https://doi.org/10.17221/444/2019-PSE

Effect of autumn nitrogen fertilization on winter oilseed rape growth and yield parameters

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Citation: Béreš J., Bečka D., Tomášek J., Vašák J. (2019): Effect of autumn nitrogen fertilization on winter oilseed rape growth and yield parameters. Plant Soil Environ., 65: 435–441.

Abstract: Autumn fertilization of winter oilseed rape with nitrogen was monitored in exactly delimited small field experiment in the period of 2013/14–2015/16. The cultivar used was DK Exstorm, sowing amount: 50 seeds/m^2 and fertilizer applied in autumn was Ureastabil – granulated urea with urease inhibitor (NBPT). The application period was at the end of October, doses 40 and 80 kg N/ha. Research results confirmed a statistically important effect of autumn fertilization on growth of the above-ground biomass and roots. Statistically important effect on seed yield was confirmed, too. The dose of 40 kg N/ha resulted in the highest seed yield, on average by 10.6% higher than reference (5.7–6.5 t/ha). On the other hand, the dose of 80 kg N/ha increased the seed yield only by 7.4% on average (5.4–6.3 t/ha). Fertilization effects on the oil content and one thousand seeds' weight were statistically insignificant. The results show that considering the given local and weather conditions and low mineral nitrogen content in the soil, the most suitable nitrogen dose for autumn fertilization is 40 kg N/ha. This dose follows the nitrate directive rules, supports oilseed rape strengthening before winter and intensifies it for better seed yield.

Keywords: *Brassica napus* L.; oilseed plant; macronutrient; genotype; nitrate fertilizer

Winter oilseed rape is the most important oilseed plant in the European Union with the overall production of 19.6 mil tonnes, and the third most important oilseed plant in the world (spring and winter cultivar together) with production of 70.3 mil tonnes (USDA 2019). Compared with cereals, e.g., winter wheat or barley, oilseed rape yield is constantly growing in many countries, mainly due to gradual planting optimization and breeding improvement. However, harvest stability has not significantly improved for the last four decades and is still lower than that of cereals (Finger 2010, Rondanini et al. 2012). The yield of winter oilseed rape is a result of complex interactions among genotype, soil and weather and managerial decisions taken during the growth and development phases (Habekotté 1997, Peltonen-Sainio et al. 2010, Weymann et al. 2015). Nitrogen is an important nutrient for plants in agricultural ecosystems. The plants take nitrogen from soil through roots either in nitrate (NO_3^--N) or ammonia (NH_4^+-N) form. They are also commonly referred to as mineral nitrogen (N_{min}). Nitrate form is the most preferred one for the growth itself, as the ammonia form can be harmful to many plants if absorbed as the only nitrogen source in high concentrations (Bittsánszky et al. 2015, Qin et al. 2017). Nitrate nitrogen in the soil (soil solution) is subject neither to physical-chemical, nor chemical sorption (it is easily washed out). It is subject to biological sorption only. Ammonia nitrogen is not subject to chemical, but to physical-chemical and biological sorption (stays longer in the soil than nitrate nitrogen). These facts determine availability of both ions in the soil, and soil management of these mineral nitrogen forms (Miller et al. 2007). Winter oilseed rape has high capacity to receive mineral nitrogen from the soil and is also able to reduce significantly nitrogen wash-out from the soil in autumn and winter (Lainé et al. 1993, Dresbøll et al. 2016). Oilseed rape is known for deep and well-distributed root system. Growth of roots to the depth is desired; however, over 80% of roots (depending on the soil treatment method and

