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Short communication

Nitrate leaching in maize after cultivation of differently managed grass-clover leys on coarse sand in Denmark

E.M. Hansen*, J. Eriksen

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

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ABSTRACT

When grass-clover leys have been ploughed nitrate leaching may increase. However, management of leys before or after ploughing may affect the leaching risk. We examined the effect of cultivating a six year ley, which the last two years had been treated differently (grazing only; spring cut followed by grazing, and spring and autumn cuts with grazing during the summer season only) on nitrate leaching in maize with/without a catch crop (per. ryegrass) and with/without slurry application (135 kg total-N ha^{-1}). An unfertilized barley harvested for silage with a catch crop of Italian ryegrass was used as reference. Shortening the grazing season in the grass-clover ley phase did not affect leaching after ploughing. In the following maize, the use of a perennial ryegrass catch crop in a high-yielding maize crop was not able to reduce nitrate leaching significantly, although leaching and maize yield tended to be lower with the catch crop. In unfertilized treatments both maize yields and nitrate leaching were significantly lower compared with treatments with slurry application. The unfertilized barley undersown with Italian ryegrass reduced leaching much more than unfertilized maize with perennial ryegrass as an undersown catch crop, despite yields of barley and ryegrass being less than half of the dry matter yields of unfertilized maize. The experiment illustrates that growing maize after ploughing of grass-clover leys without environmental consequences is difficult.

1. Introduction

When grass-clover leys are ploughed in to make way for an arable crop there is a high risk of nitrate leaching (e.g. Djurhuus and Olsen, 1997; Eriksen et al., 1999; Hansen et al., 2007; Kayser et al., 2008), especially on sandy soils under humid climatic conditions. In a grass-clover ley, soil nitrogen (N) accumulation as indicated by N surplus – and thus the risk of leaching after ploughing – may increase with grazing compared with a cutting regime (Eriksen, 2001). Thus, reducing the grazing period may be one way to reduce leaching after ploughing a ley. Another option is to increase N uptake in the following crop and adjust fertilizer N application.

Silage maize is a suitable fodder for cows and complements grass-clover in the diet (Wachendorf et al., 2006a,b). New varieties better adapted to the northern European climate have led to a dramatic increase in the area under maize; in Denmark this area was approx. 180.000 ha or 7% of the agricultural area in 2013 (Pedersen, 2014). Thus, silage maize is often grown on dairy farms and fertilized with animal manure and in crop rotations including grass-clover leys. From an environmental point of view, the suitability of maize in these crop rotations has been questioned even when moderate N fertilizer levels are adapted (Müller et al., 2011). Maize has a high N-uptake potential (Herrmann and Taube, 2005; Grignani et al., 2007). Nevertheless, wildly fluctuating levels of residual mineral N have been observed in the soil following the harvest of maize. Roth and Fox (1990) found that at economically optimum N fertilizer rates, soil nitrate accumulation ranged from 41 to 138 kg N/ha in nine N response trials. Sites with a history of manure application generally had higher nitrate accumulation rates than sites without. The study reveals a need for a more precise estimation of soil N release. Besides, there is a need for nitrate reduction strategies including management of grazed grass-clover leys and post-cultivation management in such crop rotations.

We examined the effect of three previous grazing strategies (Hansen et al., 2012) on nitrate leaching after ploughing: grazing only; spring cut followed by grazing, and spring and autumn cuts with grazing during the summer season only. The effect of previous grazing strategies was examined in maize with/without a catch crop and with/without slurry application after spring-ploughing.

* Corresponding author.
E-mail addresses: elly.m.hansen@agro.au.dk (E.M. Hansen), Jorgen.eriksen@agro.au.dk (J. Eriksen).

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As reference was used unfertilized barley (*Hordeum vulgare* L.) harvested for silage with an undersown catch crop of Italian ryegrass (*Lolium multiflorum* Lam.). A brief description of results and photos from the experiment can be found in Hansen and Eriksen (2009).

It was hypothesised that shortening the grazing period would decrease nitrate leaching after ploughing-in of the grass-clover ley. It was further hypothesised that using a catch crop and reducing fertilizer application would reduce leaching compared with fertilized maize without a catch crop.

2. Materials and methods

The experiment was started in spring 2008 after ploughing a six-year-old grass-clover ley on a commercial farm in the southern part of Denmark on a coarse sandy soil with clay, silt, fine sand and coarse sand contents of 53, 73, 208 and 624 g/kg, respectively, at 0–20 cm. The organic matter content was 42 g/kg and soil pH_{CaCl2} was 5.3, exchangeable K 26 mg/kg dry soil and extractable P was 35 mg/kg dry soil. The clay, silt, fine sand and coarse sand contents measured in 20-cm increments at 20–80 cm varied between 31 and 47, 29–50, 107–175 and 701–822 g/kg, respectively. Before the experiment was started, the grass-clover field had been part of an experiment with three grazing strategies from spring 2006–autumn 2007: grazing only; spring cut followed by grazing, and spring and autumn cuts with grazing during the summer season only. For details on this study see Hansen et al. (2012).

