Winter turnip rape as a soil N scavenging catch crop in a cool humid climate

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RESEARCH ARTICLE

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Abstract Leaching of nitrogen fertilizers such as nitrates from agricultural systems causes watershed eutrophication and is an economic loss for the farmer. This issue may be solved by including a catch crop in a crop rotation. For instance, winter turnip rape is a potential N catch crop for cold climates. Here, we studied winter turnip rape as a catch crop from 2009 to 2011 in Finland. Winter turnip rape was either undersown with barley in May or sown after harvesting barley in late July. In two reference treatments, the barley stubble was either left over the winter or ploughed into the soil in autumn. We collected samples from topsoil, 0-20 cm, and subsoil, 30-50 cm, in early autumn, before snowfall and in the following spring. We measured soil ammonium-N and nitrate-N, and the N content of winter turnip rape plants. Results show that undersown winter turnip rape did not change the yield and quality of barley. Winter turnip rape decreased nitrate-N in the subsoil by 83 % in 2009 and by 61 % in 2010, compared to ploughed barley. By the end of October 2009, winter turnip rape undersown in May took up 74 kg N/ha, whereas the crop sown after barley in July took up 57 kg N/ha. We conclude that winter turnip rape, either undersown with barley or sown after barley, is effective in depleting subsoil nitrates. Even though numerous reports describe the efficiency of different crucifers as catch crops under temperate climate, this is the first article concerning winter turnip rape as a catch crop under cold and humid climate.

Keywords Boreal climate · *Brassica rapa* · Mineralization · Nitrogen retention · Tillage · Undersowing

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1 Introduction

Concerns over the environmental load caused by leaching of nitrogen (N), release of greenhouse gases, and fluctuating fertilizer prices have resulted in the need to improve recovery of N in agricultural environments. One option to reduce the escape of mineral N is the use of catch crops that scavenge N from soil after the harvest of main crop and incorporate the N into biomass (Dinnes et al. 2002). Usually, fast-growing species with large root systems are preferred over shallow-rooted species, as they are more efficient in taking up nutrients also from deeper soil layers during the growing season (Lainé et al. 1993). Nitrogen is most prone to be lost by leaching (Thorup-Kristensen and Nielsen 1998), so recovering mineral N from deep soil layers is most beneficial. Species that have been used as catch crops include small grain cereals and legumes, ryegrass (*Lolium perenne* L.) (Francis et al. 1998), and several crucifers, such as fodder radish (*Raphanus sativus* L. var. *oleiformis*), oilseed rape [*Brassica napus* L. ssp. *oleifera* (Moench.) Metzg.], and mustard (*Sinapis alba* L.) (Dean and Weil 2009).

Winter turnip rape [*Brassica rapa* ssp. *oleifera* (DC.) Metzg.] is an oilseed crop that is adapted to a cool climate and is suitable for low-input production (Mäkelä et al. 2011), making it a potential catch crop candidate for crop rotations in boreal environment. Winter turnip rape also has a long tap root and a fibrous root system covered with fine root hairs. Due to their large and fast-developing root systems, many crops in or closely related to genus *Brassica* are known to use efficiently (Barraclough 1989) and scavenge N, even from deep soil layers (Kristensen and Thorup-Kristensen 2004). Because of their root system qualities and high capacity of taking up NO_3^--N from soil, crucifers can be more effective as N catch crops than species from other families, such as legumes and grasses (Lainé et al. 1993; Thorup-Kristensen 2001). The amount of N gathered from soil by the end of autumn by crucifers is generally in the range of 10 to 200 kg/ha. Barraclough (1989) reported that oilseed rape sown in August in southern England had gathered 100 kg/ha N by November, Thorup-Kristensen (2001) reported 148 kg/ha N in Denmark, and in Maryland, USA, Dean and Weil (2009) measured the amounts between 63 and 192 kg/ha N, depending on sowing density, site and year. Similar or higher amounts have been recorded from other crucifers, such as fodder radish (160 kg/ha N, Thorup-Kristensen 2001; 216 kg/ha N, Dean and Weil 2009) and mustard (160 kg/ha N, Francis et al. 1998).

