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The Effect of Cover Crops on the Yield of Spring Barley in Estonia

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Abstract: Using cover crops in fallow periods of crop production is an important management tool for reducing nitrate leaching and therefore improving nitrogen availability for subsequent crops. We estimated the short-term effect of five cover crop species on the yield of successive spring barley (*Hordeum vulgare* L.) for two years in Estonia. The cover crop species used in the study were winter rye (*Secale cereale* L.), winter turnip rape (*Brassica rapa* spp. *oleifera* L.), forage radish (*Raphanus sativus* L. var. *longipinnatus*), hairy vetch (*Vicia villosa* Roth), and berseem clover (*Trifolium alexandrinum* L.). The results indicated that out of the five tested cover crops, forage radish and hairy vetch increased the yield of subsequent spring barley, whereas the other cover crops had no effect on barley yield. All cover crop species had low C:N ratios (11–17), suggesting that nitrogen (N) was available for barley early in the spring.

Keywords: cover crop; nitrogen accumulation; spring barley yield

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1. Introduction

Using cover crops in fallow periods of crop production is an important management tool for reducing nitrate leaching and providing green manure service by improving the nitrogen (N) nutrition of subsequent crops [1–3]. Many studies have researched the effect of cover crops on subsequent crop yields, but the results are very variable depending on factors such as cover crop species, biomass production and quality, environmental factors, and management practices [1].

The main influence of cover crops on subsequent crop yield is through their effect on N availability in the soil. Leguminous cover crops bind N from the atmosphere and thereby provide additional nitrogen [4,5]. This causes faster mineralization of soil-incorporated leguminous residues thanks to the higher N concentration and lower C:N ratio of legumes' biomass. In contrast, a large C:N ratio can result in reduced N mobilization and lower N availability for the succeeding crop [6]. However, non-leguminous cover crops can scavenge for significant amounts of residual soil nitrate [7]. Mixtures of leguminous and non-leguminous cover crop species have been shown to be more effective in both providing nitrate supply and being employed as green manure [8–11]. Many authors have concluded that significant increases in main crop yields occur after the long-term use of cover crops in crop rotations, due to increases in both soil fertility and stores of organic matter [3,12,13]. However, the negative influence of cover crops on subsequent crops is mainly associated with the reduction of soil water storage, especially in water-limited regions [13–16]. As the effect of cover crops on subsequent crop yield has been reported to be very variable, and often depends on local climatic and soil conditions, more studies are needed from various regions. The biomass and nutrient accumulation of common winter cover crops have been recently tested in Estonia [17]. There have been some trials with winter-killed cover crops in which the effect on the following summer wheat yield was studied [18]. The aim of this experiment was to evaluate the effect of various cover crop species on the yield of subsequent spring barley, in order to find potentially beneficial cover crops that are suitable for the agro-climatic conditions prevailing in northern Europe.

2. Materials and Methods

We conducted a field experiment at the Estonian Crop Research Institute (58°44′59.41″ N, 26°24′54.02″ E) during the period of 2016–2018. The experiment was run in two sequential trials. The first trial evaluated cover crop performance (i.e., biomass and accumulation of nitrogen, phosphorus, potassium, calcium, and magnesium) in northern climatic conditions, data of which are published in Toom et al. [17]. The second and current trial evaluated the effect of cover crops on the yield of the following cash crop spring barley. However, in order to better interpret the current results, some cover crop data (biomass and nitrogen accumulation) from the first trial are referred to in the current study.

The soil in the trial site was of Cambic Phaeozem (Loamic) soil type [19]. The soil characteristics were as follows: pH_{KCl} 6.9, P 104 mg kg^{-1}, K 195 mg kg^{-1}, Ca 3700 mg kg^{-1}, Mg 510 mg kg^{-1}, C_{org} 2.1%, and N_{tot} 0.16%. The trial site is situated in a climate zone with a long-term average annual temperature of 5.3 °C and precipitation of 670 mm [20].

