility and water quality in streams and aquifers (Hernández and Hansen, 2011; Lerch *et al*., 2011). It is común, that the atrazine is applied that by direct spray on the area to be treated, a significant amount is deposited on the surface of the soil, having low sorption and high potential for percolation, which with the effect of rains is quickly transported to the surface waters and into the soil matrix.

Studies have identified that the constant use of atrazine generates, over time, resistance in weeds (decreasing their efficiency), so farmers increase the dose and periodicity of application of the herbicide. Consequently, it causes 'intermittent and cumulative cycles' of atrazine, severely increasing contamination of soil, surface water and aquifers (Abdelhafid *et al*., 2000; Azevedo *et al*., 2000; Graymore *et al*., 2001; Shukla *et al*., 2003; Hernández and Hansen, 2011; Lerch *et al*., 2011; Mudhoo and Garg, 2011).

The mobility of atrazine in the soil depends on the texture, organic matter content, soil drainage and amount of water applied, either by rain or irrigation. For example, clay soils, high in organic matter, tend to retain atrazine on the surface and their presence in drained water is limited (Hang *et al*., 2010), while, in sandy soils, it tends to infiltrate and be transported with drained water (Montoya *et al*., 2006). Heavy rains and the application of excessive irrigation, increases the risk of migration of the herbicide to bodies of water by processes of runoff and infiltration (Javanshir *et al*., 2012).

In addition, the adsorption and degradation processes of atrazine are the main natural attenuation mechanisms that control the migration of this herbicide in water and soil. Other studies indicate that adsorption of atrazine depends on soil texture and composition, pH and the applied amount of herbicide (Hang and Sereno, 2002). González-Marquez and Hansen (2009) evaluated the effect of soil parameters on natural attenuation of atrazine, and they noted that when the organic

matter content is higher, its adsorption is higher. Adsorbed atrazine is less available to participate in other dissipative processes, such as biodegradation and transport to bodies of groundwater and surface water.

The objective of this research was to evaluate the mobility of atrazine in packed columns of two types of soil that are dedicated to corn crop, the soils are located in the municipalities of San Nicolás Buenos Aires and Los Reyes de Juárez in the state of Puebla, Mexico. According to data from the Secretariat of Agriculture, Livestock, Rural Development, Fisheries and Food (SAGARPA) in 2018, a maize harvest was recorded in the municipalities of 29 951 t and 3 000 t, respectively (SIAP, 2019). It is important to contextualize that the agronomic management of atrazine in the area is a research model to understand what agricultural practices favor the migration of the herbicide and thereby generate recommendations for optimal management.

Materials and methods

Description of the study area and selection of sampling units

The area of study of this research was carried out in two municipalities of Puebla, Mexico (Figure 1). The municipality of San Nicolás Buenos Aires is located between coordinates 19° 08' 36" and 19 20' 00" north latitude and 97° 28' 36" and 97° 34' 54" west longitude of the Greenwich meridian (Figure 1A). Its approximate extension is 195.19 km^2. It is located in the morphological region of the plains of San Juan at an average altitude of 2 380 meters above sea level. It has a predominantly temperate-subhumid climate with rains in summer (C(w1)) in the southern part of the municipality and semi-dry-temperate with rains in the northern part, without rain during the winter (BS1kw). Its main economic activity is agriculture of temporary.
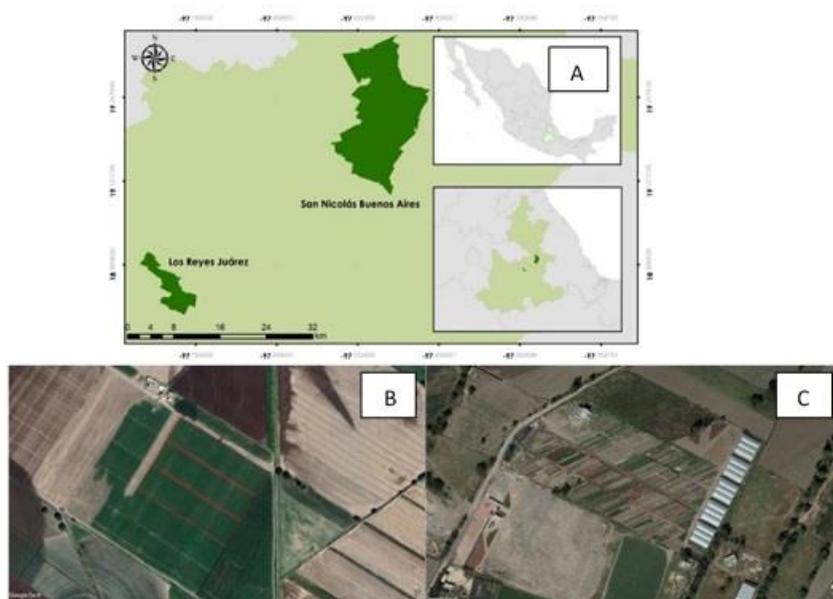
Figure 1. A) Location of the municipalities analyzed. Experimental plots; B) municipality San Nicolás Buenos Aires; and C) municipality Los Reyes de Juárez.

