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Application date as a controlling factor of pesticide transfers to surface water during runoff events

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ABSTRACT

In agricultural watersheds, pesticide contamination in surface water mostly occurs during stormflow events. When modelling pesticide fate for risks assessment, the application timing input is one of the main uncertainty sources among all the parameters involved in the river network contaminations process. We therefore aimed to assess the sensitivity of the river network pesticide concentration patterns to application timing shifts within a plausible range of application dates, considering two pre-emergence herbicides (metolachlor and aclonifen) characterised by two different octanol/water partition coefficients (K_{ow}). The Soil and Water Assessment Tool (SWAT) was applied in the 1110 km^2 agricultural watershed of the river Save (south-western France), where wheat, maize, sorghum and sunflower are intensively grown. The pesticide application date was changed within a one-month interval and the pesticide concentration at catchment outlet was simulated from March to June 2010. Total metolachlor concentration prediction could be improved by an application timing shift to 3 days later (Daily $R^2 = 0.22$ and PBIAS $= -57\%$). By testing the behaviour of the two molecules, it was shown that sorption processes were influencing the control of application timing on the transfer to surface water: metolachlor concentration in the channel depended on both discharge and delay between application date and first stormflow event whereas the transfer of aclonifen depended on rainfall intensity for exportation with suspended sediments through surface runoff. At last, the study discusses the potential implications of the sensitivity in terms of regional agricultural management practice design.

1. Introduction

The detrimental effect of intensive agriculture on surface water and groundwater quality has been shown by various authors (Burt, 2001; Cullum, 2009; Ulrich et al., 2013; Zalidis et al., 2002; Zeiger and Fohrer, 2009). The transfer of excessive pesticide loading from cultivated land to surrounding surface water, either dissolved or sorbed onto particles, may be harmful to terrestrial and aquatic ecosystems (Martin et al., 2011; Niemi et al., 2009; Polard et al., 2011). The partition between both dissolved and particulate fractions controls the bioavailability of the chemical for living organisms' contamination. Pesticide exportations, from either point losses (e.g. through leaking tools) or diffuse sources (i.e. mostly through runoff and droplet drift) (Holvoet et al., 2005; Müller et al., 2003), may make stream water and groundwater unfit for human consumption. Drinking water quality European Maximum Permissible Level (MPL) is of 0.1 μg L^{-1} for an individual pesticide concentration and 0.5 μg L^{-1} for all pesticide concentration (EC, 1998). Recent studies showed the role of one-off and intense events, such as floods, on water quality degradation regarding pesticides, including in the south-western France area (Boithias et al., 2011, 2014a; Taghavi et al., 2010, 2011). Intensity and timing of rain and irrigation were shown to be the main inducers of pesticide transfers (Chiovarou and Siewicki, 2008; Vryzas et al., 2009). Short-term (5-day) precipitation and antecedent soil water deficit were identified as the two most important explanatory variables for maximum pesticide concentrations in drainflow (Lewan et al., 2009). Reichenberger et al. (2007) listed the shift of the pesticide application to an earlier or later date as an efficient mitigation strategy. Modelling studies corroborated observations for runoff incidence on pesticide exportation (Boithias et al., 2011; Chu and Mariño, 2004; Zhang and Zhang, 2011) and for application timing role at seasonal scale (Luo et al., 2008) and at rainfall event scale (Fohrer et al., 2014; Holvoet et al., 2005; Neitsch et al., 2002; Vazquez-Amabile et al., 2006). Dubus et al. (2003) highlighted the uncertainties inherent in pesticide fate modelling, including application timing, which depends on the farmer and varies from year to year

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(Beernaerts et al., 2002; Campbell et al., 2004). Indeed, large-scale surveys with farmers often do not give precise enough information about application sites, application dates and pesticide doses, i.e. pesticide application rates, for catchment-scale daily time-step modelling purpose (Boithias et al., 2011).

In south-western France, spring floods (i.e. spring flushes) were shown to be the main inducers of pre-emergence herbicide stream network contamination, as they are mostly applied on bare soils in the most rainy periods (Boithias, 2012; Macary et al., 2013, 2014). When applied, pesticide doses are assumed to be at the most equal to manufacturer recommendation. Thus, for contaminant fate modelling and possible catchment-scale risk assessment, uncertainty lies in temporal and spatial patterns of pesticide application. Boithias et al. (2011) concluded that the Soil and Water Assessment Tool (SWAT—Arnold et al., 1998; Gassman et al., 2007) was an appropriate catchment-scale model to simulate the fate of dissolved and sorbed phases of pesticides at a daily time-step. To our knowledge, no studies were yet published that related the impact of the application timing to the hydrophobicity of applied chemicals. As a first step to assess the uncertainty of the pesticide inputs (application site, timing, and dose) when modelling pesticide fate at catchment-scale with SWAT, the aims of this study were twofold: (1) to assess the sensitivity of the river network pesticide concentration patterns to application timing shifts within a plausible range of application dates, considering two herbicides characterised by two different octanol/water partition coefficients, and (2) to discuss the potential implications of the sensitivity in terms of agricultural management practice design.

