Impacts of alternative agricultural practices on the reduction of nitric pollution in the Beauce limestone aquifer (France)

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Abstract

The general purpose of this study was to assess the impact of alternative agricultural practices on the decrease of nitric pollution in the Beauce Limestone aquifer (France). This assessment was performed on three steps. First, simulations of water and nitrate fluxes were performed throughout of soil profile. Second, analyzes and simulations of nitrate concentration evolutions in the Beauce Limestone aquifer straight on the study area were carried out. Lastly, impacts of alternative agricultural practices on nitrate concentrations in the aquifer were examined. Both water and nitrate fluxes simulations throughout of soil profile were carried out at the lysimeters scale and over the whole experimental study area. The simulations were performed using STICS agronomic model. The alternative practices, applied on three years, allowed reducing the nitrate concentration (NO_3^-) throughout of soil profile. The decrease range between 18 and 33 mg L^{-1}. The comparison of the nitrate concentration at the bottom of soil profile with those in the aquifer showed that the alternative agricultural practices impacts on nitrate concentrations in the aquifer is not perceptible. This is mainly due to important lateral fluxes of water and to the small size of the study area. Nevertheless, the alternative agricultural practices should be extended to several years and to other areas, regarding of the reduction of the nitrate concentrations obtained at the bottom of soil profile.

Keywords: nitric pollution, alternative agricultural practices, agronomic model, Beauce limestone aquifer, and groundwater model

Introduction

Agricultural fields have been managed traditionally as uniform units. Such farming approach has often lead to pollution of soil and ground or surface water (Chaney, 1990; Gaury and Benoît, 1992; Davies *et al.*, 1996; Goderya *et al.*, 1996; Nicoullaud *et al.*, 2002). The potential benefits, both economic and environmental, of variable rate input applications in agriculture have been widely reported during the last years (Cook and Bramley, 1998; Schmerler and Basten, 1999).

This paper extends the work of Schnebelen (2000). It aims to assess the impact of alternative agricultural practices on the decrease of nitric pollution in the Beauce Limestone aquifer (France). The assessment is based on measurements over an experimental area of 740 ha (Petite Beauce, France) and on simulations. This assessment was performed on three steps:

(1) simulation of water and nitrate fluxes throughout of soil profile,

(2) analyze and simulation of nitrate concentrations evolution in the Beauce Limestone aquifer straight on the study area,

(3) evaluation of alternative agricultural practices impact on nitrate concentrations in the aquifer.

The simulation of the water and nitrate fluxes throughout of soil profile was carried out at the lysimeters scale and over the whole experimental study area. The alternative practices were applied on three years and compared to usual practices. Validation procedures were performed for each step above to measure the performances of STICS model as well as the methodology carried out.

Materials and Methods

Site and climate

The study area (740 ha) is located in Petite Beauce about 30 km northwest of Orlé ans (France). The soils are developed in silty clay loam materials overlying Miocene lacustrine limestone that was cryoturbated in its upper part during the quaternary (Macaire, 1972, 1981). The study area has a temperate continental climate with an annual average temperature of 10.5°C. Mean annual rainfall (R) and potential evapotranspiration (PE) are 630 and 767 mm, respectively. About 86% of the total land surface is cultivated. The main crops have been winter wheat and maize for the last 30 yr. From 30 to 90 and 120 to 180 mm of water irrigation are usually applied to soft winter wheat and maize respectively.

STICS model

This section is limited to a brief review of STICS model used in this study. The reader should refer to paper by Brisson *et al.* (1998) for more information about theory and parameterization underlying this model.

The main processes simulated using STICS model are crops development and soil water and nitrate fluxes. Figure 1 summarized the main input data required by STICS model as well as the output data types generated by the model.

Approach developed

Simulation at lysimeter scale

To assess water drainage and nitrate leaching throughout of soil profile, STICS model was applied first at four lysimeter sites. Several simulations have been performed according to different rotation of crops, pedological and climatic scenario. Simulations allowed also comparing the efficiency of alternative agricultural practices on the reduction of nitrate contents in gravimetric water.

Two simulation types have been performed. Simulations where the STICS model have been initialized at the end of each cultural cycle and simulations in continuous. In the first type carried out successively between December 1994 and August 1999, water and N mineral contents measured in the soil profile layers after harvest were used to initialize the STICS model for the following cycle.

