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The Effect of Sowing Date on Biomass and Nitrogen Accumulation of Five Winter Cover Crop Species

Merili Toom[1,2]*, Sirje Tamm[1], Liina Talgre[2], Ilmar Tamm[1], Ülle Tamm[1], Lea Narits[1], Inga Hiiesalu[3], Liina Edesi[1], Tiina Talve[1], Andres Mäe[1] and Enn Lauringson[2]

[1]*Estonian Crop Research Institute, J Aamisepa 1, 48309 Jõgeva, Estonia*

[2]*Institute of Agricultural and Environmental Sciences, Estonian University of Life Sciences, Estonia*

[3]*Institute of Ecology and Earth Sciences, University of Tartu, Estonia*

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***Corresponding author:** Merili Toom, Estonian Crop Research Institute, Jõgeva, Estonia

Abstract

Winter cover crops are used to protect soil from nitrogen (N) loss in fallow periods of crop production. For sufficient N accumulation, it is essential to produce high amount of biomass, and therefore it is important to sow cover crop as early as possible after the main crop harvest. A two-year field experiment was carried out in northern climate to study the effect of sowing date on biomass and N accumulation of five winter cover crop species: 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.*). Cover crops were sown during a two-week period at four different dates in late summer. Biomass and accumulated N were measured at the end of the vegetation period in autumn and for overwintered species also in the following spring. Results showed that the cover crops differed in biomass and N, measured in autumn and spring. Forage radish produced the highest and berseem clover the lowest biomass and N in autumn. Delayed sowing reduced biomass and N of cover crops, while the influence of sowing date on tested species was different. Notably, the biomass and N of forage radish remained the highest at all sowing dates as measured in autumn, despite considerable decrease by delayed sowing. Winter rye was least affected by delayed sowing, whereas berseem clover and hairy vetch were most affected. Despite considerable decrease, hairy vetch accumulated the highest amount of N across all sowing dates as measured in spring.

Keywords: Winter cover crops; Delayed sowing, Biomass; Accumulated N; Winter rye; Winter turnip rape; Forage radish; Hairy vetch; Berseem clover

Introduction

Replacing fallow periods with cover crops provide many benefits to agroecosystems including reduced nitrogen (N) loss [1,2]. In northern temperate areas, the most common types of cover crops are winter annuals that are sown after the harvest of the cash crop in late summer and incorporated into the soil in the following spring. Overwintering species are valuable because they protect the soil during winter and accumulate additional biomass and N in the following spring. Cover crops that are not winter hardy, but accumulate high amount of biomass and N before the killing frost, are useful especially in reduced or no-tillage organic farming systems, eliminating the need for chemical or mechanical cover crop termination [3,4,5]. Hairy vetch is a commonly used winter annual legume, because of its winter hardiness, high biomass, and N fixation ability [6,7,8]. Similarly, berseem clover can accumulate high amount of biomass and N mostly in Southern regions, while it is winterkilled in northern latitudes [4,9]. Winter rye is a winter hardy cover crop species that accumulates high amount of biomass and soil N [10,11]. Likewise, brassica species such as a winter hardy winter turnip rape and winter-killed forage radish scavenge great amount of soil N with deep root system [12,13]. To maximize ecosystem services provided by cover crops, the major goal is the production of high biomass yield [14,15]. In northern regions with short autumns, there is often a narrow window of opportunity for establishing cover crops after harvesting a cash crop, which can result in low biomass [16]. Delayed sowing has shown to result in dramatic decrease in biomass and N accumulation [5], however, the reduction is dependent on cover crop species [17,18,19]. The biomass and N accumulation of overwintering species depends also on the termination time in spring [6,8,16,20]. In nordic latitudes cover crops are commonly sown after harvest of the cash crop in late summer and incorporated into the soil before frosts [21,22]. However, winter cover crops allow to maintain the fields covered throughout the winter season, preventing erosion of soils and loss of nutrients. This is important under changed climatic conditions, whereby temperatures are more often above freezing during recent years. Cover crops should be ideally sown early autumn, directly after harvest of early-ripening cash crops, such as winter cereals. However, delayed sowing of cover crops would allow to use them after later-ripening cash crop, such as spring cereals. Winter cover crops have been recently introduced to Estonia [23], but studies with delayed sowings have not been conducted. Therefore, this study aimed to investigate the effect of different sowing dates (during the period of two weeks) on biomass and N accumulation of five species of winter cover crops. We hypothesized that 1) winter cover crop species differ in their ability to produce biomass and accumulate N, while biomass and accumulated N will decrease with delayed sowing date; 3) biomass and N accumulation of some winter cover crop species will decrease less with delayed sowing than that of others.