2. Material and methods

2.1. Study area

The river Save is located in south-western France and drains an area of 1110 km^2 (Fig. 1). Altitudes range from 663 m at its source in the Pyrenees piedmont to 92 m at the confluence with the river Garonne after a 140 km course at a 0.4% average slope. The catchment is monitored at the Larra gauging station, whose elevation is 114 m (Fig. 1). The geological substratum is built from impermeable molassic deposits stemming from the erosion of the Pyrenees Mountains during the end of the Tertiary period. Calcic soils stem from molasses and represent 61% of the whole catchment area with a clay content ranging from 35% to 50%. They are located on the top of the hills and on their slopes. Non-calcic silty soils represent 30% of the soil in this area (40–60% silt). They are mainly located downstream, close to the Garonne alluvial plain. Alluvial deposits are found along the streams and represent 9% of the catchment area (Boithias et al., 2014b). Top soil organic matter content is about 2% (Veyssy et al., 1999).

The climate is temperate oceanic. The river Save hydrological regime is mainly pluvial with a maximum discharge in May and low flows lasting from July to October (1998–2010). The annual precipitation is 600–900 mm and the annual evapotranspiration is 500–600 mm (1998–2010). Mean annual discharge is about 6.1 m^3 s^{-1} (1998–2010). During low flows, river flow is sustained upstream by the Neste canal (about 1 m^3 s^{-1}) (data from Compagnie d'Aménagement des Coteaux de Gascogne—CACG).

About 90% of the catchment surface is devoted to agriculture. The upstream part of the catchment is a hilly agricultural area mainly covered with pasture and forest with cereals and maize on small plateaus. The downstream part is devoted to intensive agriculture with mainly both maize grown as monoculture and a 4-year crop rotation alternating winter wheat with sunflower and maize, sorghum or soybean. Water supply for irrigation is 210 mm for maize from July to September (Boithias et al., 2014b). A Cemagref/Irstea-ADBX 3-year survey (2007–2009) was performed anonymously with catchment farmers in order to avoid any risk for them to be identified. The survey reports 3-year average spatial and temporal information about site, timing and dose of pesticide application. The most applied pesticides are metolachlor and aclonifen, both are pre-emergence herbicides. Each year, 28 tonnes of metolachlor, a highly soluble and poorly hydrophobic chemical (solubility in water $S_w = 480$ mg L^{-1}, and hydrophobicity expressed by $\log(K_{ow}) = 2.9$), and 56 tonnes of aclonifen, a poorly soluble and highly hydrophobic chemical ($S_w = 1.4$ mg L^{-1}, $\log(K_{ow}) = 4.37$) (Tomlin, 2009), are applied throughout the catchment. On average, metolachlor is applied each year to maize and sorghum around the 5th of April, whereas aclonifen is applied each year to maize and sorghum around the 5th of April and to sunflower around the 20th of April. In 2009, sunflower fields covered 9% of the catchment (100 km^2), maize covered 10% of the catchment (112 km^2) and sorghum covered 6% (70 km^2).

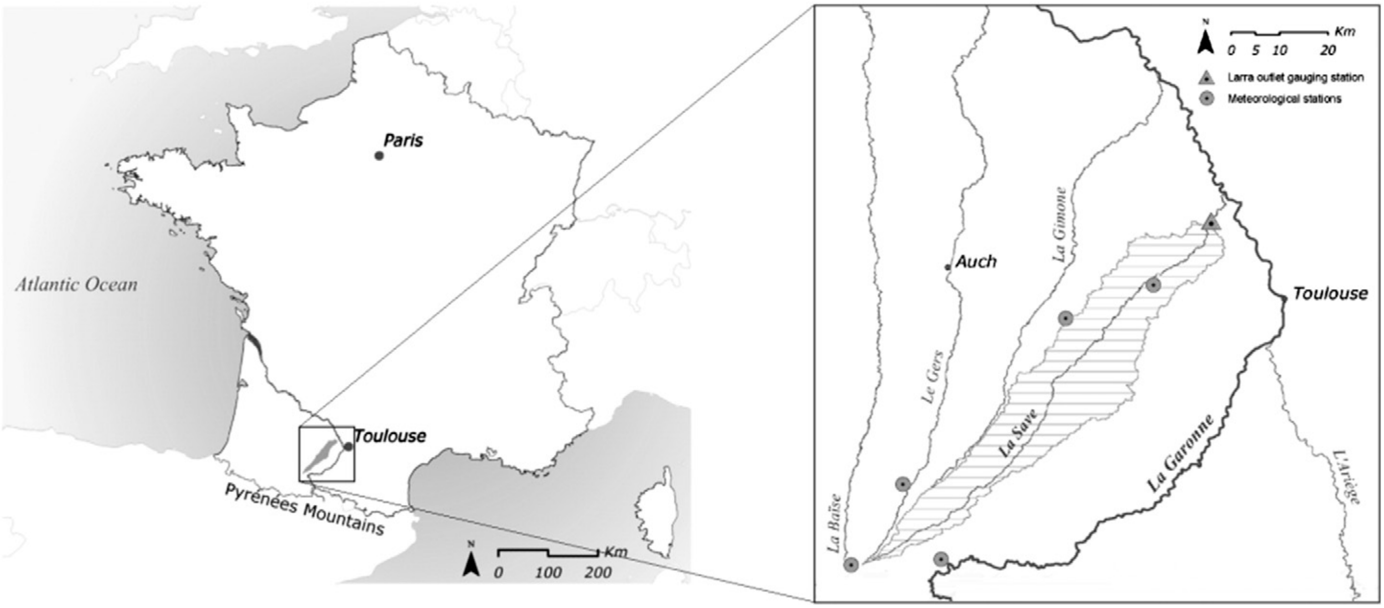

Fig. 1. Location of the Save catchment, the Larra gauging station and the 5 meteorological stations.