Nitrate leaching from arable crop rotations in organic farming

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Abstract

Nitrate leaching from crop rotations for organic grain production were investigated in a field experiment on different soil types in Denmark from 1997 to 2002. Three experimental factors were included in the experiment in a factorial design: 1) proportion of grass-clover and pulses in the rotation, 2) cover crop (with and without), and 3) manure (with and without). Two four-course rotations were compared. They had one year of grass-clover as a green manure crop, either followed by spring wheat or by winter wheat. The nitrate leaching was measured using ceramic suction cells. The nitrate leaching did not differ between the rotations, as a change in leaching following the grass-clover was compensated by a reverse effect in the grain crops. Use of cover crops reduced N leaching by 23 to 38% at crop rotation level with the highest reduction on the coarse sandy soil. Simulation of N leaching using the FASSET model showed that a practice of using part of the summer period in the grass-clover as a bare fallow to control couch grass could increase leaching substantially, in particular on the sandy soil.

Keywords: organic farming, crop rotation, cover crops, manure, nitrate leaching.

Introduction

The proportion of organic farming in Denmark has increased considerably over the past decade, and the organic farmed area constituted 6.4 % of the agricultural area in 2001 (Anonymous, 2002). This organic farming was during the 1990's mainly based on dairy farms with a high percentage of grass-clover and fodder crops in the crop rotation in combination with a stock of ruminant animals. However, during the last few years, many Danish arable farms have converted to organic farming.

The increase in organic farming is partly explained by financial support from the Danish government and the EU through agri-environmental schemes (Stockdale et al., 2001). In Denmark many of these schemes are directed towards protecting groundwater and surface waters from pollution with nitrates and pesticides. In the Aquatic Action Plan II agreed by the Danish parliament in 1998 organic farming has been included as one of the measures to reduce nitrate leaching from Danish agriculture (Grant et al., 2000). However, large uncertainties remain in the estimates of nitrate leaching from organic farming (Hansen et al., 2000).

The aim of the study presented here was to quantify the nitrate leaching from arable organic farming as affected by use of cover crops and manure application. Additionally the effect of crop rotation design and the interaction with soil and climate was included.

Materials and methods

The crop rotation experiment was designed as a factorial experiment with three factors (Olesen et al., 2000). The experimental factors were (1) fraction of grass-clover and pulses in the rotation (crop rotation), (2) cover crop (with and without cover crop) and (3) manure (with and without animal manure applied as slurry).

Results are presented for three sites representing different soil types and climate regions in Denmark. Jyndevad is located in Southern Jutland and represents a coarse sandy soil with an normal annual rainfall of 964 mm. Foulum is located in Central Jutland on a loamy sand with an annual rainfall of 704 mm. Flakkebjerg is located in Western Zealand on a sandy loam with an annual rainfall of 626 mm. The soil properties of the ploughing layer are shown for all sites in Table 1 and the climate during the experimental period 1998 to 2001 is shown in Table 2.

Table 1. Soil texture, content of organic C and total N, and pH in the top 25 cm of the soil at the three experimental sites in autumn 1996 prior to the onset of the experiment. pH is taken as pH($CaCl_2$)+0.5. Soil minerals, organic C and total N are measured in per cent of dry soil (Olesen et al., 2000).

Location	Clay < 2 μm	Silt 2-20 μm	Fine sand 20-200 μm	Coarse sand 200-2000 μm	Organic C	Total N	pH
Jyndevad	4.5	2.4	18.0	73.1	1.17	0.085	6.1
Foulum	8.8	13.3	47.0	27.2	2.29	0.175	6.5
Flakkebjerg	15.5	12.4	47.4	22.9	1.01	0.107	7.4

Tabel 2. Average annual temperature, precipitation and simulated drainage in rotation 2 during the period 1998 to 2001.

Location	Temperature (°C)	Precipitation (mm)	Drainage (mm)
Jyndevad	9.0	962	743
Foulum	8.1	716	415
Flakkebjerg	8.7	654	304

Four four-year crop rotations were compared (Olesen et al., 2000). However, results from two of the rotations are presented here (Table 3). These rotations differ with respect to the cereal following the grass-clover green manure crop. The grass-clover crop was followed by spring wheat in rotation 1, and by winter wheat in rotation 2. Crop rotation 1 was only represented at Jyndevad. Minor changes in the crop choice were made in 2001 (Table 3). All fields in all rotations were represented every year in two replicates. The plot size was 378, 216 and 169 m^2 at Jyndevad, Foulum and Flakkebjerg, respectively.

