Science of the Total Environment 542 (2016) 787–802

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Pesticide fate modeling in soils with the crop model STICS: Feasibility for assessment of agricultural practices

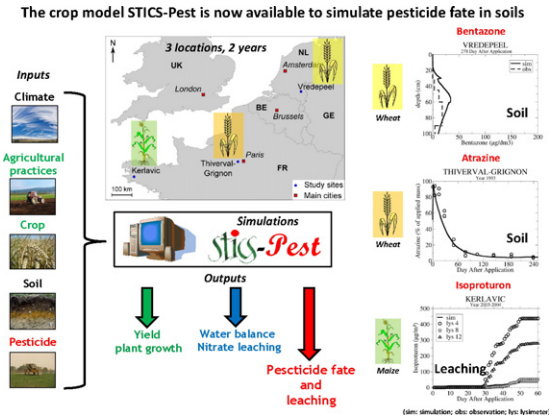
Wilfried Queyrel [a,b,*], Florence Habets [a], Hélène Blanchoud [a], Dominique Ripoche [c], Marie Launay [c]

[a] Sorbonne Universités, UPMC, Univ Paris 06, CNRS, EPHE, UMR 7619 METIS, Paris, France
[b] UMR 1347 Agroecologie, AgroSup Dijon, Dijon, France
[c] INRA US1116 Agroclim, Avignon, France

HIGHLIGHTS

- Implementation of a pesticide fate module in the crop model STICS
- STICS predictions are comparable to models widely used in the literature.
- The model is able to simulate long-term residue dynamics.
- Simulation of the impact of catch crop on pesticide transfer

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 21 May 2015
Received in revised form 11 October 2015
Accepted 12 October 2015
Available online 7 November 2015

Editor: D. Barcelo

Keywords:
Pesticide leaching
Agricultural practices
Crop model
Model evaluation
Catch crop
Herbicides
Soil

ABSTRACT

Numerous pesticide fate models are available, but few of them are able to take into account specific agricultural practices, such as catch crop, mixing crops or tillage in their predictions. In order to better integrate crop management and crop growth in the simulation of diffuse agricultural pollutions, and to manage both pesticide and nitrogen pollution, a pesticide fate module was implemented in the crop model STICS. The objectives of the study were: (i) to implement a pesticide fate module in the crop model STICS; (ii) to evaluate the model performance using experimental data from three sites with different pedoclimatic contexts, one in The Netherlands and two in northern France; (iii) to compare the simulations with several pesticide fate models; and (iv) to test the impact of specific agricultural practices on the transfer of the dissolved fraction of pesticides. The evaluations were carried out with three herbicides: bentazone, isoproturon, and atrazine. The strategy applied in this study relies on a noncalibration approach and sensitivity test to assess the operating limits of the model. To this end, the evaluation was performed with default values found in the literature and completed by sensitivity tests. The extended version of the STICS named STICS-Pest, shows similar results with other pesticide fate models widely used in the literature. Moreover, STICS-Pest was able to estimate realistic crop growth and catch crop dynamic, which thus illustrate agricultural practices leading to a reduction of nitrate and a change in pesticide leaching.
The dynamic plot-scale model, STICS-Pest is able to simulate nitrogen and pesticide fluxes, when the hydrologic context is in the validity range of the reservoir (or capacity) model. According to these initial results, the model

* Corresponding author at: UMR 1347 Agroecologie, AgroSup Dijon, Dijon, France.
E-mail address: wilfried.queyrel@agrosupdijon.fr (W. Queyrel).

http://dx.doi.org/10.1016/j.scitotenv.2015.10.066

may be a relevant tool for studying the effect of long-term agricultural practices on pesticide residue dynamics in soil and the associated diffuse pollution transfer.

1. Introduction

Since the middle of the twentieth century pesticides have been widely used to control pests (Timmons, 1970; Chauvel et al., 2012) causing a widespread release of these xenobiotics into the environment (Toccalino et al., 2014). The intensive use of pesticide leads to an increased risk of contamination of the environmental compartments and of harmful effects on water resources and biodiversity (Schwarzenbach et al., 2010; Vörösmarty et al., 2010; Malaj et al., 2014). As a consequence, there is a strong social demand for regulations to protect water resources (EU, 2000) and control the use of pesticides, as reflected in national and European legislations (e.g., French ECOPHYTO plan, EU directive 2009/128).

Moreover, in their agricultural management practices, farmers and agronomists face the major issue of having to reconcile high crop yields with a decreased use of pesticides (Malézieux, 2012; Melander et al., 2013; Lechenet et al., 2014). These observations highlight the need to evaluate the impact of farming practices on agricultural diffuse pollution such as pesticides in order to determine the contamination risk of water resources.

Pesticide fate in the environment is characterized by a number of complex processes occurring in different environmental compartments such as air (Bedos et al., 2002), plant (Wang and Liu, 2007; Fantke et al., 2011), soil (Arias-Estevez et al., 2008; Barriuso et al., 2008), and surface and groundwater (Holvoet et al., 2007; Garmouma et al., 2001; Baran et al., 2008).

