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Long-term fate of nitrogen uptake in catch crops

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Abstract

The long-term effects of undersowing a ryegrass catch crop in cereals was analysed with the FASSET simulation model. The model was tested on a 28-year field experiment with ryegrass catch crops in spring barley. The experiment included treatments with nitrogen (N) fertiliser rates, catch crop use and timing of tillage. The modelled effects of these treatments generally agreed with observations on crop production, soil carbon, soil nitrogen and nitrate leaching. Both the observations and the simulations predicted a yield increase of 7 kg N ha^{-1} and an increase in nitrate leaching of 13 kg N ha^{-1} due to a prehistory of 24 years with continuous use of catch crops compared to a prehistory without catch crops.

A range of scenarios was constructed to evaluate the fate of the reduced nitrate leaching on crop N uptake, N leaching, gaseous emissions and change in soil organic N, and how this fate interacts with soils and climate and management. These scenarios showed that 22–30% of the reduced nitrate leaching was subsequently leached during the following decades after termination of catch crop use. Between 35 and 40% of the reduced nitrate leaching was harvested in cereals. The exact distribution depended primarily on the soil texture. The scenarios showed that effects of catch crops should be evaluated on the long-term rather than consider short-term effects only.

Keywords: Catch crops; Cover crops; Dynamic simulation; Modelling; Nitrate leaching; Residual effects

1. Introduction

Nutrient pollution of the aquatic environment, especially nitrate pollution of surface- and groundwater, is regarded as a significant environmental problem in Europe. The annual mean N concentration in about one-third of European groundwater bodies exceeds the threshold of 11.3 mg NO_3^--N l^{-1}, defined in the EU drinking water directive (Nixon et al., 2003). Use of catch crops are commonly regarded an effective means of reducing N leaching (Thorup-Kristensen et al., 2003). Reductions in N leaching exceeding 90% have been shown when comparing cereal cropping systems with and without catch crops (e.g. Macdonald et al., 2005). The efficiency of the catch crop depends on soil type and climatic conditions. Askegaard et al. (2005) thus found reductions in N leaching due to the introduction of catch crops of 38, 30 and 26% in similar cropping systems on coarse sand, loamy sand and sandy loam, respectively.

The N retained in the catch crop will be incorporated into the soil and thereby increase soil organic matter content. This increased fertility will improve crop yields, but also increase N losses through leaching or gaseous emissions. Johnston (1991) noted that the benefits arising from maintaining adequate soil organic matter levels must not be overshadowed by the harm arising from the risk of nitrate leaching. However, as changes in soil organic matter occur very slowly (e.g. Paustian et al., 1992; Kuo and Jellum, 2000), the consequences of catch crop use for soil fertility and losses to the environment can only be evaluated on at least a decadal scale. Therefore, evaluation of catch crops use must consider the long-term effects (Kirchmann et al., 2002).

There is currently no consensus on the importance and consequences of the increased soil fertility. Macdonald et al. (2005) concluded, based on three 3–4 years studies, that the N mineralisation from catch crops grown once every 3–4 years in cereal based systems is unlikely to contribute greatly to nitrate leaching and adjustments of fertiliser N recommendations would not be necessary. In contrast, Hansen et al. (2000b) found that the N application could be reduced due to the use of catch crops in a 28-year study and that N leaching was higher from a crop rotation with a pre-history of catch crops than without.

Models can be useful tools for analysing the effects of catch crops on long-term environmental benefits (Blombäck et al., 2003; Thorup-Kristensen et al., 2003). Models allow the con-

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sequences of the use of catch crops to be evaluated over a considerably longer time span than is possible using existing experimental data.

The objective of the current study was to test the dynamic simulation model FASSET using data from a 28-year catch crop experiment including the effects of different catch crop use, N level and timing of tillage. To test the hypothesis that the long-term fate interacts with soil type, climate, soil fertility and crop rotation, the model was then used to investigate the long-term fate of the reduction in N leaching due to catch crops.

