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Groundwater Contamination due to the Use of Agrochemicals in Sugar Cane Agroecosystems

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ABSTRACT

Objective: To assess the risk of groundwater contamination due to the application of pesticides and the amount of nitrogen lost by leaching, in agroecosystems with sugar cane, in the area of influence of sugar mills, La Gloria y El Modelo, Veracruz, Mexico.

Methodology: The presence of pesticides in 30 groundwater sampling points was determined based on the NOM-041-SSA1-1993 standard and the methods of EPA 608 and EPA 608.1 described by the Environmental Protection Agency (EPA). Nitrogen (N) loss by leaching was assessed evaluating nine treatments by combining two factors: dose (250, 200 and 150 kg ha^{-1} of N) and application of fractionated doses (2, 3 y 4).

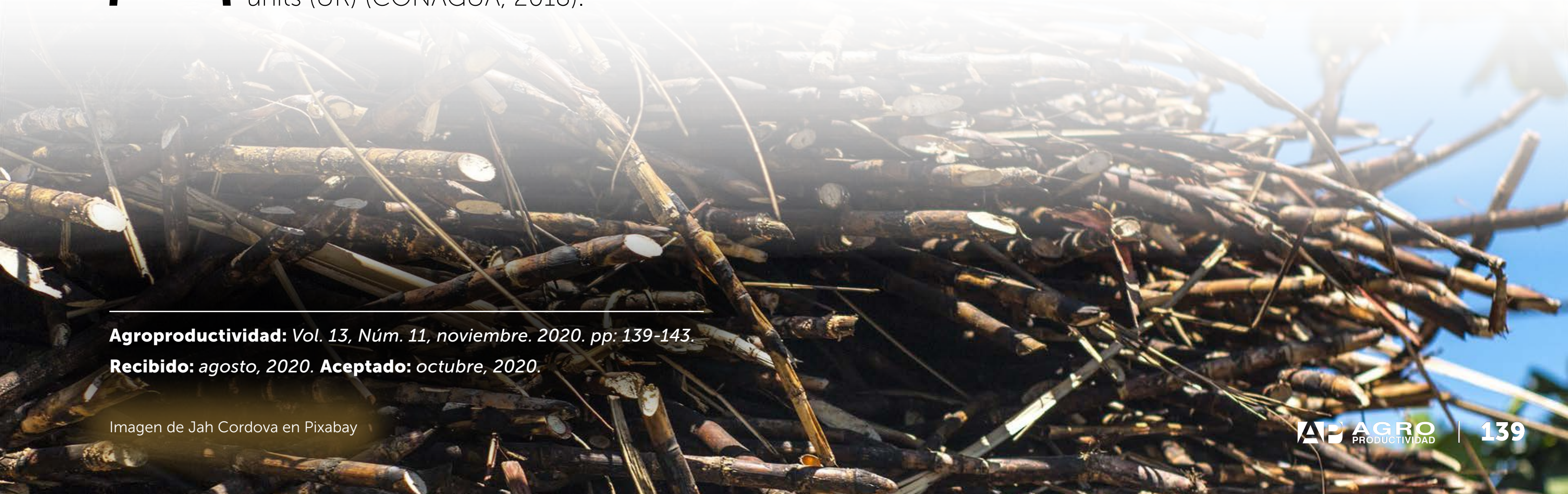
Results: Pesticides such as β-HCH, heptachlor, heptachlor epoxide, α-endosulphan, β endosulphan, endosulphan sulfate, aldrin, dieldrin and 4.4'DDE were found in deep-well water. Application of low doses of N resulted in lower losses of N due to leaching. A dose of 150 kg ha^{-1} N, applied in two, three and four fractions, resulted in losses of N between 15.40 and 18.18 kg ha^{-1}.

Conclusions: Groundwater contamination by pesticides is evident. Therefore, its reduction must be a priority for crop production, and soil and water conservation practices. This will result in a less negative impact to the environment and public health. Water and nitrogen fertilizers management, at plot level, must be improved, in order to increase water irrigation and nitrogen efficiency in agricultural areas.

Keywords: Agrochemicals, isomers, metabolites, environmental contamination.

INTRODUCTION

Mexico has a surface of 6.5 million of hectares under irrigation and 14.96 million under rainfed agriculture. From the irrigation surface, 3.3 million hectares belong to 86 irrigation districts (DR), from which 82 have already been transferred to users; the remaining 3.2 million were relocated to more than 40 000 irrigation units (UR) (CONAGUA, 2018).



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In order to obtain higher productivity per surface unit, there has been a gradual increase in the usage intensity of agroecosystem soils. This situation has risen the use of agrochemicals, mainly pesticides and nitrogen fertilizers (Castañeda, 2006; García-Gutiérrez and Rodríguez-Meza, 2012), which has had a negative impact on public health and the environment (Popp *et al.*, 2013; FAO-GTIS, 2017).