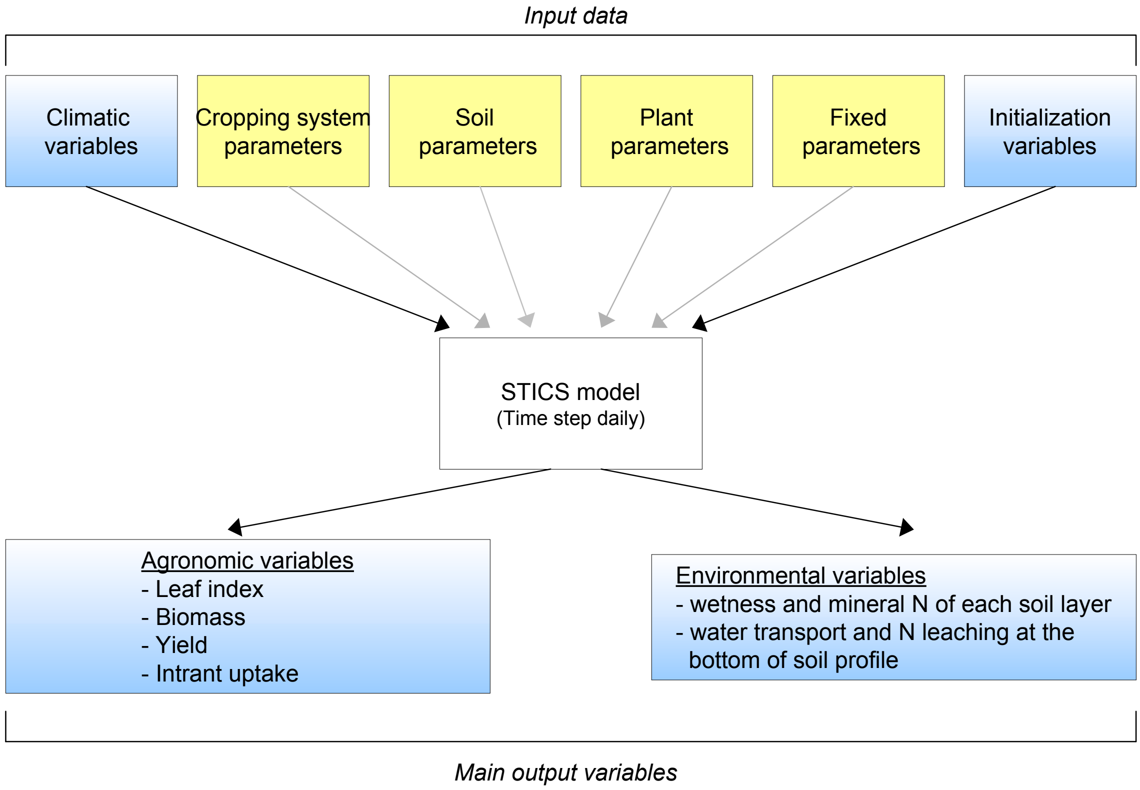

Figure 1 Global pattern of Input / output data required and generated by STICS model.

Simulation over the whole study area

Calibration and validation of the STICS model at lysimeter scale is necessary but upscale the model to the whole study area still our final aim. Indeed, farming approaches are managed over larger areas than lysimeters. Thus, an approach of STICS model spatial generalization was developed. The approach consists first on deducing uniform surfaces (simulation units) accounting for soil type, crop type, cropping system and some information about water and N mineral contents in soil profile. Using pedotransfer functions and expert knowledge's, water and N mineral contents in soil profile are estimated in a second step for each simulation unit area. These estimates were used in a third step as STICS model initialization values to simulate water and N mineral content in soil profile after harvest. All spatial analysis were performed using GIS Arc/Info (ESRI, 1999).

Results and Discussion

Local simulation results

Table 1 summarized values of simulations according to different crops as well as true lysimeter measurements or values measured in the lysimeters neighborhood. Several hypotheses could be advanced to explain the discrepancy between measured and simulated N mineral quantity in soil after harvest. For example a strong mineralization of humus related to convenient wetness and temperature conditions in upper soil layers could explained the discrepancy between measured and simulated N mineral quantity for maize in 1995 (Table 1). For green peas in 1997, the residual N mineral after harvest was 44 kg $N\text{-}NO_3^-$ ha^{-1} underestimated. In STICS model green peas are simulated using soft wheat module. Thus, a low N-mineral residual in soil after harvest, as soft wheat nitrate uptake is more important than green pea crop. Nevertheless the results of validation procedure (Table 2) allowed envisaging an upscale of the STICS model to the whole study area.

