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Regulation of diffuse pesticide pollution: Combining point source reduction and mitigation in stormwater wetland (Rouffach, France)

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ABSTRACT

The economic crisis and increasingly stringent water quality requirements demand integrative approaches to reduce pesticide pollution in aquatic ecosystems and limit water treatment. In this study, environmental economists and wetland scientists joined forces to analyze the combination of different abatement measures to reduce pollution with more efficiency.

Pesticide reduction directly at source (i.e., reduction of pesticide use), and combining pesticide source reduction with mitigation using a stormwater wetland to treat pesticide runoff are compared. The capacity of the buffer zone to reduce additional diffuse pollution with a given total abatement cost is evaluated, by placing emphasis on how the contribution of a buffer zone evolves according to the total cost. Fungicides were used as a representative class of synthetic pesticides widely used in vine growing, and more largely in conventional agriculture.

Our results show that coupling reduction of pesticide source with the use of buffer zones collecting pesticide runoff can be economically advantageous. For a given total cost, the reduction of fungicide runoff is 90% greater when pesticide reduction at source is combined with pesticide mitigation by a stormwater wetland compared to the case of pesticide reduction at source only. However, the higher the total cost is, the more it is necessary to reduce pesticides at source and thus reduce pesticide mass transfer into aquatic systems.

The results of this study is anticipated to be a starting point for considering cost and efficiency when combining different measures targeting pesticide mitigation in surface water, and in particular when using stormwater wetlands as a management practice.

1. Introduction

The European Water Framework Directive (WFD) (European Commission, 2000) aims at achieving good quality for water bodies by 2015. The European member states committed to it may request an exemption if the cost of reaching the quality objectives is deemed too expensive (see Hanley et al. (2006) for more details). Exemptions to the general objectives due to the poor ecological and chemical status of surface water involve about 30% of water bodies in Europe (European Commission, 2012). In particular, innovative solutions are required to reduce diffuse pesticide pollution without increasing the abatement cost, to reach the general objectives of the WFD and decrease the exemption rate for the next cycle in 2021.

As long as pesticides are used, a certain portion of the pesticides used in agriculture and in urban areas can move from land to aquatic ecosystems during rainfall-runoff events (Poissant et al., 2008; Lefrancq et al., 2013). Thus complementary measures at plot and catchments scale, such as conservation tillage on cultivated surfaces and buffer zone implementation on specific areas are needed (Mitsch, 1992). Buffer zones such as stormwater wetlands can intercept and partly retain runoff-related contaminants in agricultural and urban catchment areas, thereby limiting the contamination of water bodies (Fournel et al., 2013; Grégoire et al., 2009; Hatvani et al., 2011; Ockenden et al., 2012). Stormwater wetlands, storm basins or detention ponds are engineered wetlands to temporarily store runoff and are specifically designed for flood control. In addition to their capacities to detain and dampen

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storm-flow pulses, wetlands can also retain excess nutrients and solids that may pollute downstream waters (Holland et al., 2005). Recent studies have underscored the potential of wetland systems as a management practice targeting the removal of pesticides and water quality improvement (Grégoire et al., 2009; Ockenden et al., 2012). The temporary water storage in shallow pools of stormwater wetlands supports conditions suitable for the growth of wetland plants and bioremediation. Stormwater wetlands can capitalize intrinsic physical, chemical and biological detention as well as degradative processes useful for treating various organic chemicals (Imfeld et al., 2013), including pesticides (Grégoire et al., 2009; Stehle et al., 2011). In particular, recent studies have underscored the potential of stormwater wetlands as a management practice targeting pesticide attenuation and water quality improvement (Budd et al., 2009; Imfeld et al., 2013; Maillard et al., 2011).

From the economic perspective, strategies to reduce fertilizer or pesticide inputs, including the use of buffer zones to improve water quality, have been the subject of numerous studies. Since the beginning of the 2000s, several studies have emphasized the role of wetlands to limit the problems of eutrophication in the Baltic Sea in response to the Helsinki Convention (Elofsson, 2010). A cost function (Byström, 1998; Söderqvist, 2002) was used to estimate the cost-effectiveness relation of wetland systems (Byström, 2000; Byström et al., 2000), and to design incitative policies for the use of buffer zones by farmers (Lindhal and Söderqvist, 2004). More recently, Crépin, 2005 and Heberling et al. (2010) studied incentives to create or restore wetlands through subsidies and contracts. Paulsen (2007) focused on the role of uncertainty in farmers' decisions. Ribaudo et al. (2001) evaluated various options to reduce nutrients in the Mississippi River Basin, including the reduction of fertilizer use and the use of buffer wetlands for treating nutrient loads. For a large catchment area, the latter study shows that a policy based exclusively on wetlands could be more efficient beyond a particular level of total nitrogen reduction (reduction up to 26%). In contrast, measures to reduce pollution at source are more efficient below 26%. The optimal use of buffer zones treating contaminant runoff relies on the specific characteristics of the agricultural catchment (i.e., size, topography, land use). However, to the best of our knowledge, the relative advantage of combining measures to reduce source inputs and the use of a buffer zone treating contaminant fluxes before they reach aquatic ecosystems has not yet been studied.