The predominant soil is regosol, although Feozems, Fluvisols and Lithosols can also be identified (INEGI, 2017). The second sampling municipality corresponds to Los Reyes de Juárez located between the geographical coordinates 18° 55' 36" and 19° 01' 06" north latitude and the meridians 97° 47' 54" and 97° 52' 06" of western longitude (Figure 1C). It has an extension of 30.55 km^2. It is located in the Tepeaca Valley, the plain extends to the center of the poblana plateau and is characterized by its eminently limestone soil and marble deposits. The predominant soil types are Feozem and Calcisol (INEGI, 2017). The relief is flat, presenting a slight decline in a north-south direction. The predominant climate is temperate subhumid with rains in summer and very dry during the winter (INEGI, 2017). Its main economic activities are horticulture and agriculture of temporary.

In these municipalities the farmers use atrazine for weed control in corn crop, apply three pre-emergency irrigations two or three weeks before planting, during the months of march or April, incorporate spray atrazine in the first 3 to 5 cm deep, sometimes mixing it with fertilizers and other herbicides, such as carbofuram, without having an established dose. They do not use protective equipment or have controlled management for the preparation of solutions with herbicides. In addition, they rotate crops on an annual basis, sowing pumpkin, bean, carrot or broccoli (SENASICA, 2019).

Soil sampling

Two soil types were selected, one Regosol in San Nicolás Buenos Aires and the other Calcisol in Los Reyes de Juárez. The sampling units in each municipality corresponded to three agricultural plots planted with maize and without application of atrazine. Soil samples were taken in November 2018. From the first 30 cm deep, the soil sample was obtained following the methodology known as 'five golds' obtaining five subsamples of each plot.

The subsamples were placed in properly labeled plastic bags, indicating the sampling unit, they were subsequently transferred to the soil laboratory of the Department of Agricultural Science Research of the Meritorious Autonomous University of Puebla (BUAP), for their physicochemical characterization, according to the standardized methods of the Official Mexican Standard NOM-SEMARNAT-021-2000 (Official Mexican Standard, 2002). Given the homogeneity in the results obtained from the individual characterizations of the subsamples of each of the three plots of each municipality, the subsamples were mixed to generate a composite sample of each plot for two sampling units.

Characterization of soils without atrazine

For each soil the following parameters were determined: density, pH, electrical conductivity, texture, cation exchange capacity (CIC), concentrations of organic material, calcium and magnesium. The main minerals present in each soil were characterized by X-ray diffraction using a Bruker D 8m equipment with CuKα radiation, with scan ranges of 0.5° to 5° (2θ) with a step size of 0.025°. The possible presence of atrazine in the sampled soils was analyzed by performing methanol extractions from the soil. To do this, 5 g of each soil was used, which were placed in centrifugal tubes and added 25 mL of a 70/30 v/v methanol/water solution corresponding to a

weight/volume ratio extractant-soil 5:1; subsequently, they were placed in an orbital agitator at 180 rpm for 2 h. From the supernatant, 5 ml were passed through 0.45 mm pore diameter nylon filters and stored in amber bottles for further analysis.