Modeling is a suitable approach for integrating the effect of the major processes involved in the environmental fate of pesticides (sorption, degradation, leaching, volatilization, plant uptake, erosion, run-off and downstream processes in water bodies). Consequently, pesticide fate models are widely used for pesticide registration (European Council, 2009).

Pesticide fate models as mathematical tools provide a simplified virtual representation of solute or particular transfer and pesticide dissipation in the field (Leistra et al., 2001; Jarvis, 1995; Šimůnek et al., 2003). Compared to field and laboratory experiments, models are more extensive and cheaper tools for predicting the fate of pesticide (Mamy et al., 2008; Ghafoor et al., 2011).

Among several models available in the literature, the formalisms describing pesticide fate processes in soils, i.e., sorption and transformation, are relatively similar in every model. The main differences between models are mostly related to water flow (Vanclooster et al., 2000b; Siimes and Kamari, 2003; Šimůnek et al., 2003; Köhne et al., 2009a; Mottes et al., 2014). Indeed, the models can be divided into two major categories: (i) simplified water transfer or capacity models such as PELMO (Klein, 1995), PRZM (Carsel et al., 2003), GLEAMS (Leonard et al., 1987) and PLM (Nicholls et al., 2000); and (ii) more physically oriented models based on the Richards equation such as PEARL (Leistra et al., 2001), MACRO (Larsbo and Jarvis, 2003)), LEACHP, (Dust et al., 2000) Wave, (Vanclooster et al., 2000b), AGRIFLUX (Larocque et al., 1998), and RZWQM (Malone et al., 2004). Most physically based models include a dual-porosity or dual-permeability module in order to account for preferential flow (Köhne et al., 2009a, 2009b).

Although pesticide transfer models are acceptable tools for environmental risk assessment, they do not accurately take into account specific agricultural and crop management practices such as mixed cropping or mulching (Mottes et al., 2014). By contrast, crop models as tools designed to simulate cropping systems are more adapted to represent the functioning of plant growth and the great diversity in agricultural techniques (Confalonieri et al., 2010). In order to evaluate cropping systems and to simulate agricultural diffuse pollution, pesticide fate modules were integrated in crop models such as DAISY, (Hansen et al., 2012) EPIC (Williams, 1990; Sabbagh et al., 1991), CERES (Gerakis and Ritchie, 1998). In the same way, more integrative models such as SWAT (Arnold et al., 1998, 2012) or PEARL (Leistra et al., 2001) were designed by coupling pesticide fate models with crop models. However, few of them are able to fully integrate innovative agricultural practices (Mottes et al., 2014) such as mixed crops (Brisson et al., 2004; Launay et al., 2009). In this study, we used the ability of the crop model STICS (Brisson et al., 2003) to manage innovative agricultural practices in order to enhance the capacity of the model to simulate agricultural diffuse pollution.

The model STICS (Brisson et al., 2003) is a generic crop model able to simulate annual and perennial crops such as cereals (Beaudoin et al., 2008; Constantin et al., 2011; Guillaume et al., 2011), vineyards, grassland (Di Bella et al., 2005; Garcia de Cortazar-Atauri et al., 2010) and vegetables. The model has been widely evaluated in the context of national (Coucheney et al., 2015) and international projects such as the Agricultural Model Intercomparison and Improvement Project (AGMIP) (Palosuo et al., 2011; Rötter et al., 2012; Moreau et al., 2012). The STICS model was formerly applied at different scales from the field to large basins in order to simulate nitrate diffuse pollution (Beaudoin et al., 2005; Ledoux et al., 2007; Jégo et al., 2012). Moreover, foliar disease dynamics were recently added to the model in order to better define pesticide applications (Caubel et al., 2012), resulting in a new version called STICS-Pest. This extended version of STICS was chosen here to integrate pesticide fate formalism, which is the first step prior to an application of the STICS-Pest model to estimate diffuse pollution (nitrogen and pesticide) at the basin scale. The model evaluation is based on a multisite dataset approach, with several monitoring methods in order to test the model in different contexts to correctly determine its validity range. Because the future objective is to apply the STICS-Pest model at the basin scale, the simulations were carried out without calibration to limit the site-specific characteristics and to illustrate the ability of the model to predict pesticide behavior with more generic pesticide properties available in a database (PPDB, 2013). The evaluation was completed with sensitivity tests to assess the variability in model outputs according to parameters and to formulate recommendations for model input parameters.

The objectives of this study were: (i) to implement the pesticide fate module in the crop model STICS; (ii) to evaluate the ability of STICS-Pest to simulate the fate of several herbicides in different pedoclimatic contexts so as to ascertain the application limits of the model by comparison with in situ data and outputs of other pesticide fate models; and (iii) to illustrate, with an example of innovative agricultural practice, the feasibility of using crop models to evaluate the impact of crop management in terms of diffuse pollution and long-term-dynamics of pesticide residue in the soil.

After a brief description of the model basis, the implementation of the pesticide scheme is described. The results are then discussed on the basis of observation data and compared with the performance of other pesticide models previously run for the three study sites. STICS-Pest is then evaluated with a sensitivity test. Finally, a model application with innovative agricultural practices is presented.

2. Materials and methods

2.1. The STICS agronomic model

STICS is a crop model with a daily time step that uses climate, soil, and agricultural practices data to simulate yield and environmental