Much of the work concerning crucifers as catch crops is, however, conducted in temperate climate with medium or low autumn rainfall. The climate in Finland is cool and humid. Average annual runoff is about 300 mm (Kuusisto 1992). The average annual precipitation is 500–650 mm with most of it occurring in the late summer and autumn months (FMI 2013). This leads to downward movement of NO_3^- (Goulding et al. 2000) to the deeper soil layers, which may be inaccessible to the root systems of many monocot species (Thorup-Kristensen 2001), or completely out of the soil profile. In spite of rather high contents of organic matter, and consequently, total N in clay soils of Finland, the mineralization of soil N is also restricted by the climate. The soil temperature regime in Finland is cryic (Yli-Halla and Mokma 1998), the average summer soil temperatures at 50 cm being 6–14 °C and annually 2–6 °C, with lower values at higher latitudes. Even though N mineralization occurs in temperatures down to −6 °C in clay soils (Clark et al. 2009), the soil temperature in Finland during autumn restricts mineralization, which is more rapid in temperatures over 20–25 °C (Guntiñas et al. 2012). Soil in Finland is cool in the early summer months, when the crops have the highest demand for N. Higher soil temperatures and accordingly higher mineralization rates are observed in the late summer and early autumn, when the growth of spring crops has ceased and their demand for N is negligible (Sippola and Yläranta 1985).

The effect of a catch crop is based on the scavenging of N that is mineralized in soil outside the growing period of the main crop, and overwintering, catch crops tend to be more efficient than frost-killed crops in N retention (Mäkelä et al. 2011). In Finland, spring application of a moderate amount (80–100 kg/ha N) of fertilizer N for barley has a negligible effect on the amount of leached N, as the main crop takes up that amount of N during the growing season (Sippola and Yläranta 1985). Because soil usually freezes in winter in Finland, there is hardly any N mineralization and water movement in the soil profile for several months, and the amounts of leached N in barley cropping are in the range of only 14–17 kg/ha (Sippola and Yläranta 1985). This is substantially less than in Denmark, where the amounts of leached N can be up to 42 kg/ha/a of N from the same amount of fertilizer (Thomsen 2005). In a boreal climate, where soil is frozen in winter, the most substantial risk for leaching of mineralized N occurs before crop establishment or after its harvest, if a catch crop is not present. Due to the cool climate, the amount of leachable mineral N tends to be small, so in the autumn, less than 30 kg/ha of mineral N can be found in moderately fertilized clay soils in Finland (Sippola and Yläranta 1985). Nevertheless, using catch crops in a low mineral N environment can still have value. Känkänen and Eriksson (2007) reported significant reductions of NO_3^--N in all soil layers and the almost complete elimination of NO_3^--N in deeper layers in late autumn when using Italian ryegrass (*Lolium multiflorum* Lam.) as a catch crop in the boreal conditions of Finland.

The main objective of this study was to investigate whether winter turnip rape can decrease the amounts of NO_3^--N and NH_4^+-N in topsoil and subsoil where mineral N concentration is relatively low. This was tested using a moderately fertilized catch crop of winter turnip rape, sown at different times as undersown crop (Fig. 1) with barley and as a pure stand sown in July after barley. The effects of the cropping system on the amounts of mineral N in the soil were compared after the growing period, before overwintering and in the following spring.

2 Materials and methods

Two experiments were conducted at the University of Helsinki experimental farm at Viikki (60°13' N, 25°01' E, 8 m above sea level), Finland. Four different cultivation methods were investigated: (1) winter turnip rape undersown with barley (Fig. 1), (2) winter turnip rape sown after barley harvest, (3) barley alone, the stubble left for the winter, and (4) barley alone, the stubble ploughed after harvest. The soil was silty clay, and the preceding crop in both cases was barley. The fields of the farm are typically Luvic Gleysols or Luvic Stagnosols according to the WRB system (FAO 2006). In the 2009–2010 experiment, soil total C contents were 3.76 % (topsoil) and 2.23 % (subsoil), and in the 2010–2011 experiment, 5.31 % (topsoil) and 3.29 % (subsoil). In these mildly acid soils (pH 6.4), all C was assumed to be organic. Soil total N concentrations in the 2009–2010 site were 0.40 % (topsoil) and 0.26 % (subsoil), and in the 2010–2011 site, 0.49 % (topsoil) and 0.35 % (subsoil). The coefficient of variation for total C was 2.1 % and for total N 14.7 %. The experimental area was mouldboard ploughed before winter and harrowed before sowing. Plot size was 10 m^2 (8×1.25 m) in 2009 and 20 m^2 (8×2.50 m) in 2010. Six-row barley cv. Vilde (Graminor AS, Norway) was sown on 13 May 2009 and 25 May 2010 in all plots to the depth of 50 mm at a density of 500 viable seeds/m^2. All plots received fertilizer (42 kg/ha of NO_3^--N and 38 kg/ha of NH_4^+-N; N-P-K: 20-2-12, Pellon Y4, Yara, Finland) into the seed bed at the time of sowing. Plots were rolled with a Cambridge roller after sowing of barley,