https://doi.org/10.17221/444/2019-PSE

depth) are distributed inside the upper soil layer, i.e., 20–30 cm. This is also the layer with the highest concentration of nutrients needed for plant growth (Neumann and Römheld 2002, Nagel et al. 2009). The field study of two genotypes with different efficiency of the used nitrogen showed that the genotype with higher nitrogen use efficiency spends more effort for growth of roots in the upper soil layers during the vegetative growth phase at simultaneous increase of root length (Ulas et al. 2012). Because optimal winter oilseed rape fertilization plan changes according to genotype, year and local conditions, it is difficult to determine precise maximum amount of nitrogen fertilizer to be used to reach the highest seed yield (Zhang et al. 2010). Comparison of individual types of nitrogen fertilizers disclosed their different action because of their chemical composition; moreover, the rate of nitrogen use by the plant varies with the used method and nitrogen application timing. Adjustment of the optimum nitrogen requirements of the plant together with the correct timing of nitrogen doses results in improvement of the winter oilseed rape production potential (Rathke et al. 2006). Winter oilseed rape absorbs 25–30% of total nitrogen already in autumn which corresponds to 40–80 kg N/ha. Around 83% of nitrogen absorbed in the autumn period is used by the above-ground biomass, the rest goes to roots (Černý et al. 2013). Engström (2010) states that the oilseed rape absorbs approx. 47–75 kg N/ha in the above-ground biomass until late autumn. Brown et al. (2008) stated possible absorption of up to 90 kg N/ha by the winter beginning. Many authors provide different results and observations regarding autumn fertilization of winter oilseed rape. Wright et al. (1988) stated that application of nitrate fertilizers during the autumn vegetation has no or very little resulting effect on the oilseed rapeseed yield. Gunstone et al. (2004) reported that autumn fertilization caused excessive overgrowth of the above-ground biomass and only seldom increased seed yield. Li et al. (2011) found out that the late autumn application of 30–54 kg N/ha had the highest effect on oilseed rapeseed yield. Bečka et al. (2013) came to conclusion that nitrogen applied before sowing or in September is definitely insufficient for oilseed rape, not considering the fact that it is largely consumed by microorganisms of straw decomposition. Intense oilseed rape planting requires introduction of late autumn nitrogen fertilization in case of low N_{min} content in the soil – mid to late October. In this period, there is no risk of massive above-ground biomass growth due to lower air temperatures.

The goal is to determine the effect of autumn fertilization on the winter oilseed rape growth and yield parameters; more specifically, to evaluate the growth effect of the above-ground biomass and roots after autumn fertilization and compare yield, oil content and weight of one thousand seeds after harvest. The primary goal is also to determine recommended nitrogen doses to increase seed yield of winter oilseed rape in given climatic conditions.

MATERIAL AND METHODS

Small field experiments were performed in the Research Centre of the Czech University of Life Sciences Prague in Červený Újezd in vegetation years 2013/14, 2014/15 and 2015/16. The research centre is located at: latitude 50°04', longitude 14°10', average altitude 398 m a.s.l.; prevailing soil type is haplic luvisol – clay loam. Soil properties are given in Table 1. The experimental field belongs to temperate zone. Average annual precipitations are 549 mm, average annual air temperature is 6.9°C, winter oilseed rape vegetation period is 330–340 days.

Cultivation technology and experimental design. Winter wheat preceded the winter rape in all experimental years. Ploughing system used for soil preparation was down to 22 cm with compacting of rough furrow. Experimental fields were established in three sequences, each plot had area of 15 m^2. The

Table 1. Selected soil properties in the experimental locality, Mehlich 3

Season	pH_{CaCl_2}	C_{ox} (%)	P	K	Mg	Ca
			(mg/kg)			
2013/14	7.1	1.7	67	138	92	2400
2014/15	6.5	2.0	76	182	123	2030
2015/16	6.8	2.0	66	172	114	2310

Table 2. Sowing, autumn fertilization dates and average number of plants/m^2

Season	Sowing	Autumn fertilization	Plants per m^2	Harvest
2013/14	22 August	26 October	43.2	23 July
2014/15	21 August	29 October	41.8	24 July
2015/16	22 August	27 October	38.5	26 July

https://doi.org/10.17221/444/2019-PSE

Table 3. Sampling dates and plant growth phases

Season	Plant sampling 1 BBCH 16–18	Plant sampling 2 BBCH 18–23
2013/14	16 December	19 March
2014/15	17 December	10 March
2015/16	14 December	22 March

BBCH by Meier (1997)

Table 4. Sampling dates – soil samples for nitrogen determination

Season	Soil sampling		
	1	2	3
2013/14	21 October	25 November	21 January
2014/15	16 October	15 December	10 February
2015/16	19 October	7 December	15 February

winter oilseed rape cultivar DK Exstorm was used at the amount of 50 seeds/m^2. Sowing dates and number of plants are given in Table 2. After sowing, the area was treated with pre-emergent herbicide, wheat sprouts were sprayed with graminicides. No growth regulator was used in autumn. Autumn fertilization was done on dates given in Table 2, Ureastabil fertilizer was used. It is granulated nitrogen urea (46%) with urease inhibitor (NBPT). Autumn fertilization was divided into three variants – control without fertilization, 40 kg N/ha, and 80 kg N/ha. In spring, all the variants were fertilized uniformly in four doses of total 180 kg N/ha, mostly using the CAN fertilizer. In spring, insecticide treatment was done twice; the last treatment was complemented with desiccant to speed up the harvest. For harvest, a small plot harvesting machine Wintersteiger was used. Seed oil content was defined by the nuclear magnetic resonance method (NMR) and used instrument (Bruker-minispec mq-one series, Rheinstetten, Germany).

