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Nitrate leaching in intensive agriculture in Northern France: Effect of farming practices, soils and crop rotations

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Abstract

The efficacy of 'Good Agricultural Practices' (GAP) for reducing nitrate pollution is tested on the scale of a small catchment area (187 ha) which is almost entirely under arable agriculture. GAP have been introduced on all fields since 1990. They consist in applying carefully planned N fertiliser recommendations, establishing catch crops (CC) before spring crops and recycling all crop residues. Soil water and mineral nitrogen (SMN) were measured three times each year on 36 sites representative of crops (wheat, sugarbeet, pea, barley, oilseed rape) and soil materials (loam, loamy clay and rocks, sand loam and limestone, sand) during 8 years (1991–1999). These measurements (about 3600 soil samples) were used in LIXIM model to calculate water and nitrogen fluxes below the rooting zone. The model could reproduce satisfactorily the water and SMN contents measured at the end of winter. It simulated reasonably well the nitrate concentration measured in the subsoil (3–10 m deep) of nine fields. The mean calculated amounts of drained water and leached nitrogen below the rooting depth were 231 mm $year^{-1}$ and 27 kg N ha^{-1} $year^{-1}$, corresponding to a nitrate concentration of 49 mg L^{-1}. Leached N varied by a five-, four- and three-fold factor according to the year, crop and soil type, respectively. Nitrate concentration was primarily affected by soil type: it varied from 31 mg L^{-1} in deep loamy soils to 92 mg L^{-1} in shallow sandy soils, and was linked to the soil water holding capacity. The sugarbeet–wheat rotation gave the lowest concentration (38 mg L^{-1}) and the pea–wheat rotation the highest one (66 mg L^{-1}). In spite of their moderate growth (mean biomass = 0.8 Mg ha^{-1}), the catch crops allowed to reduce the mean concentration by 50% at the annual scale and 23% at the rotation scale. Straw incorporation was also beneficial since net mineralisation between harvest and late autumn was reduced by 24 kg N ha^{-1} when straw residues were incorporated. Reducing fertilisation below the recommended rate did not significantly reduce further nitrate leaching. Although GAP were not all optimal and therefore less efficient than in well controlled experiments, they appear essential in intensive agriculture in order to comply with the EU standard for nitrate concentration.

Keywords: Agricultural practices; Nitrate leaching; Nitrogen fertilisation; Catch crops; Catchment

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1. Introduction

Nitrate pollution of groundwater from agriculture is a common fact (Addiscott et al., 1991; Guillemin and Roux, 1992; Datta et al., 1997). The European Union has implemented a procedure aiming at recovering a good quality of water resources in 2015 (Directive 2000/60/EC; Letcher and Giupponi, 2005). The challenge is particularly hard in intense farming systems with high N excess as well as in arable cropping systems with low drainage (Machet et al., 1997; Hall et al., 2001; Di and Cameron, 2002). Moreover, in regions with large sedimentary basins and deep groundwater, such as Paris basin, the impact of present practices may be hidden due to the long response time of the aquifers. The complexity of the problem rules out apparently simple solutions such as taxation of nitrogen fertilisers (Haruvy et al., 1997). It raises the question as to whether the standard is achievable (Addiscott et al., 1991). Alternative agricultural practices have been encouraged since the 1990s under the generic term 'Good Agricultural Practices' (GAP) or 'Best Management Practices' (Hubbard and Sheridan, 1994). This trade off is not entirely concerned with sustainability but it does appear to be economically achievable (Lacroix, 1995).

In arable systems, the main rules to prevent nitrate pollution rest on better management of the nitrogen cycle during crop succession. Dehérain (cited by Morlon et al., 1998) explained the principles as early as 1902: "since the major losses of nitrogen from ploughed soils take place in autumn, one must reduce as far as possible the area of bare soil in winter by using green manures, incorporate crop residues and avoid applying nitrogen fertiliser greatly in excess of crop requirements". These principles seem essential to prevent nitrate pollution of groundwater (Laurent and Mary, 1992; Hansen et al., 2001). However, applying GAP in actual farming conditions may be more or less successful because there are uncertainties on N predictions and farmers may not follow the recommendations at the optimum due to lack of information, technology or time (Meynard et al., 2002).

Few studies have quantified precisely the efficiency of GAP applied in farming conditions with regard to the EU guideline for nitrate in drinkable water. The relevant spatial and temporal limits for this quantification are the loading aquifer perimeter and the renewal time of the aquifer. At this scale, the results are hampered by uncertainties but can be smoothed using a relevant aggregation (Kersebaum and Beblik, 2001). The objectives of this work are to quantify nitrogen leaching below the rooting zone in different soil types, crop rotations and farming practices, and to evaluate GAP efficacy for reducing nitrate leaching in actual farm conditions in Northern France. The method chosen has consisted in using measurements and simple modelling rather than using a pure simulation model which requires many parameters and local testing. The data presented here concern the first 8 years of the study. A large number of measurements were realized on crops (700) and soils (3600) in order to estimate the water and nitrogen fluxes below the rooting zone. The comparison with the fluxes measured at the catchment outlet will be presented in a next paper.

2. Materials and methods

2.1. Experimental site

2.1.1. General characteristics

The site investigated is located in Bruyères, near Laon, in Northern France. It is a tertiary sedimentary plateau, typical of the Paris Basin. The main characteristics of this site are: (i) a small (187 ha) and well defined loading perimeter for the aquifer (Mary et al., 1997), (ii) an aquifer showing increasing nitrate pollution with a faster response time than the surrounding chalk aquifers and (iii) an important variability of soils. Due to the concern of nitrate pollution, GAP have been adopted by farmers since 1990 and applied to all cultivated fields present in the catchment area: 21 fields composing 145 ha. The period of study described here begins in autumn 1991 and ends in autumn 1999. A set of 36 sampling sites was defined to assess the variability of crop yields, water and N losses. The sites represent the main soil types within each field (Fig. 1).

2.1.2. Soil properties

A 1:7500 soil map was established (Fig. 1). Four main soil types were defined according to their parent material (Table 1): deep loam (DL) or neoluvisols