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Effects of Sugar Cane Mechanical Harvesting Followed by No-Tillage Crop Systems on Leaching of Triazine Herbicides in Brazil

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The state of Sao Paulo, located in southeast Brazil, is an important sugarcane, soybean and corn producing area with high use of chemicals in agriculture and potential risk of environmental contamination (Pessoa et al. 1998). This region is also an important recharge area for groundwater of the Guarany aquifer, which spreads to areas of eight Brazilian states plus parts of Argentina, Uruguay and Paraguay. Also, in Brazil, currently most of the sugar cane crop is burned to facilitate harvesting and this could interfere with soil properties. In Sao Paulo State, where the agriculture is well developed, there is a new trend toward sugar cane mechanical harvesting, without burning. This practice allows the straw to decompose in soil, maintain a better soil structure, and can interfere with the movement and leaching of solutes. It is also normal to grow other crops following sugarcane in No-tillage (NT) and conventional tillage (CT), that could further affect the movement of herbicides in the environment (Smith et al. 2001).

Several studies have demonstrated the possibility of pesticides leaching to groundwater (Smith et al. 2001; Bouwer 1990). Among them, triazine herbicides such as atrazine, (2-chloro-4-ethylamino-6-isopropylamino-1,3,5-triazine) ametryn, (2-(ethylamino)-4-isopropylamino-6-methyl-thio-s-triazine), and simazine[2-chloro-4,6-bis(ethylamino)-1,3,5-triazine] are used in Brazil and can contaminate groundwater (Pessoa et al. 1998). The Brazilian Health Ministry has set the maximum amount of atrazine and simazine in drinking water at 2 μg/L (Pessoa et al. 1998).

Atrazine is a selective triazine herbicide used to control broadleaf and grassy weeds in corn, sorghum, and sugarcane and is highly persistent and moderately to highly mobile in soils with low clay or organic matter content (Extoxnet 1998). Because it does not adsorb strongly to soil particles and has a lengthy half-life (60 to >100 days), it has a high potential for groundwater contamination despite its moderate solubility in water (Wauchope et al. 1992). It has been detected in some wells in the United States located on irrigated lands in concentrations that exceed the health advisory level (Hornsby 1990). Ametryn, another member of the triazine family, is a herbicide that is used to control broadleaf weeds and annual

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grasses in sugarcane and corn in Brazil and has been found in surface water and sediments (Laabs et al. 2002). Ametryn half-life in soil is 70 to 250 days, depending on the soil type and weather conditions, moves both vertically and laterally in soil due to its high water solubility, and it may leach as a result of rainfall.

Simazine is another selective triazine herbicide (Extoxnet 1988). It is used to control broad-leaved weeds and annual grasses in fields, berry fruit, nuts, vegetable and ornamental crops, turfgrass, orchards, and vineyards. At higher rates, it is used for nonselective weed control in industrial areas. Simazine has the potential to leach, is affected by soil properties (Albarran et al. 2004) and the half life was found to vary from 41 to 91 days depending on the type of soil (Calderon et al. 2004).

Because we have multiple cropping systems, the literature indicates that there is a relationship of tillage systems and leaching. In addition, the region is located on an aquifer recharge area where herbicides are heavily used. Therefore, this research was conducted to evaluate the effect of harvesting and soil preparation systems on triazine leaching. A field experiment and a soil column leaching study in the laboratory were conducted to determine the movement of triazines where mechanical sugarcane harvesting has been followed by NT and CT peanut production. Although not all the triazines are necessarily used at the same level on all crops, we have used the three, atrazine, simazine and ametryn, as models to study the effect of soil preparation systems on leaching from those soils.

MATERIALS AND METHODS

Field research was conducted at the Alta Mogina Sao Paulo State Experiment Station, Ribeirao Preto, SP, Brazil, and laboratory studies were conducted at the Research Division of the Brazilian Department of Agriculture, Embrapa/Environment, Jaguariuna, SP, Brazil. The experimental design consisted of mechanically harvested sugarcane followed by NT and CT peanuts in a Randomized Complete Block (RCB), with three replications and plots of 10X30 m.