Fig. 1 Winter turnip rape undersown with barley. **a** Winter turnip rape stays at vegetative growth stage during the first growing season. **b** After the barley is harvested, the winter turnip rape overwinters in the field. **c** After overwintering, winter turnip rape enters the generative growth stage

then winter turnip rape cv. Largo (Svalöf Weibull, Sweden) was sown to the depth of 20 mm at a density of 150 viable seeds/m^2 for cultivation method 1 and the plots were rolled again. After the barley was harvested, plots of cultivation method 2 were cultivated with a rotary hoe and winter turnip rape was sown on 24 July 2009 and 23 July 2010 to the depth of 20 mm, and the plots were rolled again. The plots of cultivation method 4 were ploughed with a mouldboard plough on 24 September 2009 and 23 September 2010. The experiments were arranged in a randomized complete block design with four replicates.

2.1 Pest management

Barley seed was treated with Baytan I (triadimenol 150 g/kg and imazalil 25 g/kg, Bayer CropScience) 1.5 g/kg of seed against fungal diseases. The winter turnip rape seed was treated with Elado FS480 (chlothianidin 400 g/l, betacyfluthrin 80 g/l, Bayer CropScience), 18.75 ml/kg of seed against insect pests.

Flea beetles (*Phyllotreta* sp.) were controlled at barley growth stage 51 (BBCH 1997) with 0.6 l/ha Bioruiskute S (pyrethrins 100 g/l, Yara) and 0.5 l/ha Roxion (dimethoate 400 g/l, BASF AG) followed by 0.3 l/ha Biscaya OD (thiacloprid 240 g/l, Bayer CropScience) one day later. Fungal diseases of barley were controlled with 0.5 l/ha Tilt 250 EC (propiconazole 250 g/l, Makhteshim Agan) at growth stage 65. Fungal diseases of winter turnip rape were controlled with 0.9 l/ha Sportak HF (prochloraz 450 g/l, BASF AG) and 0.4 l/ha Tilt 250 EC at growth stage 17.

After overwintering of winter turnip rape, weeds were controlled with 0.3 l/ha Galera (clopyralid 267 g/l and picloram 67 g/l, Dow AgroSciences) and 1.5 l/ha Fusilade Max (fluazifop-P-butyl 125 g/l, Syngenta AG) in both years at growth stage 30. Insect pests were controlled with 0.3 l/ha Biscaya OD and fungal pathogens with 0.5 l/ha Juventus 90 (metconazole 90 g/l, BASF AG) at growth stage 60.

2.2 Sampling and measurements

Samples of topsoil were collected from each block (2009, 56 m^2/block; 2010, 106 m^2/block; 0.5 l of soil/block) prior to sowing, and samples of subsoil were collected in 2010. Following the harvesting of barley in August, sets of both topsoil (0–20 cm) and subsoil (30–50 cm) samples (0.5 l) were collected from each plot with a cylindrical auger (Ø 18 mm). Four samples were taken from each plot and mixed together. For subsoil samples, 30-cm deep holes were dug with a narrow shovel, and the samples were collected from the bottom of the hole with the auger and mixed together. Another set of samples was collected before freezing of soil in October and a further set after snow melt in April. All soil samples were stored at −20 °C until further analysis.

