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Root development of fodder radish and winter wheat before winter in relation to uptake of nitrogen

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ABSTRACT

The nitrate (N) present in soil at the end of autumn is prone to leach during winter and spring in temperate climates if not taken up by plants. In Denmark catch crops are used as a regulatory tool to reduce N leaching and therefore a shift from winter cereals to spring cereals with catch crops has occurred. Quantitative data is missing on N leaching of a catch crop compared to a winter cereal in a conventional cereal-based cropping system. The aim of the study was to investigate whether fodder radish (*Raphanus sativus* L.) (FR) would be more efficient than winter wheat (*Triticum aestivum* L.) (WW) at depleting the soil of mineral nitrogen (N_{min}) before winter. A secondary aim was to study the agreement between three different root measuring methods: root wash (RW), core break (CB) and minirhizotron (MR). The third aim of the was to correlate the N uptake of FR and WW with RLD. An experiment was made to see if and how root growth was affected by the minirhizotron tube. The experiments were conducted on a Danish sandy loam soil. From September to November the amount of soil N_{min} decreased from 49 kg N ha^{-1} to 14 kg N ha^{-1} under FR and increased from 28 kg N ha^{-1} to 44 kg N ha^{-1} under WW. A test of correlations between root measuring methods showed that there was only a significant positive correlation for FR between CB and RW (R^2 = 0.77) and for WW between CB and MR (R^2 = 0.26). We conclude that FR is more efficient than WW at tightening the N cycle in the autumn by a greater depletion of soil N_{min}. From the comparison of root methods, we conclude that root growth in the subsoil was overestimated for FR by the MR method. This was due to preferential root growth along the MR tubes. The root densities/intensities measured with the three root measuring methods were not directly comparable.

1. Introduction

Plant growth is seasonal in temperate countries like Denmark due to the large variations in temperature and day length during the year. Low temperatures and short days during the winter limit plant growth and nutrient uptake (Baggs et al., 2000; Cameron et al., 2002). The risk of nitrate leaching is highest when precipitation exceeds evaporation (Hansen and Djurhuus, 1997; Di and Cameron, 2002; Thorup-Kristensen et al., 2009). Two factors are important for the level of N leaching: the amount of mineral nitrogen (N_{min}) in the soil (Di and Cameron, 2002) and the amount of surplus precipitation (Hansen and Djurhuus, 1997; Dinnes et al., 2002; Shaffer and Delgado, 2002). Loss of N from agricultural fields is minimised when availability and plant demand for N are synchronised, and catch crops are regarded as an efficient tool to tighten the N cycle (Christensen, 2004). The catch crops take up N and thereby prevent it from being lost during autumn and winter when there is a high risk of loss due to large amounts of surplus precipitation (Hansen and Djurhuus, 1997).

Differences have been found in the ability of catch crops to deplete the soil of N_{min} (Thorup-Kristensen, 1994; Kristensen and Thorup-Kristensen, 2007). This has been explained by different factors such as rooting depth, length of growing period (Thorup-Kristensen, 1994; Thorup-Kristensen et al., 2009) and root length density (RLD) (Brady et al., 1993; Dunbabin et al., 2003; Ehdaie et al., 2010). The taprooted catch crop of fodder radish (*Raphanus sativus* L.) (FR), which is not winter hardy in Denmark, has shown vigorous growth and a large capacity for uptake of N

Abbreviations: CB, core break; FR, fodder radish; MR, minirhizotron; N, nitrogen; N_{min}, mineral nitrogen; NT area, area where there is no tube and the area around the tube; REI, root end intensity; RLD, root length density; RW, root wash; SE, standard error; T area, tube area; WW, winter wheat.

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Table 1
Climate data from Flakkebjerg showing the monthly mean temperature, the monthly sum of precipitation and the potential evaporation for the second half of 2011 and the beginning of 2012, and the long-term climatic norm (baseline), mean of 1961–1990, is also shown.

	Temperature (°C)		Precipitation (mm)		Potential evaporation (mm)	
	Norm	2011–2012	Norm	2011–2012	Norm	2011–2012
July	15.6	16.8	66	118	99	89.9
August	1.6	16.6	67	126	86	78.4
September	12.7	14.4	73	55	50	54.9
October	9.1	9.9	76	43	24	32.4
November	4.7	6.4	79	6	9	7.7
December	1.6	4.4	66	43	4	4.6
January	0	2.2	57	51	5	8.3
February	0	1	38	20	11	16.1
March[1]	2.1	5.8	46	12	27	35.9

[1] Data from March 16–21 was from weather station Tystofte about 9 km from experimental fields as data was missing from Flakkebjerg for those days.

