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Economic gains from targeted measures related to non-point pollution in agriculture based on detailed nitrate reduction maps

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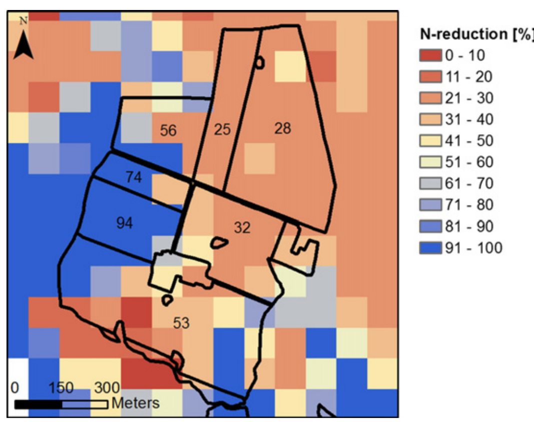
HIGHLIGHTS

- Detailed groundwater N-reduction maps help to target measures for N-loss reduction.
- Spatial targeting measures reduce overall costs for farmers.
- Not all farms can use groundwater reduction maps for location of measures due to restrictions on crop rotation.
- Cost of detailed mapping of groundwater reduction is lower than the gains.

GRAPHICAL ABSTRACT



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ABSTRACT

From 1990 to 2003, Denmark reduced N-leaching from the root zone by 50%. However, more measures are required, and in recent years, the focus has been on how to differentiate measures in order to ensure that they are implemented where the effect on N-loss reductions per ha is the greatest. The purpose of the NiCA project has been to estimate the natural nitrate reduction in the groundwater more precisely than before using a plot size down to 1 ha. This article builds on these findings and presents the possible economic gains for the farmer when using this information to reach a given N-loss level. Targeted measures are especially relevant where the subsurface N-reduction varies significantly within the same farm and national analyses have shown that a cost reduction of around 20–25% using targeted measures is likely. The analyses show an increasing potential with increasing variation in N-reduction in the catchment. In this analysis, the knowledge of spatial variation in N-reduction potential is used to place measures like catch crops or set-a-side at locations with the greatest effect on 10 case farms in the Norsminde Catchment, Denmark. The findings suggest that the gains are from 0 to 32 €/ha and the average farm would gain approximately 14–21 €/ha/year from the targeted measures approach. The analysis indicates that the economic gain is greater than the costs of providing the detailed maps of 5–10 €/ha/year. When N-loss reduction requirements are increased, the economic gains are greater. When combined with new measures like mini-wetlands and early sowing the economic advantage is increased further. The paper also shows that not all farms can use the detailed information on N-reduction and there is not a clear link between spatial variation in N-reduction at the farm level and possible economic gains for all these 10 farms.

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1. Introduction

The leaching of nitrogen from agricultural areas is an environmental problem in many countries, and so a number of national policies and European Directives (e.g. the Nitrate Directive and the Water Framework Directive) have been implemented to improve water quality. In Denmark, a number of policies have been introduced since the mid-1980s which have reduced the N-leaching (loss of nitrogen from the root zone in the form of nitrate) by 50% (Mikkelsen et al., 2010; Børgesen et al., 2009; Jacobsen, 2009; Dalgaard et al., 2014). Despite this, more measures are needed to reach the targets required in order to achieve the Good Ecological Status of the aquatic environment (Grinsven et al., 2012; Jacobsen, 2014; EU Commission, 2012). The policies have for many years focused on the N-losses from the root zone, but the focus has in recent years changed to the actual N-losses to the aquatic environment.

The measures introduced in Denmark have, so far, been based on a high degree of general regulation where all farms are regulated in the same way (horizontal measures). The current N-quota system is linked to crops and soil type, but it is not differentiated with respect to the natural N-reduction on the way to the sea and the required N-loss reduction target for a given catchment (Dalgaard et al., 2014; Mikkelsen et al., 2010). The quota system has reduced N-losses to the sea significantly. However, today the N-quota is 18% under the economic optimum (2014/15) and Danish farmers would very much like to apply the economic optimum in areas where N lost to coastal waters is limited due to a high natural N-reduction capacity (Kristensen and Jacobsen, 2013; Thysen, 2013). Other national measures such as the requirements regarding N-utilization in manure, catch crops, no cultivation in autumn etc. are also applied in the whole country (Jacobsen, 2012a). In other words, general regulation based on command and control is the main regulatory measure used today, although measures like wetlands and riparian zones along streams are, to some extent, site specific. In terms of implementation, applying the same approach to all fields makes it easier from a regulatory perspective as a detailed implementation model requires more precise data since the data will come under closer scrutiny when two farmers with the same crops are allowed to apply different nitrogen levels.