Soil samples were analyzed at Suomen Ympäristöpalvelu Oy, Oulu, Finland. NH_4^+-N and NO_3^--N were extracted from soil samples with 2 M KCl for 1 h with soil-to-solution ratio of 1:5. Soil nitrogen species (NH_4^+-N and NO_3^--N) were determined spectrophotometrically from extracts with an automated flow injection analyzer (FIAStar 5000 System, Foss A/S, Hillerød, Denmark) according to SFS-EN ISO 11732 (NH_4^+-N) and SFS-EN ISO 13395 (NO_3^--N) standards. Soil total C and N concentrations were determined at the University of Helsinki. Samples of 0.5 l were collected from topsoil and subsoil, sieved through 5-mm mesh and air dried. Samples were analyzed with the Dumas combustion method in a VarioMAX CN (Elementar Analysensysteme GmbH, Hanau, Germany).

Five winter turnip rape plants per plot were collected before overwintering in October 2009 at growth stage 17. Plant samples were divided into leaves, hypocotyls and roots, dried in a forced air chamber at 80 °C for 48 hours, weighed, and ground (200-μm mesh, Retsch ZM 200, Retsch GmbH, Haan, Germany). C and N concentrations were determined from 0.5-g samples of the ground plant material by the Dumas combustion method.

Barley was harvested with a plot combine harvester and weighed. Grain test weight and moisture content were determined with a Dickey-John GAC2000 grain analyser (Dickey-John Inc., Chatham, Illinois, USA), and thousand seed weight was determined from the mean of two samples, each of 200 seeds, counted with a Contador semi-automated counter (Pfeuffer GmbH, Kitzingen, Germany).

Even though winter turnip rape overwintered normally, the seed yield was not harvested in 2010 due to damage caused by birds at growth stage 79. In 2011, after biomass samples were taken at growth stage 65, the winter turnip rape was crushed and incorporated into the soil with a rotary hoe.

2.3 Weather conditions

June and July in 2009 were exceptionally wet, with July having over twice the long-term average precipitation (Fig. 2). August and September were drier than average, followed by a more humid October. In 2010, the precipitation was close to the average, with the exception of a drier than average October. The air temperatures in both years were close to the average, with winter months being slightly colder. In both winters, snowfall was heavier and the snow pack was thicker than the long-term average.

2.4 Statistics

Data were subjected to analysis of variance using PASW 18 (SPSS Inc., Chicago, IL, USA). Multiple comparisons of means were performed with Tukey's test. For selected comparisons, Pearson's correlation coefficient was calculated.

3 Results and discussion

The amounts of NO_3^--N and NH_4^+-N did not differ significantly between the treatments directly after barley harvest and after winter at any time (Table 1). Before winter, the highest amounts of NO_3^--N both in topsoil and subsoil were in the treatment where the barley stubble was ploughed in, and the lowest was in the treatment with undersown winter turnip rape. In 2009, there was more NO_3^--N in the ploughed barley stubble treatment in autumn than in other treatments, in both soil layers (Table 1). In 2010, there was more NO_3^--N in topsoil after the autumn ploughing of barley stubble than in the two winter turnip rape stands. Moreover, the subsoil of the undersown winter turnip rape stand contained less NO_3^--N than the same layer of the pure barley stands, both ploughed and stubble. In 2009, however, there was less NH_4^+-N in the topsoil after ploughed barley in October than in the undersown winter turnip rape plots.

The differences between management practices in the amount of soil NO_3^--N before winter indicate that winter turnip rape can scavenge NO_3^--N from the soil. The differences in the amounts of soil NO_3^--N between winter turnip rape and barley stands were large in 2010, which would have resulted from the initially higher amounts of NO_3^--N in the soil. It seems that low levels of NO_3^--N early in 2009 led to differences being negligible between winter turnip rape stands and barley stubble later in the year. However, differences between the two winter turnip rape stands could have been more pronounced, if the winter turnip rape sown after barley had been sown later, as it is usually not possible to harvest