Materials and Methods

Field experiments were established in 2017 and 2018 at Estonian Crop Research Institute. The cover crops included winter turnip rape (cultivar (cv.) Largo 10 kg ha^{-1}), forage radish (Tillage radish® 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}). Cover crops were sown on August 3, 8, 14 and 18 in 2017 and August 3, 8, 13, 17 in 2018, after winter wheat harvest (*Triticum aestivum L.*). Plots with an area of 24 m^2 (4 × 6 m) were laid out in a randomized complete block design with four replications. Biomass samples were collected from four squares of 0.25 m^2 in each plot at the end of vegetation period (October 20 and 23 in 2017 and 2018, respectively). Biomass of the overwintered species was determined again in spring, before the cover crops were ploughed into the soil (May 7 in 2018 and 2019). Above ground biomass was collected by cutting the shoots on the ground level. Roots were collected with a shovel to a depth of 25 cm and washed from soil on a sieve. The biomass samples were oven-dried at 65 °C until constant weight in order to determine dry weight and ground for elemental analysis. Shoot and root dry weight values were merged. Plant total N was determined by the Dumas Combustion method on a varioMAX CNS elemental analyser (‘Elementar’, Germany). Statistical analyses were carried out by statistical package Agrobase 20TM. To test the effect of cover crop species, sowing date and their interaction on biomass and N accumulation of cover crops, analysis of variance (ANOVA) was performed. Fisher’s LSD was used to test the significance of differences between cover crop species within sowing dates and across sowing dates.

Results

Weather conditions

The average air temperature during the cover crops’ main growing period from August until the end of October was similar in 2017 (10.8 °C) and higher in 2018 (12.7 °C) compared to the long-term average (LTA; 10.4 °C) of these months (Table 1). The average amount of precipitation from August until the end of October was higher in 2017 (92 mm) than the LTA (74 mm). In 2018, the soil was dry during cover crop establishment, because of very low amount of precipitation in July (15mm) compared to the LTA of this month (79 mm). The rainfall started from August 4 and the average amount of precipitation (75 mm) by the end of October was similar to the LTA. The average temperature during the main growing period in April was higher in 2018 and 2019 (6.2 and 6.6 °C, respectively) than the LTA of this month (3.8°C). Precipitation in April was 21 mm in 2018 and only 4 mm in 2019 which is lower compared to the LTA (36 mm).

Table 1: Average air temperature and precipitation per month, monthly sums of effective air temperatures > +5 °C (ETS) during the experimental period and long-term average (LTA; 1922–2017).

Month	Average air temperature per month (°C)	LTA temperature per month (°C)	Precipitation per month (mm)	LTA precipitation per month (mm)	ETS per month (°C)	LTA ETS per month (°C)
2017/2018						
July	14.9	16.8	57	79	308	365
August	15.9	15.3	83	89	337	320
September	11.8	10.6	86	66	206	177
October	4.8	5.3	107	66	53	60
November	2.1	0.3	47	56	4.8	8
December	0.1	-3.7	80	47	0	1
January	-2.4	-6.5	35	41	0	0.06
February	-8.7	-6.8	25	31	0	0.2