Plant sampling and measurement of growth parameters. Each experimental variant had its sampling plot for plant sampling and monitoring of growth parameters, and harvest plot for evaluation of seed yield, oil content and one thousand seeds weight. Plant sampling used the square iron structure of 0.5 m^2 on the sampling plot and was done by careful digging of plants. Sampling dates and growth phases are given in Table 3. After sampling, the plants were thoroughly washed from dirt. Monitoring of growth parameters was done on ten plants: number of leaves (pcs.), longest leaf (cm), root neck thickness (mm), root length (cm) and dry matter mass of the above-ground biomass and roots (g). The first four indicators were measured in the fresh biomass. After measurements, the plants were dried at 105°C for 24 h. After drying, dry matter of the above-ground biomass and root was weighed separately.

Soil sampling – determination of nitrogen content. NO_3^--N, NH_4^+-N content and total mineral nitrogen were measured three times in the given vegetation year. The first soil sampling was done before the autumn fertilization, the second one approximately 1–1.5 months after the autumn fertilization, and the third one before the first pre-spring fertilization. Exact dates are given in Table 4. Soil samples were taken by soil probe to 30 cm depth. Five sub-samples were taken from each plot. After sampling, the sub-samples were thoroughly mixed to one summary sample and sent immediately to an accredited laboratory for mineral nitrogen analysis. 20 g of fresh soil were taken from each sample and extracted in KCl solution 1 mol/L, ratio 1:5, for 45 min. The soil extract was filtrated and analysed using the standard colorimetry method on the AutoAnalyzer 3 instrument (Norderstedt, Germany). The results of analyses are given in Tables 5 and 6.

Statistical analysis. Obtained results were statistically evaluated using the dispersion analysis (ANOVA). Differences between the mean values were evaluated by the Tukey's *HSD* (honestly significant difference) test at the significance level $\alpha = 0.05$ (statistically significant difference) in the Statgraphics Plus program, version 4.0 (Statgraphics, Warrenton, USA).

RESULTS AND DISCUSSION

Growth parameters. Winter oilseed rape growth was significantly affected by higher average air tem-

Table 5. Soil sampling results – determination of mineral nitrogen (mg/kg) before autumn fertilization

	Soil sampling 1		
	2013	2014	2015
NH_4^+-N	5.3	13.7	3.6
NO_3^--N	7.6	3.6	8.7
N_{min}	12.9	17.3	12.3

N_{min} – mineral nitrogen

https://doi.org/10.17221/444/2019-PSE

Table 6. Soil sampling results – determination of mineral nitrogen (mg/kg) after autumn fertilization

N form (kg N/ha)	2013			2014			2015		
	NH_4^+-N	NO_3^--N	N_{min}	NH_4^+-N	NO_3^--N	N_{min}	NH_4^+-N	NO_3^--N	N_{min}
Soil sampling 2									
0	1.5	7.1	8.6	41.9	4.9	46.8	1.5	14.3	15.8
40	12.0	11.1	23.1	47.9	9.0	56.9	2.5	18.1	20.6
80	21.6	4.4	26.0	31.4	17.5	48.9	5.9	26.0	31.9
	2014			2015			2016		
Soil sampling 3									
0	1.9	3.1	5.0	3.4	5.4	8.8	1.8	6.5	8.3
40	2.0	6.3	8.3	3.5	5.9	9.4	1.5	6.1	7.6
80	2.4	17.6	20.0	3.0	17.4	20.4	1.4	7.9	9.3

N_{min} – mineral nitrogen

perature (for the period September–March) during the vegetation period in all experimental years and connected with above-average precipitations in the first growth phases (BBCH 12–16) and following normal to drier winter and pre-spring period (Table 7). The late autumn fertilization with different nitrogen doses has a significant effect on the winter oilseed rape growth parameters (Table 8). Use of autumn dose of 40–80 kg N/ha results in a statistically significant larger number of leaves (L1) and the longest leaf on the plant (L2) at pre-spring plant sampling (PS2). The highest number of leaves was reached at the dose of 80 kg N/ha – an excessive overgrowth of leaves in one experimental year was observed for this alternative. In general, the above-ground biomass volume was observed to rise significantly after the autumn nitrogen application together with the extended vegetative growth phase. Similar results were also obtained by Li et al. (2016). A significant increase of the root neck thickness (R1) was observed in the pre-spring period – namely at the dose of 80 kg N/ha, except for the first experimental year. The recorded difference of the root neck thickness was on average by 0.4–2 mm higher than the control. The root length (R2) positively increases during winter, yet without statistical significance in this experiment. Recorded average root length in the pre-spring period (PS2) ranged from 18 cm to 27 cm. Dresbøll et al. (2016) found out the average maximum root length to reach up to 20 cm from December to March, and the total efficiency of the root system to double in the same period. Other studies gave different values for winter oilseed rape rooting – Barraclough (1989) and Perkons et al. (2014).