The study used the following cover crop species with seeding rates that were adjusted for Estonia: forage radish (Tillage radish® at 10 kg ha^{-1}), winter turnip rape (cultivar (cv.) Largo at 10 kg ha^{-1}), hairy vetch (cv. Villana at 50 kg ha^{-1}), berseem clover (cv. Akenaton at 15 kg ha^{-1}), and winter rye (cv. Sangaste at 180 kg ha^{-1}). The study also included control plots where the cover crop was omitted. In both years, the cover crops were sown on 3 August, immediately after winter wheat (*Triticum aestivum* L.) had been harvested. Each test plot was 4 × 6 m in size and arranged in a randomized complete block design that was repeated four times. At the end of October, cover crop above- and below-ground biomass samples were collected from four randomly placed squares sized 0.25 m^2 from each plot. The biomass of the overwintered species was measured again in spring, before the cover crops were ploughed into the soil (on 4 May 2017 and 7 May 2018). After the cover crop was incorporated into the soil, spring barley was established. The above-ground biomass was cut at the ground level for measurements. In order to measure the below-ground biomass, the soil inside the squares was excavated to a depth of 25 cm and the roots were washed on a sieve (mesh size 0.5 mm). The weight of the biomass was measured after desiccating the material at 65 °C to a constant weight. For C and N analysis, the samples were milled, and plant total C and total N concentration was analyzed by the Dumas Combustion method on a VarioMAX CNS elemental analyzer ("Elementar Analysensysteme", GmbH, Langenselbold, Germany) in the Soil Science and Agrochemistry laboratory at the Estonian University of Life Sciences.

The biomass of cover crops was ploughed into soil in spring by using a mold-board plough Kverneland to a depth of 22–24 cm. Immediately after ploughing, the spring barley cultivar Maali (at 400 seeds m^2) was sown without any additional fertilizers. When barley had reached its physiological maturity, it was harvested with a Hege plot combine harvester (on 30 August 2017 and 6 August 2018). The grain yield of dried and cleaned seeds was adjusted to 14% moisture level and expressed in kg ha^{-1}.

In order to study the effect of cover crops on the yield of spring barley, an analysis of variance (ANOVA) was carried out. The models included the effect of cover crops, the year, and the interaction between the two. The differences between individual cover crop species were calculated using the post hoc Fisher's Least Significant Difference (LSD) test. Statistical analyses were carried out using the statistical software package Agrobase Generation II SQL ("Agronomix Software", Inc., Winnipeg, Manitoba, CA, USA).

3. Results and Discussion

3.1. Weather Conditions

The average air temperature during the cover crops' main growing period from August until the end of October in 2016 and 2017 (10.5 and 10.8 °C, respectively) was similar to the 10.4 °C long-term average of these months. Compared to the long-term average precipitation (74 mm), the average amount of precipitation was higher in 2016 (84 mm) and slightly lower in 2017 (70 mm). The average temperature during the main growing period in April was lower in 2017 (2.8 °C) and higher in 2018 (6.2 °C) than the long-term average (3.8 °C). Compared to the long-term average of precipitation in April (36 mm), the average amount was considerably higher in 2017 (52 mm) and lower in 2018 (21 mm). More detailed data about the weather conditions during the growing period of cover crop species can be found in Toom et al. [17].

The air temperatures during the growing period of barley in 2017 were 0.8 °C lower than the long-term average in May. In June it was 1.1 °C lower and in July it was 1.9 °C lower. August was 0.5 °C warmer than the long-term average (Table 1). The amount of precipitation from May until the end of August (278 mm) was similar to the long-term average (285 mm). The weather in 2018 was warm and dry: The air temperatures were higher than the long-term average by 4.1 °C in May; 0.5 °C in June; 3.5 °C in July; and 2.5 °C in August. The amount of precipitation from May until the end of August (131 mm) was lower than the long-term average (285 mm).

Table 1. Average air temperature and precipitation per month during the experimental period and their long-term average (1922–2017).