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March	-4.3	-3	21	31	0	2.9
April	6.2	3.8	52	36	73.5	46
May	14.5	10.4	17	50	39.3*	
2018/2019						
July	20.2	16.8	15.5	79	474	365
August	17.9	15.3	76	89	401	320
September	13.6	10.6	72	66	260	177
October	6.5	5.3	78	66	86	60
November	2.2	0.3	22	56	18	8
December	-2.8	-3.7	37	47	0	1
January	-6.7	-6.5	39	41	0	0.06
February	-0.7	-6.8	34	31	0.4	0.2
March	4.3	-3	49	31	7.6	2.9
April	6.6	3.8	4	36	108	46
May	10.6	10.4	50	50	11.5*	

*ETS until ploughing cover crops into the soil.

Biomass Accumulation

The ANOVA results showed that there were significant differences in biomass produced by different species of cover crops as an average of sowing dates in both trial years, measured in autumn as well in spring (Tables 2 & 3). Out of the five tested winter cover crop species forage radish produced the highest average biomass and berseem clover the lowest measured in autumn during both trial years. Among three overwintering cover crop species winter turnip rape and hairy vetch produced higher biomass compared to winter rye, as measured in the following spring, during both trial years. The amount of biomass as an average of cover crop species was significantly affected by the sowing date measured in autumn as well in spring in both trial years (Table 2 & Table 3). In general, cover crops in average produced lower biomass in case of later sowing date. As an exception, the biomass of cover crops sown in the 1st (Aug 3) and 2nd (Aug 8) sowing dates remained on the same level in the second trial year. The decrease of average biomass in autumn was higher in the first trial year, from 1940 kg ha^{-1} as sown in the 1st sowing date on Aug 3 to 710 kg ha^{-1} as sown in the last date on Aug 18 (Table 2). However, the decrease of average biomass was lower in the second trial year, from 2016 kg ha^{-1} as sown in the 1st sowing date on Aug 3 to 1191 kg ha^{-1} as sown in the last date on Aug 17 (Table 3). The average biomass of the overwintering cover crops measured in the following spring decreased much less compared to the biomass measured in autumn, from 2382 to 1609 kg ha^{-1} in the first trial year and from 2901 to 2054 kg ha^{-1} in the second trial year.

Table 2: Biomass production of cover crops (mean±standard error; dry matter kg ha^{-1}) depending on the date of sowing in the field experiment established in autumn 2017. The results of two-way analysis of variance (F-statistics and p-values) of the factors cover crop (Crop), sowing date (Date) and cover crop by sowing date interaction (Crop*Date) are also presented.

Cover crop	1st sowing date 8/3/2017	2nd sowing date 8/8/2017	3rd sowing date 8/14/2017	4th sowing date 8/18/2017	Average of sowing dates
Autumn 2017	Crop: $F_{4,57}=155$, p<0.001; Date: $F_{3,57}=196$, p<0.001; Crop*Date: $F_{12,57}=25$, p<0.001				
Winter turnip rape	1752±124$^{b/A}$	1321±72$^{b/B}$	1041±28$^{b/C}$	801±30$^{b/D}$	1229±97^{b}
Forage radish	3841 ±269$^{a/A}$	2146±78$^{a/B}$	1401±98$^{a/C}$	1164±74$^{a/D}$	2138±279^{a}
Winter rye	1188±32$^{d/B}$	1404±50$^{b/A}$	1191±57$^{b/B}$	873±58$^{b/C}$	1164±54^{b}
Berseem clover	1556±48$^{bc/A}$	737±53$^{c/B}$	440±24$^{d/C}$	285±35$^{c/C}$	754±128^{d}
Hairy vetch	1362±61$^{cd/A}$	1230±82$^{b/A}$	723±46$^{c/B}$	425±11$^{c/C}$	935±101^{c}
Average of crops	1940±229^{A}	1367±107^{B}	959±81^{C}	710±75^{D}	
Spring 2018	Crop: $F_{2,33}=39$, p<0.001; Date: $F_{3,33}=120$, p<0.001; Crop*Date: $F_{6,33}=5$, p<0.001				
Winter rye	2086±70$^{c/A}$	2116±35$^{c/A}$	1788±33$^{b/B}$	1646±41$^{a/C}$	1909±55^{c}
Winter turnip rape	2372±127$^{b/A}$	2294±44$^{b/A}$	1895±23$^{b/B}$	1531±31$^{a/C}$	2023±92^{b}