The undersown cover crops were either a pure stand of perennial ryegrass (*Lolium perenne*) or a mixture of perennial ryegrass and four clover species (hop medic *Medicago lupulina*, trefoil *Lotus corniculatus*, serradella *Ornithopus sativus* and subterranean clover *Trifolium subterraneum*). In 2001 chicory (*Chicorium intybius*) was also included with ryegrass in all cover crop mixtures. These cover crops were undersown in the cereal or pulse crop in spring. In the spring cereals the sowing took place on the same day as the cereal or pulse crop was sown, except for Jyndevad where sowing was delayed in order to permit weed harrowing in the rotations with cover crops. In the winter cereals the cover crop was sown in April just after the first weed harrowing.

The plots receiving manure were supplied with anaerobically stored slurry at rates corresponding to 40% of the N demand of the specific rotation. The N demand was based on a Danish national standard (Plantedirektoratet, 1997). The N demands from grass-clover and from peas/barley were set to nil. Cereal crops received slurry corresponding to a target of 50 kg NH_4-N/ha.

Table 3. Structure of the two different four-course crop rotations with and without cover crops. The sign ':' indicates that a grass-clover ley, a clover or a ryegrass/clover cover crop is established in a crop of cereals or pulses. The sign '/' indicates a mixture of peas and spring barley.

Cover crop	Entry point	Rotation 1	Rotation 2
Without	1	S. barley:ley	S. barley:ley
	2	Grass-clover	Grass-clover
	3	Spring wheat[1]	Winter wheat[3]
	4	Lupin[2]	Peas/barley[4]
With	1	S. barley:ley	S. barley:ley
	2	Grass-clover	Grass-clover
	3	S. wheat:Grass[1]	W. wheat:Grass[3]
	4	Lupin:Grass-clover[2]	Peas/barley:Grass-clover[4]

[1]: S. oats in 2001, [2]: Peas/barley in 2001, [3]: Winter rye at Jyndevad in 2001, [4]: Lupin in 2001.

The experimental treatments were started in 1997. In 1996 a spring barley crop undersown with grass-clover was grown at all sites. No pesticides were applied in 1996. All locations were previously under conventional cropping. The crops during the five years prior to initiation of the experiment included different arable crops at Jyndevad and Flakkebjerg, and grass-clover and cereal crops at Foulum (Djurhuus & Olesen, 2000).

The experiment was unirrigated at all sites except at Jyndevad. All straw and grass-clover production was incorporated or left on the soil in all treatments. In 2000 and 2001 the grass-clover at Jyndevad was ploughed in early June (rotation 1) or late June (rotation 2) followed by harrowing several times to control couch grass (*Elymus repens*). In rotation 1 this bare fallow was followed by sowing of a cover crop of winter rye, winter vetch and rapeseed in mid July. In rotation 2 the following winter rye was sown mid August.

Leaching of nitrogen was measured using porous ceramic cups in selected plots. Four suction cells are permanently installed in each of these plots at a depth of 80 cm at Jyndevad and 100 cm at the other sites. The leaching is measured at all sites in those plots that corresponded to entry point one in the rotations when the experiment was initiated in 1997 (Table 3). At Foulum and Flakkebjerg leaching was additionally measured in all plots in rotation 2 without cover crops and with fertiliser. At Jyndevad leaching was measured in all plots with the manure treatment. Every 1-4 weeks, depending on site and precipitation, a suction of approximately 80 kPa was applied 3 days prior to sampling. The samples were bulked with equal sample volume from each of the four replicates per plot before analysis of nitrate concentrations.

The water balance was calculated using the Evacrop model (Olesen & Heidmann, 1990) for which inputs were daily meteorological measurements (precipitation, temperature and potential evapotranspiration). The observed precipitation at 1.5 m height was corrected to ground level using the methodology of Plauborg et al. (2002). Nitrate leaching was estimated using the trapezoidal rule (Lord & Shepherd, 1993), assuming that nitrate concentrations in the extracted soil water represents flux concentrations on the observation dates, and that concentrations change between measurement points in proportion to drainage. The accumulated annual leaching was calculated from 1 April to 31 March. The mean leaching was calculated for the four years from April 1998 to March 2002.

