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Nitrogen field balances and suction cup-measured N leaching in Danish catchments

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ABSTRACT

In Denmark suction cup-measured nitrate concentrations in soil water and N leaching has been used as a means for monitoring the impact of changes in consumption of commercial fertilizer and improved utilisation of nitrogen in manure by agriculture. The measurements are a part of the Danish Agricultural Monitoring Programme (NOVANA) and are carried out in five small agricultural dominated catchments covering differences in climate, soil types and farming practices within the country. Statistical analyses allowing for annual variations in climate showed that nitrate concentrations in root zone water from loamy and sandy catchments decreased by, respectively, 23 and 48% during 1991–2003, after which no further decrease occurred until 2010/11. The aim of this study is to describe how the year to year variations in percolation and field balance characterise N leaching for 30 soil water stations in the period 1991–2010. A general linear model for annual observations of N leaching, N leaching = 3479 + 0.140 × percolation + 0.080 × surface N balance − 1.737 year, explained 29% of the variation. When N leaching was calculated as a mean for each soil water station for the period 1991–2010, the field N balance explained about 44% of the variation in leaching between the 16 soil water stations located in loamy catchments. A lower proportion, 36%, was recorded for the 14 soil water stations located in sandy catchments, but the signature increased to 60% if an outlier field, having a large excess input of manure, was omitted. From these results for Danish catchments, we conclude that field N balances are able to predict the risks of leaching provided that measurements are integrated over 30 soil water stations or a relatively long monitoring period. However the data showed that the leaching responses to the field balance are different for loamy and sandy soils and depend on farm type.

1. Introduction

Even though nitrate easily dissolves and diffuses in water, nitrate concentrations measured in agricultural soil water vary tremendously (Djurhuus and Jacobsen, 1995; Lord and Shepherd, 1993). The variability exists both spatially and temporally and is caused by homogeneities in the hydraulic properties of the soil (e.g., root channels, variation in pore-size distribution), inhomogeneous distribution of the mineralogical inputs (precipitation, fertilizer) and spatial distribution of crop residues, manure and soil organic matter that all produce nitrate through mineralisation and nitrification processes (Grossmann and Udluft, 1991). As suction cups are able to sample the most mobile water, this method has been justified for accurate evaluation of nitrate leaching in homogeneous soils containing a moderate amount of clay (Poss et al., 1995; Webster et al., 1993).

In Denmark, nutrient pollution of groundwater and eutrophication of surface water and monitoring have been on the political agenda since 1987 when the first Action Plan for the Aquatic Environment (I) was introduced with the aim of meeting the national goal of a 50% reduction of the N load to aquatic waters (Kronvang et al., 1993). Since then, further action plans have been introduced along with the EU Nitrates Directive from 1991 requiring that groundwater nitrate concentration should be limited 50 mg nitrate l^{-1} and that the average annual application rate of N by manure should be less than 170 kg N ha^{-1} or 230 kg N ha^{-1} for cattle farms having a derogation giving that fodder crops cover more than 70% of the farmed area. The action plans include the Danish code of good agricultural practice as mandatory measures and further restrictions in the use of nutrients such as mandatory fertilizer accounts, improved utilisation of nitrogen in manure, reduced nitrogen application rates for crops as compared to the economic optimum, as well as

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area-related measures such as re-establishment of wetlands and afforestation (Kronvang et al., 2008).

In Denmark, at 30 soil water stations suction cups installed below the root zone have been used as a means of monitoring to follow trends in the impact of agriculture on nitrate leaching. Subsequently, the measurements have been used to set up and calibrate empirical N leaching models (Kristensen et al., 2008) for the purpose of up-scaling the level of N leaching from measuring points to catchment level (Andersen et al., 1999, 2001) and to national level (Grant et al., 2011).

The objective of this study was to investigate differences in N leaching and causes for these differences. We present results from suction cup-measured nitrate concentrations in soil water and N leaching from the Danish Agricultural Monitoring Programme and identify how variations in percolation and in field balance can describe N leaching measured annually in the period 1991–2010 at 30 soil water stations.

2. Background

Due to action plan regulation and better utilisation of organic manure, the input of inorganic fertilizers in Denmark has decreased substantially from about 142 kg N ha^{-1} yr^{-1} in 1990 to 71 kg N ha^{-1} yr^{-1} in 2010, a total reduction of 50%; in contrast, the input of organic N fertilizers has been almost constant throughout this period (Fig. 1A) (Blicher-Mathiesen et al., 2012). In Denmark, the field level N surpluses are used as indicators for the development in nutrient loads from agriculture at the national level. The national field surplus has been reduced steadily since the introduction of the first action plans in 1987, from about 161 kg N ha^{-1} yr^{-1} in 1990 to 90 kg N ha^{-1} yr^{-1} in 2010, amounting to a total reduction of 44% (Fig. 1B). A temporary increase in the field balance in 1992–1993 was caused by a severe drought in 1992 with resulting low harvest yields.

