Agriculture, Ecosystems and Environment 212 (2015) 75–84

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Nitrate leaching and residual effect in dairy crop rotations with grass–clover leys as influenced by sward age, grazing, cutting and fertilizer regimes

J. Eriksen*, M. Askegaard[1], J. Rasmussen, K. Søegaard

Department of Agroecology, Aarhus University, PO Box 50, 8830 Tjele, Denmark

ARTICLE INFO

Article history:
Received 27 February 2015
Received in revised form 30 May 2015
Accepted 5 July 2015
Available online xxx

Keywords:
Cutting
Grazing
Grass–clover
Crop rotation
Nitrate leaching

ABSTRACT

Intensive dairy farming, with grass-arable crop rotations is challenged by low N use efficiency that may have adverse environmental consequences. We investigated nitrate leaching and N fertility effects of grass–clover leys for five years in two organic crop rotations with different grassland proportions (33 and 67%) and five grassland managements in terms of cutting, grazing, fertilization and combinations thereof. In grass–clover, the combination of fertilization and grazing caused excessive leaching (average 60 kg N ha^{-1}) but leaving out either fertilization or full-time grazing substantially reduced leaching losses to on average 23 kg N ha^{-1}. There was no linear relationship between sward age and nitrate leaching. The annual N surplus of the grasslands was only weakly related to nitrate leaching (R^2 = 0.05, P < 0.01). The residual effect of grassland cultivation was highest following grazing and fertilization and lowest without fertilization or cutting-only management and was not influenced by grassland age. The arable part of the mixed crop rotation was nitrate leaky where crop coverage in autumn was insufficient. Nitrate leaching following the crops may roughly be divided into four groups: (1) low leaching (<10 kg N ha^{-1}) consisting of the barley wholecrop undersown with Italian ryegrass, (2) medium–low leaching (10–20 kg N ha^{-1}) consisting of barley with grass–clover undersown and the 1-yr-old grasslands, (3) medium leaching (25–50 kg N ha^{-1}) consisting of barley–pea and 2-4-yr-old grasslands with the 2-yr-old leaching the most (36–46 kg N ha^{-1}), and (4) high leaching (>50 kg N ha^{-1}) with lupin and maize, where especially maize was consistently high in all five years (average 81 kg N ha^{-1}). Great care should be taken during all phases of the dairy crop rotation where grasslands cause considerable build-up of fertility. With due care and the best management practice, nitrate leaching losses may be reduced to low levels.

1. Introduction

Although nitrogen (N) utilization has generally been optimized in agriculture, intensive dairy farming is still characterized by low N use efficiencies (Davies, 2000; Jarvis and Aarts, 2000; Ledgard et al., 2009) and improvements are necessary to avoid adverse environmental impacts of nitrate leaching. In parts of Europe, dairy production systems are based on ley-arable rotations with three phases: grassland, ploughing out, and subsequent arable cropping, with each phase having challenges in terms of utilizing N efficiently (Vertés et al., 2007; Watson et al., 2005).

In the grassland phase, especially grazing animals have significant effects on nitrogen dynamics through its removal by grazing and redistribution through excreta. Generally, in pastures grazed by dairy cows the conversion of consumed N into product is low and a substantial quantity of N (>70%) is recycled through the direct deposition of animal excreta, resulting in inorganic soil N concentrations under urine patches that are up to 10 times greater than under dung patches, and more than 30 times greater than in areas unaffected by excreta (Afzal and Adams, 1992). This markedly increases the risk of N losses to waterways and the atmosphere (Ledgard et al., 2009). In terms of leaching, cutting-only systems are the most advantageous, and a management system that combines cutting and grazing is preferable to a pure grazing system (Ledgard et al., 2009; Wachendorf et al., 2004). The dual advantage is in a lower N loading due to less recycling of animal excreta and a higher N removal in herbage, both reducing NO_3 leaching. This is exemplified by the nitrate leaching model of Vellinga et al. (2001), where grazing from mid-April to mid-

* Corresponding author.
E-mail addresses: jorgen.eriksen@agrsci.dk (J. Eriksen), MGA@seges.dk (M. Askegaard), jim.rasmussen@agro.au.dk (J. Rasmussen), karen.soegaard@agro.au.dk (K. Søegaard).
[1] SEGES, Agro Food Park 15, 8200 Aarhus N, Denmark.

http://dx.doi.org/10.1016/j.agee.2015.07.001
0167-8809/© 2015 Published by Elsevier B.V.

October caused a NO_3 concentration of 69 mg l^{-1} in leachate; this was reduced to 59 mg l^{-1} by ending grazing in mid-September. The EU Nitrates Directive target of 50 mg l^{-1} was met by ending grazing mid-August in the model exercise (Eriksen et al., 2010). However, some farmers especially in mainland Europe choose to start grazing their herds later in the spring and do not turn out cows until after the whole grassland area has been cut for silage. This practice only eliminates urine patches in spring, which may generally not be efficient for reducing nitrate leaching from urine patches (Cuttle and Bourne, 1993). However, in one study on course sandy soil, time of urination has been found not to affect leaching (Hansen et al., 2012).