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Hairy vetch	2689±107$^{a/A}$	2602±22$^{a/A}$	2107±42$^{a/B}$	1651±37$^{a/C}$	2262±111^{a}
Average of crops	2382±92^{A}	2337±63^{A}	1930±44^{B}	1609±25^{C}	

Mean values without common lowercase letters (a,b,c,d) within sowing dates (in columns) and mean values without common uppercase letters (A,B,C,D) within cover crops (in rows) are statistically significantly different ($p < 0.05$, Fisher LSD test).

Table 3: Biomass production of cover crops (mean±standard error; dry matter kg ha^{-1}) depending on the date of sowing in the field experiment established in autumn 2018. The results of two-way analysis of variance (F-statistics and p-values) of the factors cover crop (Crop), sowing date (Date) and cover crop by sowing date interaction (Crop*Date) are also presented.

Cover crop	1st sowing date 8/3/2018	2nd sowing date 8/8/2018	3rd sowing date 8/13/2018	4th sowing date 8/17/2018	Average of sowing dates
Autumn 2018	Crop: $F_{4,57}$=493, p<0.001; Date: $F_{3,57}$=170, p<0.001; Crop*Date: $F_{12,57}$=13, p<0.001				
Winter turnip rape	2178±65$^{b/A}$	2157±81$^{b/A}$	1834±60$^{b/B}$	1212±39$^{b/C}$	1845±105^{b}
Forage radish	3581±95$^{a/A}$	3661±98$^{a/A}$	2643±63$^{a/B}$	2020±107$^{a/C}$	2976±181^{a}
Winter rye	1486±75$^{c/A}$	1487±96$^{c/A}$	1404±73$^{c/A}$	1070±85$^{bc/B}$	1362±58^{c}
Berseem clover	820±47$^{d/A}$	879±51$^{d/A}$	642±57$^{d/B}$	463±29$^{d/C}$	701±47^{d}
Hairy vetch	2243±83$^{b/A}$	2267±90$^{b/A}$	1786±75$^{b/B}$	1016±29$^{c/C}$	1828±135^{b}
Average of crops	2062±213^{A}	2090±216^{A}	1662±152^{B}	1156±118^{C}	
Spring 2019	Crop: $F_{2,33}$=74, p<0.001; Date: $F_{3,33}$=112, p<0.001; Crop*Date: $F_{6,33}$=9, p<0.001				
Winter rye	2350±73$^{b/A}$	2472±89$^{b/A}$	2364±38$^{b/A}$	1928±46$^{b/B}$	2279±61^{b}
Winter turnip rape	3123±106$^{a/A}$	3147±126$^{a/A}$	2598±35$^{a/B}$	2270±49$^{a/C}$	2785±103^{a}
Hairy vetch	3231±38$^{a/A}$	3239±74$^{a/A}$	2706±55$^{a/B}$	1963±14$^{b/C}$	2785±136^{a}
Average of crops	2901±125^{A}	2953±115^{A}	2556±49^{B}	2054±51^{C}	

Mean values without common lowercase letters (a,b,c,d) within sowing dates (in columns) and mean values without common uppercase letters (A,B,C,D) within cover crops (in rows) are statistically significantly different ($p < 0.05$, Fisher LSD test).