Month	Average Air Temperature per Month (°C)		Long-Term Average Temperature per Month (°C)	Precipitation per Month (mm)		Long-Term Average Precipitation per Month (mm)
	2017	2018		2017	2018	
May	9.6	14.5	10.4	8	17	50
June	13.4	15.0	14.5	99	23	68
July	14.9	20.3	16.8	73	15	78
August	15.9	17.9	15.4	98	76	89

3.2. Cover Crop Biomass, Nitrogen Accumulation, and C:N Ratio

According to the ANOVA results, there were significant differences between the biomass and N values of cover crop species, measured in both autumn and spring (Table 2). Post hoc analyses of Fisher's LSD test showed that among the tested leguminous and non-leguminous cover crop species, forage radish produced the highest average biomass (3178 kg ha^{-1}) and contained the highest amount of N (86 kg ha^{-1}) when measured in autumn. However, among the three cover crops that survived the winter (hairy vetch, winter turnip rape, and winter rye), hairy vetch accumulated the highest average biomass (2210 kg ha^{-1}) and N (73 kg ha^{-1}) when measured in spring (Table 3). The C:N ratio of all the cover crop species remained relatively low; it ranged on average from 12 to 17. Specifically, hairy vetch had the lowest C:N ratio. More detailed analyses on the amount of biomass and nutrients of all the tested cover crop species are found in Toom et al. [17].

Table 2. Analyses of variance for cover crop biomass and nitrogen accumulation depending on species, year, and the interaction between the two. *

Characteristic	Source of Variation	df	SS	MS	F	p
Autumn						
Biomass	Species	4	23,837,346.850	5,959,336.713	125.18	<0.001
	Year	1	2,522,550.625	2,522,550.625	52.99	<0.001
	Species × year	4	2,262,263.250	565,565.813	11.88	<0.001
Nitrogen	Species	4	17,698.269	4424.567	106.58	<0.001
	Year	1	3301.489	3301.489	79.53	<0.001
	Species × year	4	1886.884	471.721	11.36	<0.001
Spring						
Biomass	Species	2	1,783,399.693	891,699.847	20.64	<0.001
	Year	1	5,513,483.760	5,513,483.760	127.64	<0.001
	Species × year	2	55,743.960	27,871.980	0.65	0.5385
Nitrogen	Species	2	4146.318	2073.159	47.80	<0.001
	Year	1	2042.415	2042.415	47.09	<0.001
	Species × year	2	54.768	27.384	0.63	0.5454

Notes: df—degrees of freedom; SS—sums of squares; MS—mean squares. F—treatment mean square/error mean square. *p*—significance probability value. * Table modified from Toom et al. [17].

Table 3. Cover crop biomass, nitrogen accumulation, and C:N ratio.

The Time of Sampling	Cover Crop	Winter Turnip Rape	Winter Rye	Hairy Vetch	Berseem Clover	Forage Radish
*Autumn 2016	Biomass kg ha^{-1}	1169c	667d	1422b	1415b	2515a
	N kg ha^{-1}	29c	16d	52b	33c	69a
	C:N	16	17	11	18	15
*Autumn 2017	Biomass kg ha^{-1}	1752b	1188d	1362cd	1556bc	3841a
	N kg ha^{-1}	64b	28e	53c	42d	103a
	C:N	11	17	10	15	14
Autumn 2016–2017 average	Biomass kg ha^{-1}	1461b	928c	1392b	1486b	3178a
	N kg ha^{-1}	47c	22e	53b	38d	86a
	C:N	14	17	11	17	15
**Spring 2017	Biomass kg ha^{-1}	1531a	1009b	1731a	x	x
	N kg ha^{-1}	48b	31c	62a	x	x
	C:N	13	14	11	x	x
**Spring 2018	Biomass kg ha^{-1}	2372b	2086c	2689a	x	x
	N kg ha^{-1}	62b	51c	84a	x	x
	C:N	16	17	13	x	x
Spring 2017–2018 average	Biomass kg ha^{-1}	1952b	1548c	2210a	x	x
	N kg ha^{-1}	55b	41c	73a	x	x
	C:N	15	16	12	x	x

Notes: Different lowercase letters within row are significantly different ($p < 0.05$; ANOVA, Fisher's Least Significant Difference (LSD) test). * The biomass of the winter-killed species, measured at the end of October. ** The biomass of the overwintered species, measured in the following spring before incorporating the cover crops into the soil, x no data (winter-killed species).