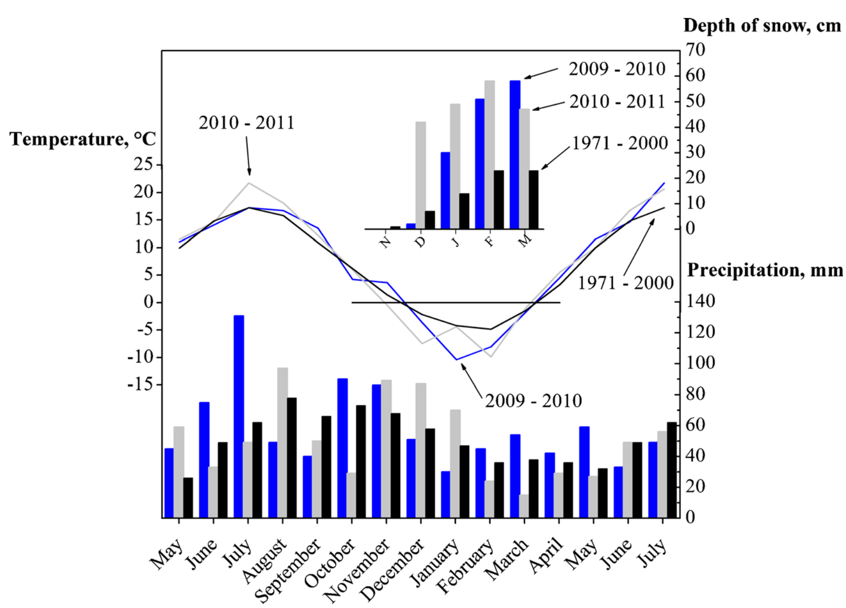

Fig. 2 Monthly mean temperatures, average precipitation, and depth of snow during the experiments in 2009–2011 and the long term averages 1971–2000 at Kaisaniemi (60°10' N, 24°56' E, 4 m above sea level), Helsinki, Finland (FMI 2013)

Table 1 Amount of soil mineral nitrogen (NH_4^+-N, ammonium-nitrogen; NO_3^--N, nitrate-nitrogen) species (kg/ha N) in topsoil (0–20 cm) and subsoil (30–50 cm) under different combinations of barley and winter turnip rape (WTR) and management practices. Data shown are means (n=4), except before growing season, in which case the results represent the mean (n=4) of the entire experimental area

Year	Soil layer	Crop and management	Before growing season		After barley harvest		Before winter		After winter	
			NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N
2009–2010	Topsoil	WTR, sown with barley	17.4	28.5	14.3 a	7.3 a	19.6 a	7.7 a	22.9 a	13.9 a
		WTR, sown after barley	17.4	28.5	13.5 a	10.2 a	19.3 ab	8.4 a	17.8 a	10.9 a
		Barley, left to stubble	17.4	28.5	17.4 a	11.1 a	18.1 ab	9.9 a	16.1 a	12.8 a
		Barley, ploughed	17.4	28.5	18.1 a	12.5 a	12.2 b	15.6 b	17.5 a	12.6 a
		Standard error of the mean	0.6	1.9	1.6	1.7	1.2	1.0	3.5	1.2
	Subsoil	WTR, sown with barley	NA	NA	11.1 a	5.5 a	7.3 a	3.7 a	9.8 a	12.7 a
		WTR, sown after barley	NA	NA	8.4 a	6.2 a	7.1 a	3.1 a	10.2 a	11.4 a
		Barley, left to stubble	NA	NA	8.9 a	7.9 a	6.8 a	7.1 a	8.1 a	13.7 a
		Barley, ploughed	NA	NA	9.9 a	7.1 a	8.0 a	18.5 b	9.5 a	11.9 a
		Standard error of the mean	NA	NA	1.8	1.5	0.5	2.3	1.2	2.7
2010–2011	Topsoil	WTR, sown with barley	5.5	35.5	5.5 a	27.0 a	5.4 a	18.6 a	3.7 a	24.5 a
		WTR, sown after barley	5.5	35.5	13.0 a	40.5 a	7.6 a	28.7 a	3.6 a	23.5 a
		Barley, left to stubble	5.5	35.5	4.2 a	37.0 a	6.0 a	32.5 ab	5.1 a	24.0 a
		Barley, ploughed	5.5	35.5	4.4 a	35.5 a	4.3 a	44.5 b	3.2 a	23.5 a
		Standard error of the mean	1.8	0.5	2.7	6.2	1.9	3.4	1.0	1.5
	Subsoil	WTR, sown with barley	4.6	15.9	6.2 a	13.0 a	3.8 a	8.3 a	3.4 a	18.6 a
		WTR, sown after barley	4.6	4.6	5.8 a	13.2 a	3.1 a	14.9 ab	5.6 a	24.1 a
		Barley, left to stubble	4.6	4.6	6.0 a	15.6 a	3.7 a	21.1 b	3.0 a	18.7 a
		Barley, ploughed	4.6	4.6	5.3 a	16.0 a	5.3 a	21.5 b	4.8 a	21.2 a
		Standard error of the mean	0.5	1.8	1.2	1.4	1.0	2.2	1.4	2.2

