Semi-dwarf genotypes—a chance to reduce the N problem after oilseed rape?

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Abstract

In NW Europe oilseed rape (OSR) is often used as preceding crop for winter wheat. Due to its low N harvest index and to favorable soil conditions, large N amounts remained in the soil, which, however, cannot completely be taken up by the subsequent wheat crop and increases the risk of N leaching into the groundwater during the following winter. Several approaches to reduce N leaching have been discussed (e.g. growing of catch crops, reducing soil tillage in autumn, reducing N fertilization), however, the farmer's acceptance remains low due to economical losses. In the last years, OSR semi-dwarf genotypes were developed. We assumed that semi-dwarf genotypes accumulate less vegetative biomass and need therefore less nitrogen to achieve yield maximum compared to conventional hybrids or open pollinating varieties, which in consequence reduce the risk of N leaching. In order to test this working hypothesis, a field trial was performed in 2003/04 and 2004/05 at the Hohenschulen Experimental Station located near Kiel in NW Germany. Four varieties (Express, Talent, Trabant and Belcanto as semi-dwarf genotype), two seeding date (mid of August, beginning of September) and eight mineral N fertilization (0 to 240 kg N ha^{-1}) were varied. On average, the semi-dwarf genotype Belcanto achieved significantly less seed yield (4.44 t ha^{-1}) than the other varieties (4.65 – 4.88 t ha^{-1}), however, all tested varieties needed similar N fertilization for their yield maximum. In addition, N offtake by the seeds did not differ. No interaction between genotype and N treatment occurred. Detailed analysis of dry matter accumulation and N uptake during the growth period revealed only small differences between the varieties on average of all N treatments and both years. At harvest, Belcanto produced more pods m^{-2} and a slightly higher thousand seed weight. However, harvest index and N harvest index were similar for all genotypes. We conclude that despite its lower plant height the semi-dwarf genotype Belcanto does not provide the opportunity to reduce the N problem in OSR based rotations.

Key words: Oilseed rape, *Brassica napus*, semi-dwarf genotype, nitrate problem, yield, harvest index

Introduction

The 'Nitrate Directive' (Directive 91/676/EEC) released 1991 by the EU aimed at reducing water pollution caused or induced by nitrates from agricultural sources and preventing such pollution. The German implementation of the Nitrate Directive ('Düngeverordnung') became effective in 2006 and defines among other regulations for the first time thresholds for the N balance. The surplus 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 in order to reduce the environmental impact of N fertilization.

In NW Europe oilseed rape (OSR) is often used as preceding crop for winter wheat. Due to its low nitrogen (N) harvest index and to favourable soil conditions after growing OSR, large N amounts remained in the soil, which, however, cannot completely be taken up by the subsequent wheat crop and increases the risk of N leaching into the groundwater during the following percolation period. Several approaches to reduce N leaching have been discussed (e.g. growing of catch crops, reducing soil tillage in autumn, reducing N fertilization), however, the farmer's acceptance remains low due to economical losses. In the last years, OSR semi-dwarf genotypes were developed with a reduced plant height. Our working hypothesis was that semi-dwarf genotypes accumulate less vegetative biomass at a similar yield level and need therefore less nitrogen to achieve yield maximum compared to conventional hybrids or open pollinating varieties. In consequence less N remained within the system and N surpluses and the risk of N leaching are reduced.

In order to test this hypothesis, we compared four OSR genotypes with varying growth pattern in a 2 year field trial in terms of their response to N fertilization and their dry matter and N partitioning patterns. Eight different N treatments (0-240 kg N ha^{-1}) allowed us to estimate N response curves for each genotype and to derive the N amount to achieve yield maximum.

Material and Methods

In 2003/04 and 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.

Four varieties, two sowing dates and eight mineral N amounts were varied (Table 1). Belcanto is a French semi-dwarf hybrid, which was commercially available at the beginning of the experiment. Although already released in 1993 Express was used because of its relatively small canopy, whereas Talent and Trabant represent modern hybrids. Practical constraints required the field trial design to be a split-split-plot design with three levels of splitting. The sowing dates were main plots, the genotypes were sub plots split within main plots, and the mineral N treatments were sub-sub plots split within sub plots. The N treatments were replicated four times within the sub plots. Since no significant interactions between sowing date and genotype of N treatment occurred in most of the cases, results are presented as average of the sowing dates. The late sowing date 2005 received 30 kg N ha^{-1} in October 2004 to ensure crop N supply and adequate crop growth before winter.

At four dates (end of autumn growth, start of spring growth, stem elongation, pod filling, harvest), plant samples were taken from the N1, N2, N5 and N8 treatment for above-ground total dry matter (TDM) and total N determination from areas each 0.5 m^2. Two weeks before combine harvest, seed yield, number of pods, thousand weed weight, and straw yield were measured and number of seed per pod were calculated. 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.

Table 1: Experimental factors and levels of factors used in the field trial in 2003/04 and 2004/05.

