Autumnal N fertilization of late sown oilseed rape after minimum tillage

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Abstract

Oilseed rape (OSR) is considered as nitrogen (N) inefficient crop. Due to its low N harvest index and to favourable soil conditions, large N amounts remained in the soil, which, however, cannot completely be taken up by a subsequent wheat crop and increases the risk of N leaching into the groundwater during the following winter. In the long-term, N leaching correlates positively with the N balance. In order to reduce the environmental impact, in Germany therefore N balance must not exceed a threshold of 60 kg N ha^{-1} on a 3 year average as from 2009-2011. To reduce energy costs, farmers increasingly pass on ploughing during seedbed preparation, but they additionally apply about 30-50 kg N ha^{-1} in autumn, often directly upon the stubble of the preceding crop to ensure crop N supply before winter. However, OSR poorly utilizes autumn N. In order to test the effects of N applied in autumn on crop growth and N uptake before and after winter and on seed yield, a field trial was performed in 2002/03 till 2004/05 at the Hohenschulen Experimental Station located near Kiel in NW Germany. OSR was established at the end of August, later than recommended, following wheat and using minimum tillage without ploughing. Spring N fertilization was also varied (80/80, 120/80, 80/120 kg N ha^{-1}), but had no significant effects. Apart from an unfertilized control (N1), 40 kg N ha^{-1} as calcium ammonium nitrate were applied after the first stubble cultivation (N2), directly after sowing (N3) or at the 2-4 leaf stage (mid of September) (N4). On average of the three years, N applied to the crop (either after sowing or at the 2-4 leaf stage) significantly increased above-ground dry matter and N uptake at both sampling dates. Seed yield significantly differed by 0.22 t ha^{-1} between the N1 and N4 treatments. Assuming a seed N concentration of 3%, only 17 % of the applied N was removed by the seeds from the soil-plant system. We conclude that autumn N, if at all, should be applied to the OSR crop and not before sowing.

Key words: Oilseed rape, *Brassica napus*, nitrate problem, autumn N fertilization, N uptake, seed yield

Introduction

In 1991 the EU implemented the 'Nitrate Directive' (Directive 91/676/EEC) in order to reduce water pollution caused or induced by nitrates from agricultural sources and to prevent such pollution. In Germany, the national implementation of the Nitrate Directive ('Düngeverordnung') entered into force as from 2006. Among other regulations this directive defines for the first time thresholds for the N balance. In order to reduce the environmental impact, N balance in Germany must not exceed a threshold of 90 kg N ha^{-1} on a 3 year average as from 2006-2008, declining to 60 kg N ha^{-1} in 2009-2011.

Oilseed rape (OSR) is considered as nitrogen (N) inefficient crop. Due to its low N harvest index, large N amounts remained in the soil resulting in partly large N surpluses. The favorable soil conditions and the early harvest date allow an intensive N mineralization, which increases the nitrate pool in the soil, especially if stubble cleaning was performed. However, the subsequent winter wheat crop which normally is grown following OSR cannot completely take up the available nitrate-N increasing the risk of N leaching into the groundwater during the following winter.

In the last years farmers changed crop rotation replacing barley by wheat, however, seeding date is often delayed. In addition, they increasingly pass on ploughing during seedbed preparation to reduce energy costs. To compensate for these worsening of establishment conditions, they additionally apply about 30-50 kg N ha^{-1} in autumn, often directly upon the stubble of the preceding crop, to ensure crop N supply and adequate crop growth before winter. However, OSR poorly utilizes autumn N for yield formation resulting in increased N balance.

Together with other approaches e.g. optimized N fertilization in spring and reduced soil tillage after OSR harvest, we tried to find strategies to reduce N surpluses of the OSR crop. The objective of this experiment was to investigate how N applied in autumn affects growth and N uptake before and after winter, seed yield, soil mineral N (SMN), and, in consequence, N balance of late sown OSR following winter wheat.