The concentration of atrazine residues was determined by a high-efficiency liquid chromatograph (HPLC) coupled to a dynamic equipment consisting of a model 1 525 high-pressure binary pump system, a 2 707 model self-sampler, a UV-Vis detector model 2 489 and an xSelect CSH analytical column (4.6 x 150 mm) of 3.5 µm particle size, all of them of the Waters brand. Acetonitrile HPLC grade was used as a mobile phase in isocratic mode with an extraction flow of 1 ml min^{-1} with a wavelength of 220 nm and samples were taken automatically every 5 min, the calibration curve was performed for the verification of this method. The chromatographic data obtained were stored in a data acquisition system using Waters Corp's Empower 3.0 software. This methodology was based on the proposal by Salazar *et al*. (2018).

Columns packed with soil and study of atrazine mobility

The two types of soil were packed in random consecutive columns of transparent polychloride vinyl (PVC) approximately 8.5 cm internal diameter by 30 cm in height. Each column was packed to a height of 20 cm and its weight and density were determined. Field capacity was estimated using the Bodman and Mahmud formula, soil porosity, infiltration and leaching speed.

At the beginning of the experiment each column was added a restorative solution (0.001M KCl, 0.006M CaCl$_2$, 0.001M MgCl$_2$ and 0.018M NaCl) in continuous flow using a drip irrigation system to simulate the pH, electrical conductivity and ion force conditions of the soil solution (Duwig *et al*., 2009).

Once pore saturation had been reached, the flow of distilled water was restarted again steadily (2.62 ± 0.3 ml min^{-1}). A 6.25 g L^{-1} atrazine (Gesaprim$^®$) solution was applied by spraying at the top of the column on days 1, 11 and 21. To do this, a solution volume of 250 ml was used for the columns of Regosol and 200 mL for those of Calcisol. Drip irrigation was used every other day only with distilled water. The experiment was conducted during the months of august and September 2019, having an average temperature of 25 °C.

Because the inflow of water and outflow of the leachates during the experiment was different for each soil column, during the 30 days of the experiment, the percentage of leached water was calculated relative to the amount of volume applied. This compares the leaching process in each of the columns in a more homogeneous way.

Leachate recovery

The leachates were obtained daily from the packed columns for 30 days, the volume of the leached samples was recorded, 5 ml of each sample was filtered and preserved in amber bottles at 4 °C for further analysis. The quantification of atrazine was performed by HPLC, in the same way as in the analysis of methanol extractions (Salazar *et al*., 2018) .

Atrazine transport parameters in columns packed with soil

At the end of the 30 days of irrigation, the soil was unpacked from the columns previously treated with atrazine, each column was divided into three sections to the following depths: 0-2 cm, 2-10 cm, and 10-20 cm. Each section of the soil was homogeneously mixed, it was weighed and dried on a stove at 60 °C for 8 h, subsequently the extraction of atrazine was performed following the method proposed above. Finally, the delay coefficient was determined.

This coefficient provides a first approximation of the leaching potential of atrazine through the soil, taking into account the adsorption and distribution between the solid and liquid phases, is calculated by the following equation: $R = 1 + (\rho/\eta)K_d$ (1). Where: R= delay coefficient (dimensionless), ρ: apparent density (g cm^{-3}), η: porosity (dimensionless), K_d: distribution coefficient (cm^3 g^{-1}) (Eweis *et al*., 1999). The mass balance for atrazine was estimated with the following equation (Raymundo *et al*., 2011): $M_A = M_L + M_R + M_D$ (2). Where: M_A is the applied atrazine mass, M_L is the total leached mass, M_R is the mass of atrazine retained in the soil of the column and M_D is the degraded atrazine mass. By difference, with equation (2) the amount of degraded atrazine is obtained.

A constant rate of degradation (χ) was assumed with the following equation (Raymundo *et al*., 2011): $\chi = -\ln\left(\frac{M_A-M_D}{M_A}\right)/t$ (3). Where: t is the total time of the duration of the experiment. The half-life time of atrazine was estimated in both soil types with the following equation (Raymundo *et al*., 2011): $t_{0.5} = \ln(2)/\chi$ (4).