The FASSET soil-plant-atmosphere model (Olesen et al., 2002) was used to simulate the nitrate leaching from crop rotations 1 and 2 in all combinations with and without cover crops and with and without manure application. The simulations were also performed for soil and climate data from Foulum and Flakkebjerg. The observed management at the Jyndevad site from 1996 to 2002 was used for all simulations. However, irrigation was omitted at these two sites. The annual leaching was calculated from 1 April to 31 March and results are presented for the four years from April 1998 to March 2002.

Results and discussion

The nitrate-N concentration measured in the suction cups showed considerably larger and quicker fluctuations over time at Jyndevad compared with both Foulum and Flakkebjerg (Figure 1). This reflects the low retention of water and nutrients in the coarse sandy soil. The nitrate-N concentration tended to decrease over time at Foulum and to increase at Flakkebjerg. This may be an effect of the site history prior to onset of the experiment, which included a large proportion of grass crops at Foulum and continuous cereal cropping at Flakkebjerg. This thus indicates that soil N fertility plays an important role for the general or background N leaching at a given site.

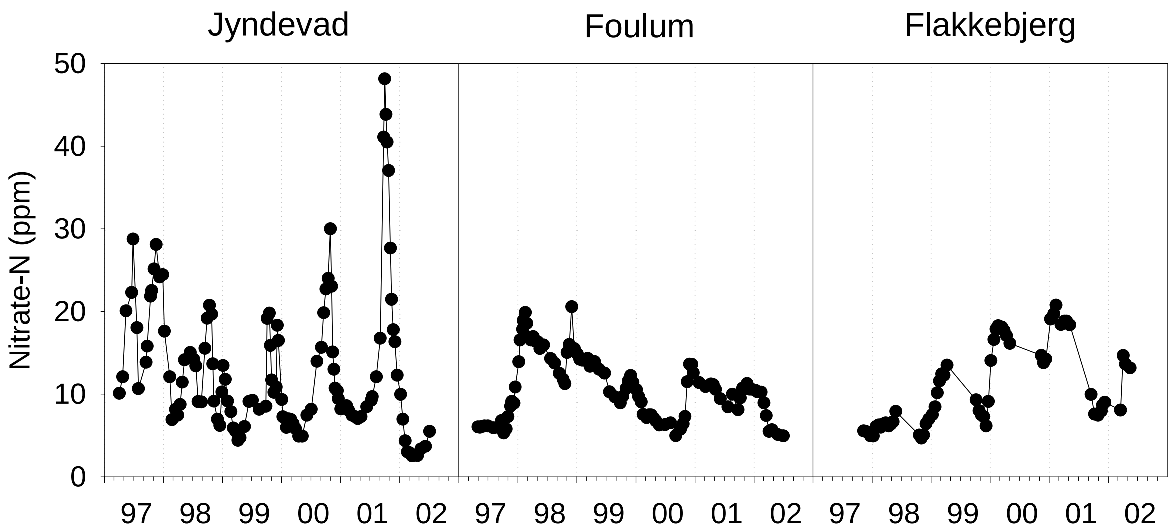

Figure 1. Mean measured nitrate-N concentration in soil solution from in rotation 2 without cover crops and with manure application.

There were only small effects of manure application on nitrate leaching (data not shown). On average manure application increased N leaching by 1 kg N/ha/yr. The results also showed no difference between crop rotations 1 and 2 in N leaching (Figure 2). There was a substantial effect of cover crops on N leaching. Cover crops thus reduced N leaching by 38% at Jyndevad and 23 to 25% at Foulum and Flakkebjerg (Figure 2). The reduction from cover crops was identical at Jyndevad in rotations 1 and 2 at rotation level (Figure 2). The magnitude of the leaching reduction is in line with other studies on cover crops in Denmark, which have shown the highest reductions on sandy soils and least reduction on loamy soils (Hansen & Djurhuus, 1997).

The pattern of the N-leaching was substantially different in the two rotations (Figure 3). In rotation 2 the highest leaching occurred following the ploughing of grass-clover in the autumn prior to winter wheat, whereas leaching peaked after the pulse crop in rotation 1. Other studies have also shown substantial N leaching following the cultivation of grass-clover leys, in particular with winter cereals (Watson et al., 1993; Djurhuus & Olsen, 1997).