Sugar cane was planted in 1977 and mechanically harvested until the last cutting in October 2002. After the last mechanical sugar cane harvest in October, soil samples were collected from trenches before and after peanuts were sown under NT and CT conditions. Samples were collected every 10 cm from 0 to 100 cm depths in November and March of 2002/2003 and taken to the laboratory. Soil density (Mg/m^3), the relationship of soil mass to volume was measured using the Kopeck ring method described by Black (1965). Total porosity was measured based on the percentage of saturation in volume (Vomocil 1965). Microporosity was determined by the tension table method at a potential of 0.006 Mega Pascal (Mpa). After saturation and drying under tension, the samples were oven dried at

105°C to obtain the volume of micropores ≤ 0.05 mm. Macroporosity was obtained by the difference between micro and total porosity. Also evaluated were the % organic matter and physical properties of the soils for each depth (Klute 1986). The soil saturated hydraulic conductivity and the leaching potential of the herbicides were accomplished with leaching experiments conducted in 20 cm diameter PVC columns. The soil samples were collected from the field experiment and were placed in the columns at the same depths and density as in the field with a vacuum extractor used for collecting solutes.

Soil columns were saturated with water from bottom to top to extract the remaining air, the soil saturated hydraulic conductivity was measured. The columns were allowed to drain for three days to reach field capacity according to Klute (1986). After that, 1570 ml of solution containing the equivalent of 8 Kg/ha a.i. each of the herbicides was applied at the top of the columns.

The herbicides were applied at the top of the columns. Water was applied until it reached 5cm; equivalent to a 50 mm rain. The time interval for the solution to reach the bottom was measured. The solutes were collected at 20 cm depths using vacuum extractors for each 10 cm depth and analyzed for residues by HPLC in a Completely Randomized Design (CRD) with two replications.

The stock solutions of simazine (Dr. Ehrenstorfer, 98%), atrazine (Chem Service, 98%), and ametryn (Supelco, 100%) were prepared in HPLC-grade methanol (Tedia) at a concentration of 100 mg/L. The working solutions for the herbicides were prepared at concentrations of 31.25, 62.50, 125.00, and 250.00 µg/L for simazine and 62.50, 125.00, 250.00, and 500.00 µg/L for atrazine, and ametryn. Chromatography was performed by HPLC (Agilent 1100), equipped with UV/Vis absorbance detector. The analytical column (150 x 4.6 mm i.d.) was a Synergy fusion 80A, 5 µm. The mobile phase was methanol:H_2O (60:40, v/v). All chromatographic measurements were carried out at room temperature. The flow rate was 1 ml/min, UV detection at 230 nm and injection volume 20 µl. The detection limit of this method was 10µg/L and recovery of 97%.

All the data were analyzed by ANOVA with the Duncan's Multiple Range using an alpha of 0.05 for comparing all the parameters: sand, fine sand, silt, clay, moisture, pH and organic content at each depth under both tillage systems.

RESULTS AND DISCUSSION

Samples collected from different depths, showed a high percentage of clay. No effect of depth on the physical properties of the soils under NT or CT was observed (Table 1). Organic carbon content was higher, but not statistically, in the top layer for NT soils (Table 2). There was also a trend of increasing moisture content and decreasing organic carbon content with depth under both cultivation systems (Table 2).

Table 1. Physical properties (%) under various depths of soils submitted to No-tillage and Conventional Tillage systems.

Depth (cm)	No-tillage				Conventional Tillage			
	Sand	Fine Sand	Silt	Clay	Sand	Fine Sand	Silt	Clay
0-10	4.0	10.0	30.6	55.3	3.3	9.3	28.8	58.6
10-20	3.7	9.9	28.3	58.1	3.8	9.4	29.6	57.2
20-30	3.3	9.4	28.2	59.1	3.7	9.1	23.4	63.8
30-40	3.5	8.9	25.7	61.8	3.6	8.6	23.9	63.9
40-50	3.0	9.9	25.2	61.9	3.5	8.9	23.3	64.4
50-60	3.5	9.8	25.9	60.8	3.2	10.0	26.2	60.6
60-70	3.5	9.9	25.9	60.7	3.2	11.0	24.9	60.8
70-80	3.4	8.8	26.8	61.0	3.9	8.9	26.5	60.7
80-90	3.6	10.0	25.7	60.7	3.5	10.0	24.7	61.8
90-100	3.5	9.5	28.4	58.6	3.3	9.7	28.3	58.6

Average of three replications. No significant differences were found using the Duncan's Multiple Range using alpha of 0.05 comparing both systems at each depth.