2. Materials and methods

2.1. Experimental data

A 28-year experiment with spring cereals – spring barley (*Hordeum vulgare* L.) and spring wheat (*Triticum aestivum* L.) – and different use of catch crop was analysed. The main treatments considered were (1) catch crop (with or without), (2) N level (low, medium and high) and (3) timing of ploughing (spring or autumn). The experiment has been described previously (Hansen and Djurhuus, 1997a,b; Hansen et al., 2000a,b) so only a brief outline will be given here. The experiment was located at Jyndevad, Denmark (54°54′N, 09°07′E). The soil texture of the upper 20 cm was 4% clay (<2 μm), 4% silt (2–20 μm), 12% fine sand (20–200 μm) and 77% coarse sand (200–2000 μm). The experiment was initiated in 1968 and terminated in 1996. Between 1968 and 1986, the catch crop (Italian ryegrass, *Lolium multiflorum* Lam.) was fertilised and removed by cutting in the autumn. From 1987, the catch crop (perennial ryegrass, *Lolium perenne* L.) was not fertilised and was incorporated by ploughing. In 1992, the treatments were changed so that the residual effects of growing catch crops could be evaluated (Table 1). The catch crop treatments in the autumn ploughed treatment with catch crop (PA++) and the spring ploughed treatment without catch (PS−−) crop were continued unaltered. The autumn ploughed treatment without catch crop was changed to with catch crops (PA−+). The spring ploughed treatment with catch crop was changed to without catch crops (PS+−). All treatments received three different levels of fertiliser. Between 1968 and 1986, the fertiliser rates were 70, 110 or 150 kg N ha^{-1}. In 1968, the levels were changed to 60, 90 and 120 kg N ha^{-1}. In 1993, the main crop was changed from spring barley to spring wheat because of poor growth in spring barley. Grain and straw was removed from the plots in all treatments for the whole duration of the experiment.

Table 1
The four experimental treatments with timing of ploughing and use of catch crops

Treatment	1968–1992		1993–1996	
	Catch crop	Ploughing	Catch crop	Ploughing
PA−+	−	Autumn	+	Autumn
PA++	+	Autumn	+	Autumn
PS+−	+	Spring	−	Spring
PS−−	−	Spring	−	Spring

Cereal dry matter (DM) and N yields of grain and straw were measured at harvest. Before 1986, the catch crop yield of DM and N was measured with a plot harvester. After 1986, the catch crops were measured for total-N shortly before ploughing by clipping an area of 0.5 m^2 in each plot. Nitrate in soil water was measured from 1987 using samples from porous ceramic cups installed at a depth of 0.8 m. The annual leaching was estimated by multiplying daily interpolated N concentrations with the daily water percolation simulated by FASSET. Soil organic C and N content was measured in 1991 for the whole soil profile.

2.2. Model

The FASSET model (Berntsen et al., 2003) was tested on the above experiment. This model includes a detailed crop-soil-atmosphere model that simulates N turnover and crop production as affected by daily climate and availability of water and N (Olesen et al., 2002). The soil model has a one-dimensional vertical structure and simulates the daily movement and plant availability of water and N. Competition between intercropped species for water, light and N is simulated as described in Berntsen et al. (2004).

The model used the observed ploughing, sowing, fertilisation, irrigation and harvest dates. Climatic data were taken from a nearby climatological station. The soil was initialised with the observed texture. There was no initial measurement of soil C and N content, therefore the soil was initialised with the average measured C and N content in 1991. The soil C was initially distributed between soil organic matter (SOM) pools according to Berntsen et al. (2005). N was distributed among SOM pools by assuming that the C/N ratio in the native organic matter pool (NOM) was 11 and the C/N ratio of the inert pool (IOM) was set to match the measured C/N ratio. There were no measurements of dry bulk density in whole soil profile at the experimental site, so values were taken from a nearby experiment (Djurhuus and Olesen, 2000). No calibration of crop or soil parameters was performed to improve the simulations.

2.3. Scenarios

The modelled residual effect was analysed using a range of scenarios, focusing on different soil types, soil fertilities and climates. Each scenario consists of a 100-year run with spring barley without catch crop and a run with spring barley undersown with catch crop. The reference treatment in all scenarios was spring barley without catch crop on a loamy sand with climatic data from Foulum (Table 2). In the catch crop treatment, barley was grown with catch crop for 25 years and thereafter without

Table 2
Mean annual precipitation and temperature for the locations used in the scenario analysis

Location	Geographical location	Precipitation (mm)	Temperature (°C)
Tystofte	55°15′N, 11°20′E	557	7.8
Foulum	56°30′N, 9°35′E	627	7.3
Jyndevad	54°54′N, 9°08′E	859	7.9