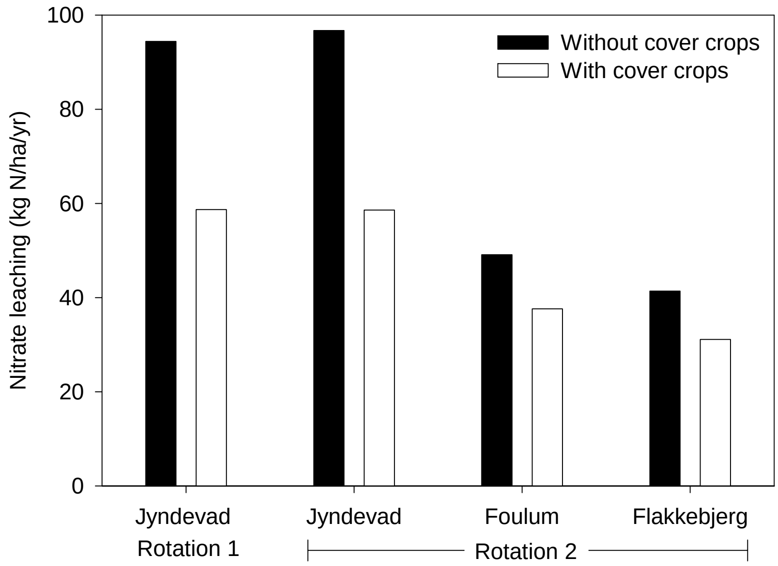

Figure 2. Mean annual measured nitrate leaching for rotations 1 and 2 at the three sites for the period 1998 to 2002.

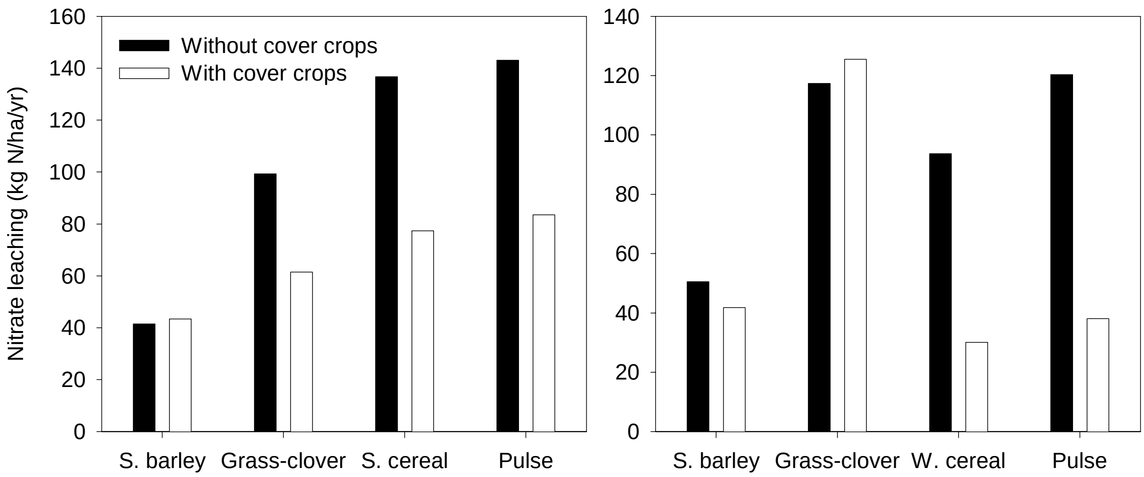

Figure 3. Mean annual measured nitrate leaching in rotations 1 (left) and 2 (right) at Jyndevad with manure application and with and without cover crops for the period 1998 to 2002.

The cover crops effectively reduced nitrate-N concentration during the winter period (Figure 4). However, the nitrate-N concentration at Jyndevad was high at Jyndevad in the autumn until the grass cover crop had grown to fully cover the ground. This did not happen until late October after which the nitrate-N concentrations were reduced markedly. This suggests a need for cover crops that are more effective in taking up soil nitrogen during the autumn period. Faster growing undersown grass crops may achieve this. However, such effective cover crops may also compete with the cereal crop thus reducing yields.