Within a year and soil layer, means followed by the same letter are not significantly different at P=0.05 by Tukey's test

barley already in July. The ploughed barley plots were distinguished from winter turnip rape in the amount of NO_3^--N before winter in both years and in both soil layers, probably because of the enhancement of mineralization by ploughing (Arnott and Clement 1966). The size of the differences between the ploughed barley and the rest of the treatments can be partly attributed to the high soil organic matter content, which results in the mineralization of higher amounts of N after ploughing than in soils with less organic matter.

NO_3^--N was the only mineral N species that was depleted under winter turnip rape. It is possible that winter turnip rape prefers NO_3^--N over NH_4^+-N, if it is similar to oilseed rape (Arkoun et al. 2013), and according to Dean and Weil (2009), cruciferous cover crops have no effect on the soil NH_4^+-N. This assumption is also supported by the presence of slightly higher levels of NH_4^+-N in topsoil with undersown winter turnip rape than after ploughed barley, although this difference could also be a result of the increased nitrification of NH_4^+-N caused by ploughing (Rice and Smith 1983).

In the winter turnip rape plots, NO_3^--N was nearly always higher in spring than before winter, particularly in the undersown treatment. This may indicate that similarly to oilseed rape (Dejoux et al. 2000), the turnip rape released some of the N in its tissues in spring, possibly due to the death of leaves during the winter. Undersown winter turnip rape had more leaf biomass, so it gathered more N in its leaves before winter (Table 2), and it is not surprising to find more NO_3^--N in spring in the soil of these plots than in those sown after barley. Nevertheless, as winter turnip rape can withstand colder temperatures than spring crops used as catch crops in autumn, it retains N for a longer period, even in the leaf tissues. In spring, after successful overwintering, the roots and hypocotyls of the plants are still alive, and most of the N gathered before winter is in these tissues.

NH_4^+-N is the initial product of N mineralization. The observed differences in the ratio of NO_3^--N to NH_4^+-N between years can be related to the weather conditions in 2009 and 2010. The high precipitation in summer would have contributed to localized waterlogging and, hence, enhanced denitrification and inhibited nitrification (Mikkelsen 1987) during the early autumn. The drier weather in August and September was more favorable to nitrification, but the high rainfall in October would then have promoted NO_3^--N leaching (Goulding et al. 2000) or denitrification (Sheehy et al. 2013) before the final sampling prior to winter. The summer months in 2010 were closer to the long-term average

Table 2 Biomass (kg/ha), nitrogen (N) content (%) and N uptake (kg/ha) of winter turnip rape (WTR) established with barley as undercrop or following barley as pure crop in October 2009. Data shown are means, $n=4$

		Leaves	Hypocotyl	Tap root	Total
Biomass, kg/ha	WTR with barley	1,756 a	469 a	1,002 a	3,227 a
	WTR following barley	1,076 a	499 a	864 a	2,439 a
	Standard error of the mean	230	252	237	555
N content, %	WTR with barley	2.55 a	2.29 a	1.93 a	
	WTR following barley	2.49 a	2.41 a	1.91 a	
	Standard error of the mean	0.16	0.12	0.13	
N uptake, kg/ha	WTR with barley	44.7 a	10.6 a	19.0 a	74.3 a
	WTR following barley	27.2 a	12.8 a	16.8 a	56.8 a
	Standard error of the mean	6.0	6.6	4.4	13.7

Means followed by the same letter are not significantly different at $P=0.05$ by Tukey's test

in terms of precipitation and created more favorable conditions for nitrification, resulting in a lower NO_3^--N to NH_4^+-N ratio than in 2009.