Many pastures include legumes, in temperate regions particularly white clover, to improve feed quality and supply N from N_2 fixation (Ledgard, 2001; Lüscher et al., 2014; Phelan et al., 2014). The N concentration of the pasture exceeds that required by grazing animals, resulting in poor utilization of clover-protein, increased urinary N output and consequently a greater risk of environmental N pollution (Ledgard et al., 2009). However, the clover-N feedback mechanism, whereby N_2 fixation decreases with high N inputs, acts to enhance N efficiency, so where N inputs from excreta occur there will be a relatively lower input from N_2 fixation. Thus, Eriksen et al. (2004) observed higher leaching losses from a grazed N-fertilized ryegrass pasture (on average 47 kg N ha^{-1} yr^{-1}) than from a grazed non-N-fertilized clover/ryegrass pasture (on average 24 kg N ha^{-1} yr^{-1}), explained by a reduction in N_2 fixation together with a reduction in DM production, which in turn led to a lower grazing intensity and lower rate of recycling of animal excreta.

In the arable phase, the release of N following grassland cultivation is often substantial (Eriksen et al., 2008; Francis, 1995), and therefore fertilizer-N use can be reduced or even eliminated in the first following crop (Eriksen, 2001; Hansen et al., 2005). Furthermore, catch crops in the arable phase of the crop rotation have proved efficient at reducing NO_3 leaching by removing soil mineral N from the soil profile before winter drainage occurs (Hansen et al., 2007).

The common motivation for grassland cultivation is yield loss due to sward deterioration caused by e.g. compaction from wheeled traffic and invasion of less productive natural grasses (Hoving and de Boer, 2004), but also the maintenance or increase of soil fertility and nutrient utilization play a role. Thus, with these things in mind a key objective in designing grass-arable crop rotations is to optimize the grass phase, i.e., the number of grassland cultivations in relation to the length of the grass phase. For the individual farmer this depends on the requirement for feed and access to grazing. Increasing herd sizes on many dairy farms lead to grass-rich crop rotations with grasslands of longer duration close to the buildings and more arable crops in the rotations further away, which may potentially affect the overall N utilization.

The aim of the study was to quantify the N fertility and nitrate leaching effect of grass–clover leys differing in sward age, and fertilizer and cutting/grazing management during both the ley phase and in the subsequent crops in the crop rotation. The specific objectives during the ley phase were to:

(i) determine the effect of five management strategies (cutting/grazing and fertilization) on nitrate leaching,
(ii) investigate any relation between sward age and nitrate leaching,
(iii) quantify the residual N effect in subsequent crops, and
(iv) determine the effect of ley management on nitrate leaching in subsequent crops and in the crop rotation as a whole.

The study was based on the hypotheses that there is a positive correlation between N loading and nitrate leaching, a positive correlation between sward age and nitrate leaching, and a positive correlation between N loading during the ley phase and the residual N effect on subsequent crops.

2. Materials and methods

Nitrate leaching was determined during five years (2006–2011) in two crop rotations (Table 1) with different grassland proportions and five different grassland managements in terms of cutting, grazing, fertilization and combinations thereof. The crops in both rotations were present each year.

2.1. Site

The dairy/crop rotation is located at Research Centre Foulum, in the central part of Jutland, Denmark (9°34′E, 56°29′N). The soil is classified as a Typic Hapludult with 7.7% clay and 1.6% carbon in the topsoil. The fields were converted to organic farming in 1987, when a six-year rotation was introduced replacing a conventional cereal rotation (Eriksen et al., 1999; Eriksen et al., 1999). From 2004 the six-year rotation was split into two (Table 1). In rotation 1, the crops were barley, two years of grass–clover, barley for wholecrop silage with Italian ryegrass undersown, maize for silage and finally lupin (2006–2008) or barley/pea (2009–2010). In rotation 2 the crops were barley, four years of grass–clover and barley for wholecrop silage with Italian ryegrass undersown. In a real-farm situation rotation 2 represents the crop rotation closest to the farm buildings where a large proportion of grassland is needed for grazing, and rotation 2 represents the situation further away from the buildings.

2.2. Management of crop rotations

The grass–clover was undersown in a spring-barley cover crop. The seed mixture (26 kg ha^{-1}) consisted of 15% white clover and 85% perennial ryegrass until 2005, and from 2006 of 4% red clover, 14% white clover and 82% perennial ryegrass. After ploughing of the grass–clover ley, spring barley was established with an undersown Italian ryegrass. The barley was harvested as a green crop for silage in June and the Italian ryegrass harvested twice in respectively the summer and autumn. In both rotations the Italian ryegrass crop was left until the following spring when maize with an undersown catch crop of perennial ryegrass and winter rape was sown in rotation 1 and barley with undersown grass–clover was sown in rotation 2. In rotation 1 the ryegrass/winter rape catch

Table 1
The experimental crop rotations. Catch crop in brackets.

	Rotation 1 (33% grassland)	Rotation 2 (67% grassland)
1	Barley/grass–clover	Barley/grass–clover
2	1st yr grass–clover	1st yr grass–clover
3	2nd yr grass–clover	2nd yr grass–clover
4	Barley wholecrop/Ital. ryegrass	3rd yr grass–clover
5	Maize (ryegrass/winter rape)	4th yr grass–clover
6	Lupin (winter rye) or barley/pea wholecrop (ryegrass)	Barley wholecrop/Ital. ryegrass