Long-term annual mean precipitation and temperature for this site are 858 mm 7.9 °C, respectively. The winter 2008-09 was slightly warmer than the long-term mean and precipitation from December to February was 69 mm less than the long-term mean.

After rotovating and ploughing in early May 2008, five treatments with maize and barley were established in each of three former grazing treatments (Hansen et al., 2012): two unfertilized maize (*Zea mays* L., variety Rosalie, maize maturity class FAO 210) treatments – with and without an undersown catch crop of perennial ryegrass (*Lolium perenne* L.); two fertilized maize treatments – with and without a catch crop; and one unfertilized barley (*Hordeum vulgare* L.) crop with a catch crop of Italian ryegrass (*Lolium multiflorum* Lam.). The five treatments were established in a randomised split-plot design with three previous grazing strategies as the main plot factor, five treatments with maize/barley as the subplot factor and in four replications, i.e. a total of 12 main plots and 60 subplots. The maize subplots measured 3 × 20 m and the barley subplots 6 × 20 m.

Maize was sown on 15 May 2008 and spring barley on 16 May, which in the case of barley was relatively late under the prevailing weather conditions. The fertilized treatments received 135 kg total-N ha^{-1} (78 kg NH_4-N ha^{-1}) in cattle slurry injected into the soil at sowing. The Italian ryegrass catch crops in the barley plots were sown late (8 June) due to very dry soil conditions. Because of a continuous drought, the Italian ryegrass was resown on 17 June, when also perennial ryegrass was sown in maize. On 23 May the barley emerged and the following day maize. Weeds were controlled by a combination of burning, interrow cultivation and springtine weeding. On 19 June the field was irrigated with 25 mm. Harvest of the barley for silage was carried out on 16 July 2008 and two cuts of Italian ryegrass were made on 25 August and 28 October. Harvest of maize for silage was carried out on 28 October 2008. Yield and N-uptake were determined in all subplots.

For calculation of nitrate leaching, soil water isolates were evacuated using porous ceramic cups (Soilmoisture Equipment Corporation, CA, USA) mounted on PVC pipes and installed at 80 cm depth in spring 2008. All reference plots had suction cups installed but the maize plots had only suction cups in three out of four replications (the omitted plots were randomly chosen). In each of the chosen plots two suction cups were installed with 7.5 m distance between cups. In the reference treatment 24 suction cups were installed in total, and 18 suction cups were installed in each of the four maize treatments, i.e. 96 cups in total. The equipment and installation were as described by Djurhuus and Jacobsen (1995). A suction of approximately 70–80 kPa was imposed two to three days before sampling. During this period the suction decreased as a result of water sampling. Generally, sampling was carried out once every other week, except in periods of drought or frost. The soil water isolates from each pair of ceramic cups were bulked and analysed as described in Hansen et al. (2012).

Values for precipitation, air temperature and potential evapotranspiration were measured daily by an automatic meteorological station situated 2 km away. Percolation was calculated using the model EVACROP 3.0, which is an updated version of EVACROP 1.5 (Olesen and Heidmann, 1990).

Nitrate leaching was estimated using the trapezoidal rule (Lord and Shepherd, 1993), assuming that nitrate concentrations in the extracted soil water represented average flux concentrations. The accumulated leaching was calculated from 1 April 2008 to 30 March 2009.

As suction cups for estimating nitrate leaching were not installed in all subplots, analyses of variance for the effect of previous grazing treatments and maize treatments were carried out according to the split-plot design with missing observations. As yield and N-uptake in maize were measured in all subplots, analyses of variance for the effect of previous grazing treatments and maize treatments were carried out according to the split-plot design. The variables were analysed by general linear mixed models (e.g. Searle, 1971) in SAS (SAS Institute, 1996), assuming that the errors of each stratum had a normal distribution with mean zero and constant variance.

3. Results and discussion

3.1. Maize yields

Maize benefited from warm weather during May and June 2008. In the southern part of Denmark the accumulated maize heat units (from 15 April to 15 October) were 18% higher than the 20-year average, resulting generally in high yields (Mikkelsen et al., 2008). There were no significant effects of the previous grazing strategy on maize yields or N-uptake (Table 1).

Maize responded to fertilization with a 2.8 Mg ha^{-1} higher yield when applying 78 kg ha^{-1} NH_4-N (Table 2). A dry matter

Table 1
Effect of grazing strategy in previous years' pasture on maize yield, N uptake and nitrate leaching following maize cropping. (There were no significant effects of grazing strategy).

Previous grazing strategy	Maize yield Mg DM ha^{-1}	Maize N uptake kg N ha^{-1}	Nitrate leaching kg N ha^{-1}
Grazing only	14.6	157	79
Spring cut—grazing	14.2	156	79
Spring cut—grazing—autumn cut	14.3	160	94