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Effects of catch crop type and root depth on nitrogen leaching and yield of spring barley

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ABSTRACT

Catch crop root growth and nitrogen (N) uptake from both shallow and deeper soil layers are important for N management in arable farming systems, particularly in climates where excess winter precipitation induces N leaching. We simulated the root growth and biomass yield of three common catch crops [chicory (*Cichorium intybus* L.), fodder radish (*Raphanus sativus* L.) and perennial ryegrass (*Lolium perenne* L.)] and their effect on soil mineral N (NO_3^- and NH_4^+) in different soil layers by using the FASSET model. The simulated results of catch crop biomass and root growth and mineral N in the soil profile were validated against two years (2006 and 2007) of observations taken in Foulum and Flakkebjerg, Denmark. Once the model was validated, the effect of these three catch crops on N leaching and grain yield of spring barley monoculture was simulated for 30 years.

Both measurements and model simulations showed that fodder radish developed the deepest root system and depleted N from deeper soil layers than chicory and ryegrass. Thirty years of simulations showed that the system with ryegrass catch crop had a smaller amount of N leaching from 1 m depth than the system with other catch crops and without catch crops. However, estimated total N leached at 2 m soil depth was smallest in the system with fodder radish followed by the system with chicory, indicating that these catch crops are capable of taking soil N also from below 1 m depth. On average, the system with fodder radish was estimated to decrease N leaching from 2 m depth by 79% compared with the system without catch crops, resulting in an average spring barley grain yield increase of 2%. Chicory and ryegrass correspondingly contributed to reducing N leaching from 2 m soil depths by 71 and 67% when compared with the system without catch crop. The system planted to chicory and ryegrass catch crops decreased spring barley yield by 3 and 5%, respectively, probably because of competition between the cereal crop and the catch crop for N, water and light. Discontinuation of catch crop use increased slightly not only the spring barley yield but also N leaching by about 17%. Inclusion of catch crop in the system increased soil total N and C content by 16–46 kg N ha^{-1} year^{-1} and 170–498 kg C ha^{-1} year^{-1}, respectively, as compared to the system without catch crop. The increase was largest with the use of ryegrass catch crop.

1. Introduction

In arable cropping systems, large amounts of nitrogen (N) that remain in soil or are mineralized after harvest may be leached before the next crop is established. In Northern Europe, surplus winter precipitation often induces leaching of considerable amounts of N to the environment (Pedersen et al., 2009). One possible method of reducing this problem is to grow catch crops after the main crop and allow the former to grow during off-season. Catch crops take up and retain surplus N left in the soil that would otherwise be lost from the root zone by leaching (Thorup-Kristensen et al., 2003). The N retained by the catch crop is mainly returned to the surface soil layer when it is killed, either during winter frost or by spring tillage. In this way, the catch crop acts as fertilizer for the next crop in the rotation. Due to these beneficial effects, catch crop is an important management tool in arable cropping systems for reducing N losses and increasing N retention and crop N supply.

The risk of nitrate leaching differs greatly between soil types, precipitation regimes and nutrient management strategies (Thorup-Kristensen et al., 2003). For example, a combination of high precipitation and low water holding capacity of soil leads to higher N leaching than under low precipitation and/or soils with higher water holding capacity (Askegaard and Eriksen, 2007). Presumably, different types of catch crop would need to be used for

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Table 1
Particle size fraction, organic matter percent, bulk density and C:N ratio of the soils at the two study sites for different depths.

Soil depth (cm)	Clay (<2 μm)	Silt 2 (20 μm)	Fine sand (20–200 μm)	Coarse sand (200–2000 μm)	Organic matter (%)	Bulk density ($g\,cm^{-3}$)	C:N ratio
Foulum							
0–25	8.8	13.3	47.4	27.2	3.8	1.43	13.1
25–50	11.2	12.9	46.2	27.6	2.1	1.56	13.3
50–75	13.5	11.9	47.0	26.8	0.7	1.61	9.4
75–100	14.4	11.3	46.4	27.5	0.4	1.66	7.0
Flakkebjerg							
0–25	15.5	12.4	47.4	22.9	1.7	1.70	9.9
25–50	17.2	12.6	46.7	21.7	1.1	1.68	9.1
50–75	19.0	12.1	45.5	20.9	0.6	1.67	8.1
75–100	19.4	11.9	44.1	20.5	0.4	1.67	7.0

