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Can non-inversion tillage and straw retainment reduce N leaching in cereal-based crop rotations?

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ABSTRACT

Finding ways of reducing nitrate leaching in Northern Europe has become an extremely important task, especially under the projected climate changes that are expected to exacerbate the problem. To this end, two field experiments were established under temperate coastal climate conditions to evaluate the effect of tillage, straw retainment and cropping sequences, including cover crops, on nitrate leaching. The experiments were established in autumn 2002 on a loamy sand with 92 g clay kg^{-1} and a sandy loam with 147 g clay kg^{-1}. The tillage treatments were stubble cultivation to 8–10 cm or 3–4 cm, direct drilling, or ploughing to 20 cm. The hypothesis was that (i) decreasing soil tillage intensity would decrease leaching compared to ploughing, (ii) leaving straw in the field would decrease leaching compared to removing straw, and (iii) a spring/winter crop rotation with catch crops would be more efficient in reducing nitrate leaching than a winter crop rotation. Overall, we were not able to confirm the three hypotheses. The effect of soil tillage on leaching might be blurred because the studied crop rotations had a high proportion of winter crops and because catch crops were grown whenever the alternative would have been bare soil in autumn and winter. The spring/winter crop rotation with catch crops was not found to be more efficient in reducing nitrate leaching than the winter crop rotation. In contrast, in a single year the winter crop rotation showed significantly lower leaching than the spring/winter crop rotations, probably due to the spring/winter crop rotation including peas, which may be considered a high-risk crop. Our study highlights that management practices that improve biomass production throughout the year are crucial in order to tighten the nitrogen cycle and thereby reduce nitrate leaching.

1. Introduction

Nitrate leaching has been of major concern in Northern Europe during recent decades due to its effect on human health and the environment. This has led to the introduction of EU (e.g. European Community, 1998, 2000, 2006) and national legislation, e.g. Danish Action Plans I, II and III for the Aquatic Environment (Dalgaard et al., 2005).

In Northern Europe climate changes can increase the risk of nitrate leaching unless preventative measures are taken. Warmer temperatures and higher CO_2 concentrations may lead to higher demands for nitrogen (N) fertiliser (Olesen and Bindi, 2002; Olesen et al., 2007), but extreme weather events, such as heavy storms or droughts, will make fertiliser recommendations less reliable than in a stable climate. Besides, a warmer climate may result in increased turnover of soil organic matter especially during winter (Olesen et al., 2004b), which may further increase the risk of nitrate leaching. Cost-efficient strategies to tighten the N cycle are therefore urgently needed. Such strategies should aim to minimise N availability when there is minimal root uptake and risk of percolation. Viable strategies may include non-inversion tillage, straw retainment and cropping sequences that include cover crops (Christensen, 2004).

Surprisingly few studies have been published on the effect of tillage on N mineralisation and nitrate leaching in temperate coastal climates. A number of studies have shown that over-winter losses of nitrate can be reduced by up to 25% when intensive autumn tillage is omitted before sowing a spring crop (Hansen and Djurhuus, 1997; Stenberg et al., 1999; Thomsen, 2005).

Mixed results have been found when comparing different intensities of tillage before sowing a spring crop (literature quoted by Hansen and Djurhuus, 1997; Hooker et al., 2008). It is remarkable that the quoted studies were carried out in cropping systems based on spring-sown crops when currently autumn-sown crops dominate in many temperate coastal climate areas such as Northwestern Europe. Postponement of intensive tillage to the spring is not an option when growing autumn-sown crops. Thus, it is highly relevant to investigate the effect of tillage on

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nitrate leaching in cropping systems with a high proportion of winter crops.

Retainment of straw, i.e. plant material with a high C:N ratio, is expected to immobilise a significant amount of N in the autumn. Experiments under controlled conditions have shown that 1–3 kg N per Mg straw can be immobilised (Christensen, 1985). The immobilisation of N was also found to depend on the placement of the straw. Straw left on the soil surface decomposes more slowly than when incorporated (Christensen, 1986). This means that there is a slower decomposition of straw in untilled than in tilled soil. In practice, immobilisation of N is only one aspect of the complex effect of straw retainment on crop growth and N utilisation in different tillage systems. There is a lack of studies investigating the effects of straw retainment at cropping system level.

In order to examine N leaching in ploughed and non-inversion tillage systems in Denmark an experiment was started in autumn 2002 on a sandy loam and a loamy sand soil. The experiment was placed on a previously ploughed soil in order to compare the transition phase from ploughing to non-ploughing with continuous ploughing. The overall aim was to study the effect of soil tillage intensity and crop rotation on several aspects of crop development, environment and economics. This paper deals with the aspect of N leaching as affected by tillage, straw management and crop rotation in the years 2003–06. We hypothesized that decreasing soil tillage intensity would decrease mineralisation and thus decrease leaching compared to ploughing. We also expected leaching to be lower where straw was retained in the field due to immobilisation of N. In addition, we wanted to evaluate differences in leaching between a winter crop-based rotation and a spring/winter crop rotation.