Table 1 Measured and simulated values for different crops at lysimeter scale.

	Cumulative Drainage (mm)			*Cumulative leaching (kg N ha^{-1})*			*N mineral concentration (mg L^{-1})*			*Water quantity in soil after harvest (mm)*		*N mineral quantity in soil after harvest (kg $N\text{-}NO_3^-$ ha^{-1})*	
	Measured		*Simulated*	*Measured*		*Simulated*	*Measured*		*Simulated*	*Measured*	*Simulated*	*Measured*	*Simulatec*
Lysimeter	*21*	*22*		*21*	*22*		*21*	*22*		*Plot*		*Plot*	
Maize 95	204	219	202	23	21	23	50	43	50	416	389	**42**	**60**
Winter wheat 95/96	138	138	145	14	11	10	46	35	31	261	288	39	25
Mustard 96	0	0	0	0	0	0	-	-	-	no data	346	42	31
Green Peas 97	84	50	49	8	4	3	44	33	29	393	420	**125**	**81**
Mustard 97	0	0	0	0	0	0	-	-	-	352	346	39	66
Winter wheat 97/98	122	117	120	18	8	8	66	31	29	294	292	61	33
Winter colza 98/99	127	104	89	15	20	13	52	84	66	no data	328	no data	51

Table 2 Validation procedure results.

	Cumulative drainage (mm)			*Cumulative N leaching (kg N ha^{-1})*			*Concentration NO_3^- (mg L^{-1})*		
Crop	*N*	*ME*	*RMSE*	*N*	*ME*	*RMSE*	*N*	*ME*	*RMSE*
Winter wheat	11	-10	20	9	-6	9	9	-18	25
Winter Colza	6	10	30	6	0	3	6	5	13
Maize	7	-10	48	7	-3	14	7	-13	49
Green pea	2	-18	24	2	-3	4	2	-9	11
Mustard	-	-	-	-	-	-	-	-	-
Other crops	26	-6	32	24	-3	10	24	-10	31

	Soil profile water quantity (mm)			Soil profile N mineral quantity (kg N ha^{-1})		
Crop	*N*	*ME*	*RMSE*	*N*	*ME*	*RMSE*
Winter wheat	6	4	18	5	-16	20
Winter Colza	2	37	37	2	-19	20
Maize	4	-44	47	4	-30	61
Green pea	2	30	30	2	-51	52
Mustard	2	2	9	3	1	18
Other crops	16	-1	31	15	-15	26

N: sample size; ME: mean error; RMSE: root mean square error

Spatial simulation

Figure 2 is an example of spatial simulation results using STICS model and GIS (Arc/info). This figure summarized water drainage and N mineral leaching quantities as well as N mineral concentration at the bottom of soil profile and for each simulation unit. These results correspond to the simulation between October 1992 – September 1993 over the whole study area. An analysis (no reported) of such results showed that N mineral concentration at the bottom of soil profile depends mainly on the previous crop and the soil type.

Alternative versus usual agricultural practices impact on nitrate concentrations

Alternative agricultural practices has consists on various rate nitrate fertilizer inputs that take account of the local requirements of the crop. These practices consist also to avoid bare soils for long time by introducing catch crops between two successive principal crops over the same area.

Figure 3 showed the nitrate concentration results for both agricultural practices. These maps allowed concluding that alternative agricultural practices lead to a decrease of nitrate concentration for most simulation units comparing to usual agricultural practices. Indeed, mean nitrate concentration values over the whole study area for period 1993–1994 were 98 and 69 mg L^{-1} respectively for usual and alternative agricultural practices.

Impact of agricultural practices on nitrate concentration in the upper part of limestone aquifer

Using a groundwater model, nitrate concentration in the upper part of the limestone aquifer was simulated. The model allows simulating nitrate concentration accounting for nitrate concentration, both in gravimetric water at the bottom of soil and in the upper part of the aquifer. The model was applied for period 1991-1994 and for the two agricultural practice scenario (alternative and usual). The results showed that nitrate concentration in the upper part of the aquifer is not significantly different whatever the agricultural practice scenario. This is mainly due to important lateral fluxes of water and to the small size of the study area. Lateral fluxes are more important than fluxes from the bottom of soil.