Material and Methods

In 2002/03 till 2004/05, a field trial was performed at the Hohenschulen Experimental Station located near Kiel in NW Germany (10.0° E, 54.3° N, 30 m a.s.l.). The climate of NW Germany can be described as humid. Total rainfall averages 750 mm annually at the experimental site, with c. 400 mm received during April - September, the main growing season, and c. 350 mm during October – March. At the beginning of the trial, the straw of the preceding wheat crop was shredded and remained on the plots. Soil tillage consisted of two passes with a cultivator at a depth of 18-20 cm. OSR (cv. Talent, hybrid) was established in the 3rd decade of August (23 Aug 2002; 26 Aug 2003; 24 Aug 2004), later than recommended, using minimum tillage without ploughing. The N treatments tested are presented in Table 1. The experimental design was a completely randomized design with 4 replications. The plot size was 12 x 3 m.

Table 1: Experimental factors and levels of factors used in the field trial

Application of N in autumn:	1 – Unfertilized control
	2 – 40 kg N ha^{-1} on the stubble of the preceding crop (1st decade of August)
	3 – 40 kg N ha^{-1} directly after sowing (3rd decade of August)
	4 – 40 kg N ha^{-1} at the 2-4 leaf stage (Mid of September)
Application of N in spring†:	1 – 80/80 kg N ha^{-1}
	2 – 120/80 kg N ha^{-1}
	3 – 80/120 kg N ha^{-1}
	† - 1st application at the beginning of spring growth (25 Feb 2003; 04 Mar 2004; 23 Apr 2005) 2nd application at stem elongation (04 Apr 2003; 05 Apr 2004; 18 Apr 2005)

At the end of autumn growth and at the beginning of spring growth, plant samples were taken for above-ground total dry matter (TDM) and total N determination from areas each 0.5 m^2. The N uptake was obtained by multiplying the TDM (standardized to g m^{-2}) by the total N content of the plants determined by NIR spectroscopy.

Soil mineral nitrogen (NO_3-N plus NH_4-N: SMN) was determined corresponding to plant sampling at the end of autumn growth and at the beginning of spring growth (0-90 cm). Two cores per plot, averaged to one sample, were taken. SMN samples were taken to the laboratory and stored frozen until analysis. They were thawed overnight at room temperature. From one subsample, NO_3-N and NH_4-N were extracted using 0.033n $CaCl_2$ and analyzed colorimetrically. A further subsample was oven-dried to determine soil moisture content.

At harvest an area of 9 m^2 was harvested by combine and seed yield was standardized to t ha^{-1} at 91 % DM based on the moisture content of a seed subsample. Due to insufficient crop establishment, 5 plots in 2003 and 3 plots in 2004 have been omitted. The N uptake of the seed was obtained by multiplying the yield by the total N content of the seed determined by NIR spectroscopy.

The simple N balance was calculated from N fertilization minus N offtake by the seeds.

Results

Years highly affected crop growth (Table 2). In autumn 2002 and spring 2003 OSR accumulated significantly more above-ground biomass (160 g DM m^{-2}) and took up more N (>60 kg N ha^{-1}) on average over the N treatments than in the other years. In contrast, poorest crop growth was observed in 2003/2004. On average over the years, N fertilization in autumn significantly enhanced OSR growth compared to the unfertilized control (Table 2). The effect was more pronounced if N was applied directly to the crop, e.g. after sowing or at the 2-4 leaf stage resulting in a doubling of the N uptake.

At the end of autumn growth, soil mineral N in 0-90 cm was significantly increased by an application of N in autumn (Table 3). Highest values of 49 kg N ha^{-1} occurred after N supply at the 2-4 leaf stage of OSR (mid of September), whereas N application on the stubble of the preceding wheat crop or after sowing of OSR caused an increase of 9 kg N ha^{-1} compared to the unfertilized control (30 kg N ha^{-1}). In the subsequent spring, no differences in SMN between the autumn N treatments were found

On average, OSR seed yield varied with the years between 4.2 and 5 t ha^{-1} (Table 4). Applying 40 kg N ha^{-1} in autumn increased seed yield by 0.1-0.2 t ha^{-1}, however, the difference was not significant at $p=0.05$. The effect was not consistent over all years, as indicated by the significant interaction between year and autumn N. A supply of 200 kg N ha^{-1} in spring, irrespective of its distribution, resulted in slightly higher yields (+0.2 t ha^{-1}) than 160 kg N ha^{-1}. The interaction between N fertilization in autumn and N supply in spring was not significant, indicating that the amount of N applied in autumn cannot be deducted from N fertilization in spring.