2. Materials and methods

2.1. Experimental sites

The experiment was established on sandy loams at Foulum (56°30′N, 9°35′E) and at Flakkebjerg (55°19′N, 11°23′E), Denmark. Both soils are based on ground morainic deposits from the last glaciation. The soil at Foulum is classified as a Mollic Luvisol and the soil at Flakkebjerg as a Glossic Phaeozem according to the WRB (FAO) system (Krogh and Greve, 1999). The clay (<2 μm), silt (2–20 μm), fine sand (20–200 μm) and coarse sand (200–2000 μm) contents of the soil (0–25 cm) at Foulum were 92, 126, 444, 307 g kg^{-1} and at Flakkebjerg 147, 137, 426 and 270 g kg^{-1}, respectively. The organic carbon content at Foulum was 18 g kg^{-1} and at Flakkebjerg 12 g kg^{-1}.

The mean annual temperature (1961–90) at Foulum and Flakkebjerg is 7.3 °C and 7.7 °C, respectively, and annual precipitation is 626 and 558 mm, respectively (Olesen, 1993). Precipitation and average temperatures for 3-month periods are shown in Table 1.

Soil physical properties (e.g. bulk density and penetration resistance) in the different tillage systems were reported by Munkholm et al. (2008). In autumn 2005 the bulk density at Foulum and Flakkebjerg was 1.25 and 1.31 g cm^{-3}, respectively in ploughed plots. In short, it was found that the former ploughed layer in plots with non-inversion tillage was noticeably compacted as indicated by increasing bulk density and penetration resistance.

Table 2
Crop rotations (R2–R4) and straw management.

	R2	R3	R4
2003	W. barley	W. wheat/CC	W. wheat/CC
2004	W. rape	S. barley/CC	S. barley/CC
2005	W. wheat	Pea	Pea
2006	W. wheat	W. wheat	W. wheat
Straw	Left	Removed	Left

CC, catch crop of undersown perennial ryegrass.

2.2. Treatments

The experiment was established in autumn 2002 as part of a larger experiment. The actual design was a randomized complete split-plot design in four replications with two factors: crop rotation as main plot and soil tillage as sub-plots. In this study we used rotations R2, R3 and R4 (Table 2).

In crop rotation R2 and R4, straw was cut and retained after harvest, in R3 straw was removed. The catch crop in winter wheat and spring barley (Table 2) was perennial ryegrass (*Lolium perenne* L.), which was undersown in spring. Before the experiment was established in autumn 2002 the field had been cropped and cultivated according to normal agricultural practices. In 2002 the crop was oat (*Avena sativa* L.).

The tillage systems were direct drilling (D), harrowing to 3–4 cm (H_{3-4}) or 8–10 cm (H_{8-10}) and ploughing (P). The H_{8-10} and H_{3-4} treatments were only stubble cultivated. A rotary harrow (Bomford Dyna Drive) was used in H_{8-10} and H_{3-4}, but in Foulum a spring-tine harrow (CMN maskintec A/S) was used in H_{3-4} when the soil was not too dry. The crops were sown with a single-disc drill (Gaspardo Scan-Seeder DP300) in D, H_{3-4} and H_{8-10} and with a traditional seed drill (Nordsten Lift-o-matic CLH300) in P. In all treatments crops were sown at the same row distance of 17.5 cm.

At Flakkebjerg the P treatment was ploughed in late autumn prior to the sowing of spring crops. Catch crops in the non-ploughed treatments were killed by herbicide around 1 November and 30 kg N ha^{-1} of the fertiliser recommendation for winter rape was applied in autumn. All other crops received the total amount of manure/fertiliser in spring. At Foulum the catch crops in all treatments were killed by herbicides around 1 November, and the soil was ploughed in spring. All crops except peas were fertilised with 100 kg NH_4–N ha^{-1} in pig slurry and the rest of the fertiliser recommendation was supplied as mineral fertiliser (Table 3).

Analyses of slurry were carried out prior to application and the N content was used to calculate an application rate to meet a target of 100 kg NH_4–N ha^{-1}. At spreading, slurry samples were collected to determine the actual N content. The slurry was applied with

Table 1
Precipitation (P) and average temperature (T) for 3-month periods at Foulum and Flakkebjerg meteorological stations.

	Long-term mean 1961–90				2002–03				2003–04				2004–05			
	Foulum		Flakkebjerg		Foulum		Flakkebjerg		Foulum		Flakkebjerg		Foulum		Flakkebjerg	
	P	T	P	T	P	T	P	T	P	T	P	T	P	T	P	T
December–February	115	0.0	118	0.2	79	−0.7	60	−0.4	144	1.3	155	1.5	143	2.1	118	2.3
March–May	121	5.9	112	6.2	136	7.0	116	7.6	129	7.2	109	7.4	117	6.2	94	6.5
June–August	185	14.9	161	15.5	172	16.5	169	16.9	204	14.8	275	15.0	188	14.9	194	14.3
September–November	205	8.3	167	8.9	125	8.3	91	8.7	239	8.8	155	9.4	126	9.7	101	10.2
All years, December–November	626	7.3	558	7.7	512	7.8	433	8.2	716	8.0	694	8.3	574	8.2	460	8.6

Precipitation measured at 1.5-m height.