By the end of October 2009, the two winter turnip rape stands had taken up equal amounts of N per hectare (Table 2). Winter turnip rape stand density (data not shown) and N concentration in different plant parts (Table 2) did not differ significantly in the undersown and pure stands. The N concentration was higher in the leaves and hypocotyls than in the roots. The differences in leaf, hypocotyl, and tap root biomass between different winter turnip rape stands were not significant at the end of October 2009, even though the leaf biomass of undersown crop was 1.6 times the biomass of the crop sown after barley (Table 2).

Although some of the N in the undersown winter turnip rape tissues certainly originated from the spring fertilizer application, the observations of soil NO_3^--N content demonstrate the suitability of this crop, undersown in early May, as a catch crop. This is consistent with earlier work by Francis et al. (1998) in New Zealand showing that a cover crop needs to be planted as early as possible to have any marked effect on NO_3^--N leaching.

The difference in soil NO_3^--N between undersown winter turnip rape and the two barley treatments without a catch crop was evident especially in subsoil before winter 2010, which is consistent with the density of cruciferous root system being usually highest below the topsoil (Kutschera 1960). Indeed, according to Thorup-Kristensen (2001), cruciferous species are highly effective in depleting NO_3^--N from depths of 50–100 cm or even below, expressly due to the high frequency of roots in the subsoil. The number of lateral roots increases as the growing season advances, and in crucifers, this root growth is concentrated in the soil layers below the depth of 50 cm (Thorup-Kristensen 2001). Although there was no significant difference in the tap root biomass, the lateral and fine roots were not sampled, so their significance cannot be evaluated and it is likely that the overall dimensions of the root systems of the early and late sown winter turnip rape differed from each other.

The effectiveness of the undersown winter turnip rape plant stand in depleting subsoil NO_3^--N can be further attributed to its having almost 10 more weeks to form fine roots than the stand sown after the barley was harvested. Therefore, over 50 % less NO_3^--N in topsoil and 60–80 % less in subsoil was measured by the end of autumn when comparing undersown winter turnip rape to ploughed soil after barley. This is of practical importance even under Finnish conditions where the topsoil usually freezes, and plant growth and mineralization cease in November.

The amounts of mineral N in this study were slightly higher than those observed in some other studies conducted in Finland (Sippola and Yläranta 1985; Känkänen and Eriksson 2007), probably because of the rather high organic matter content of the study site. Assuming a soil bulk density of 1.3 kg/dm^3, there were 21 and 27 Mg/ha of total N in the 0–50 cm soil layer in the 2009–2010 and 2010–2011 sites, respectively, giving rise to a substantial N mineralization potential. The high organic matter of the soil may be a consequence of the long history of manure-spreading (Edmeades 2003) on this site that has been farmed, with cattle, since the sixteenth century. The amounts of mineral N before the growing season were slightly higher than those reported by Sippola and Yläranta (1985), whose results were from 0–100 cm soil profiles from various sites in southwest Finland. Also, the amounts of mineral N in topsoil after barley harvest and in the following spring were much higher than those observed in the 0–30 cm layer (Känkänen and Eriksson 2007). However, the amount of NO_3^--N in the soil at different times of year were similar to those in southwest Sweden (Borg et al. 1990).

The undersown winter turnip rape did not significantly affect the yield and quality of barley in this study. However, the barley yield and protein content were higher, and the test weight, single seed weight, and starch content were lower, in 2010 than in 2009 (Table 3). Even though the barley yield was not affected by the winter turnip rape and the differences between years are probably the result of different weather conditions, in other experiments, winter turnip rape adversely affected the yield formation of spring cereals (A. Tuulos,

Table 3 Barley yield (kg/ha) and its quality when grown or not with winter turnip rape (WTR) in 2009 and 2010. Data shown are means, *n*=4