With the implementation of the Water Framework Directive, it is clear that the reduction requirements must be more differentiated than before (Naturstyrelsen, 2014). The basic problem is that N-loss from agriculture is diffuse pollution, and so the polluter cannot be identified directly as is the case with point source pollution. However, with new techniques and approaches, it is possible to estimate the losses with greater precision than before. In other words, the idea is to regulate diffuse pollution almost as point source pollution, or at least as a diffuse pollution source where some knowledge of the emission level is available.

In Denmark this has led to a strong focus on the option of more targeted regulation as included in the recommendations for the Danish Nature and Agricultural Commission, where recommendation 11 on new regulation of N-application in Denmark says that: “A new, differentiated and targeted nitrogen regulation would mean that the regulation can vary between types of fields and farms” (NLK, 2013). The idea is to implement site-specific measures where the environmental effect is the greatest. The concepts of “robust” areas, with little or no N-losses, and vulnerable areas, where the N-losses are high, have been widely discussed by the Danish Farmers' Union, but researchers have warned that the current measurements do not allow assessments of these areas at e.g. the field level without considerable uncertainties (Lemming and Knudsen, 2012; Hansen et al., 2014b).

Nitrate (NO_3^-) can be naturally transformed to N_2 by a microbial mediated reduction process under anoxic conditions (Appelo and Postma, 2005). Nitrate reduction can occur in several places within a catchment (soils, groundwater, wetlands, riparian areas and streams), but in Denmark, nitrate reduction in the groundwater zone is the dominant sink (Ernstsen et al., 2006; Højberg et al., 2015). Because of this natural reduction process the efficiency of the existing general regulations in Denmark is, on average, only 1/3, because roughly 2/3 of the nitrate leaching from the root zone is naturally removed by N-reduction processes in the subsurface before reaching streams. In this paper, N-reduction is defined as N which is transformed to N_2 on the way from the root zone to the coastal waters. This is also referred to as N-retention in some articles. The term ‘reduction of N-loss’ is used to describe the change in the N-loss to the aquatic environment which is the target for the economic scenarios in the paper.

Nitrate must be transported below the redox interface, which delineates the transition from oxic to anoxic conditions, with the flowing groundwater in order for reduction to occur. The amount of nitrate reduction in groundwater within a catchment depends, therefore, both on the depth of the redox interface, but also on the groundwater flow patterns. The natural nitrate reduction potential therefore often varies greatly within even small areas because of the large heterogeneity of the subsurface. This leads to the existence of both vulnerable areas from where nitrate leaching reaches the surface water with very little reduction, and robust areas where almost all leached nitrate is reduced. Because of this geographical variation in N-reduction potential, a general regulation approach will lead to inefficient solutions as the effect of the N-loss reduction measures will vary between farms and between fields. A regulation approach with focus on applying the measures on the vulnerable area would be more cost-effective. However, it is at present not possible to differentiate between these types of areas with large enough certainty, which is a serious constraint on designing cost-effective water management measures (Refsgaard et al., 2014; Jacobsen, 2007).

The average N-reduction from the root zone to the sea for a catchment covers a large spatial variation combined with a spatial variation in N-leaching from the root zone that is not known with certainty, but the uncertainties, at the local scale, are to a large extent balanced out when aggregating to the catchment scale. If reliable local information is available, measures can be targeted to the areas where the effect is the greatest facilitating a cost-efficient implementation of measures. However, more detailed regulation based on very uncertain maps with few observations might result in measures being implemented in the wrong locations. Therefore, the NiCA project was initiated to develop new techniques and approaches to gain more knowledge in order to estimate the N-reduction potential in the subsurface at the local scale and also assess the uncertainty on the estimate and try to improve it (Refsgaard et al., 2014).

Abildtrup et al. (2004) carried out analyses, which resemble those conducted in this paper, although the scale was less detailed, the authors also gave recommendations regarding the specific location of measures such as wetlands and catch-crops based on N-reduction mapping (see also Refsgaard et al., 2007). The findings show that there is significant variation in the environmental effect across the catchment area. So targeting the measurers will increase the environmental effect per ha. The analysis also shows that the income lost from taking land out of production varies mainly with livestock density or the share of high income crops (potatoes). The analysis demonstrates a clear advantage in terms of cost efficiency of targeting measures at both N-losses (kg N/ha) and income lost. The approach concerning targeting was adopted by the AGWAPLAN project in relation to increased stakeholder involvement (Wright and Jacobsen, 2010 and Wright and Jacobsen, 2011). The project describes how detailed mapping will influence the decisions made by the farmer. This is also reflected in Vejre et al. (2007), which focuses more on the variation in the landscape and services provided.

Blicher-Mathiesen et al. (2014) analysed the risk of N-losses on agricultural fields and how it varies with climate, weather and soils. They also discussed how this knowledge could be used to target measures and reduce costs in the Odense Catchment area. The economic incentives with respect to targeting are also discussed in Jensen and Ørum