Statistical analysis of soil characterization results, field capacity, porosity, infiltration rate and infiltration flow rates were performed by a student t-test for independent samples with significance level $p \leq 0.05$. The data obtained for the retention of atrazine and its transport parameters were statistically analyzed using a variance analysis (Anova) and the study of differences between means per Tukey test. The relationship between the properties of the soils studied and the mobility of atrazine was established through Pearson's linear correlation method. In all cases a significance value of $p \leq 0.05$ was considered, all analyses were performed in R statistical program version 3.1.3.

Results and discussion

Characterization of soils without atrazine

Table 1 shows the results obtained on the characterization of the soils evaluated. The regosol soil of the municipality of San Nicolás Buenos Aires is moderately acidic (5.8). It does not have high salinity (Castellanos, 2000) as it shows a relatively low electrical conductivity value (0.142 dS m^{-1}). This soil is of a loam-sandy texture class with 80% sands, with medium concentration organic matter (1.95%). This is because in this region the soil is under constant labor and is cultivated devoid of plant cover that could provide a greater amount of organic material. Cation exchange capacity (CIC) is low (8 cmol$^+$ kg^{-1}), therefore, the soil's ability to

retain cations and nutrients for maize cultivation (Castellanos, 2000) is limited. Concentrations of interchangeable Ca2$^+$ and Mg2$^+$ ions are medium (4.9 meq 100 g^{-1} soil) and low (1.16 meq 100 g^{-1} soil), respectively.

The Calcisol-type soil in the municipality of Reyes de Juárez, presented a pH close to neutrality (7.1); its electrical conductivity is very low (0.25 dS m^{-1}), so they are not considered saline (Castellanos, 2000). This type of soil has a loam textural class with predominance of sands (47%) and clays (36%). The concentration of organic material is 1.84 %, value considered as medium (Castellanos, 2000). Its CIC is medium (18.9 Cmol kg^{-1}) (Official Mexican Standard, 2002),due to the presence and nature of the clays. It has high concentrations of interchangeable ions of Ca^{2+} and Mg^{2+}, 9.7 and 3.2 meq 100 g^{-1} soil, respectively (Castellanos, 2000).

Table 1. Physicochemical properties of the evaluated soils.

Property	Regosol	Calcisol
Depth (cm)	0-30	0-30
Density (g cm^{-3})	1.4 ±0.08 a	1 ±0.08 b
pH	5.8 ±0.017 a	7.1 ±0.21 b
Electrical conductivity (dS m^{-1})	0.142 ±0.09 a	0.25 ±0.01 b
Organic matter (%)	1.95 ±0.01 a	1.84 ±0.151 a
Sand (%)	80 a	47 b
Clay (%)	13 a	36 b
Limo (%)	7 a	17 b
CIC (cmol$^+$ kg^{-1})	8 ±0.1 a	18.9 ±0.1 b
Ca^{2+} (meq 100 g^{-1} soil)	4.9 ±0.1 a	9.7 ±0.1 b
Mg^{2+} (meq 100 g^{-1} soil)	1.16 ±0.01 a	3.2 ±0.01 b

Means with different letter are statistically different between soil types ($p \leq 0.05$).

As for mineralogy, the Regosol presented an X-ray diffractogram (Figure 2) indicating the presence of albite and quartz, as reported by Lebgue-Keleng *et al*. (2014) for Regosol from the state of Chihuahua. These crystalline minerals do not provide significant contributions of nutrients to the soil (Sadeghian *et al*., 2012). Regarding Calcisol, the X-ray diffractogram indicated that it is rich in CaCO₃, (Sadeghian *et al*., 2012), although the presence of albita is also observed.

Weber (1995) reported that atrazine adsorption is pH-independent when it has values greater than 4 and Koskinen and Clay (1997) reported that the maximum pH value affecting atrazine adsorption is 6. Therefore, in the soils studied there is no influence of pH on the adsorption of atrazine because the pH of the soils used are 5.8 and 7.1. Organic material concentrations are relatively low in both soils without significant differences ($p \leq 0.05$). According to the studies of Wan Ting *et al*. (2005), this property can negatively affect the adsorption of atrazine in Regosol soil, while for Calcisol, which has significant difference ($p \leq 0.05$) and high clay content, atrazine adsorption would be favored, but biodegradation processes would be limited.
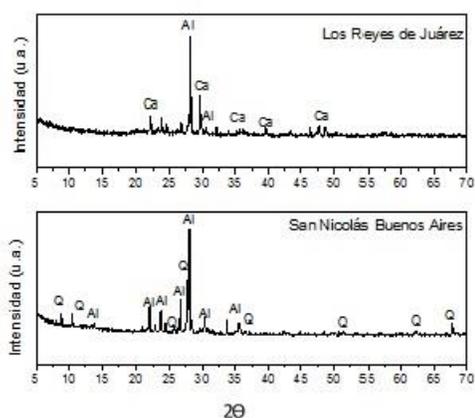
Figure 2. X-ray diffractograms of soil samples at large angles ([Ca] calcite, [Al] albite, [Q] quartz).