N leaching abatement (Vos et al., 1998). In addition, the efficiency of catch crops to retain N differs depending on the factors such as the length of the growing season and the capacity of the catch crop to take up N, which is affected by root growth. For example, when cruciferous catch crops have too short growing season either due to late sowing or poor germination, their ability to deplete soil N is reduced (Vos and van der Putten, 1997). To be able to deplete the soil of inorganic N, a catch crop must develop its root system capable to be in contact with the available N in the soil. Some studies (e.g. Aufhammer et al., 1992; Thorup-Kristensen, 2001) have shown that soil N depletion by catch crop species is highly linked to their rooting depth, thereby stressing the importance of studying the root growth of different catch crop species to understand N dynamics and options for reducing N leaching. For example, Thorup-Kristensen (2001) estimated that after 1000 day degrees of sowing, a crucifer catch crop would have a rooting depth of 1.5 m, winter rye and oats 0.9–1.0 m and ryegrass only 0.6 m. Laine et al. (1993), on the other hand, found that crucifer catch crops had much higher maximum nitrate uptake rates than monocots and maximum uptake rate increased with shoot/root ratio, suggesting a regulatory role for the shoots in nitrate uptake. Karlsson-Strese et al. (1998) tested many species and genotypes of potential catch crops and found that the ryegrass species, most commonly used for under-sown catch crops, were not optimal, as they competed too strongly with the main crop.

In most experimental and model simulation studies of N leaching losses, the bottom of the rooting zone has been assumed to be located at 0.8–1.0 m depth, and it has been assumed that N leached below this depth is lost (e.g. Askegaard et al., 2005; Vos et al., 1998). However, studies have shown that many species extend their roots much deeper than 1.0 m. For instance, the average maximum rooting depth of arable crops on a global scale is estimated to be 2 m (Canadell et al., 1996). So, the question is whether N leached below 1 m depth is really lost from the agro-ecosystem. For example, Kristensen and Thorup-Kristensen (2004), by studying the root growth and N uptake of three different catch crops, reported fodder radish root growth and N depletion down to 2.5 m. Deep-rooted catch crops can be used to recycle the N left in deeper soil layer by the preceding crop. Such understanding is important in designing cropping systems that better retain and recycle N. To our knowledge, there are very few studies on root depth and root frequency of catch crops and their efficiency of N depletion from deeper soil layer (e.g. Kristensen and Thorup-Kristensen, 2004; Thorup-Kristensen, 2001).

The objectives of this study were to quantify the extent to which different types of catch crops could recover N that was already leached below 1 m depth and the effect of these catch crops on N retention and crop yield. We examined, from field observations and model simulation, the root growth and above-ground biomass of three commonly used catch crops [chicory (*Cichorium intybus* L.), fodder radish (*Raphanus sativus* L.) and perennial ryegrass (*Lolium perenne* L.)] and their effect on N depletion in different soil layers and on spring barley (*Hordeum vulgare* L.) yield.

2. Materials and methods

2.1. Study site

This study was conducted within two long-term crop rotation experiments initiated in 1997 at Foulum (56°30′ N, 98°04′ E) and Flakkebjerg (55°19′ N, 11°23′ E) in Denmark. The experimental stations at Foulum and Flakkebjerg have Typic Hapludult and Typic Agrudalf soils, respectively. The soil and climatic characteristics of the study sites are summarized in Tables 1 and 2, respectively.

2.2. Experimental design, treatment structure and management

The details of the long-term experiments can be found in Olesen et al. (2000). Briefly, the experiment consisted of a four-course crop rotation of winter wheat (*Triticum aestivum* L.), spring barley, faba

Table 2
Monthly temperature and precipitation during catch crop growing season of 2006 and 2007 and for the long-term averages for the period (1961–1990) in the study sites (Olesen et al., 2000).

	Temperature (°C)			Precipitation (mm)		
	2006	2007	Long-term average	2006	2007	Long-term average
Foulum						
August	16.5	16.2	15.1	98	41	71
September	15.7	12.2	12.1	44	93	75
October	11.4	7.7	8.5	114	36	76
November	7.4	4.4	4.2	59	41	78
Flakkebjerg						
August	16.8	17.3	15.9	114	41	60
September	16.1	13.4	12.9	46	45	65
October	12.1	8.8	9.2	73	3	59
November	7.7	5.0	4.7	61	2	62