	Yield, kg/ha	1,000 seed weight, g	Test weight, kg/hl	Protein content, %	Fibre content, %	Starch content, %
2009						
Barley with WTR	7439 a	40.1 a	60.8 a	9.43 a	4.80 a	55.45 a
Barley, left for stubble	7304 a	39.4 a	60.7 a	9.65 a	4.83 a	55.35 a
Barley, ploughed	7823 a	39.5 a	60.5 a	9.43 a	4.85 a	55.35 a
Standard error of the mean	180	0.4	0.3	0.22	0.06	0.33
2010						
Barley with WTR	7670 a	32.0 a	55.2 a	12.93 a	4.88 a	52.93 a
Barley, left for stubble	7905 a	29.9 a	53.6 a	13.55 a	5.00 a	52.23 a
Barley, ploughed	8246 a	30.5 a	54.7 a	13.38 a	4.95 a	52.48 a
Standard error of the mean	164	0.6	0.7	0.3	0.09	0.30

Means followed by the same letter are not significantly different at *P*=0.05 by Tukey's test

unpublished). Yield or quality reductions of the companion crop are common with undersowing (Känkänen and Eriksson 2007).

The amount of N removed in the barley grain was positively correlated with residual topsoil and subsoil NO_3^--N contents before winter in 2010 (Fig. 3), but not in 2009. The positive relationship of N removed by barley and soil NO_3^--N content indicates that winter turnip rape may affect the yield of barley, as the lowest soil NO_3^--N content was observed in stands with winter turnip rape, even though no actual effect on yield due to winter turnip rape was observed in this work. Due to the short growing season in boreal climates, winter turnip rape can seldom be sown following a cereal (Mäkelä et al. 2011), so undersowing can be considered as the most suitable establishment method. Our results indicate that it is possible to retain substantial amounts of N in an overwintering winter turnip rape crop, and thus decrease the amounts of leachable nitrate in subsoil in the autumn, when the risk for leaching is high due to rainfall. The effect of winter turnip rape on soil NO_3^--N content is most evident in the subsoil, which is inaccessible to more shallow-rooted species.

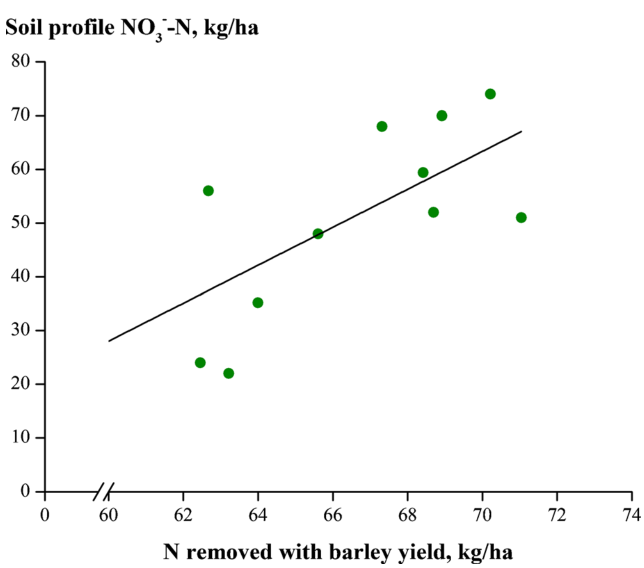

Fig. 3 Nitrogen (N) removed in barley yield and soil profile nitrate-nitrogen (NO_3^--N) content before winter in 2010. Y=3.53x–184.10, correlation coefficient squared=0.521, P=0.005

4 Conclusions

Winter turnip rape can successfully function as a catch crop for scavenging mineral N in the low temperatures of a humid climate at high latitudes. Winter turnip rape depletes subsoil NO_3^--N effectively. Nevertheless, the efficacy of the catch crop depends on the weather conditions of the year, particularly precipitation. The differences in soil NO_3^--N contents following winter turnip rape are of practical importance, since reductions of over 50 % in topsoil and 60 to 80 % in subsoil were observed by the end of autumn. This report shows that undersown winter turnip rape is at least as effective a catch crop as that sown after harvesting of barley, and this management option could be introduced into crop rotations based on spring cereals. As a deep-rooted species, winter turnip rape is more effective in depleting deeper soil layers from leachable N than more shallow-rooted species, such as grasses. The possibility of sowing winter turnip rape simultaneously with a cereal and its ability to produce high-value yield make winter turnip rape also an economically appealing option as a catch crop.

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