3.3. Spring Barley Yield

According to the ANOVA results, the spring barley yield was significantly affected by cover crop species and year, but not the interaction between the two (Table 4). Barley yield level was relatively low because no fertilizers were added. The average yield was higher in the first year of harvest compared to the second year (3223 and 2693 kg ha^{-1}, respectively). The difference was caused by heavy drought in the second harvest year. However, the effect of cover crop species on the subsequent yield of barley was similar in both years, as indicated by the lack of significant interaction between the effects of cover crop species and the year.

Table 4. Analyses of variance for spring barley yield depending on cover crop species, year, and the interaction between the two.

Characteristic	Source of Variation	df	SS	MS	F	*p*
Spring barley yield	Cover crop	5	785,047	157,009	3.52	0.0127
	Year	1	8,709,144	8,709,144	195.35	0.001
	Cover crop × year	5	222,218	44,444	1.00	0.4364

Notes: df—degrees of freedom; SS—sums of squares; MS—mean squares. F—treatment mean square/error mean square. *p*—significance probability value.

Among the tested cover crop species, forage radish and hairy vetch significantly increased the grain yield of subsequent barley by 11 and 9%, respectively (Figure 1). The level of grain yield of barley after other cover crop species (winter turnip rape, winter rye, and berseem clover) remained similar to the control.

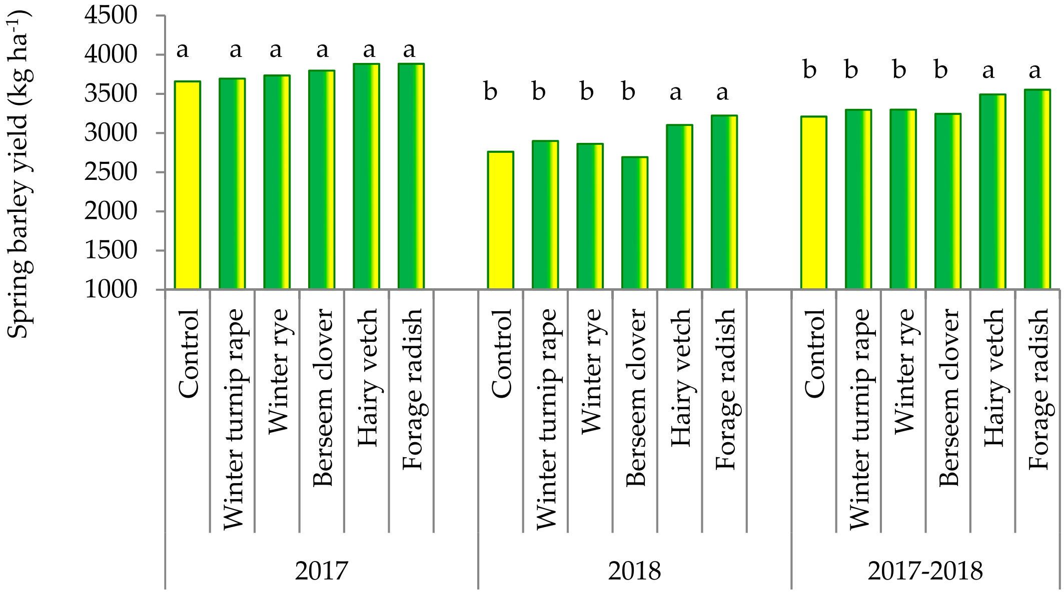

Figure 1. The effect of cover crops on the yield of spring barley (kg ha^{-1}) in 2017 and 2018, and the average of these years compared to the control (without cover crop). Within years, bars marked with different lowercase letters indicate significant differences at $p < 0.05$ according to the Fisher's LSD test.

