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Research article

Assessing the impacts of Best Management Practices on nitrate pollution in an agricultural dominated lowland catchment considering environmental protection versus economic development

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A B S T R A C T

Water quality is strongly affected by nitrate inputs in agricultural catchments. Best Management Practices (BMPs) are alternative practices aiming to mitigate the impacts derived from agricultural activities and to improve water quality. Management activities are influenced by different governmental policies like the Water Framework Directive (WFD) and the Renewable Energy Sources Act (EEG). Their distinct goals can be contrasting and hamper an integrated sustainable development. Both need to be addressed in the actual conjuncture in rural areas. Ecohydrological models like the SWAT model are important tools for land cover and land use changes investigation and the assessment of BMPs implementation effects on water quality.

Thus, in this study, buffer strip, fertilization reduction and alternative crops were considered as BMPs and were implemented in the SWAT model for the Treene catchment. Their efficiency in terms of nitrate loads reduction related to implementation costs at the catchment scale was investigated. The practices correspond to the catchment conditions and are based on small and mid areal changes. Furthermore, the BMPs were evaluated from the perspective of ecologic and economic policies. The results evidenced different responses of the BMPs. The critical periods in winter were addressed by most of the BMPs. However, some practices like pasture land increase need to be implemented in greater area for better results in comparison to current activities. Furthermore, there is a greater nitrate reduction potential by combining BMPs containing fertilization reduction, buffer strips and soil coverage in winter. The discussion about efficiency showed the complexity of costs stipulation and the relation with arable land and yield losses. Furthermore, as the government policies can be divergent an integrated approach considering all the involved actors is important and seeks a sustainable development.

1. Introduction

Water quality is strongly affected by land cover and land use. In this aspect, agriculture has been greatly responsible for water quality degradation over the last decades (Aouissi et al., 2014; Glavan et al., 2013b Laurent and Ruelland, 2011; Ruidisch et al., 2013). The assessment of agricultural activities contribution to pollution is complex due to the generation of nonpoint pollution sources (León et al., 2000; Liu et al., 2013; O'Shea and Wade, 2009). In this regard, studying pollution from agriculture requires elaborated approaches and is still a challenge (Behera and Panda, 2006; Liu et al., 2013; Ullrich and Volk, 2009).

River catchments are naturally bounded spatial units, in which complex interacting processes occur, influencing rivers water and converging at the outlet. Due to the integrated value of discharge, one can use the catchment water courses as monitoring points of ecological conditions in the catchment. Lowland catchments have attributes which influence the natural processes. They are characterized by flat topography, high subsurface water table and so a greater, faster interaction of surface and ground water (Hesse et al., 2008; Kiesel et al., 2010; Schmalz et al., 2007). These properties also influence nutrient dynamics (Lam et al., 2011; Schmalz et al., 2007; Wriedt and Rode, 2006). Commonly drainages tiles are implemented in lowland arable lands to better control moisture conditions (Kiesel et al., 2010). Therefore, drainages are an extra challenge for water quality investigation in agricultural areas since

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they affect natural dynamics of water and nutrients in soil (Fang et al., 2012; Jaynes, 2013).

Nitrate is one of the most abundant pollutants in water of rural areas, coming specifically from chemical and organic fertilization (Beaudoin et al., 2005; Bonton et al., 2011; Garnier et al., 2014). It is an important nutrient for plants, vital for their growth and development (Kunrath et al., 2015; Saiz-Fernández et al., 2015). However, an excessive presence of nitrate in soil and water leads to environmental and human health problems (Anderson et al., 2014; Askegaard et al., 2011; Ferrant et al., 2013).

Faced with the problem of large nitrate contamination of water resources, many policies were developed. These initiatives are organized in different governmental levels. Inside the Europe Union (EU) the Nitrate Directive from 1991 (Council Directive 91/676/EEC, 1991) regulated the amounts and periods for nitrate application under fertilization or manure form. Later, in a broader spectrum but also considering nitrate, the Water Framework Directive (WFD, Directive, 2000/60/EC, 2000) enters into force. It attempted to achieve a good ecological and chemical status for all water bodies by the year 2015. Despite the initiatives, Germany did not achieve the expected results until 2015. In April 2016 Germany was sued by the European Commission for the lack of initiatives for nitrate pollution reduction according to the WFD. The report of the German federal state Schleswig-Holstein in 2014 showed that many water bodies did not achieve a good ecological status. Inside the state, the predominantly agricultural catchment of the river Treene is an example for the problem of nitrate pollution.

In Germany, in parallel with the WFD the Renewable Energy Sources Act (EEG, Federal Ministry for Economic Affairs and Energy, 2014) was delivered. The legislation is in accordance with the EU policy for Renewable Energy Directive (Directive, 2009/28/EC, 2009) and establishes higher utilization of renewable energies in the country and regulates their uses. It creates incentives for increased utilization of bioenergy crops. This perspective may lead to a greater pressure on the environment, resulting in negative impacts due to higher fertilization rates, for example.