The presence of atrazine was not observed before starting the treatments in the sampled soils when performing high-efficiency liquid chromatography studies of the extracts from each of the soils, because the peak corresponding to atrazine was not observed.

Atrazine leaching in soil columns

The value obtained for field capacity is consistent with those reported by Saxton and Rawls (2006) for the evaluated soils, Regosol and Calcisol. Porosity presented statistically significant difference *(p ≤ 0.05)* for soil types, being for Regosol of 32% and for Calcisol of 50%, this is a variable that determines the infiltration and leaching processes that influence the transport of water and agrochemicals (Horowitz and Walling, 2005). The volume of water in the pores for Calcisol (254 cm^3) and for Regosol (156 cm^3) indicated the relationship with porosity, which in both soils was favorable for crop development (Volverás-Mambuscay *et al*., 2016) . These results can be explained from the perspective of agronomic management of plots and the temporal effect of farm implements, which improve soil properties such as porosity and moisture retention capacity, in soils such as Calcisol, other studies report similar results in tropical agricultural systems (Sustaita *et al*., 2000)

Infiltration flow and leaching flow, Table 2, present significant statistical difference *(p ≤ 0.05)* for soil types presenting higher values for Regosol, due to the formation of a greater number of preferential flow routes, characteristic of soils with a higher percentage of sand, which capture some of the surface flow and transport it into the soil, facilitating the mobility of water and contaminants (Shakesby, 2000).

Table 2. Leaching characteristics of packaged columns.

Soil type	M (g)	CC (%)	ϕ (%)	υ (cm^3)	Q_I ($cm^3 min^{-1}$)	Q_L ($cm^3 min^{-1}$)
Regosol	690 ±0.08a	11.5 ±0.08a	32 ±0.08a	156 ±0.08 to	4.87 ±0.05 to	1.91 ±0.05 a
Calcisol	495 ±0.08b	27.3 ±0.08b	50 ±0.08 b	254 ±0.08 b	0.53 ±0.05 b	0.09 ±0.05 b

m= soil mass; CC= field capacity; ϕ= porosity; υ= volume of water in pores; Q_I= infiltration flow; Q_L= leaching flow. Means with different letter are statistically different between soil types *(p ≤ 0.05)*.

Elution curves (Figure 3) show the concentration of atrazine in leachates in parts per million (ppm) versus the daily pore volume of 200 ml for Regosol and 180 ml for Calcisol. After 5 volumes of pore, Calcisol presented the concentration of atrazine accumulated in leachates of 99.3 ppm. For the case of the regosol of San Nicolás Buenos Aires, a cumulative concentration of atrazine was obtained in leachates of 114.2 ppm after five volumes of pore, being statistically different $(p \leq 0.05)$.

It is important to note that, even though the atrazine solution was also added on days 11 and 21, the presence of herbicide was not observed in the leachates of both soils. Soils with a low organic matter content have been reported to be more susceptible to leaching (DeSutter *et al*., 2003) . However, the leaching flow rate and infiltration flow rate is 9 and 21 times, respectively larger for the Regosol soil, resulting in a higher leaching speed.
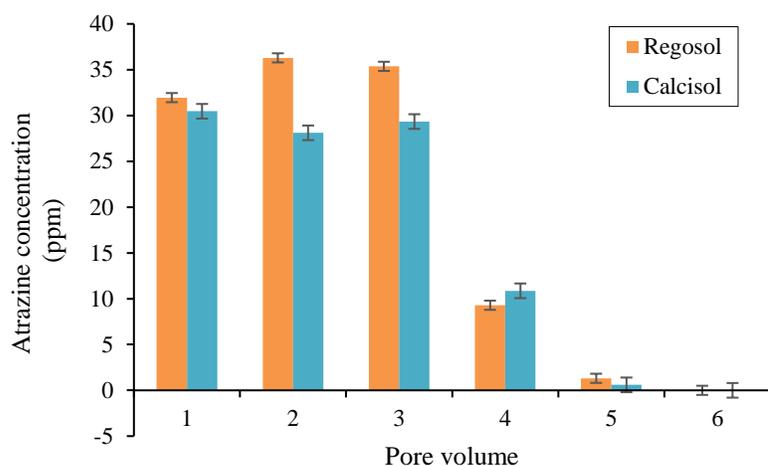
Figure 3. Relative elution curves for the soils studied.