The ANOVA results showed that the variation of biomass depended significantly on the interaction between cover crop species and sowing date in both trial years, measured in autumn as well as in spring (Table 2 & 3), meaning that there were differences in the degree of reduction in biomass of different cover crop species depending on the sowing date. According to the autumn measurements, the biomass of winter rye was least affected by the sowing date, varying between 1188–873 kg ha^{-1} in the 1st trial year and between 1486–1070 kg ha^{-1} in the 2nd trial year. In the 1st trial year the biomass of berseem clover decreased the most (1556–285 kg ha^{-1}), whereas in the 2nd trial year, biomass of hairy vetch decreased the most (2243–1116 kg ha^{-1}) between the first and the last sowing dates. Out of the five tested cover crop species forage radish produced significantly highest amount of biomass in all sowing dates in both trial years despite of considerably reduced biomass in the delayed sowing dates (3841 versus 1164 kg ha^{-1} in the 1st and 3581 versus 2020 kg ha^{-1} in the 2nd trial year).

According to the spring measurements, overall biomass decrease caused by delayed sowing was considerably lower than in autumn (Table 2 & 3). Among the three overwintering cover crop species winter rye was the most stable, with the lowest overall biomass decrease due to delayed sowing date. Specifically, in the earlier sowing dates, the biomass of winter rye was smaller compared to winter turnip rape and hairy vetch. However, in the later sowing dates the biomass of winter rye reached the same level than of the other two cover crops, except winter turnip rape which had the highest biomass as measured in spring 2019 from the variant of most delayed sowing date.

N accumulation

The ANOVA results showed that there were significant differences in accumulated N by different species of cover crops as an average of sowing dates in both trial years, measured in autumn as well in spring (Table 4 & 5). Out of the five tested winter cover crop species forage radish accumulated the highest average N and berseem clover the lowest accumulated N measured in autumn during both trial years. Among the three overwintering cover crop species hairy vetch accumulated the highest amount of N, as measured in the following spring, during both trial years.

The accumulated N as an average of cover crop species was significantly affected by the sowing date as measured in autumn as well as in spring in both trial years (Table 4 & 5). In general, cover crops in average produced lower N in case of later sowing dates, however, in most cases the decrease of accumulated N was not significant in the 2nd sowing date compared to the 1st. When comparing the 1st and last sowing date, the overall decrease

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of average accumulated N in autumn was somewhat higher in the first trial year than in the second trial year. In the first trial year average N reduced from 58 kg ha^{-1} to 25 kg ha^{-1} and in the second trial year N reduced from 73 kg ha^{-1} to 38 kg ha^{-1} (Table 4 & 5). The average accumulated N of the overwintering cover crops measured in the following spring decreased less compared to the N measured in autumn – N in spring decreased from 65 to 46 kg ha^{-1} in the first trial year and from 84 to 56 kg ha^{-1} in the second trial year.

Table 4: Nitrogen accumulation of cover crops (mean±standard error; N kg ha^{-1}) depending on the date of sowing in the field experiment established in autumn 2017. The results of two-way analysis of variance (F-statistics and p-values) of the factors cover crop (Crop), sowing date (Date) and cover crop by sowing date interaction (Crop*Date) are also presented.

Cover crop	1st sowing date 8/3/2017	2nd sowing date 8/8/2017	3rd sowing date 8/14/2017	4th sowing date 8/18/2017	Average of sowing dates
Autumn 2017	Crop: $F_{4,57}$=186, p<0.001; Date: $F_{3,57}$=180, p<0.001; Crop*Date: $F_{12,57}$=16, p<0.001				
Winter turnip rape	64±5$^{b/A}$	46±3$^{b/B}$	35±1$^{b/C}$	30±1$^{b/C}$	44±4^{b}
Forage radish	103±7$^{a/A}$	70±3$^{a/B}$	42±3$^{a/C}$	43±1$^{a/C}$	65±7^{a}
Winter rye	28±2$^{e/A}$	30±1$^{c/A}$	27±1$^{c/AB}$	22±1$^{c/B}$	27±1^{d}
Berseem clover	42±2$^{d/A}$	22±2$^{d/B}$	13±1$^{d/C}$	9±1$^{d/C}$	22±3^{e}
Hairy vetch	53±3$^{c/A}$	45±2$^{b/A}$	31±2$^{bc/C}$	21±1$^{c/D}$	38±3^{c}
Average of crops	58±6^{A}	43±4^{B}	30±2^{C}	25±3^{D}	
Spring 2018	Crop: $F_{2,33}$=358, p<0.001; Date: $F_{3,33}$=131, p<0.001; Crop*Date: $F_{6,33}$=14, p<0.001				
Winter rye	50±2$^{c/A}$	50±1$^{c/A}$	44±1$^{c/B}$	37±1$^{c/C}$	45±1^{c}
Winter turnip rape	61±3$^{b/B}$	67±1$^{b/A}$	57±1$^{b/C}$	46±1$^{b/D}$	58±2^{b}
Hairy vetch	83±4$^{a/B}$	94±1$^{a/A}$	70±2$^{a/C}$	54±1$^{a/D}$	75±4^{a}
Average of crops	65±4^{B}	70±6^{A}	57±3^{C}	46±2^{D}	