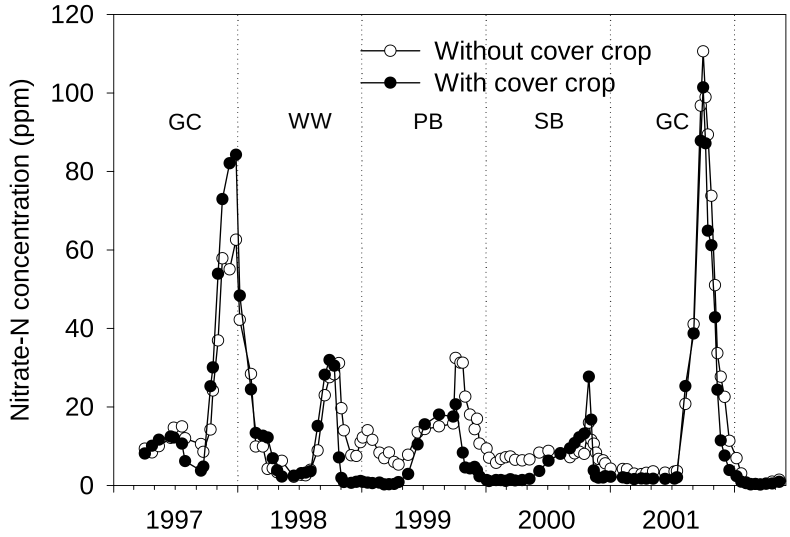

Figure 4. Mean measured nitrate-N concentration in soil solution at Jyndevad in rotation 2 with manure application in treatments with and without cover crop. The crop codes shown are GC: grass-clover, WW: winter wheat, PB: pea/barley, and SB: spring barley.

The simulated N leaching showed only small differences between the three sites using the observed management from Jyndevad (Figure 5). However, N leaching was substantially reduced following grass-clover at Foulum and Flakkebjerg. The simulations also showed a substantial effect of cover crops on N leaching. Surprisingly there was no difference between the two rotations in N leaching from the grass-clover crop, despite the fact that grass-clover was followed by spring wheat in rotation 1 and winter wheat in rotation 2. This may be explained by the fact that a bare summer fallow was applied to the grass-clover in 2000 and 2001. In the simulations this increased N leaching more in rotation 1 than in rotation 2, which may have been an effect of differences in the timing of the bare fallow between the two rotations. As the bare fallow and harrowing during autumn offers some of the few possibilities of controlling perennial weeds in organic farming, this indicates the dilemma between obtaining good weed control and reducing N leaching losses.

Conclusions

There was only a small effect of using either a winter cereal or a spring cereal on nitrate leaching at rotation level. Using a spring cereal reduced N leaching following the grass-clover, but this was compensated by a higher leaching in the following grain crops. Use of cover crops reduced N leaching by 23 to 38% at crop rotation level with the highest reduction on the coarse sandy soil. Simulation results showed that a practice of using part of the summer period in the grass-clover for a bare fallow to control couch grass could increase leaching substantially, in particular on the sandy soil.

