Agricultural Systems 133 (2015) 167–176

Contents lists available at ScienceDirect

Agricultural Systems

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

Ecological recycling agriculture can reduce inorganic nitrogen losses – model results from three Finnish catchments

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ARTICLE INFO

Article history:
Received 28 February 2014
Received in revised form 30 September 2014
Accepted 27 October 2014
Available online 4 December 2014

Keywords:
Nutrient recycling
Catchment scale modeling
Fertilizer
Nitrogen leaching
Organic agriculture

ABSTRACT

Protection measures are needed to control nutrient leaching from agriculture to the Baltic Sea. Ecological Recycling Agriculture (ERA) is based on local nutrient resources, integrating animal and crop production on farms or in their proximity. In Finland, three agricultural study catchments were chosen to demonstrate environmental impacts of ERA. Inorganic nitrogen (N) leaching from the catchments was simulated with INCA-N model in prevailing and ERA farming conditions. Lepsämänjoki catchment is a crop production area, in the Yläneenjoki catchment animal husbandry is common and in the Lestijoki catchment the main production line is dairy production. A theoretical crop rotation was developed to represent ERA cultivation consisting of leys, cereals and mixture of cereals and pea. N fixation, mineralization and manure were sources of N. INCA-N was calibrated in the catchments using present cultivation practices. Next, crop parameters were modified to describe ERA cultivation. The model results showed that ERA has potential to decrease N losses: the highest inorganic stream N concentrations and average annual inorganic N losses from agricultural fields decreased, compared to those resulting from present production relying on inorganic fertilizers. Therefore, ERA may serve as one of the measures to achieve the N reduction targets set for agriculture in the Baltic Sea Action Plan.

1. Introduction

The brackish Baltic Sea ecosystem suffers from the symptoms of severe eutrophication, e.g. large hypoxic bottom-areas and release of nutrients from sediment back to water, late summer blue-green algal blooms and bias in the coastal fish communities (HELCOM, 2011). The downward development in the status can be tracked back to excessive input of nutrients from catchment, mainly from municipalities and agriculture, causing eutrophication in the main basin and the Gulf of Finland (HELCOM, 2011).

The nutrient loading, especially that of phosphorus (P), has been decreasing since the 1980s without significant improvement in the status of the Baltic Sea and it is evident that more reductions in nutrient loading are needed. The agreement in the HELCOM Baltic Sea Action Plan defines "good status" of the Baltic marine environment and sets input ceilings for both nitrogen (N) and P, to reach the status by 2021 (HELCOM, 2007; Backer et al., 2010). In new EU-countries and Russia a major part of the reduction target can be fulfilled by improving the reduction capacity of the municipal sewage treatment plants toward the levels in the western countries. However, most of the reductions set for N are targeted to diffuse sources and especially for agriculture. Here, the Action Plan requires the countries to apply agricultural practices that aim at minimizing nutrient fluxes and optimizing nutrient use in animal feeding, manure handling and crop cultivation (HELCOM, 2007; Backer et al., 2010). The N reductions may be especially relevant in the sub-basins, where the primary production is limited mainly by N (Tamminen and Andersen, 2007).

In Finland, the impacts of agri-environmental measures have been followed since the start of the EU's subsidy program in 1995 (MYTVAS studies, e.g. Ekholm et al., 2007; Aakkula et al., 2010; Aakkula et al., 2011). The results have shown that agricultural nutrient balances have decreased for N and P during 1990–2009, mostly due to decrease of use of artificial fertilizers. However, leaching of nutrients from manure in areas of intensive animal farming is a problem because livestock and plant production are separated from each other. In the catchment of the Baltic Sea the separation of crop and animal production has been suggested to be the main reason for the high load of N and P to the Baltic Sea (Granstedt, 2000). In Finnish rivers Total P loads have mostly decreased whereas Total N loads have increased in 18 of 22 rivers studied. The increase was highest in Ostrobothnia (western Finland), where animal husbandry is centered and field area has been increasing due to need of manure spreading area (Aakkula et al., 2010, 2011). Ecological

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http://dx.doi.org/10.1016/j.agsy.2014.10.015

Recycling Agriculture (ERA) is defined as an organic agriculture system aiming at closed nutrient cycles. It is based on local and renewable resources that integrate animal and crop production on each farm or farms in close proximity (Granstedt et al., 2008). Lower overall input of nutrients to the agricultural system can be achieved by increasing the recycling of nutrients, so that the number of animals on the farm is in balance with the amount of fodder the farm can produce. As a result, a large part of the nutrient uptake in the fodder is efficiently recycled which may decrease the leakage of nutrients from agriculture (Granstedt et al., 2008).

The Finnish Organic Production Development Program, stated in the government platform, aims at 20% of cultivated area to be under organic farming by 2020. Furthermore, Prime Minister Matti Vanhanen set a national target for nutrient recycling in Finland (Baltic Sea Action Group, 2013), recognizing the problem that energy and nutrients are resources not to be wasted. Positive attitudes among the consumers and good market conditions, together with the new European rural development program, starting in 2014, contribute to increasing organic production (EVIRA, 2012). At present, there are around 4300 organic farms, and the area of cultivated organic fields is about 205,000 hectares (9% of the total cultivated area).

Soils in organic farming systems have on average a higher content of soil organic matter (SOM) and farming contributes positively to agro-biodiversity and natural biodiversity (a meta-analysis including studies around the world by Mondelaers et al., 2009). SOM is an important indicator for soil quality because it has positive effects, e.g. on erosion control and water retention (Shepherd et al., 2002). Concerning the impact of organic farming on nutrient leaching, the result of the analysis by Mondelaers et al. (2009) was not straightforward. When expressed per production area organic farming was better, but due to lower land use efficiency in developed countries, the positive effect per unit product was less pronounced or not present at all. It is argued that organic agriculture may have lower yields and therefore needs more land to produce the same amount of food as conventional systems (Seufert et al., 2012). When comparing the yields of organic and conventional agriculture in a meta-analysis, Seufert et al. (2012) found that with good management practices, particular crop types and growing conditions organic systems can almost match conventional yields.

