Science of the Total Environment 547 (2016) 114–124

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Insecticide concentrations in stream sediments of soy production regions of South America

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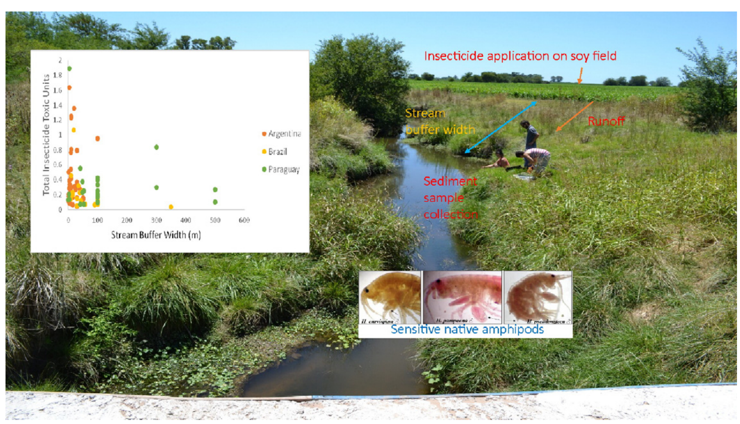
HIGHLIGHTS

- Characterized insecticides in stream sediments of Argentina, Paraguay, and Brazil
- Chlorpyrifos, cypermethrin, lambda-cyhalothrin and endosulfan frequently detected
- Most sediment samples contained multiple insecticides
- Highest toxic units occurred in sediment at sites with stream buffer widths <20 m Pyrethroids found at concentrations toxic to aquatic invertebrates

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 22 August 2015
Received in revised form 28 December 2015
Accepted 29 December 2015
Available online xxxx

Editor: D. Barcelo

Keywords:
Insecticides
Pyrethroids
Soybean production
South America

ABSTRACT

Concentrations of 17 insecticides were measured in sediments collected from 53 streams in soy production regions of South America (Argentina in 2011–2014, Paraguay and Brazil in 2013) during peak application periods. Although environmental regulations are quite different in each country, commonly used insecticides were detected at high frequencies in all regions. Maximum concentrations (and detection frequencies) for each sampling event ranged from: 1.2–7.4 ng/g dw chlorpyrifos (56–100%); 0.9–8.3 ng/g dw cypermethrin (20–100%); 0.42–16.6 ng/g dw lambda-cyhalothrin (60–100%); and, 0.49–2.1 ng/g dw endosulfan (13–100%). Other pyrethroids were detected less frequently. Banned organochlorines were most frequently detected in Brazil. In all countries, cypermethrin and/or lambda-cyhalothrin toxic units (TUs), based on *Hyalella azteca* LC50 bioassays, were occasionally > 0.5 (indicating likely acute toxicity), while TUs for other insecticides were < 0.5. All samples with total insecticide TU > 1 were collected from streams with riparian buffer width < 20 m. A multiple regression analysis that included five landscape and habitat predictor variables for the Brazilian streams examined indicated that buffer width was the most important predictor variable in explaining total insecticide TU values. While Brazil and Paraguay require forested stream buffers, there were no such regulations in the Argentine pampas, where

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http://dx.doi.org/10.1016/j.scitotenv.2015.12.140
0048-9697/

Stream buffers
Aquatic toxicity

buffer widths were smaller. Multiple insecticides were found in almost all stream sediment samples in intensive soy production regions, with pyrethroids most often occurring at acutely toxic concentrations, and the greatest potential for insecticide toxicity occurring in streams with minimum buffer width < 20 m.

1. Introduction

In recent years, soybean production has become a major export crop for multiple countries in South America, including Brazil, Argentina, Paraguay, Uruguay, and Bolivia. Between 1986 and 2010, the total area in soy production in the Americas increased from 37 to 79 million hectares (Mha), and most of this expansion occurred in Argentina, Brazil, and Paraguay (Garrett et al., 2013). Between 1995 and 2011, soy cultivation area expanded by 126% and 209% in Brazil and Argentina, respectively (Castanheira and Freire, 2013). In Paraguay, soy cultivation area increased from 1.3 Mha in 2000–2001 to 2 Mha in 2007–2008 (Garcia-Lopez and Arizpe, 2010). Land use changes caused by expansion of soy cultivation in South America have raised a number of environmental concerns, including reductions in ecosystem complexity, loss of biodiversity, deforestation, increased erosion, adverse effects of agrochemicals, and increased greenhouse gas emissions (Botta et al., 2011; Castanheira and Freire, 2013; Lathuilliere et al., 2014).

A life cycle analysis of the soy-biodiesel crops produced in Argentina for export concluded that the aquatic toxicity impacts from soy-production pesticides were substantially higher than their terrestrial toxicity impacts, with the pyrethroid insecticide cypermethrin being the main contributor (Panichelli et al., 2009). Although application rates of the herbicide glyphosate in the cultivation of genetically modified soy are much higher than those of fungicides and insecticides, the potential toxic impact of glyphosate and other herbicides in aquatic areas near soy production systems of South America are considered to be negligible compared to those of fungicides and insecticides (Nordborg et al., 2014). Insecticide application rates are approximately double those of fungicides, and the insecticides most frequently used in soy production have very high aquatic toxicity (Nordborg et al., 2014).