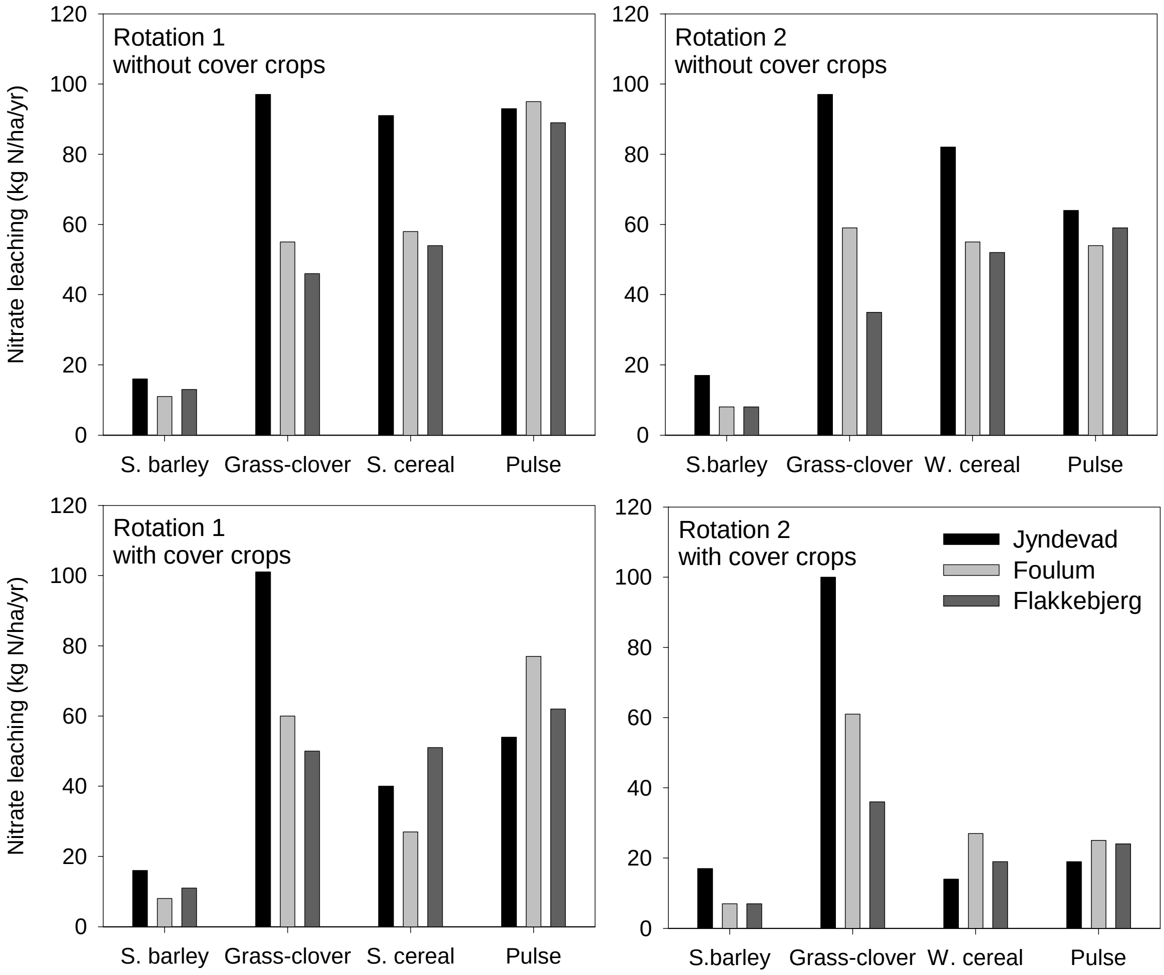

Figure 5. Simulated nitrate leaching for crop rotations 1 and 2 with and without cover crops and an average over four seasons from years 1998 to 2002.

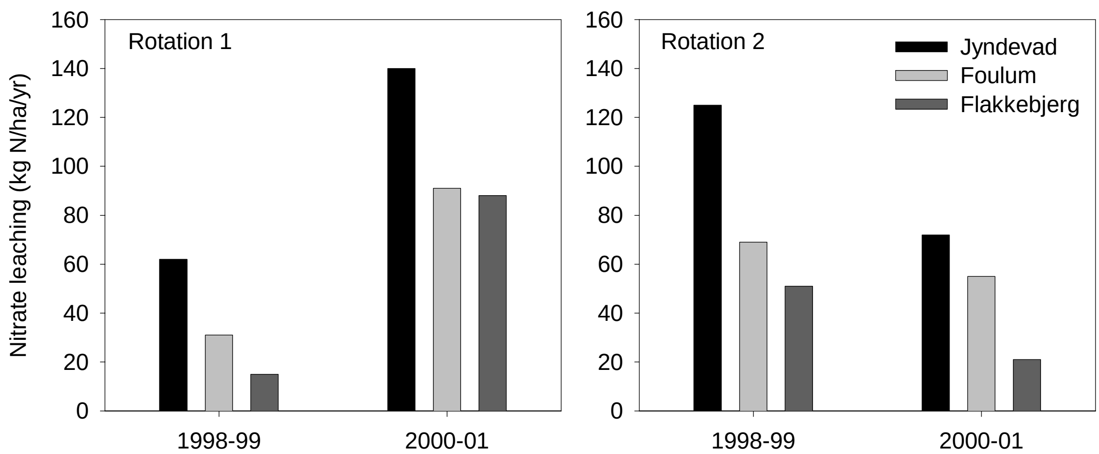

Figure 6. Simulated nitrate leaching for grass-clover from the two periods (each two years) in rotations 1 and 2. The grass-clover during the first period was managed as a green manure crop, whereas the grass-clover during the second period was managed as a bare fallow during the summer period to control couch grass.

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