Comparing the atrazine concentration results obtained in this study with those reported by Ndongo *et al*. (2000) it can be mentioned that the high concentration of atrazine in leachate in the first days is related to the presence of preferential paths in soil pores. The amount of leachate volume decreased 50% after 21 pore volumes for Regosol and 22 pore volumes for Calcisol, due to pore saturation and moisture accumulation within columns (Figure 4).
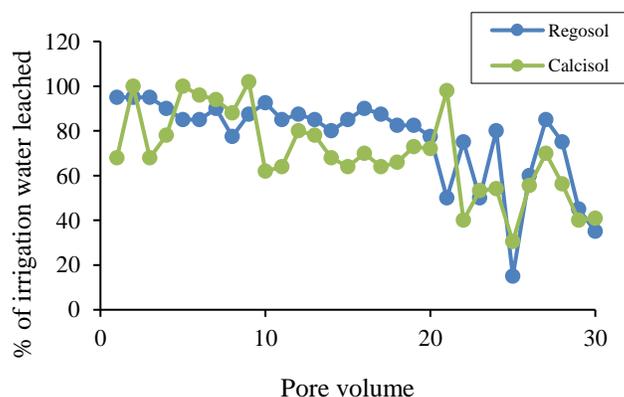
Figure 4. Percentage of leached irrigation water in relation to the amount of pore volume applied.

Salazar-Ledesma *et al*. (2018) assessed the adsorption-desorption capacity of atrazine in three soil types under different agricultural management, concluding that the elution of the herbicide depends on the content of organic matter, its chemical composition and the agricultural management of each soil, therefore, having a similar organic matter content, both types of soil contain a similar concentration of atrazine in their leachates (Salazar *et al*., 2018).

Atrazine retained in soil columns

Table 3 reports the values of atrazine per gram of soil retained at different depths of the columns of each soil type. It is observed that the herbicide is at higher concentration in the first two centimeters of the column, 2.4 and 2.3 mg of atrazine g^{-1} soil for Regosol and Calcisol, respectively, without presenting significant difference ($p \leq 0.05$). For Regosol, atrazine had a lower retention inside the column, because sandy soils facilitate leaching, have no retention and have high permeability (Sadeghian and Arias, 2017). In this soil, the function of atrazine in weed control is guaranteed, because it remains on the surface longer. For Calcisol there is migration to a deeper surface of the column (1.8 mg atrazine g^{-1} soil) in this case, there is a high risk of contamination of surface and groundwater.

Table 3. Atrazine retained at different depths of the columns.

Depth (cm)	Regosol	Calcisol
	(mg of atrazine g^{-1} soil)	
0-2	2.4 ±0.02 a	2.3 ±0.04 a
2-10	0.19 ±0.03 a	2.2 ±0.03 b
10-20	0 ±0 a	1.8 ±0.02 b

Means with different letter are statistically different between soil types ($p \leq 0.05$).

Atrazine transport parameters

Table 4 presents the values of the distribution coefficient (Kd) of atrazine, without presenting statistical difference ($p \leq 0.05$), 1.99 for Regosol and 1.88 for Calcisol. The value of the delay coefficient (R) indicated that the atrazine is mobile in both soil types (Bernard *et al*., 2005), presenting statistical difference ($p \leq 0.05$), being the Regosol the largest R= 1.08 ±0.18 indicator of faster leaching processes in this type of soils and groundwater contamination (Gutiérrez *et al*., 2007). The importance of calculating the delay coefficient (R) of atrazine in the columns is due to the advection and adsorption effects, considering moisture and porosity in a soil type. Therefore, the conditions of the hydraulic behavior of the soil would be similar to those used in real conditions (Eweis *et al*., 1999).