At the same time, the inefficient management of irrigation water and nitrogen fertilizer at plot level contributes to increase nitrogen leaching to the surface current and aquifers. Castro-Luna *et al*. (2006) have stated the need to develop and establish cheaper and more efficient alternative sustainable fertilization practices, as there is evidence that the growing of sugar cane (*Saccharum officinarum*) utilizes only 57% of N applied under a conventional management (Landeros-Sánchez *et al*., 2007). Even though agrochemicals provide immediate benefits, their use implicates a high environmental and public health cost, mainly because of the fact that these products are transported, in high concentrations, to riverbeds, lakes, and other water bodies. Therefore, the objective was to assess the risk of groundwater contamination due to the application of pesticides and the amount of nitrogen lost by leaching, in agroecosystems with sugar cane, in the area of influence of sugar mills, La Gloria y El Modelo, Veracruz, Mexico.

MATERIALS AND METHODS

Pesticide determination in the aquifer

Well location

Thirty groundwater-sampling points were randomly selected, 23 were from public supply deep wells for human consumption, six from agricultural irrigation and one from a shallow well (Table 1).

Field sample collection

A one-liter water sample was taken on each sampling site at a point close to the well discharge and before the chlorine application. For this, amber plastic flasks, washed with neutral soap and sterilized water, were used. Immediately after taking samples, the flasks were closed, labeled and refrigerated at approximately 4 °C until analyte extraction was done at the laboratory. When wells did not have water taps, samples were taken from the closest water tap to the well. Samples were collected according to the Official Mexican Standard NOM-014-SSA1-1993, which states the "Health procedures for water sampling for human use and consumption, in public and private water supply systems."

Table 1. Sampled well locations and types.

Potable water	Agricultural irrigation	Shallow
El Bobo	Despoblado I	Chachalacas
La Gloria I	Despoblado II	
La Gloria II	La Florida	
Real Del Oro	El Canal	
El Despoblado	El Aguaje	
Cempoala	El Zapote	
Tolome		
El Hatito		
Carretas		
La Víbora		
La Ceiba		
El Faizan		
La Charca (El Paraíso)		
Cempoala		
El Zapotito		
El Mango		
El Salmoral		
San Pancho		
El Modelo		
ÚrsuloGalván I		
Úrsulo Galván II		
Mata Verde		
Chalahuite		

Official methods for pesticide analysis

The method used for determining pesticides is described in the N0M-041-SSA1-1993, which determines a group of ten organochlorine pesticides by using the Liquid-Liquid Extraction (ELL) as an extraction technique and the Gas Chromatography with Electron Capture Detector (GC-ECD) for the later analysis of extracts. The EPA 608 and EPA 608.1 methods described by the Environmental Protection Agency (EPA) were also used (1995a). Regarding organochlorine pesticides, the methods consider the analysis of up to 45 analytes. Both methods describe the use of GC-ECD for the analysis of these compounds (EPA, 1995b).

To assess the loss of nitrogen by leaching, an experimental plot with sugar cane, CP 72-2086 variety, in the first ratoon production cycle was established. Soils in this plot are alluvial type with clayey crumb texture and water table is from 75 to 95 m in depth. The nine treatments (Table 2) used were the result of combining the following factors: dose (200, 250, and 150 kg ha^{-1} of N) and the fragmentation of doses (2, 3 and 4). The first application of fertilizer was done five days after the ratoon cane regrowth and the following ones were 30, 60 and 90 days after the first application. The nutrition of plants from all treatments was balanced by adding phosphorus (P_2O_5) and potassium (K_2O) at doses of 20 and 60 kg ha^{-1}, respectively. During the growing season, six irrigations were applied at all experimental units and the nine installed lysimeters, with a 15-cm water depth. A randomized experimental block design was used. Nitrogen leaching was measured by installing nine water balance lysimeters in which the field treatment conditions were replicated.

Table 2. Treatments assessed to study the effect of nitrogen dose and fragmentation.

N°	Code	Dose (kg N ha^{-1})	Applied fragmentation (kg N ha^{-1})
1	D1F1*	250	Two applications (125 and 125).
2	D1F2	250	Three applications (80, 90 and 80).
3	D1F3	250	Four applications (60, 70, 60 and 60).
4	D2F1	200	Two applications (100 and 100).
5	D2F2	200	Three applications (70, 70 and 60).
6	D2F3	200	Four applications (50, 50, 50 and 50).
7	D3F1	150	Two applications (75 and 75).
8	D3F2	150	Three applications (50, 50 and 50).
9	D3F3	150	Four applications (40, 40, 40 and 30).

*Control: equals to the fertilizer dosage and application recommended by the sugar cane mills.

RESULTS AND DISCUSSION

Pesticide presence and concentration

All wells registered the presence of some pesticides, their isomers or metabolites. Table 3 shows the mean concentrations of these compounds.

As for HCH, the isomer β-HCH was the only one detected. This may be related to the fact that the diverse isomers have different physicochemical properties. Although HCH isomers have low solubility in water, the beta isomer is the one with the lowest solubility (Rodríguez, 2009). α-endosulphan, β-endosulphan, and β-HCH isomers exceeded the limits provided by the standards. Endosulphan and its by-products have been found more frequently in drinking water wells (Martínez *et al.*, 2004). Even if the other pesticides found (isomers or metabolites) did not exceed the permissible limits in the standards, their presence itself indicates contamination of groundwater.