Conclusion

The alternative practices, applied on only three years, allowed reducing the nitrate concentration (NO_3^-) throughout of soil profile. The decrease range between 18 and 33 mg L^{-1}. The comparison of the nitrate concentration at the bottom of soil profile with those in the upper part of the Limestone aquifer showed that the alternative agricultural practices impacts on nitrate concentrations in the aquifer is not perceptible at the study scale. This is mainly due to important lateral fluxes of water comparing to water fluxes originate from the bottom of soil. Nevertheless, the alternative agricultural practices should be extended to several years and to other areas, regarding of the reduction of the nitrate concentrations obtained at the bottom of soil profile.

Further analysis is needed to improve water and solute transport simulations for some crops (e.g. green peas) by STICS model. Moreover, a hydrologic model accounting for aquifer heterogeneity and borings interference is needful to well assess the nitrate concentration throughout aquifer layers.

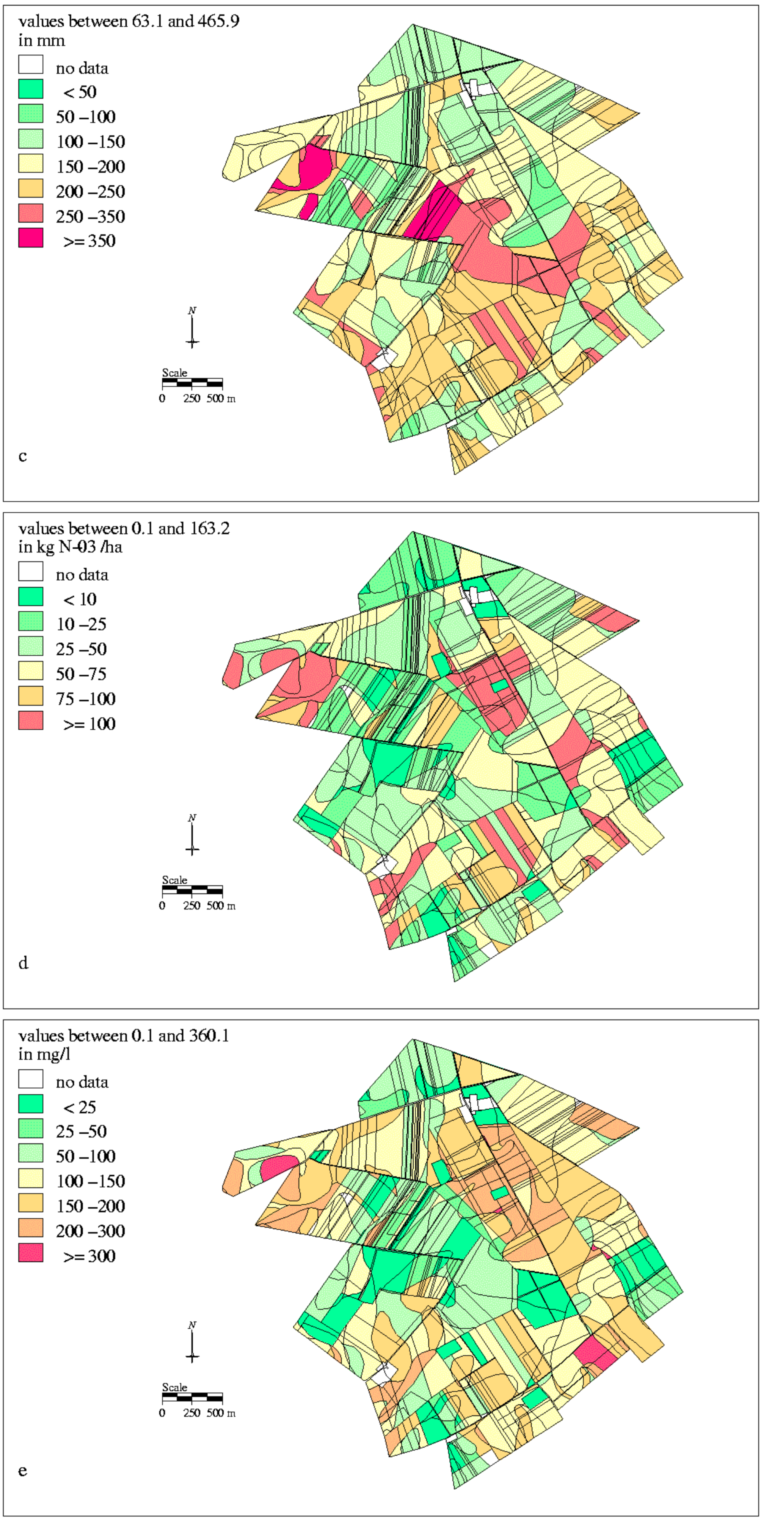

Figure 2 Spatial simulation using STICS model (c) water drainage, (d) N mineral leaching, (e) N mineral concentration (October 1992 – September, 1993).