Table 2. Moisture (M, %), pH, Organic Carbon (OC, g/Kg), and Standard Deviations (SD for OC) under various depths of soils submitted to No-tillage and Conventional Tillage systems.

Depth (cm)	No-tillage				Conventional Tillage			
	M	pH	OC	SD	M	pH	OC	SD
0-10	5.1	6.3	23.3	3.1	4.8	5.9	19.3	2.4
10-20	9.2	6.1	15.9	0.7	7.2	5.5	17.7	2.8
20-30	8.3	6.2	15.2	1.6	8.6	5.2	13.3	2.9
30-40	10.2	5.9	9.4	1.2	10.1	5.4	12.0	3.6
40-50	11.7	6.6	9.0	0.4	9.7	5.3	9.7	1.3
50-60	11.8	6.4	8.6	0.6	12.0	6.9	9.4	0.6
60-70	14.4	6.0	8.4	0.6	14.4	6.2	8.7	0.2
70-80	13.8	6.0	7.6	0.8	15.3	6.1	7.3	0.5
80-90	15.7	6.3	7.4	1.0	18.9	6.5	7.8	1.1
90-100	12.9	7.0	7.3	1.4	13.8	6.1	6.4	0.1

Average of three replications. No significant differences were found using the Duncan's Multiple Range using alpha of 0.05 comparing both systems at each one depth.

Our results showed a general trend of higher soil density under NT, mainly in the top layer (Table 3). Roscoe and Buurman (2003) studying the Brazilian cerrados (savannas) following cultivation on a dark red latisol (Oxisol) also found that

Table 3. Soil density ($g.cm^{-3}$) under No-tillage (NT) and conventional tillage (CT) peanuts at various depths.

Depth (cm)	NT	CT	F Value
0-10	1.24	1.12	23.27*
10-20	1.22	1.14	5.53
20-30	1.30	1.19	1.82
30-40	1.20	1.20	0.00
40-50	1.16	1.14	1.27
50-60	1.09	1.09	0.37
60-70	1.06	1.04	0.29
70-80	1.05	1.04	0.02
80-90	1.03	1.06	NA**

* Significant different at $p \leq 0.005$. All the other depths were not statistically different. **NA: Not available

Table 4. Soil micro, macro, and total porosity (%) under No-tillage (NT) and conventional tillage (CT) peanuts at various depths.

Depth (cm)	Microporosity		Macroporosity		Total Porosity	
	NT	CT	NT	CT	NT	CT
0-10	48	51	11	12	59	63
10-20	49	50	12	13	61	63
20-30	48	48	11	12	59	60
30-40	49	48	11	12	60	60
40-50	49	49	12	11	61	60
50-60	50	51	13	12	63	63
60-70	49	50	12	12	62	62
70-80	50	51	13	14	63	65
80-90	50	51	12	12	62	63

Average of three replications. No significant differences were found using the Duncan's Multiple Range using alpha of 0.05 comparing both systems at each depth.

cultivation led to compaction, which significantly increased soil bulk density and that using either CT or NT systems did not alter the total C and N stocks in the first 45 cm of soil after 30 years of cultivation. Studies of Ishaq et al. (2001) also found that soil penetration resistance was lower for CT than NT.

Most of the literature is contradictory on the effects of tillage systems on micro, macro, and total porosity of soils. Our data, analyzed by ANOVA with the Duncan's Multiple Range, show no effect on these parameters under both CT and NT (Table 4).