Finally, hydraulic conductivity was significantly higher ($p \leq 0.05$) for Regosol (1.91 ml min^{-1}) than for Calcisol (0.09 ml min^{-1}), indicating a greater ability of Regosol to transmit water to the soil profile. In addition, the percentage of degraded mass was 94% for Regosol and 69% for Calcisol. The rate of degradation was significantly higher ($p \leq 0.05$) in Regosol (0.097 days) with respect to Calcisol (0.039 days), therefore, atrazine persists longer in Calcisol, with half-life time of 17.77 days.

Table 4. Atrazine transport parameters.

Property	Regosol	Calcisol
Distribution coefficient (Kd) (ml g^{-1})	1.99 ±0.04 a	1.88 ±0.05 a
Delay coefficient	1.08 ±0.09 a	1.03 ±0.04 b
Hydraulic conductivity (ml min^{-1})	1.91 ±0.04 a	0.09 ±0.09 b
χ (days)	0.097 ±0.06 a	0.039 ±0.06 b
t $_{0.5}$ (days)	7.14 ±0.06 a	17.77 ±0.04 b

Kd= foc∗Koc; Foc= fraction of organic carbon available in soil; Koc= organic carbon partition coefficient. For the atrazine Koc= 102.32 ml g^{-1}; χ= constant rate of degradation; $t_{0.5}$= half-life time. Means with different letter are statistically different between soil types ($p \leq 0.05$).

The results of the correlation analysis between atrazine mobility and soil properties are presented in Table 5. The correlation coefficients obtained indicate that the factors that affect the mobility of atrazine in the soil are the content of clays, organic matter, texture and cationic exchange capacity, which is consistent with Eweis *et al*. (1999). Soils with higher clay and organic matter content have greater potential to retain herbicides, so their availability decreases in the soil solution to be absorbed by plants.

Table 5. Pearson correlation matrix between atrazine mobility and soil properties.

	Leached atrazine	Atrazine retained in soil	Degraded atrazine	pH	Electrical conductivity	Organic matter	Sand	Clay	Slime	CIC	Ca	Mg
Leached atrazine	1											
Atrazine retained in soil	-0.82	1										
Degraded atrazine	0.82	-0.97	1									
pH	-0.55	0.33	-0.33	1								
Electrical conductivity	0.29	0.26	-0.26	-0.55	1							
Organic matter	-0.81	0.99	0.99	0.25	0.26	1						
Sand	0.82	-0.98	0.97	-0.33	-0.26	-0.99	1					
Clay	-0.82	0.97	-0.96	0.33	0.26	0.99	-0.99	1				
Slime	-0.82	0.99	-0.95	0.33	0.26	0.99	-0.98	0.98	1			
CIC	-0.83	0.89	-0.89	0.47	0.05	0.87	-0.89	0.89	0.89	1		
Ca	-0.79	0.95	-0.95	0.47	0.21	0.91	-0.95	0.95	0.95	0.96	1	
Mg	0.78	-0.96	0.96	-0.26	-0.23	-0.98	0.96	-0.96	-0.96	-0.78	-0.84	1

Conclusions

The characterization of Regosol and Calcisol showed low organic material concentrations (1.95% and 1.84%, respectively), the concentration of clays and cationic exchange capacity were significantly different between the two soils, being higher in Regosol with values of 36% and 18.9 cmol$^+$ kg^{-1}. These properties showed high correlation (>0.8) with the mobility of atrazine in soil columns, so the delay coefficient was 1.08 in Regosol and 1.03 in Calcisol. Because the hydraulic conductivity atrazine was higher in Regosol (1.91 ml min^{-1}) is that it was transported nine times faster than Calcisol (0.09 ml min^{-1}). Atrazine was maintained in greater quantity in the first two centimeters of soil columns, 2.4 and 2.3 mg atrazine g^{-1} soil for Regosol and Calcisol and the percentage of degraded mass of atrazine was 94% for regosol and 69% for Calcisol.

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