3. Methods

3.1. Agricultural catchment monitoring

The Danish Agricultural Monitoring Programme on nitrate leaching from agricultural soils was established during winter 1989/90, based on the Action Plan for the Aquatic Environment passed by the Danish Parliament (Grant et al., 2011). The monitoring is carried out in five small agricultural catchments (Fig. 2), which have been chosen to represent the main soil types and the variation in livestock density, crops and climatic conditions found in Denmark. By interviewing farmers, the monitoring encompasses collection of intensive information on agricultural practices: application of mineral and organic fertilizer and crop cover at field level and number of livestock, total production of manure and manure storage capacity at farm level. The monitoring includes direct measurements of soil water, tile drainage water, upper groundwater and stream water.

The catchments are regarded as study areas in which the main objectives are: (i) to characterise and evaluate current agricultural practices; (ii) to establish time series of nutrient concentrations in waters of agricultural catchments representative of Denmark; (iii) to extrapolate observations to national level; (iv) to set up models for the nutrient flow in the entire hydrological pathway of agricultural catchments and (v) to calculate scenarios on the effects of measures introduced in agriculture, impacts of climate changes etc. The results from this programme have provided data and information specifically for evaluation of Danish action plans and for justification of the Danish derogation from the Nitrates Directive (Grant et al., 2011). The catchments have light textured soils (sand, loamy sand, sandy loam) (Table 2) and are dominated by agricultural land cover types (70–98%) and forest (0–30%).

3.2. Methods for sampling and measurements in groundwater and streams

To monitor the water and nutrient leaching, each catchment is instrumented with four to eight soil water stations and 15–30 groundwater wells placed at three depths in the sediment with the aim to sample the shallow groundwater. Additionally, a piezometer was drilled to 5–7 m below surface and located next to fields with soil water stations in order to monitor the groundwater level. Design of groundwater screens, groundwater sampling and measurements is described in Rasmussen (1996).

Discharges and N loads of the studied catchment areas are gauged at the catchment outlet. Instantaneous discharge (Q) is measured 12–20 times per year using a low friction propeller, and daily discharge values are calculated using relationships between Q and continuously measured fluctuations in stream water levels (H). Water sampling at the monitoring stations is usually conducted every fortnight and analysed for total N concentrations according to Danish standards. The nitrogen load in the gauged streams is calculated using a linear interpolation method for nutrient concentrations and multiplying the results by average daily discharges (Kronvang and Bruhn, 1996). The annual flow-

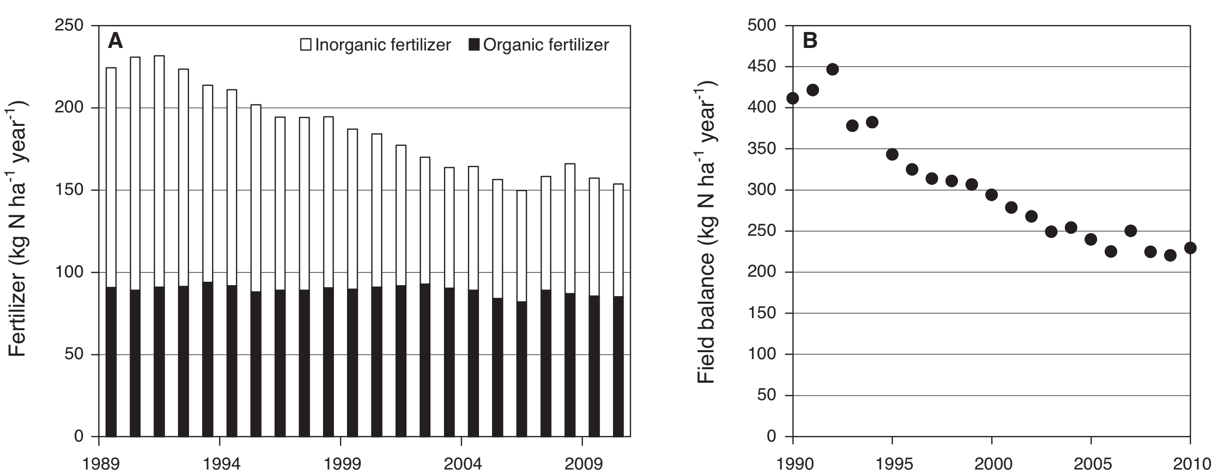

Fig. 1. Average consumption of inorganic and organic fertilizer in Denmark (A) and surface N balances for Denmark (Blicher-Mathiesen et al., 2012) (B), both for the period 1990–2010.