Sowing date:	1 – normal (20 Aug 2003; 23 Aug 2004)
	2 – late (05 Sep 2003; 09 Sep 2004)
Genotype:	1 – Belcanto (semi-dwarf hybrid)
	2 – Express (open pollinating)
	3 – Talent (hybrid)
	4 – Trabant (hybrid)
Application of N in spring[†]:	1 – 0/ 0 kg N ha^{-1}
	2 – 40/ 40 kg N ha^{-1}
	3 – 80/ 40 kg N ha^{-1}
	4 – 40/ 80 kg N ha^{-1}
	5 – 80/ 80 kg N ha^{-1}
	6 – 120/ 80 kg N ha^{-1}
	7 – 80/120 kg N ha^{-1}
	8 – 120/120 kg N ha^{-1}

1st application at the beginning of spring growth (04 Mar 2004; 24 Mar 2005)
2nd application at stem elongation (05 Apr 2004; 14 Apr 2005)

In all plots an area of 9 m^2 was harvested by combine at maturity and seed yield was standardized to t ha^{-1} at 91 % DM based on the moisture content of a seed subsample.

Analyses of variance were done by using the SAS statistical package. Year was used as replication of main plots (sowing date). $LSD_{0.05}$ for genotype is based on year x sowing date x genotype interaction effects, that for the mineral N treatments is based on year x sowing date x genotype x N treatment x replication. The $LSD_{0.05}$ applies only to individual treatment means

To facilitate the comparison of 8 N treatments, a quadratic N response curve for each genotype was estimated and the yield maximum and the corresponding N amount were calculated.

Results

At the end of autumn growth and at the start of spring growth, above-ground DM and N uptake were similar for all genotypes (Table 2). During spring growth, Talent accumulated more aerial biomass and took up more N than the other varieties, but the differences were significant only at harvest. Against the expectance, Belcanto as semi-dwarf hybrid did not show the lowest values.

N fertilization in spring significantly enhanced crop growth and N uptake at stem elongation and the subsequent sampling dates (Table 3). At harvest, unfertilized OSR took up about 112 kg N ha^{-1}, whereas the 120/120 kg N ha^{-1} treatment incorporated 300 kg N ha^{-1} in total. No genotype by N treatment occurred indicating that all tested varieties similarly responded to an increased N supply.

Concerning the seed yield derived from plant sampling at harvest, Talent and Trabant significantly outyielded Belcanto and Express (Table 4). Talent also achieved the highest DM of straw and pod walls. It should be pointed out that the vegetative biomass of Belcanto was higher than that of Express and only slightly reduced compared to Trabant. However, the differences were not significant.

Table 2: Above-ground dry matter accumulation (g m^{-2}) and N uptake (kg N ha^{-1}) of four oilseed rape genotypes throughout the growing period (mean of two years (2003/04-2004/05), two sowing dates, and the 160 and 240 kg N ha^{-1} treatments).

	Dry matter accumulation (g m^{-2})				N uptake (kg N ha^{-1})			
	Belcanto	Express	Talent	Trabant	Belcanto	Express	Talent	Trabant
End of autumn growth	50	46	48	51	19	17	18	19
Start of spring growth	61	72	71	66	30	36	34	32
Stem elongation	396	462	539	470	194	200	229	204
Pod filling	1212	1430	1420	1264	257	270	262	236
Harvest	1552[bc†]	1502[c]	1740[a]	1645[ab]	269[b]	251[c]	287[a]	267[b]

[†] Within one growth stage means followed by the same letter are not significantly different at P = 0.05.

Detailed analysis of the yield components at harvest revealed that Belcanto produced more pods m^{-2} and slightly larger seeds than the other genotypes on average of the 160 and 240 kg N ha^{-1} treatments, both sowing dates and both years. In contrast, the calculated number of seeds per pod was markedly reduced. The amount of N in the straw varied between 41 and 46 kg N ha^{-1} and that in the pod walls between 24 and 31 kg N ha^{-1}, however, without clear trends. The harvest index, the proportion of seed DM to the total aerial biomass, hardly varied between 0.38 and 0.40, while the N harvest (N amount in the seeds/N amount of total aerial biomass) ranged between 0.72 and 0.74.

Table 3: Effect of N fertilization on above-ground dry matter accumulation (g m^{-2}) and N uptake (kg N ha^{-1}) of oilseed rape throughout the growing period (mean of two years (2003/04-2004/05), two sowing dates, and four genotypes).

kg N ha^{-1}	Dry matter accumulation (g m^{-2})				N uptake (kg N ha^{-1})			
	0/0	40/40	80/80	120/120	0/0	40/40	80/80	120/120
End of autumn growth	50	46	48	51	19	17	18	19
Start of spring growth	61	72	71	66	30	36	34	32
Stem elongation	262^{c†}	405^{b}	460^{ab}	473^{a}	69^{c}	161^{b}	198^{a}	216^{a}
Pod filling	664^{c}	1172^{b}	1231^{b}	1433^{a}	89^{d}	182^{c}	218^{b}	294^{a}
Harvest	857^{c}	1312^{b}	1524^{a}	1696^{a}	112^{d}	186^{c}	236^{b}	300^{a}

† Within one growth stage means followed by the same letter are not significantly different at P = 0.05.

