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Relationships between past and present pesticide applications and pollution at a watershed outlet: The case of a horticultural catchment in Martinique, French West Indies

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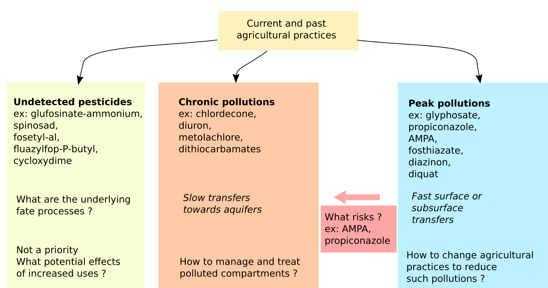
HIGHLIGHTS

- We monitored pesticides uses with catchment outlet pollution for 67 weeks.
- Outlet polluted by 16 pesticides: 4 forbidden, 2 metabolites and 10 authorized.
- Risk of chronic pollution by AMPA, fosthiazate, propiconazole and dithiocarbamates.
- Several pesticides frequently applied on the catchment remain barely or undetected.
- Requirement to change cropping systems to less dependent on identified pesticides.

GRAPHICAL ABSTRACT



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ABSTRACT

The understanding of factors affecting pesticide transfers to catchment outlet is still at a very early stage in tropical context, and especially on tropical volcanic context. We performed on-farm pesticide use surveys during 87 weeks and monitored pesticides in water weekly during 67 weeks at the outlet of a small catchment in Martinique. We identified three types of pollution. First, we showed long-term chronic pollution by chlordecone, diuron and metolachlor resulting from horticultural practices applied 5–20 years ago (quantification frequency higher than 80%). Second, we showed peak pollution. High amounts of propiconazole and fosthiazate applied at low frequencies caused river pollution peaks for weeks following a single application. Low amounts of diquat and diazinon applied at low frequencies also caused pollution peaks. The high amounts of glyphosate applied at high frequency resulted into pollution peaks by glyphosate and aminomethylphosphonic acid (AMPA) in 6 and 20% of the weeks. Any intensification of their uses will result in higher pollution levels. Third, relatively low amounts of glufosinate-ammonium, difenoconazol, spinosad and metaldehyde were applied at high frequencies. Unexpectedly, such pesticides remained barely detected (<1.5%) or undetected in water samples. We showed that AMPA, fosthiazate and propiconazole have serious leaching potential. They might result in future chronic pollution of shallow aquifers alimenting surface water. We prove that to avoid the past

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errors and decrease the risk of long-term pollution of water resources, it is urgent to reduce or stop the use of pesticides with leaching potential by changing agricultural practices.

1. Introduction

The increasing population worldwide and especially in tropical countries results in an increase of cultivated areas and in an intensification of cropping systems, especially through intense fertilizer and pesticide uses. Water pollution from agricultural activities affects tropical regions such as Central America, the Caribbean and South-East Asia (Kammerbauer and Moncada, 1998; Rawlins et al., 1998; McDonald et al., 1999; Cabidoche et al., 2009; Charlier et al., 2009; Toan et al., 2013; Crabit et al., 2016). These regions show severe levels of pesticides in water when compared to the European Water Framework (2000/60/CE) and the European Drinking Water Directive (98/83/EC) thresholds that define 0.1 μg L^{-1} as the acceptable limit of individual pesticide content in raw water for good ecological status and in drinking water. For instance, Toan et al. (2013) evidenced a mean concentration above 3 μg L^{-1} for isopropionate in the Mekong delta (Vietnam). Kammerbauer and Moncada (1998) reported chlordane concentrations as high as 250 μg L^{-1} in the Choluteca river basin in Honduras (7000 km^2). In the Caribbean, Cabidoche et al. (2009) estimated that streams will be polluted by chlordecone for at least 500 years and Charlier et al. (2009) measured concentrations of cadusafos higher than 1 μg L^{-1} in streams and higher than 10 μg L^{-1} in aquifers. This is the reason why, the assessment of mid- to long-term persistent pollution of surface water resulting from agricultural practices is highly needed to ensure sustainable water resource management.

