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Defoliation affects seed yield but not N uptake and growth rate in two oilseed rape cultivars differing in post-flowering N uptake

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ABSTRACT

Genotypic variation in nitrogen efficiency of winter oilseed rape is closely related to variation in post-flowering N uptake. In this study the hypothesis was tested that assimilate supply from the leaves is decisive for a high N uptake during reproductive growth.

Two winter oilseed rape cultivars differing in N efficiency were cultivated in a three-year field experiment at three N rates, ranging from deficiency to optimal N supply. In sub-plots, 50% of the leaves were removed at the beginning of flowering. Seed yield, total biomass, N uptake and yield components were assessed.

Defoliation caused substantial yield decrease at all N rates and for both cultivars. This was not related to decreased growth rates or post-flowering N uptake, but mainly to the reduction in total N by leaf removal. In addition, harvest index and seed number per area were reduced by the defoliation treatment.

The results demonstrate that leaves are important for yield formation in oilseed rape. The hypothesis, that assimilate supply from the leaves enhances N uptake during reproductive growth could not be confirmed by this experiment. Instead, the importance of the leaves for yield may be due to assimilate remobilization from the leaves during reproductive growth.

1. Introduction

In European agriculture a serious problem in the cultivation of winter oilseed rape is the high nitrogen (N) balance surplus which has a negative impact on the environment and reduces the economic return. To reduce the high N balance surplus without yield penalty, improvement of soil- and fertilizer-N management and the breeding and cultivation of N-efficient cultivars are necessary (Rathke et al., 2006; Sylvester-Bradley and Kindred, 2009). Identification of plant characteristics correlating with N efficiency could facilitate the selection process of N-efficient cultivars. Previous studies reported that N-efficient rape cultivars are characterized by a prolonged photosynthetic activity through delayed leaf senescence (stay-green) during reproductive growth at limiting N (Schulte auf'm Erley et al., 2007). Also, it was found that maintaining a high N uptake activity during reproductive growth is an important characteristic of N-efficient cultivars (Schulte auf'm Erley et al., 2011). The high N uptake activity during reproductive growth was associated with an efficient and vigorous root growth of the N-efficient cultivar (Kamh et al., 2005; Ulas et al., 2012). From these results it was concluded that continuous assimilate supply from the leaves is necessary for the high N uptake during reproductive growth of N-efficient cultivars. The aim of this study was to investigate the role of leaves and the impact of defoliation on yield and N uptake of oilseed rape cultivars differing in N efficiency. It was hypothesized that defoliation causes a shortage of assimilates to the roots and thus decreases N uptake during reproductive growth.

2. Materials and methods

2.1. Experimental setup

Field experiments were performed near Göttingen, Germany, at the experimental station of the Institute of Plant Breeding, University of Göttingen (51°30′N, 9°55′E, 155 m asl) during the growing

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periods 1998/1999, 1999/2000 and 2000/2001. The silty clayey soil classified as fluvisol (FAO, 2006) contained on average 9% sand, 73% silt, 18% clay and 1.0% C_{org} with a pH of 7.1. The climate at the study site is humid with 8.7 °C mean annual air temperature and 645 mm total annual rainfall.

Two commercial open pollinating oilseed rape lines (*Brassica napus* L.) were used in the study. The cultivars Apex (Syngenta Seeds, Bad Salzuflen and Capitol (Deutsche Saatveredelung, Lippstadt) were selected due to their differences in N efficiency (Schulte auf'm Erley et al., 2011). They were sown on 20th August 1998, 31th August 1999 and 22th August 2000 at a density of 80 seeds m^{-2}. Each plot consisted of six plant rows of 7.5 m length and a row distance of 25 cm.

Soil mineral N contents at the beginning of the vegetation period amounted to 17 kg N ha^{-1} in 1999, 23 kg N ha^{-1} in 2000 and 18 kg N ha^{-1} in 2001. N was fertilized as calcium ammonium nitrate. Half of the N dose was applied at the beginning of the vegetation period and the second half at the beginning of shooting (BBCH 30; Lancashire et al., 1991). Three different N rates were established: no N fertilization (N0), 120 kg N ha^{-1} (N120) and 240 kg N ha^{-1} (N240), with soil mineral N contents deducted from the first N dose. Apart from N, plants received 225 kg ha^{-1} potassium magnesium sulphate (30% K_2O, 10% MgO and 17% S) at the beginning of shooting. Pest, disease, and weed control, and all other agronomic treatments followed the recommendations for oilseed rape production in Germany.

The experiments were laid out in a split plot design with N rates as main plots and cultivars as sub-plots with four block replicates. The defoliation treatment was carried out at the beginning of flowering (BBCH 61). In each research plot every second leaf of the plants was cut with scissors within a marked area of one square meter. The dry matter removed by the cut leaves presented around 19% (17 to 23%) of the total shoot dry matter at BBCH 61, and the N removal accounted to around 23% (19 to 26%) of the shoot N at that time.