The objectives of this study were as follows:

(i) To evaluate the pollution reduction achieved when pesticide reduction at the source is combined with pesticide mitigation using a buffer zone for a given total cost *TC*, i.e., the cost of pesticide input reduction for the farmers (upstream cost) plus the cost of building a stormwater wetland at the catchment outlet for the public authorities (downstream cost);
(ii) To measure the relative advantage of using buffer zones by evaluating how the total cost is shared between upstream and downstream.

This study is in line with the European Water Framework Directive which obliges member states to reach good ecological status and therefore select the most efficient cost measures.

The case study is a 42.7 ha vineyard catchment area in Alsace (eastern France), including 28.9 ha of vine plants (Fig. 1). Conventional winegrowers generally apply several fungicides during a growing season to limit the occurrence of fungal diseases such as powdery mildew, downy mildew and botrytis. Since the transport of runoff-related fungicides from the vineyards represent a significant threat to drinking water resources, human health (Israeli et al., 1983) and aquatic ecosystems, the present study focuses on fungicides as a representative class of pesticides used worldwide. The buffer zone considered is a stormwater wetland located at the catchment's outlet, primarily built to temporarily collect runoff water from the vineyard catchment. The potential of the stormwater wetland to mitigate runoff-related fungicides has been demonstrated previously (Maillard et al., 2011).

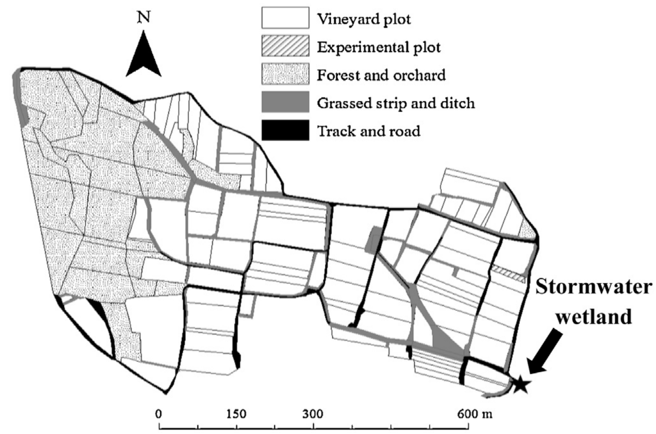

Fig. 1. Scheme of the vineyard catchment (Rouffach, Alsace, France; 47°57′9″N, 07°17′3″E).

The study is structured in two major sections. In Section 2, the theoretical optima are calculated, including (i) the levels of pesticides applications which optimize the objective function with an upstream action only, and (ii) the levels of pesticides application and size of wetland, which optimize the objective function when upstream and downstream actions are combined. Moreover the model functions based on field observations are estimated.

In Section 3, the empirical optima are calculated, before comparing the pesticide reduction obtained with the optimal combination of upstream and downstream actions for a given total cost *TC* to the pesticide reduction obtained with an abatement cost *TC* upstream only. Finally, the evolution of the distribution of the total cost between upstream and downstream is evaluated, with respect to changes in the total cost, while combining upstream and downstream actions.

2. Materials and methods

2.1. Theoretical equilibria

2.1.1. Notations and hypotheses

We considered a system consisting of a vineyard catchment area upstream of a river composed of n winegrowers using fungicides and a public authority in charge of pollution regulation called: the regulator. The regulator is introduced in order to reduce the runoff-related mass of fungicides transported from the vineyard catchment to aquatic ecosystems downstream. The following theoretical part is valid for any type of farm and any diffuse pollutant.

To achieve this goal, the regulator can use two complementary measures to reduce the export of fungicides from the catchment, namely the reduction of fungicide use directly at source, and the building of a buffer zone at the catchment outlet to mitigate fungicide runoff. Hence, the regulator considers the economic effort to be undertaken at source (abatement cost for the winegrowers) and at the catchment outlet (cost of the buffer zone), in order to combine for a given total cost, measures for reducing fungicide runoff.

f_i is the quantity of fungicides applied by a winegrower i. $\bar{f}_i$ is the maximum quantity applied without regulation.