A meta-analysis of European research on environmental impacts of organic farming also showed that organic farms tend to have higher SOM and lower N leaching per unit of field area, but leaching per product unit was higher (Tuomisto et al., 2012). Higher nitrate (NO_3^-) leaching per hectare in conventional farming results from larger amounts of fertilization, lower use of green cover crops, lower C/N ratio and higher stocking density (Mondelaers et al., 2009). In organic farming the main reason for lower N leaching per unit area is the lower amount of N applied (e.g. Torstensson et al., 2006; Korsaeth, 2008). However, poor synchrony between the nutrient availability and crop uptake may result in higher N leaching, e.g. after incorporation of leys (Aronsson et al., 2007; Syväsalo et al., 2006). Field experiments in Denmark showed that management of crop and soil during autumn was the main determinant of N leaching from organic crop rotations (Askegaard et al., 2011).

The meta-analysis of Mondelaers et al. (2009) and Tuomisto et al. (2012) point out the wide variation between the environmental impacts within both farming systems. Mondelaers et al. (2009) stated that nitrate is a typical local environmental problem and concluded that the importance of local aspects (e.g. soil type, climate and legislation) becomes evident and calls for caution when generalizing results of different studies. So far, conclusions about nutrient leaching from organic agriculture in Finland have been mostly based on field studies (Syväsalo et al., 2006; Lemola et al., 2012) and profile scale modeling (Rankinen et al., 2007; Nykänen et al., 2009). However, manure produced is excessive in many places relative to the utilized agricultural land and needs of crops, due to the concentration of livestock production (Niemi and Ahlstedt, 2013), and manure has thus become a regional problem. Therefore, catchment scale analysis is needed to find solutions for controlling nutrient losses in areas with high proportion of agricultural land in intensive cultivation or high level of manure application, and to show potential water quality impacts of environmentally sustainable management systems.

The objective of this study was to demonstrate environmental impacts of ERA farming in terms of nutrient leaching. Organic systems are strongly dependent on organic sources of N, such as legumes and manures (Berry et al., 2002) but in Finland organic farms have not suffered from lack of P (Ylivainio et al., 2009). Therefore, this study was focused on N cycle and N leaching in ERA farming. Three agricultural catchments in Finland (Lepsämänjoki, Yläneenjoki and Lestijoki) were chosen as case study areas. Catchment scale INCA-N nitrogen model (Wade et al., 2002; Whitehead et al., 1998) was applied in the catchments in order to study inorganic N leaching in prevailing conventional and ERA farming conditions. The selected catchments with different intensity of animal production represent typical Finnish agricultural areas. A theoretical crop rotation was developed consisting of leys, cash crop, mixture of cereals and pea, and a fodder cereal, to represent Finnish ERA cultivation. Crop parameters in the INCA-N model were modified to represent the ERA crops. Agricultural inorganic N losses, inorganic stream N concentrations and exports from the catchments were calculated by INCA-N to show the potential of ERA agriculture in controlling N leaching, compared to losses resulting from current cultivation practices and crops.

2. Materials and methods

2.1. Study catchments

The INCA-N model was applied to three well monitored agricultural catchments which represent typical land use and soil types in Finland (Fig. 1). The Lepsämänjoki catchment is a crop production area while in the Yläneenjoki catchment the main production line is animal husbandry. In Lestijoki the main production line is dairy production with increasing interest to beef production. In the river basin plan of the Water Framework Directive (WFD, 2000) the river Lepsämänjoki is estimated to achieve good ecological status by 2021 (Joensuu et al., 2010), the river Yläneenjoki by 2027 (Kokemäenjoen – Saaristomeren – Selkämeren vesienhoitoalueen vesienhoitosuunnitelma vuoteen 2015, 2009.) and the river Lestijoki and its estuary by 2015 (Kokemäenjoen – Saaristomeren – Selkämeren vesienhoitoalueen vesienhoitosuunnitelma vuoteen 2015, 2009). In all catchments most of the farmers are committed to fulfill environmentally sound cultivation practices included in the Finnish agri-environmental support scheme, the main tool for the WFD (Mattila et al., 2007).

Lepsämänjoki catchment (214 km^2) is a sub-basin of the Vantaanjoki river basin in southern Finland. The river Vantaanjoki discharges to the Gulf of Finland outside Helsinki and the area is very important for outdoor recreation. The mean discharge in the river Lepsämänjoki was 2.2 $m^3 s^{-1}$ in 2000s (Korhonen and Haavanlammi, 2012). The mean annual precipitation in the area is 650 mm, and mean annual temperature is +4 °C (data from Finnish Meteorological Institute). Main soil types in the Lepsämänjoki catchment are clay (*Vertic Cambisol*) and rocky soils (*Dystric Leptosol*) (Lilja et al., 2006). Arable fields cover 23% of the area, the rest being mainly forest. Arable fields are located on clay soils. Main crops are spring cereals barley (*Hordeum vulgare* L.), spring wheat (*Triticum aestivum* L.) and oat (*Avena sativa* L.), but at the upper reaches of the catchment there is also some cabbage (*Brassica oleracea* var. *capitata*) cultivation (about 3% of the area). In 2005 animal density was 0.08 animal units (AU) ha^{-1} of field (Mattila et al., 2007).