Studies were performed at the catchment scale in temperate conditions to better understand the effects of hydrology, pesticide application rates, land uses, and molecular characteristics on the water contamination by pesticides (Blanchard and Lerch, 2000; Guo et al., 2004; Leu et al., 2004; Lewis et al., 2016). Studies focused on water pollution resulting either from pesticides used in agriculture (Palma et al., 2004; Wightwick et al., 2012; Xing et al., 2012) or in urban area (Blanchoud et al., 2004). In the tropical context, several research has been conducted on water contamination by pesticides (Lewis et al., 2016), but few were conducted in tropical context at the catchment scale (Houdart et al., 2009). Tropical studies, that explicitly consider the catchment scale, were focused on one pesticide or one cropping system and did not account for the diversity of horticultural cropping systems of such places (Castillo et al., 2000; Charlier et al., 2009; Varca, 2012; Crabit et al., 2016; Della Rossa et al., 2017). This makes it difficult for water resource managers to select priority measures on such context. Nowadays, there are mitigation options to handle pesticides pollution associated with runoff events such as grassed buffer strips or constructed wetlands (Reichenberger et al., 2007). On the contrary, there is actually no efficient sustainable mitigation option for persistent water contamination resulting from contaminated aquifers discharging in streams. For the drinking water issue, the only costly way is to treat water with several processes to bring water drinkable (Jekel et al., 2015). As a result, the best way to mitigate river pollution is to avoid the appearance of persistent contaminations. Based on a combination of water quality monitoring and farmers' survey, we present and analyze both farmers' practices and water contamination at the outlet of a catchment. We identify and classify present and future risks of river contamination by pesticides according to pesticide use intensity and transfer pathways. Finally, we propose research priorities to improve the knowledge and control of water contamination by pesticides in tropical contexts.

2. Material and methods

Our research analyses farmers' pesticide use practices and water contamination data acquired on an experimental catchment. Our complete dataset rely on different data acquired over different periods: Fig. 1 summarizes data acquired from 2011 to 2013. We started acquiring farming practices before the water sampling campaign to take into account potential pesticide transfer lags. The 67 weeks period lasting from the 11/10/2011 to the 01/02/2013 is an overlapping period of pesticide practices and water quality samples (Fig. 1). For past farming practices, Houdart provided us with the practices of the Ravine catchment farmers for years 2001–2002 (Houdart, 2005).

2.1. Study site

The experimental horticultural catchment studied is the Ravine catchment (Mottes et al., 2015). It is located on the Northeast side of the Martinique Island, French West Indies (14°49′2″ N, 61°7′14″ W). This catchment is part of the Capot catchment (57 km^2) that provides 20% of the drinking water in Martinique while being chronically contaminated by pesticides. In Martinique, the climate is tropical humid with a maritime influence. Rainfall pattern is characterized by two seasons: a dry season from January to March and a wet season from June to September. The average annual rainfall on the catchment is 3600 mm. The Ravine catchment covers 131 ha with elevation ranges varying from 312 m to 628 m. The mean slope of the catchment is 14% with the upper part slopes comprised between 15 and 30% while the lower part slopes ranges from 0 to 15%. The land use is agriculture, with more than 200 fields which belong to 20 farms (Fig. 2): 18% of agricultural lands are chayote (*Sechium edule*), 13% banana (*Musa* spp.), 6% pineapple (*Ananas comosus*), 17% are covered by other horticultural species, 6.5% by fallow (multiple species), and less than 2% are covered by roads and tracks roads. Forests, meadows and pastures cover the remaining surface (37.5%).

The soils are andosol (Colmet-Daage and Lagache, 1965; Quantin, 1972), which are young volcanic ash soils with high infiltration rates (Cattan et al., 2007; Charlier et al., 2008). Drillings showed that subsoil is constituted by a 1–12 m pumice layer and multiple layers of pyroclastic block and ash flow deposits ("nuées ardentes") with different levels of alteration. The total height of block and ash flow deposits exceeds 70 m. Pumices and block and ash flow deposits are porous materials which contain aquifers drained by the volcanic streams (Charlier et al., 2008).

An in-depth analysis of the hydrological functioning of this catchment is presented by Mottes et al. (2015). In particular, they showed that the hydrological functioning of the catchment is dominated by groundwater flows (50–60% of annual flows) and that aquifers are highly connected to surface water.