Table 4: Yield and yield components of four oilseed rape genotypes (mean of two years (2003/04-2004/05), two sowing dates, and the 160 and 240 kg N ha^{-1} treatments), derived from plant sampling at harvest.

	Belcanto	Express	Talent	Trabant
Above-ground dry matter (g m^{-2})	1552^{bc†}	1502^{c}	1740^{a}	1645^{b}
Seed yield dry matter (g m^{-2})	588^{b}	604^{b}	692^{a}	657^{a}
Straw and pod walls dry matter (g m^{-2})	964	898	1048	988
Total N uptake (kg N ha^{-1})	269^{ab}	251^{b}	287^{a}	267^{ab}
N in the seeds (kg N ha^{-1})	193^{bc}	184^{c}	212^{a}	197^{b}
N in the straw (kg N ha^{-1})	46	42	45	41
N in the pod walls (kg N ha^{-1})	30	24	31	29
Number of pods m^{-2}	9302^{a}	7381^{b}	7428^{b}	7153^{b}
Number of seeds per pod	14.7^{c}	19.4^{b}	21.4^{a}	20.9^{ab}
Thousand seed weight (g)	4.58	4.20	4.38	4.40
Harvest Index	0.38	0.40	0.40	0.40
N harvest index	0.72	0.73	0.74	0.74

† Within one growth stage means followed by the same letter are not significantly different at P = 0.05.

On average of all other treatments, combine harvested seed yield ranged in a similar way as observed by seed yield of the plant sampling. Highest yields were observed in Trabant (4.88 t ha^{-1}) and Talent (4.81 t ha^{-1}), while Express (4.65 t ha^{-1}) and Belcanto (4.44 t ha^{-1}) yielded less. Without N fertilization, Belcanto achieved 2.29 t ha^{-1}, Express 2.59 t ha^{-1}, Talent 2.84 t ha^{-1} and Trabant 2.80 t ha^{-1}. The N response curves estimated for each genotype separately showed that N fertilization increased seed yield similarly for the varieties, but at different levels (Fig. 1). All tested varieties required similar fertilizer N amounts for their yield maximum, namely 231 kg N ha^{-1} for Belcanto (5.15 t ha^{-1}), 219 kg N ha^{-1} for Express (5.29 t ha^{-1}), 218 kg N ha^{-1} for Talent (5.42 t ha^{-1} and 218 kg N ha^{-1} for Trabant (5.52 t ha^{-1}), respectively. In addition, N offtake by the seeds did not differ (data not shown. No interaction between genotype and N treatment occurred.

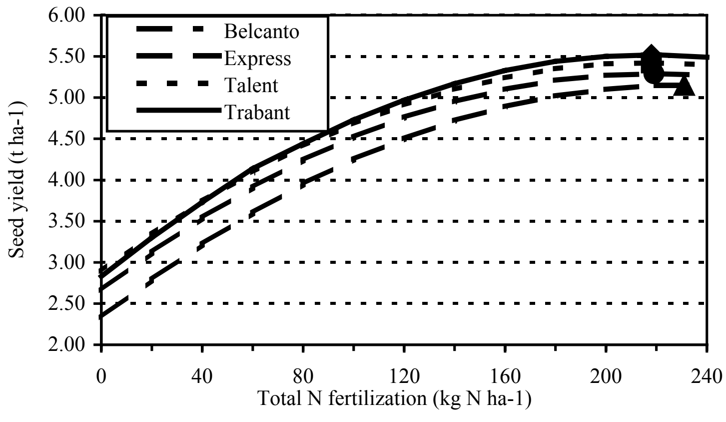

Fig. 1: Effect of the N fertilization on seed yield (t ha^{-1} at 86 % DM) of four oilseed rape genotypes (mean of two years (2003/04+2004/05) and two sowing dates). Symbols indicate yield maximum.

Discussion

In order to minimize the N surpluses of OSR we compared a semi-dwarf hybrid with conventional hybrids and open pollinating variety. We assumed that this new type of genotype with its shorter plant height accumulates less above-ground biomass without yield penalties and, therefore, requires less nitrogen to achieve yield maximum resulting in an increased (N) harvest index. In consequence, less N remains in the system after harvest and the risk of N leaching is reduced. However, our results clearly show that we have to reject this hypothesis. Belcanto representing the semi-dwarf genotype produced similar total aerial dry matter, took up similar amounts of N, showed similar (N) harvest indices and required similar N supply for yield maximum as other varieties. It has to be noted that Belcanto was one of the first varieties which was commercially available at the beginning of the experiment. Since the breeding process was at the beginning, Belcanto did not show the same yield level as modern conventional genotypes. Additional experiments with another modern semi-dwarf variety supported our results (data not shown). Our study only referred to the effects on N balance. However, semi-dwarf genotypes may be favored by the farmers for other reasons, i.e. their higher lodging resistance.

We conclude that semi-dwarf OSR genotypes *per se* do not provide the opportunity to reduce the N problem in OSR based rotations.