Concerning the N offtake by the seeds, a similar pattern can be observed as for the seed yield (Table 4). A 40 kg N ha^{-1} higher spring N application increased N offtake by about 10 kg N ha^{-1}, whereas 40 kg N ha^{-1} applied autumn only slightly affected this parameter by 4 kg N ha^{-1}. Due to the small variation in N offtake due to the N treatments, N balance was mainly affected by the amount of N supply. Despite the yield increase in the 200 kg N ha^{-1} treatment, N surplus consequently rose by 30 kg N ha^{-1}. Since autumn N had only a negligible effect on N offtake, nearly all N from this application remained in the soil and boosted the N balance.

An increasing N supply in spring decreased seed oil concentration, whereas N in autumn increased it by 0.5 %.

Discussion

Against the background of the implementation of the EU Nitrate Directive in Germany (Düngeverordnung) with its thresholds for the N balance and together with the relatively low N use efficiency of OSR, the challenge to reduce the large N surpluses has to be investigated. Several approaches are possible: to reduce the amount of N fertilizer, to improve N offtake at a given N supply and/or to reduce N leaching by changing soil tillage after OSR or growing catch crops. Farmers often apply N in autumn to OSR in order to ensure a sufficient crop growth to ride the winter out, especially if the crop is following wheat, the sowing date is delayed, and/or minimum tillage without ploughing is performed. However, N fertilization in autumn is a crucial point, because according to out results, no distinct effect on seed yield could be expected, although crop growth and N uptake in autumn was significantly enhanced. The yield increase of about 0.2 t ha^{-1} was related to an additional N offtake by the seeds of about 4 kg N ha^{-1}, meaning that in maximum only 10 % of the applied N amount was removed from the system, whereas 36 kg N ha^{-1} remained in the soil and charged the N balance.

Although OSR took up more N during autumn after N fertilization, SMN was markedly increased, and in consequence also the risk of N leaching during the subsequent percolation period.

We conclude that under the conditions of the experimental site no N fertilizers normally should be applied to OSR in autumn. If the farmer hold that the OSR crop needs N in autumn, N fertilizer should be applied to the crop itself and not before sowing.

Table 2: Effect of year and timing of 40 kg N ha^{-1} applied in autumn on above-ground dry matter accumulation (g m^{-2}) and N uptake (kg ha^{-1}) at the end of autumn growth and at the beginning of spring growth of OSR in 2002/03-2004/05.

	Above-ground dry matter (g m^{-2})		N uptake (kg N ha^{-1})	
	End of autumn growth	Beginning of spring growth	End of autumn growth	Beginning of spring growth
2002/2003 (n=16)				
Unfertilized control	129.9	97.5	46.6	40.3
40 kg N ha^{-1} on the stubble	145.6	118.5	49.2	49.1
40 kg N ha^{-1} after sowing	180.6	143.0	75.7	61.0
40 kg N ha^{-1} at the 2-4 leaf stage	195.3	157.6	77.1	67.7
2003/2004 (n=16)				
Unfertilized control	9.2	15.4	3.1	7.9
40 kg N ha^{-1} on the stubble	24.6	36.3	8.2	18.2
40 kg N ha^{-1} after sowing	25.3	36.4	8.7	18.2
40 kg N ha^{-1} at the 2-4 leaf stage	16.6	27.8	7.3	14.1
2004/2005 (n=16)				
Unfertilized control	12.9	28.5	7.2	13.0
40 kg N ha^{-1} on the stubble	33.2	54.2	16.4	23.8
40 kg N ha^{-1} after sowing	53.6	90.3	24.5	38.7
40 kg N ha^{-1} at the 2-4 leaf stage	49.3	80.6	25.6	35.6
Years				
2002/2003	161.0	128.0	61.6	54.2
2003/2004	19.1	28.7	6.9	13.9
2004/2005	37.3	63.4	18.5	28.2
Autumn N				
Unfertilized control	48.2	45.6	18.2	20.0
40 kg N ha^{-1} on the stubble	68.1	69.3	24.7	30.0
40 kg N ha^{-1} after sowing	86.6	88.7	36.3	39.1
40 kg N ha^{-1} at the 2-4 leaf stage	87.0	89.9	36.7	39.4
$LSD_{0.05}$ for year	17.59	12.22	6.91	4.01
$LSD_{0.05}$ for autumn N	28.72	19.95	11.28	7.86
$LSD_{0.05}$ for autumn N x year	n.s.†	24.44	13.81	9.62

