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Environmental impacts of innovative dairy farming systems aiming at improved internal nutrient cycling: A multi-scale assessment

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HIGHLIGHTS

- Closing internal nutrient cycles (INC) significantly reduced dairy farm energy use.
- INC farming reduced the global warming, acidification and eutrophication potential.
- Nitrogen losses to air and water decrease on average by 5 to 10% by INC farming.

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ABSTRACT

Several dairy farms in the Netherlands aim at reducing environmental impacts by improving the internal nutrient cycle (INC) on their farm by optimizing the use of available on-farm resources. This study evaluates the environmental performance of selected INC farms in the Northern Friesian Woodlands in comparison to regular benchmark farms using a Life Cycle Assessment. Regular farms were selected on the basis of comparability in terms of milk production per farm and per hectare, soil type and drainage conditions. In addition, the environmental impacts of INC farming at landscape level were evaluated with the integrated modelling system INITIATOR, using spatially explicit input data on animal numbers, land use, agricultural management, meteorology and soil, assuming that all farms practised the principle of INC farming. Impact categories used at both farm and landscape levels were global warming potential, acidification potential and eutrophication potential. Additional farm level indicators were land occupation and non-renewable energy use, and furthermore all farm level indicators were also expressed per kg fat and protein corrected milk. Results showed that both on-farm and off-farm non-renewable energy use was significantly lower at INC farms as compared with regular farms. Although nearly all other environmental impacts were numerically lower, both on-farm and off-farm, differences were not statistically significant. Nitrogen losses to air and water decreased by on average 5 to 10% when INC farming would be implemented for the whole region. The impact of INC farming on the global warming potential and eutrophication potential was, however, almost negligible (<2%) at regional level. This was due to a negligible impact on the methane emissions and on the surplus and thereby on the soil accumulation and losses of phosphorus to water at INC farms, illustrating the focus of these farms on closing the nitrogen cycle.

1. Introduction

The adverse effects of agricultural practices on environmental quality have increasingly been recognized in the Netherlands since the 1980s. Initially, the regulatory measures to improve water and air quality, taken in the early 1990s, had a generic character, because they did not take into account site-specific circumstances. For instance, groundwater quality in terms of nitrate contents was regulated in the EU

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Nitrates Directive of 1991 (EC, 1991) by country-wide proxy values in terms of not allowing application of more than 170 kg N from livestock manure. However, since the 2000s, regulatory measures in view of manure and ammonia legislation have become more and more specific, especially with regard to manure and fertilizer rates recommendations per crop type. Dutch legislation in 1993 further required farmers to apply liquid manure by so-called low-emission techniques, by using trailing shoes or shallow injection, while the use of trailing shoes will be forbidden in 2017. This was intended to reduce ammonia emission, and thereby nitrogen (N) deposition, adversely affecting biodiversity in adjacent nature sites (Kros et al., 2013). Some farmers, especially in the Northern part of the Netherlands, do not accept this legislation as they fear that using heavy machinery, needed for the low-emission technique, would damage their soils, especially the soil biology (e.g. Sonneveld et al., 2008). Besides, equipment was expensive and could only be afforded by contractors, making farmers dependent of them for field work.

Since the 2000s, agriculture increasingly faces the challenge of contributing to a whole range of ecosystem services, defined as "benefits that people obtain from ecosystems" (Millennium Ecosystem Assessment, 2005). This does not only include provisioning services, such as the production of food, but also regulating services such as the regulation of climate, by enhancing carbon sequestration and reducing nitrous oxide emission and ensuring an adequate water quality by enhancing the buffer and filter capacity of the soil (i.e., water purification). Many of these services are critically dependent on the underlying soil processes and soil properties (Bennet et al., 2010; EU, 2006), involving inherent fixed soil properties as well as dynamic manageable soil properties that change under the influence of soil management (Dominati et al., 2010; Powlson et al., 2011; Robinson et al., 2012).

