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Research article

Using biophysical models to manage nitrogen pollution from agricultural sources: Utopic or realistic approach for non-scientist users? Case study of a drinking water catchment area in Lorraine, France

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ABSTRACT

The objectives of this comparison of two biophysical models of nitrogen losses were to evaluate first whether results were similar and second whether both were equally practical for use by non-scientist users. Results were obtained with the crop model STICS and the environmental model AGRIFLUX based on nitrogen loss simulations across a small groundwater catchment area (<1 km^2) located in the Lorraine region in France. Both models simulate the influences of leaching and cropping systems on nitrogen losses in a relevant manner.

The authors conclude that limiting the simulations to areas where soils with a greater risk of leaching cover a significant spatial extent would likely yield acceptable results because those soils have more predictable leaching of nitrogen. In addition, the choice of an environmental model such as AGRIFLUX which requires fewer parameters and input variables seems more user-friendly for agro-environmental assessment. The authors then discuss additional challenges for non-scientists such as lack of parameter optimization, which is essential to accurately assessing nitrogen fluxes and indirectly not to limit the diversity of uses of simulated results. Despite current restrictions, with some improvement, biophysical models could become useful environmental assessment tools for non-scientists.

1. Introduction

The preservation of water resources relative to agricultural diffuse pollution remains a major environmental issue in France and in all countries practicing intensive agriculture. Despite real changes in fertilization practices since the 1990s[1] and a trend of overall improvement, environmental observations regularly confirm significant losses of nitrogen to water systems in France (SOeS, 2012) and the EU-27 (European Commission, 2013). A recent study estimated that nearly 900 drinking water catchments were definitively closed because of agricultural diffuse pollution in France between 1998 and 2008 (Secrétariat d'état chargé de la santé, 2012). Among these diffuse pollutants, nitrate remained the first cause of catchment abandonment during this period.

Considering the relatively slow improvement in water quality and the pressure from national and European environmental regulations, it is important that agricultural development actors provide agro-environmental support to farmers. This technical support is particularly reflected by the introduction of collective advisory operations across water protection areas. These local operations are based on action plans that aim to change cropping systems to minimize the risks of nitrogen transfer to water resources. To support and guide these action plans, these actors must prioritize local changes in agricultural practices to implement and evaluate

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[1] The statistical analysis of "Union des industries de la fertilisation" (UNIFA) on the use of nitrogen fertilizers in France shows a decrease of 24% from 1990 to 2012; over the same period, crop production increased by 30% according to the"Service de la statistique et de la prospective" (SSP) du Ministère de l'agriculture, de l'agro-alimentaire et de la forêt (Balny et al., 2013).

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their environmental effectiveness. Thus, they must use environmental assessment tools to link cropping systems and nitrate losses.

Among the assessment methods, biophysical models are considered by the scientific community as relevant analytical tools because of their ability to simulate the environmental impacts of agricultural practices on water resources (Rao et al., 2000; Gabrielle et al., 2002a; Borah and Bera, 2003; Kyllmar et al., 2005; Santhi et al., 2006; Beaudoin et al., 2008; Boote et al., 2010; Payraudeau and Gregoire, 2012, among others). Indeed, their abilities to integrate a large amount of soil, climate and agricultural data and to quickly simulate the impacts of cropping systems on nitrogen losses are important properties for agro-environmental assessment.

Since the 1990s, biophysical models have become highly developed because of their use in research aimed at understanding and/or managing diffuse pollution from agricultural sources at scales exceeding those of the agricultural plot (Van Ittersum et al., 2003; Grizzetti et al., 2010). Particularly, the use of models to simulate soil water and nitrogen cycles has increased due to the variety of possible applications (Gabrielle et al., 2002a; Kersebaum et al., 2007; Cannavo et al., 2008) and, consequently, are frequently used in water science or agronomy research to estimate nitrogen losses across territories with existing water resources (Dupuy et al., 1997; Refsgaard et al., 1999; Beaudoin et al., 2005; Schnebelen et al., 2004; Kyllmar et al., 2005; Almasri and Kaluarachchi, 2007; Ledoux et al., 2007 . Nendel, 2009; Rode et al., 2009; Sohier and Degré, 2010; Bonton et al., 2011; Bossa et al., 2012; among others).