(Thorup-Kristensen et al., 2009) and is efficient in depleting the soil of N_{min} (Nett et al., 2011). A reduction in leaching of 44% compared with a fallow field has been shown by Baggs et al. (2000) with FR on a sandy loam/loamy sand in spring when FR was ploughed in. In Denmark, the use of catch crops to control nitrate leaching is mandatory for farmers and new stricter regulations are scheduled (Anonym, 2009). This may result in a shift on many farms from rotations dominated by winter cereal to spring cereal rotations that include catch crops. Many farmers are concerned about converting to spring cereal rotations due to a higher yield potential in winter cereals. There is a lack of quantitative data on the influence on N leaching of growing a catch crop rather than a winter cereal during the autumn in a conventional cereal-based cropping system. Therefore, it would be relevant to compare the difference in soil N_{min} at the end of autumn after growing a catch crop and a winter cereal, as this is a good indicator of how much N is prone to be lost from the agricultural system during winter. The measurements of N_{min} give a momentary picture of the N status in the soil while root investigations enable us to find out why the changes in N status have occurred.

Different methods can be used to determine the root distribution in soil, where the workload associated with the method varies a lot (Bengough et al., 2000). The root wash (RW) method is very time-consuming in comparison with the minirhizotron (MR) and core break (CB) methods. Another difference between the methods is that RW gives a root density in a volume of soil (three-dimensional), where the other two methods give a measure of root intensity on an exposed area of soil (two-dimensional). With the RW method the roots are washed free of soil and RLD determined (Munkholm et al., 2005); with the CB method root intensity is determined from the number of root ends emerging from vertical soil surfaces (Ellis and Barnes, 1980) and with the MR method root intensity is determined from a count of root intersections on a grid on an MR tube surface (Thorup-Kristensen, 2001).

The objectives of this study were: (1) To investigate the root development of FR and winter wheat (*Triticum aestivum* L.) (WW) using different methods and relating it to uptake of N in the plant and N_{min} in soil, (2) To assess whether the results of the three root registration methods, MR, CB and RW, are comparable for the tested crops, (3) To correlate the N uptake of FR and WW with RLD. The hypotheses were: (1) The use of FR will decrease the risk of nitrate leaching during winter more than WW due to deeper roots, (2) The results of the MR, CB and RW methods are comparable for both FR and WW.

2. Materials and methods

Two experiments were conducted at Research Centre Flakkebjerg (55°19′N, 11°23′E), Zealand, on a sandy loam soil. Experiment 1 was an investigation of root growth, plant biomass and N_{min} in soil in two crop rotations, one with FR and one with WW. The experiment took place in the period from autumn of 2011 to spring 2012. Experiment 2 was conducted to study whether and how root growth of FR would be affected by the presence of an MR tube, to support the findings of Experiment 1.

2.1. Climatic conditions

At Flakkebjerg the mean annual temperature and summed annual precipitation for 2011 was 9.0 °C and 557 mm, respectively. This is somewhat warmer than normal whereas the precipitation was at a normal level, i.e. the baseline for 1961–1990 baseline is 7.7 °C and 558 mm (Olesen, 1993). The mean temperature at Flakkebjerg from July 2011 to January 2012 was higher than the long-term baseline (Table 1) and precipitation in July (118 mm) and August (126 mm) was approximately 50% higher than the long-term baseline, while from September to March precipitation was substantially lower (Table 1). Potential evaporation in the second half of 2011 and at the beginning of 2012 did not differ much from the long-term baseline.

2.2. Experiment 1

The topsoil (0–25 cm) consisted of 14.7, 13.7, 42.6, 27.0 and 1.2 g 100 g^{-1} soil of clay (<2 μm), silt (2–20 μm), fine sand (20–200 μm), coarse sand (200–2000 μm) and organic matter, respectively (Hansen et al., 2010). The soil is a typical Danish arable soil with a loose annually-ploughed layer overlying a moderately hard plough pan at 25–35 cm depth (penetration resistance <2.0 MPa at field capacity) as shown by Munkholm et al. (2008).

Experiment 1 was part of a larger split plot tillage and rotation experiment in four replications. The experiment included four crop rotations (main plot factor), four tillage intensities (subplot factor) and allowed the placement of six subsubplots (2.5 m by 10 m) within the tillage subplots. In Experiment 1 the ploughed treatments within rotations R1 and R4 were used (Table 2), with four replications (subplots) of the plant treatments. We used two subsubplots per ploughed subplot. Please consult Hansen et al. (2015) for more detailed information on the experiment. The MR tubes were installed in one of the subsubplots and the soil and plant samples were taken in the other subsubplot. In crop rotation R1 oats (*Avena sativa* L.) was harvested in 2011 and was followed by WW. In crop rotation R4 spring barley (*Hordenum vulgare* L.) was harvested in August 2011 and followed by FR broadspread at 13 kg ha^{-1} about a month before the harvest of spring barley (Table 3. The crop rotations have been fertilised according to Danish norms as detailed in Hansen et al. (2015).