Farming practices affect soil properties, such as soil organic matter content, and contents of nutrients, such as nitrogen (N) and phosphorus (P) in the soil, which in turn may affect soil services in terms of water and nutrient supply (Creamer et al., 2010), and water quality through N and P leaching and runoff. There is thus a need to develop sustainable soil and nutrient management practices that result in the continuous supply of ecosystems services with acceptable environmental impacts. This should not only include on-farm impacts but also off-farm impacts, related to emissions and impacts from the entire product supply chain, as considered in Life Cycle Assessments (LCAs) (Van Der Werf and Petit, 2002). Hence, not only input–output balances at farm level need to be evaluated, but also impact categories such as land use, energy use and global warming potential related to off-farm production of fertilizer and cattle feed (Thomassen and De Boer, 2005). In this way, supply chain processes and impacts related to the production of feed, fertilizer, bedding material etc. are included (Thomassen et al., 2009).

In view of both potential reductions in costs and in the adverse environmental impacts, a group of Dutch dairy farmers explored possibilities to reduce N use by reducing protein contents in dairy cattle diets, leading to lower total N and mineral N contents in liquid manure (Misselbrook et al., 2005; Reijs et al., 2007). This lower N content can potentially decrease N losses through ammonia volatilization when application takes place under appropriate weather conditions (e.g. Sonneveld et al., 2008). In addition to a low protein diet, this group of Dutch dairy farmers increasingly focused on improving internal nutrient cycling (INC) by minimizing use of synthetic N fertilizer (further denoted as fertilizer) and reducing the frequency of grassland renovation. In common farming practices, grasslands are ploughed and reseeded about every 5 to 10 years to improve yield levels (through improving the botanical composition of the sward), or rotated with other crops, such as maize silage. However, this practice occurs implies loss of soil organic matter and also causes high nitrogen losses, such as nitrous oxide emissions and nitrate leaching (Vellinga and Hoving, 2011). The innovative farms will hereafter be referred to as INC farms. In general, those farms focus on increased use of on-farm available resources, such as soil organic matter, nutrients from manure and home-grown feed production, thus reducing purchased feed and fertilizer while maintaining a sufficient farm-income in the long term (Hees et al., 2009). Regular farms (REG farms), in contrast, follow more conventional management. INC farms claim to have a lower environmental impact of milk production while realizing a higher level of soil organic carbon (SOC), which is an important indicator of soil quality. Previous studies indicated that nitrate concentrations in the upper groundwater at INC farms are relatively low compared to dairy farms with regular farming practices on similar soils (Bouma et al., 2008; Sonneveld et al., 2010). Furthermore, soil organic matter contents are relatively high on INC farms (Van Apeldoorn et al., 2011), though this may also be a historic characteristic of these soils Moreover, the economic, environmental and societal performance of INC farms, as compared to REG farms, are generally better, as recently reported by Dolman et al. (2014).

Dolman et al. (2014), however, compared only a limited number of INC and REG farms. Until now, the implications of different farming systems on environmental quality at landscape scale have not been considered, while this is a highly relevant scale for environmental policies (see e.g. Cellier et al., 2011). Especially for N deposition, the landscape scale is relevant because ammonia emission can be recaptured by the foliage of nearby ecosystems (Dragosits et al., 2006; Fowler et al., 1998; Theobald et al., 2004). From a spatial perspective, upscaling the assessment of environmental impacts from farm to landscape level is needed because of non-linear behaviour of pollutants and the spatial heterogeneity of sensitive sites, such as relatively undisturbed natural habitats. This requires the use of spatial models that allow an assessment of environmental impacts of farming practices to the landscape level (W. De Vries et al., 2003; Kros et al., 2011; Sonneveld et al., 2012).

Here, we present approaches and results of a study focusing on the environmental impacts of INC and REG production systems both at farm level and at landscape level, with a focus on nitrogen emissions. Impacts at farm level are not only reported per kg of fat and protein corrected milk (FPCM), typical for an environmental economic focus, as used by Dolman et al. (2014), but also per hectare of land, typical

Fig. 1. Location of the Northern Friesian Woodlands (shaded) in the province of Friesland in the Netherlands.