2.2. Measurements

An intermediate harvest was performed at the beginning of flowering (BBCH 61). Plants were cut shortly above soil level on one square meter. Plants were weighed, and 20 representative plants were selected and fractionated into stems and leaves. Each fraction was weighed and dried at 65 °C until a constant dry weight was attained.

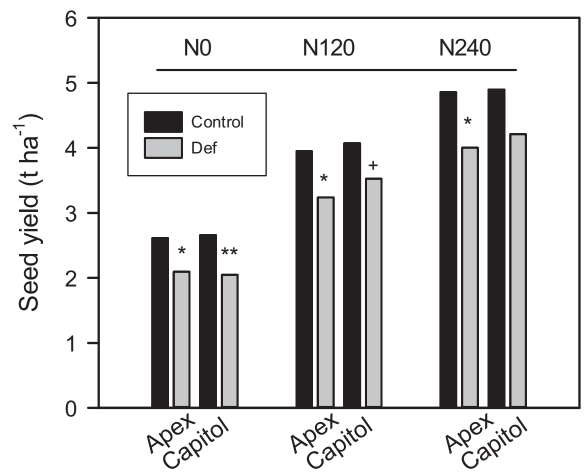
The second harvest was performed around two weeks before maturity (BBCH 89), following the same procedure as at BBCH 61. Plants were fractionated into stems, leaves (if present), pod walls and seeds. In addition, the pod numbers of the harvested plants were counted, and thousand kernel weight was determined to enable the calculation of yield components.

N analyses of all dried and milled plant fractions were performed by Dumas analysis (Vario EL, Elementar Analysensysteme, Hanau, Germany).

2.3. Calculations and statistics

N utilization efficiency was calculated as seed yield divided by total shoot N uptake. Harvest index was calculated by dividing the seed yield by the total biomass (sum of all plant fractions).

N rate, cultivar and defoliation effects as well as the interactions were analysed by a mixed model using R (The R Foundation for Statistical Computing, 2014) with year and block effects as random factors. Defoliation effects were tested separately for each N rate by multiple comparisons within cultivars with a probability of 5% after a Tukey–Kramer adjustment.



Anova:

C	N	Def	C*N	C*Def	N*Def	C*N*Def
ns	***	***	ns	ns	ns	ns

Fig. 1. Seed yield of two winter oilseed rape cultivars grown in a three-year field experiment at three N rates (0, 120 and 240 kg N ha^{-1} incl. N_{min}) for control plants and plants which were 50% defoliated at beginning of flowering (Def). Stars indicate significant difference between control and defoliation (* $P<0.05$; ** $P<0.01$). Anova results show the significance probability for cultivar (C), N rate (N) and defoliation (Def) effects and its interactions (ns, not significant; ***, $P<0.001$).

3. Results

Seed yield increased with increasing N supply ($P<0.001$), but did not differ between cultivars in this experiment (Fig. 1). The defoliation treatment reduced seed yield at all N rates ($P<0.001$). For cv Apex, the defoliation effect was similar at all N rates, while for cv Capitol it was more obvious at low N supply (Fig. 1).

Total shoot dry matter at maturity (Fig. 2) was also increased by N rate ($P<0.001$) and reduced by the defoliation treatment ($P<0.001$), but did not differ between cultivars. The dry matter reduction by the defoliation treatment was solely caused by the removal of the cut leaves, which fully account for the dry weight difference of control and defoliated plants (Fig. 2). The shoot growth rate after beginning of flowering, in contrast, was not affected by the defoliation (Table 1).

N uptake was also increased with increasing N supply ($P<0.001$), but did not differ between cultivars in this experiment (Fig. 2). The defoliation caused a clear reduction in total N uptake at maturity ($P<0.001$). Like for shoot dry matter, this effect was also caused completely by the N removal by cut leaves (Fig. 2) and not by a reduction in N uptake after beginning of flowering (Table 1).

Growth rate between beginning of flowering and maturity increased with N supply and was higher for cv Apex compared to cv Capitol (Table 1). Defoliation did not lead to a reduction in shoot growth rate.

N uptake between beginning of flowering and maturity increased at the highest N supply rate. Although cultivars did not generally differ in N uptake after beginning of flowering, the separate statistical analysis for N rates revealed a cultivar difference in this trait without N fertilization ($P<0.001$).

N utilization efficiency decreased with increasing N supply and was higher for cv Capitol especially at high N supply (Table 1). Defoliation led to a decrease in N utilization efficiency for cv Capitol at low N supply.

Harvest index increased with increasing N supply, particularly for cv Capitol (Table 1). The defoliation treatment caused a general reduction in harvest index. The nitrogen harvest index, in contrast,