Some authors found reduction in runoff and increased leaching of atrazine and simazine in NT as opposed to CT (Triplett et al. 1978; Edwards et al. 1980),

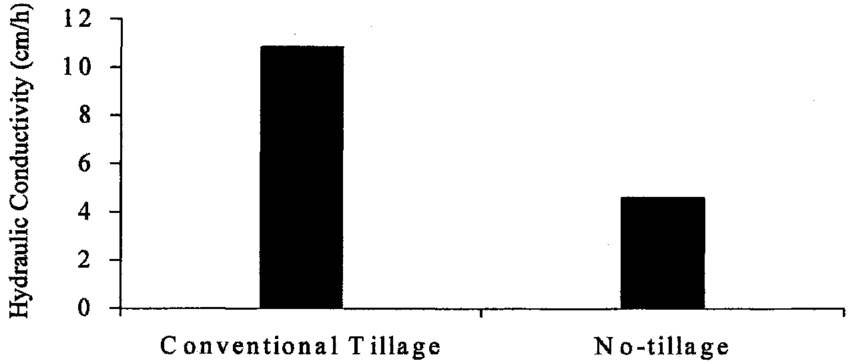

Figure 1. Hydraulic conductivity (cm/h) of soils under No-tillage (4.59*) and conventional tillage systems (10.82). *Statistically different F=4.0.

which appears contradictory to our findings (Figure 1). Others have found the opposite, NT runoff was higher and leaching was lower (Baker and Johnson 1979), results similar to those found in our study (Figure 1). There were also reports of no effect of the tillage systems, CT or NT on runoff of pesticides (Logan 1990). Wauchope (1987) considered that the results and conclusions of effects of tillage on runoff and leaching losses of pesticides are generally inconsistent and often contradictory. Such effects are likely soil specific.

There were also great differences in the literature regarding tillage effects on hydraulic conductivity. In our study, there was a higher conductivity for soils submitted to CT than NT but this did not reflect on the movement of the triazines (Figure 1).

The soil column studies have shown leaching of the herbicides atrazine and simazine down to the maximum of 20 cm. No herbicide was detected below 20 cm under the conditions of the experiment, indicating less mobility under the experimental conditions than in mathematical modeling simulations (Pessoa et al. 1998). Ametryn was not detected at any depths.

For both tillage systems, atrazine leached more than simazine, as expected according to studies conducted using mathematical simulation (Pessoa et al. 1998) but it was statistically different only under the NT system (Figure 2). There was no clear difference on mobility of both herbicides due to the tillage systems in our study.

Since most of the soil properties that affect leaching were similar in both systems at various depths (Tables 1, 2, and 4), the lower hydraulic conductivity of soils under NT could be attributed mainly to the higher density of the top layers of soils under NT (Table 3). Although organic matter and organic carbon content were not statistically different, those parameters were also higher for top layers of soils under NT and could also play an important role in lower hydraulic conductivity

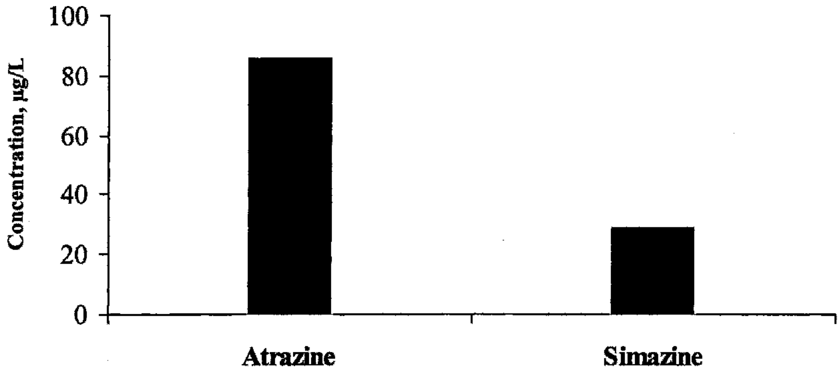

Figure 2. Concentrations (µg/L) of the herbicides atrazine (85.8*) and simazine (28.5) found in 0-20 cm layer of No-tillage soils. *Statistically different F=5.79.

(Table 2, Figures 1 and 2). It was also found that the difference in hydraulic conductivity for soils under NT and CT did not affect the leaching of the triazine herbicides.

Further studies will be conducted with lysimeters in order to understand better the effects of the soil tillage systems and consequent impact on groundwater quality.

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