Thus, on the one side there is a policy seeking a return to a good ecological status of water resources, and on the other, a policy that indirectly stimulates land use intensification. This situation creates in the last years a conflict of goals between two spheres, the economic development and environmental protection. This dichotomy between ecology and economy creates a detachment between two important concerns that need to be considered and managed.

With such a diverse presence of interests for land uses, there is a need of approaches to prevent or reduce environment pollution. The subject of water quality and nonpoint pollution sources has led to many studies and attempted solutions; one of these are the Best Management Practices – BMPs (Arabi et al., 2006a; Chaubey et al., 2010; Chen et al., 2015; Qi and Altinakar, 2011). The implementation of BMPs is an approach with actions for control and reduce the sources of sediments and nutrients degrading water quality in relation to current activities (Cerro et al., 2014; Strauch et al., 2013; Tuppad et al., 2010). The BMP approach can provide management alternatives to achieve better ecological conditions keeping the agricultural activities. Thus, they are measures able to reconciling economic development and environmental protection.

Water quality models are important tools for the investigation of environmental processes, principally in the catchment scale (Bärlund et al., 2007; Cerro et al., 2014; Panagopoulos et al., 2011; Strauch et al., 2013). Complex ecohydrological models are of great importance in studies regarding the understanding of nutrient dynamics (Haas et al., 2015), pollution mitigation and future scenarios (Cerro et al., 2014; Guse et al., 2015b; Ullrich and Volk, 2009). Thus, models addressing water quantity and quality are widely used to simulate BMPs for environment pollution reduction and investigation of better natural resources use.

In order to obtain reliable scenario simulations, an accurate representation of discharge and nutrient dynamics is required. This is based on a good understanding of these processes both in the catchments and in models (Gupta et al., 2009). To achieve this, it is required to identify the driving elements of nutrient dynamics and the controlling factors in models such as demonstrated by Haas et al. (2015) in deriving the dominant model parameters to nitrate loads. A good reproduction of the nutrient dynamics can be considered by evaluating models using different contrasting performance measures capturing different parts of magnitude and dynamics in nutrients as proposed recently in Haas et al. (2016) using a method developed by Pfannerstill et al. (2014a).

The Soil and Water Assessment Tool (SWAT, Arnold et al., 1998) has been applied for a wide range of environmental conditions across the globe to predict flow, sediment and nutrient loads from catchments of various sizes (Bieger et al., 2014; Cerro et al., 2014; Haas et al., 2016; Niraula et al., 2013). Likewise, numerous studies have used the SWAT model to evaluate the impact of BMPs on water quality at catchment scale (Arabi et al., 2006a; Cerro et al., 2014; Dechmi and Skhiri, 2013; Glavan et al., 2013a, 2011; Lam et al., 2011). The SWAT model proved to be a good ecohydrological tool for the investigation and assessment of these management practices and nitrate dynamics, as was shown by Haas et al. (2015).

In this way, by applying the SWAT model the results in potential reduction of nitrate pollution for different initiatives (BMPs) can be investigated. The assessment can be done according to different land use trajectories and interests, as the dual situation on ecology and economy created by distinct policies.

Thus, the nutrient dynamics occurring under different agricultural activities can be investigated with model simulations. For this, it is also required to represent in the model discharge and nitrate processes from the catchment under study. Following, based on this introduction, the main objectives of this study are:

- To assess to which extent regional adapted agricultural BMPs, with small and medium- change proportions, lead to a reduction on the nitrate pollution at the catchment scale;
- To evaluate the nitrate reduction and the costs of agricultural BMPs jointly in the context of two government policies having contrasting goals;

Based on these main objectives, the approach can contribute to improve the understanding of nitrate dynamics and water quality regarding agricultural catchments.

2. Materials and methods

The study is based on the following approach in Fig. 1. At first, an ecohydrological model is set-up and calibrated for a lowland catchment. Following on this, individual BMPs are implemented in the model and their impacts on nitrate are investigated using model simulations. The results of model simulations are assessed

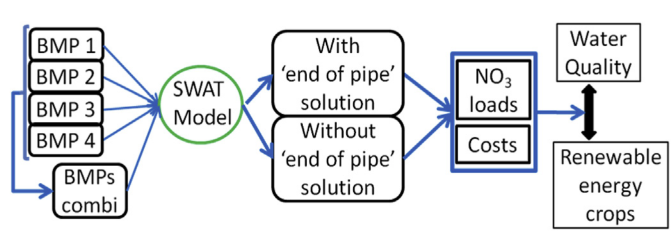

Fig. 1. Flowchart of study approach.