Initially, these models were mainly developed, optimized and evaluated by researchers at the experimental plot and soil column spatial scales and over a timescale of one year (Addiscott and Mirza, 1998; Refsgaard et al., 1999; Beaudoin et al., 2008; Nendel, 2009). The use of these models across larger areas has faced various difficulties, including access to input data over a wide area (Refsgaard et al., 1999; Meynard et al., 2002; Kersebaum et al., 2007; Gascuel-Odoux et al., 2009) and poor outcomes because of the uncertainties associated with the input data (Addiscott and Mirza, 1998; Thorsen et al., 2001). In research, these difficulties are overcome by users with time and knowledge of mathematical methods for integrating the spatial and temporal variabilities of the input variables and optimizing the model parameters (Hansen and Jones, 2000; Thorsen et al., 2001; Durand et al., 2002). Researchers frequently have access to extensive sets of experimental data from networks of experimental plots that can be used to parameterize the models (Schnebelen et al., 2004; Beaudoin et al., 2008). Therefore, in the specific context of research, these biophysical models have progressively become appropriate tools for studying diffuse pollution from agriculture.

Researchers have gradually become interested in the use of biophysical models, especially crop models, for management purposes and have made recommendations or expressed reservations (Addiscott and Wagenet, 1985; Kauark Leite, 1990; Passioura, 1996; Boote et al., 1996). Kauark Leite (1990) stated that mathematical models cannot be considered as operational tools for managing diffuse pollution from agriculture. Particularly, he pointed out that extrinsic limitations related to users seemed more important than intrinsic limitations related to performance models (accuracy, predictive quality …). Passioura (1996) and Boote et al. (1996) insisted that the nature of the models, simple or complex, should consider the nature of the uses. These authors distinguished between research models and models for action, with the latter being used in contexts that were physically similar to the context used for calibration.

The design and development of decision support tools in agriculture, including those based on agronomic models, has become a major activity for agronomists (Meynard and Sebillotte, 1989). Consequently, the issue of model use was discussed within the agronomic research community (Boote et al., 1996; Cox, 1996; Sinclair and Seligman, 1996; McCown, 2001; Matthews et al., 2002; McCown and Parton, 2006). Thus, agronomists have observed that using crop models for action is not widespread outside of research. Among the advanced causes, agronomists have noted that models are complex tools that are difficult to configure, difficult to validate and ultimately require specialists (Boote et al., 1996; Sinclair and Seligman, 1996; Meynard et al., 2002; Matthews et al., 2002; McCown and Parton, 2006; CORPEN, 2006; Jeuffroy et al., 2008; Gascuel-Odoux et al., 2009).

Similarly, water science researchers have studied the difficulties of practically applying models since the 2000s (Borowski and Hare, 2007; Brugnach et al., 2007; Højberg et al., 2007; Janssen et al., 2009). In the context of implementing the Water Framework Directive (EC, 2000), researchers have observed the communities of decision makers and water managers. Thus, Højberg et al. (2007) specifies the following limitations of using models: the lack of skill required, the amount of time required, lacking confidence in the models, and lacking awareness of how the models can be used. Brugnach et al. (2007) and Borowski and Hare (2007) stated that the low use of information derived from models is related to the lack of confidence of the potential users. Brugnach et al. (2007) added that this mistrust is related to the presence of uncertainties that are an intrinsic component of the models. Yang and Wang (2010) stated that the complexity of the engineering models of diffuse water pollution may affect the reliability of the results but recognized that these models can be used to estimate the impacts of the action plans on water resource quality. Finally, several authors have pointed out that one major difficulty is the limitations of observational data that penalize the optimization of models for simulating surface water quality (Silgram et al., 2009; Panagopoulos et al., 2011).

The needs of local actors in term of environmental assessment methodologies are generally known (Benoit, 2011; MEDDE-MAAF, 2013; Menard et al., 2014). The local actors in charge of setting out action plans are often practitioners from agricultural extension services or water management services who face certain constraints (unpublished data). As a general rule, they do not have the time or resources that are necessary for acquiring experimental data to improve the parameterization of a biophysical model and do not have access to information for optimizing model operation. Indeed, installing instrumentation and monitoring fields requires large human and financial resources and long term agreements with the farmers.

The design and evaluation of biophysical models, particularly agronomical models, has resulted in numerous scientific publications; however, the design methodology used to build models and the considerations for end-users have received little attention in the scientific literature (Cerf et al., 2012; Prost et al., 2012). Based on a literature analysis of agronomic modeling practices, Prost et al. (2012) showed that most authors do not specify the use of their models and that very few authors indicate that their models could be used outside of research. Furthermore, most of these authors claim that the main purpose of their models is to improve understanding and not to support action.

Strong evidence suggests that models are rarely mobilized by stakeholders working outside of research, and the various difficulties mentioned above explain this fact. Based on these various findings, we asked the following question: *Is the use of biophysical models for action definitively unrealistic for non-scientist users?*

In light of the above, the objectives of the work presented herein are to (i) compare the results of two biophysical models for accurately simulating drainage and nitrogen losses at the catchment scale; (ii) assess conditions of use to improve confidence in model