Mean values without common lowercase letters (a,b,c,d) within sowing dates (in columns) and mean values without common uppercase letters (A,B,C,D) within cover crops (in rows) are statistically significantly different (p < 0.05, Fisher LSD test).

Table 5: Nitrogen accumulation of cover crops (mean±standard error; N kg ha^{-1}) depending on the date of sowing in the field experiment established in autumn 2018. The results of two-way analysis of variance (F-statistics and p-values) of the factors cover crop (Crop), sowing date (Date) and cover crop by sowing date interaction (Crop*Date) are also presented.

Cover crop	1st sowing date 8/3/2018	2nd sowing date 8/8/2018	3rd sowing date 8/13/2018	4th sowing date 8/17/2018	Average of sowing dates
Autumn 2018	Crop: $F_{4,57}$=448, p<0.001; Date: $F_{3,57}$=140, p<0.001; Crop*Date: $F_{12,57}$=14, p<0.001				
Winter turnip rape	75±2$^{c/A}$	76±4$^{c/A}$	62±2$^{b/B}$	41±2$^{b/C}$	64±4^{c}
Forage radish	126±6$^{a/A}$	127±6$^{a/A}$	95±3$^{a/B}$	71±4$^{a/C}$	105±6^{a}
Winter rye	36±2$^{d/A}$	35±3$^{d/A}$	35±2$^{c/A}$	28±2$^{c/B}$	34±1^{d}
Berseem clover	27±2$^{e/AB}$	30±2$^{d/A}$	22±2$^{d/BC}$	15±1$^{d/C}$	24±2^{e}
Hairy vetch	102±4$^{b/A}$	90±4$^{b/B}$	67± 3$^{b/C}$	37±1$^{b/D}$	74±7^{b}
Average of crops	73±9^{A}	72±8^{A}	56±6^{B}	38±4^{C}	
Spring 2019	Crop: $F_{2,33}$=450, p<0.001; Date: $F_{3,33}$=152, p<0.001; Crop*Date: $F_{6,33}$=24, p<0.001				
Winter rye	59±2$^{c/A}$	60±3$^{c/A}$	62±1$^{b/A}$	45±1$^{c/B}$	57±2^{c}
Winter turnip rape	81±2$^{b/A}$	81±4$^{b/A}$	61±1$^{b/B}$	57±2$^{b/B}$	70±3^{b}
Hairy vetch	112±1$^{a/A}$	106±3$^{a/B}$	95±2$^{a/C}$	65±1$^{a/D}$	95±5^{a}
Average of crops	84±7^{A}	82±6^{A}	73±5^{B}	56±2^{C}	

Mean values without common lowercase letters (a,b,c,d) within sowing dates (in columns) and mean values without common uppercase letters (A,B,C,D) within cover crops (in rows) are statistically significantly different (p < 0.05, Fisher LSD test).