Insecticides are typically applied several times to each soy crop, and are used primarily to control lepidopteran pests during plant growth, and hemipteran pests during the fruiting stage. Lepidopteran pests are often controlled by applications of chlorpyrifos, an organophosphate, and hemipteran pests by endosulfan, an organochlorine. Pyrethroids, especially cypermethrin, are commonly used for both types of pests, and are often applied at the same time as other pesticides (Di Marzio et al., 2010; OPDS, 2013). In Brazil, diamides and growth inhibitors are becoming more frequently used to control lepidopteran pests, while mixtures of neonicotinoid and pyrethroid insecticides are often used to control hemipteran pests. Contrary to recommendations from pest control advisors, pesticide applications for soy production in Brazil are primarily done prophylactically, with four to six applications per year (Bueno et al., 2011). The same trend is true in Argentina, with cypermethrin often being added to herbicide applications in order to prevent lepidopteran pests from laying eggs (OPDS, 2013). Moreover, the systemic neonicotinoid insecticide imidacloprid is commonly used in Paraguay and Brazil as a seed treatment, and is also applied as a spray later in the season along with pyrethroids, such as lambda-cyhalothrin or cypermethrin.

Multiple studies have detected soy production insecticides in both sediment and water collected from streams in Argentina and Brazil; however, most studies did not include all of the most frequently used insecticides, and data were not always comparable because of the use of variable matrices, methods, and reporting limits (Jergentz et al., 2004a; Mugni et al., 2010; Di Marzio et al., 2010; Marino and Ronco, 2005; Possavatz et al., 2014; Casara et al., 2012; Miranda et al., 2008; Laabs et al., 2002). Several studies in Argentina and Brazil have found associations between stream insecticide concentrations and effects to aquatic invertebrates and/or fish (Jergentz et al., 2004a; Rico et al., 2010; Di Marzio et al., 2010; Mugni et al., 2010; Chelinho et al., 2012); however, no studies of this type have been published on data collected from Paraguay.

Stream buffer width may be one of the most important factors in mitigating transport of pesticides to streams in agricultural areas (Bunzel et al., 2014; Rasmussen et al., 2011), but buffer zone requirements differ substantially among the three countries included in the present study. Riparian buffer zones are required to be maintained in both Brazil and Paraguay, although specific requirements are in flux. For example, in Paraguay, Resolution 485/03 by the Ministry of Agriculture requires a protected zone of 100 m around all water bodies. In Brazil, a new forest code was approved in 2012 (Law No. 12.651/12) establishing that riparian buffer zone requirements should vary with the general use of the land adjacent to the water body, the aquatic environment, the stream width, and the size of the rural property. As a general rule for stream widths of 10 m or less, the legislation requires a buffer width of 15 m of native riparian forest in rural areas or 30 m if in areas newly converted for rural activities. In contrast, in Argentina there are no national requirements for stream buffers. Moreover, stream buffer zones in the Argentine Pampas are generally unregulated, and many small streams in the most intensive soy production regions of the Santa Fe and Cordoba provinces are completely channelized with crops planted right up to the banks (no buffer zones). Some Argentine provinces do prohibit pesticide application within a specific distance from surface water (Chaco: Law 7032 — DR 1567/13; Formosa: Law 1163 — DR 109/02; Río Negro: Law 2175 — DR 769/94).

The objectives of the present study were to: (1) measure and compare insecticide concentrations in sediments collected from streams in four soy production regions: two in the Pampas of Argentina, one in eastern Paraguay, and one in south Brazil; (2) evaluate the potential for acute toxicity of insecticides on sensitive aquatic invertebrate taxa, such as *Hyalella* spp.; and, (3) evaluate the relationship between buffer strip widths and insecticide concentrations in stream sediments, taking into account the influence of other environmental variables.

2. Methods

2.1. Study locations and sampling schedule

The study sites included small streams that flowed through agricultural fields in four soy production regions: two regions in the Argentina Pampa (La Plata-Magdalena and Arrecifes), and one region each in the former Atlantic forest habitat of Brazil and Paraguay (Fig. 1). In the La Plata-Magdalena region, the principal land use was cattle grazing, with scattered plots of soy production and other agriculture. In the three other regions, intensive soy production was the predominant land use. In the La Plata-Magdalena region, five streams were sampled during five monitoring events in the 2011 to 2012 season only, including three sampling sites in one watershed and the remaining sites were located in separate watersheds. In the Arrecifes region, 16 sites were sampled over three years (2012–2014), and all sampling sites were on tributaries of the Arrecifes River. In Paraguay, 17 sites were sampled over two seasons (January and December 2013), and all sampling sites were on tributaries of the Pirapó River in the state of Itapúa. In Brazil, 18 sites were sampled once in November 2013, and all sampling sites were on tributaries of the San Francisco River in the state of