† - not significant at P=0.05

Table 3: Effect of year and timing of 40 kg N ha^{-1} applied in autumn on soil mineral N in 0-90 cm (kg ha^{-1}) at the end of autumn growth and at the beginning of spring growth of OSR in 2002/03-2004/05.

	Soil mineral N (0-90 cm) (kg N ha^{-1})	
	End of autumn growth	Beginning of spring growth
Years		
2002/2003 (n=16)	22	n.d.‡
2003/2004 (n=16)	52	29
2004/2005 (n=16)	44	20
Autumn N		
Unfertilized control	30	24
40 kg N ha^{-1} on the stubble	39	27
40 kg N ha^{-1} after sowing	39	25
40 kg N ha-1 at the 2-4 leaf stage	49	23
LSD0.05 for year	6.8	5.0
LSD0.05 for autumn N	7.9	n.s.†

† - not significant at P=0.05
‡ - not determined

Table 4: Effect of year, timing of 40 kg N ha^{-1} applied in autumn and spring N application on seed yield (t ha^{-1}), N offtake by the seeds (kg N ha^{-1}), simple N balance (kg N ha^{-1}), and oil concentration (% of DM) in the seeds of OSR in 2002/03-2004/05.

	Seed yield (t ha^{-1})	N offtake by the seeds (kg N ha^{-1})	N balance (kg N ha^{-1})	Oil concentration (% of DM)
2002/2003 (n=43)				
Unfertilized control	5.01	162.8	23.8	48.3
40 kg N ha^{-1} on the stubble	4.68	148.5	78.1	48.7
40 kg N ha^{-1} after sowing	4.73	150.6	74.8	48.8
40 kg N ha^{-1} at the 2-4 leaf stage	5.00	159.0	66.4	48.7
2003/2004 (n=45)				
Unfertilized control	4.16	117.9	68.8	51.2
40 kg N ha^{-1} on the stubble	4.43	125.3	101.4	51.5
40 kg N ha^{-1} after sowing	4.31	121.4	105.3	51.3
40 kg N ha^{-1} at the 2-4 leaf stage	4.28	120.9	105.7	51.3
2004/2005 (n=48)				
Unfertilized control	4.70	130.0	56.6	49.1
40 kg N ha^{-1} on the stubble	4.96	132.7	93.9	49.8
40 kg N ha^{-1} after sowing	5.02	134.3	92.4	49.6
40 kg N ha^{-1} at the 2-4 leaf stage	4.17	136.9	89.8	50.1
Years				
2002/2003	4.84	154.7	62.9	48.6
2003/2004	4.29	121.1	94.9	51.3
2004/2005	4.96	133.5	83.2	49.6
Autumn N				
Unfertilized control	4.59	134.6	52.1	49.6
40 kg N ha^{-1} on the stubble	4.71	136.4	90.2	49.8
40 kg N ha^{-1} after sowing	4.69	135.0	91.3	49.9
40 kg N ha^{-1} at the 2-4 leaf stage	4.81	138.4	87.9	50.1
Spring N				
80/80 kg N ha^{-1}	4.54	129.0	61.5	50.3
120/80 kg N ha^{-1}	4.79	140.3	89.5	49.7
80/120 kg N ha^{-1}	4.76	139.3	91.3	49.6
$LSD_{0.05}$ for year and for spring N	0.210	4.37	4.35	0.30
$LSD_{0.05}$ for autumn N	n.s.†	n.s.	4.87	0.34
$LSD_{0.05}$ for autumn N x year	0.498	9.54	9.49	n.s.

† - not significant at P=0.05