The beneficial effect of radish cover crop is mainly associated with rapid growth during autumn and the ability to scavenge large amounts of residual N from deep soil layers with its large tap root [2,7]. This was confirmed in our experiment, where forage radish accumulated highest biomass and N in autumn, compared to other leguminous and non-leguminous species. As a result, it is likely that a major amount of N became available to the subsequent crop. With winter-killed cover crops it is recommended to sow the subsequent main crop early in spring to recapture the accumulated N. Minimizing spring leaching losses is of essential importance in soils that are coarse-textured and well-drained to excessively drained [21]. Our results on the positive effect of forage radish confirm several previous studies. For example, in Denmark, Sapkota et al. [2] evaluated the effect of different cover crop species on N leaching and barley yield. They found that fodder radish grown before barley (which was sown in the previous autumn) grew its roots deeper and depleted N from deeper soil layers. When chicory and ryegrass were used as barley undersows, they decreased N leaching, but also reduced spring barley yield. This was probably caused by competition for light, water, and nutrients.

In our study, none of the tested cover crop species reduced the yield of spring barley. Jahanzad et al. [7] found that when choosing a cover crop for potato, forage radish was a better option than rye, as it needed less N fertilizer and sustained tuber yield and mineral nutrient concentration in tubers. Using rye as a cover crop gave a higher potato yield than using no cover crop at all, but it did not release enough N for the potatoes since it was terminated in early spring when it had a limited biomass. In addition to N cycling, forage radish can contribute to the yield of succeeding crops through other mechanisms. According to Weil and Kremen [22], forage radish is effective in suppressing weeds and reducing the effects of soil compaction. They also found that using forage radish resulted in improved soybean growth and higher soybean seed yields.

In accordance with our results, previous studies have also reported the beneficial effects of hairy vetch. Campiglia et al. [23] found that in Italy, hairy vetch ensured a similar potato yield to that obtained by mineral fertilization, but rye or ryegrass monoculture either did not affect or had a negative effect on corn yield and N availability in soil. According to Sainju et al. [24], hairy vetch and crimson clover caused an increase in tomato yield.

Berseem clover in our study did not increase barley yield significantly. This is likely because it did not produce a sufficient biomass and could not provide enough N for barley, since berseem clover was killed by frosts. However, when sown in spring, berseem clover can produce sufficient biomass and increase the yield of subsequent winter cereals [25].

In order to prevent the loss of accumulated N, it is recommended to sow subsequent crops as soon as possible after incorporating the biomass of leguminous cover crops with low C:N ratios, such as hairy vetch. Sievers et al. [26] pointed out that most of the N in hairy vetch tissues is released in the first two weeks after termination. Therefore, it is susceptible to leaching out or denitrification if the following crop is not planted on time or it is not able to reach the growth stage where it could use the N from hairy vetch. In our study, barley was sown immediately after cover crop incorporation and was presumably able to use the accumulated N.

Rye has been found in some cases to make less N available to the following crop. This happens due to microbial immobilization if rye is terminated when its C:N ratio has risen above 30 [21]. In our study, winter rye produced a modest biomass and had quite a low C:N ratio (14–17), probably because it did not reach maturity before termination.

4. Conclusions

The results of our two-year experiment in northern Europe (Estonia) show that cover crops have either a positive effect or no effect on subsequent barley yield, depending on the cover crop species. Specifically, forage radish and hairy vetch showed the potential to increase the yield of subsequent crops, likely due to their ability to provide N for the barley. Although forage radish was winter-killed, it accumulated both a high biomass and high N levels in autumn, whereas hairy vetch was the best biomass producer and N accumulator in spring. Nevertheless, the rest of the tested cover crops did not reduce the yield of subsequent barley crops.

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