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ANOVA results showed that the variation in accumulated N depended significantly on the interaction between cover crop species and sowing date in both trial years, measured in autumn as well as in spring (Table 4 & 5), meaning that there were differences in the degree of reduction in N of different cover crop species depending on the sowing date. According to the autumn measurements, the accumulated N of winter rye was least influenced by the sowing date, varying between 28-22 kg ha^{-1} in the 1st trial year and between 36-28 kg ha^{-1} in the 2nd trial year. In the 1st trial year the accumulated N of berseem clover decreased the most (42-9 kg ha^{-1}), whereas in the 2nd trial year, biomass of hairy vetch decreased the most (102-37 kg ha^{-1}) between the first and the last sowing dates. Out of the five tested cover crop species forage radish accumulated significantly highest amount of N in all sowing dates in both trial years, reducing from 103 to 43 kg ha^{-1} in the 1st and from 126 to 71 kg ha^{-1} in the 2nd trial year.

According to the spring measurements, overall N decrease was less influenced by the delayed sowing compared to autumn (Table 4 and 5). Among the three overwintering cover crop species winter rye was the most stable, with the lowest overall N decrease due to delayed sowing date. Hairy vetch accumulated significantly the highest amount of N across all sowing dates, despite the highest overall decrease in N when comparing the 1st and the last sowing date. As an exception to the general tendency, the amount of N accumulated by hairy vetch and winter turnip rape increased significantly in the 2nd sowing date compared to the 1st sowing date in the first trial year.

Discussion

Cover crop species differ in biomass and N accumulation

Our results from a two-year field experiment showed that there were significant differences in biomass and N accumulated by different species of winter cover crops measured in autumn and in the following spring as an average across all sowing dates. Out of the five tested cover crop species forage radish produced the highest and berseem clover the lowest average biomass and N in autumn. Due to the large taproot, it is able to scavenge N from deeper soil layers. After winterkill and biomass decomposition in early spring, N can be released back into the upper soil layer [13]. Our results show that forage radish is a suitable winter cover crop species also in Nordic climate conditions, due to ability to produce high biomass and accumulate N. In the current study, berseem clover produced lower amount of biomass and N compared to other species. This has been confirmed in our previous study, where we also found that berseem clover is not suitable for winter cover crop when sown in autumn [23], probably because of sensitivity to cooler temperatures [4]. Additionally, when coupled with drought conditions during crop establishment as in our second trial year, berseem clover yields in extremely low biomass and N accumulation. However, when sown in spring berseem clover can accumulate high biomass and N also in Northern climate [24].

Among the five tested winter cover crop species, berseem clover was killed in autumn by the first frosts whereas forage radish was more tolerant to cold temperatures and decomposed by the end of April. Hairy vetch, winter turnip rape and winter rye overwintered in both trial years and therefore these three species were available for measurements in the following spring. Among the overwintering species hairy vetch accumulated the highest amount of biomass and N in spring. Hairy vetch is characterized as a legume with cold tolerance, fast growth and high N fixation capacity and reported to be a suitable cover crop in northern climatic conditions [6,25]. Impact of sowing date on biomass and N accumulation depend on cover crop species We found that biomass and N accumulation of cover crops in general decreased due to delayed sowing. Due to insufficient precipitation during cover crop establishment in the scond trial year, cover crops sown on Aug 3 and Aug 8 emerged at the same time and accumulated similar amount of biomass and N. The influence of sowing date on tested species was different. In particular, winter rye was least affected, whereas berseem clover and hairy vetch were most affected by the delayed sowing dates. Forage radish produced the highest amount of biomass and accumulated N in case of all sowing dates, although it was considerably affected by delayed sowing. According to autumn measurements the biomass of winter rye decreased up to 28%, while the biomass of berseem clover and hairy vetch decreased up to 82 and 69%, respectively. In addition, the accumulated N of winter rye decreased only up to 22%, whereas the accumulated N of berseem clover and hairy vetch decreased up to 79 and 64%, respectively.