Nitrogen leaching

It was found that applying lower nitrogen doses, losses of this element by leaching are lower. When a dose of 250 kg ha^{-1} of N was applied and fragmented in two, three and four applications, there were cumulative losses of N from 30.62 to 40.86 kg ha^{-1}. When applying 200 kg ha^{-1} of N, fragmented in two, three and four applications, a cumulative loss varied between 21.82 and 30.16 kg ha^{-1}; this represented a loss of up to 15%. These results coincide with those of Bergström & Johansson (1991), who reported similar percentage of N lixiviation losses applying the same dose. Upon applying a dose of 150 kg ha^{-1} N, fragmented in two, three and four applications, it was observed that N losses oscillated between 15.40 and 18.18 kg ha^{-1}, which represents a loss of up to 12.1% (Figure 1). The lowest N loss occurred in treatment nine (D3F3). This is similar to that reported by Chávez (1999), who stated that the

Table 3. Pesticide level comparison according to official standards (mean±DE).

Pesticide	Permissible limit (mg L^{-1})	Mean±DE in samples (mg L^{-1})	Minimum detectable (mg L^{-1})
β-HCH	0.01	0.032456 ± 0.014937	0.0001
Heptachlor	0.03	0.026467 ± 0.025572	0.0001
Heptachlor epoxide	0.03	0.014995 ± 0.018524	0.0001
α-endosulphan	0.0003	0.024500 ± 0.013373	0.0001
β-endosulphan	0.0003	0.016594 ± 0.021799	0.0001
Sulphate-endosulphan	0.0003	0.001071 ± 0.001714	0.0001
Aldrin	0.03 (Combined with dieldrin)	0.005287 ± 0.008432	0.0001
Dieldrin	0.03 (Combined with aldrin)	0.002156 ± 0.014252	0.0001
4.4’DDE	1 (Total isomers DDT)	0.016444 ± 0.021863	0.0001

β-HCH=β-hexachlorocyclohexane, DDE=dichlorodiphenyldichloroethylene, DDT=dichlorodiphenyltrichloroethane.

nitrogen fertilizer fragmentation is a practice that reduces nitrogen losses due to lixiviation.

Fertilizer management to reduce aquifer and natural stream water contamination

One practical and realistic alternative to reduce water contamination depends on training technicians and producers about nitrogen fertilizers management required by the plant for its development. This means reducing excessive amounts of such fertilizer. On the other hand, raising awareness among producers on the fact that water contaminated with nitrogen affects public health, wild flora and fauna, water ecosystems and the environment is a priority. Also, it is important to train them on the use of organic fertilizer instead of mineral ones. Besides, the application of nitrogen fertilizers of slow release must be introduced in order to extend their availability at the plant´s root zone, which occurs similarly when organic compost is applied. Not burning sugar cane before and after the harvest means utilizing the nitrogen contained in leaves and top of sugar cane stems. Training is also necessary on subjects related to environmental protection and the effect that sugar cane burning has on the climate change phenomenon (Landeros-Sánchez *et al*., 2016).

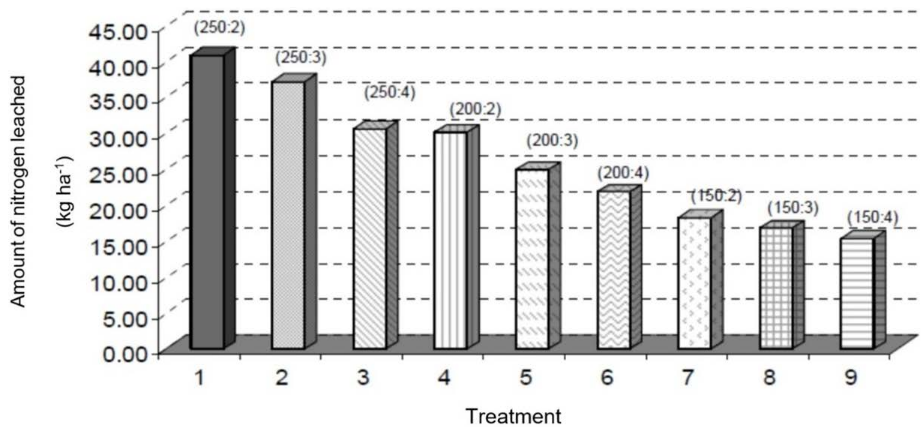

Figure 1. Total N cumulative leaching recorded in lysimeters. In parentheses: doses of N (kg ha^{-1}) and applied fragmentation (Source: Landeros-Sánchez *et al*., 2016).

CONCLUSIONS

Groundwater contamination by pesticides in agricultural areas is evident; therefore, reducing such contamination shall be a priority task for those involved in the production of sugar cane and other crops, along with the application of soil and water conservation practices. This will result in a lower negative impact to the environment and public health. The water and nitrogen management modernization at plot level may aid to increase the efficiency of water and nitrogen usage in tropical and the country's agroecosystems. The formulation of strategies for the integrated utilization of natural resources through an agroecological and agrosystemic approach that result in an environmentally friendly agricultural development is urgent.

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