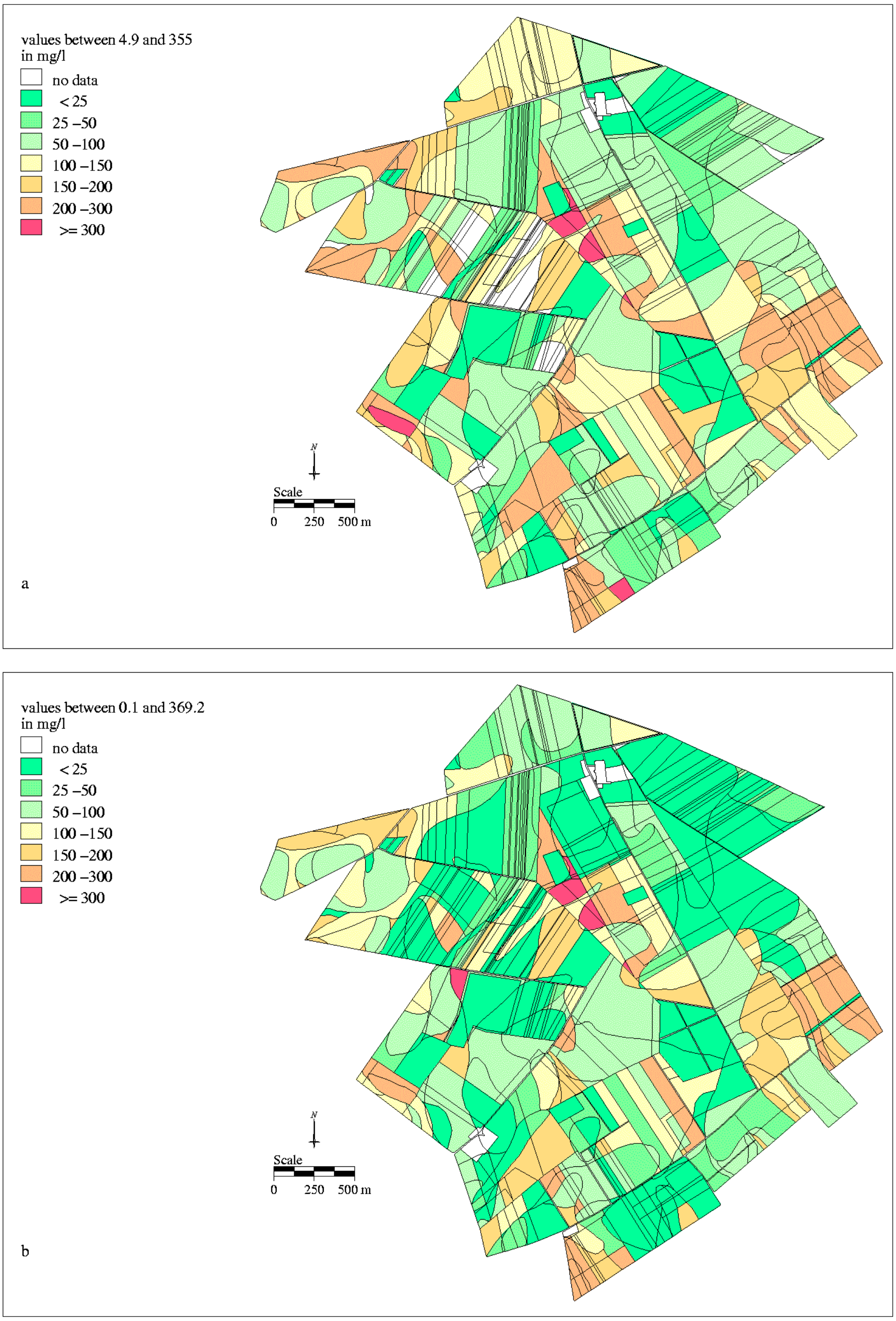

Figure 3 Spatial simulation of N mineral concentration (a) usual agriculture practices, (b) alternative agricultural practices (October 1993 – September, 1994).

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