Therefore, it can be concluded, that although winter rye had relatively low biomass and N in the current study, which can be attributed to the low tillering ability of cultivar Sangaste [26], winter rye can be suitable cover crop in case of delayed sowing. For instance, studies from Ontario, Canada have found no decrease in biomass and N of winter rye even when sowning has been delayed for one month [18,19]. It is evident from our results that berseem clover is particularly sentitive to delayed sowing – in the first trial year, already 5-day delay reduced its biomass and accumulated N by 53 and 48%, respectively. Therefore, this crop can be used as a winter cover crop only in the case of sowing early in the autumn, as it can not tolerate low temperatures [4]. Earlier studies in Estonia have shown that legumes field pea and faba bean can produce higher biomass in Northern climate [21,22] and therefore could be considered as more suitable winter killed legume cover crops than berseem clover. The susceptibility of legume cover crop species to delayed sowing date has also been reported previously. For example, in Central Europe, legume cover crops biomass sown in mid-August was 95% higher compared to mid-September and low temperatures in mid-October did not allow legume growth at all [27].

As measured in autumn, forage radish produced the highest biomass and N across all sowing dates, despite considerable

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decrease (up to 70 and 58%, respectively). A previous study conducted in the USA, Missouri evaluated the effect of delayed sowing on radish biomass and concluded that radish produced 820–1670 kg ha^{-1} more biomass at the first sowing date compared with delayed sowing [28]. Forage radish will be winterkilled and decomposes during early spring releasing N back into the upper soil layer, which can then be available for the following cash crops [13]. This was the case in our previous study, where forage radish increased significantly the yield of subsequent spring barley [29]. Therefore, forage radish can be recommended as one of the most favorable winter cover crops.

Overwintering cover crop biomass and N accumulation in the spring is influenced by the sowing date and the weather conditions during the growing period [8,16,18,30,]. Among the three overwintering species the biomass and accumulated N of winter rye decreased the least due to delayed sowing dates (up to 21 and 26%, respectively), while hairy vetch decreased the most (up to 39 and 42%, respectively). Despite considerable decrease, hairy vetch accumulated the highest amount of N across all sowing dates as measured in spring. Later termination could partially compensate for cover crop growth in case of delayed sowing [6,8]. On the other hand, delaying the termination date may decrease residue N concentration, increase C:N ratios, and result in higher residue hemicellulose and lignin concentration [20]. Previously, Teasdale et al. [6] observed that delayed sowing by 2 to 3 weeks reduced hairy vetch biomass by 43% when harvested vegetative and by 20% when harvested at the flowering stage. However, Lawson et al. [16] reported average winter cover crop biomass decrease by 50%, and N accumulation by 40% with delayed sowing and found similar reductions in biomass and N accumulation when terminated in late March compared with late April.

Conclusion

Results from a two-year field trial showed that the tested five winter cover crop species (winter turnip rape, forage radish, winter rye, berseem clover and hairy vetch) differed in biomass and accumulated N as measured in autumn and in the following spring. Forage radish produced the highest and berseem clover the lowest average biomass and accumulated N in autumn. Furthermore, we found that biomass and accumulated N of cover crops decreased due to delayed sowing, but there were exceptions due to specific weather conditions such as drought. The influence of sowing date on tested species was different. Notably, the biomass and accumulated N of forage radish remained the highest at all sowing dates as measured in autumn, despite considerable decrease by delayed sowing. Winter rye was least affected by delayed sowing, whereas berseem clover and hairy vetch were most affected. Despite considerable decrease, hairy vetch accumulated the highest amount of N across all sowing dates as measured in spring.

Therefore, we conclude that earlier sowing of winter cover crops will result in higher biomass and accumulated N both in autumn and in the following spring. Among the tested winterkilled species forage radish turned out to be the most favourable cover crop in terms of biomass and accumulated N. Due to low biomass production berseem clover is not suitable for a cover crop in northern climate conditions when sown in autumn. When sown early over-wintering cover crops such as hairy vetch and winter turnip rape can result in high biomass and accumulated N in the following spring, particularly in case of leguminous hairy vetch.

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