Dry matter volume in the leaves (DML) statistically rose after the autumn fertilization already at the first sampling in December PS1 (Table 9). The most intense accumulation of the dry matter started after the fifth leaf of the winter rape sprouting. This is also confirmed by the results of other authors – Velička et al. (2012) and Jankowski and Sokólski (2018). Efficiency of individual nitrogen doses on the dry matter growth was significantly influenced by weather conditions after the fertilizer applica-

Table 7. Average temperatures (T, °C) and precipitations (P, mm): monitored period September–March

	September			October			November			December			January			February			March		
	2013	2014	2015	2013	2014	2015	2013	2014	2015	2013	2014	2015	2014	2015	2016	2014	2015	2016	2014	2015	2016
Month overall																					
T	12.6	16.1	14.6	10.1	10.7	8.2	4.3	5.8	6.7	1.5	2.3	4.8	0.5	1.8	–0.4	3.0	0.7	3.3	7.6	5.5	4.4
P	39.7	76.7	11.5	47.6	54.1	53.2	27.5	24.1	52.3	6.1	31.6	11.3	19.7	19.1	28.4	1.7	1.6	41.7	35.3	32.6	21.9
Normal																					
T		13.4			8.4			3.0			–0.5			–2.3			–0.8			2.9	
P		33.0			26.5			29.9			22.3			21.6			21.4			26.3	

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Table 8. Growth parameters – leaves and root measurements

N form (kg N/ha)	2013				2014				2015			
	L1	L2	R1	R2	L1	L2	R1	R2	L1	L2	R1	R2
Plant sampling 1												
0	7.0^{a}	10.2^{a}	5.8^{a}	17.6^{a}	8.2^{a}	40.1^{a}	9.9^{a}	20.7^{a}	6.0^{a}	14.8^{a}	6.3^{a}	19.8^{a}
40	7.1^{a}	12.3^{b}	6.2^{a}	18.9^{a}	8.1^{a}	46.7^{b}	9.9^{a}	20.8^{a}	7.2^{b}	17.5^{b}	7.8^{b}	22.8^{b}
80	6.9^{a}	12.2^{b}	6.4^{a}	17.8^{a}	8.0^{a}	41.9^{a}	9.8^{a}	20.9^{a}	7.8^{c}	19.8^{c}	7.7^{b}	21.7^{ab}
	2014				2015				2016			
Plant sampling 2												
0	9.3^{a}	13.4^{a}	8.0^{a}	18.3^{a}	9.5^{a}	40.8^{a}	11.2^{a}	24.4^{a}	9.2^{a}	12.4^{a}	8.9^{a}	22.6^{a}
40	13.9^{b}	13.7^{a}	8.4^{a}	20.0^{a}	10.7^{b}	42.3^{ab}	12.4^{ab}	26.3^{a}	10.7^{b}	15.8^{b}	9.9^{ab}	22.6^{a}
80	10.8^{a}	16.4^{b}	8.4^{a}	19.5^{a}	11.2^{b}	45.4^{b}	13.2^{b}	24.6^{a}	11.9^{b}	20.2^{c}	10.0^{b}	22.5^{a}

L1 – number of leaves (pieces); L2 – longest leaf (cm); R1 – root neck thickness (mm); R2 – root length (cm), n = 30 ANOVA (Tukey's test *HSD* (honestly significant difference)) differences between the mean values are significant (P < 0.05) in case they have a different letter

tion. The highest values of leaf dry matter in the pre-spring sampling (PS2) were reached at the dose of 80 kg N/ha. An increase of the leaf dry matter volume, compared to the control, ranged on average from 60.4% in the experimental year 2013/14 up to 80% in 2015/16. Dry matter volume in roots (DMR) does not show any statistically significant changes after the use of individual fertilizer doses in the first sampling (PS1). One of the reasons is short time (3 weeks on average) for dry matter increase. Root dry matter grew substantially during the autumn and winter periods. Establishment of robust root system during autumn and winter influenced the early spring growth of the winter oilseed rape. These statements are in line with the observations of Rathke et al. (2006) and Su et al. (2015). Pre-spring sampling (PS2) had statistically higher root dry matter, especially after the dose of 40 kg N/ha. Thus, autumn fertilization with nitrogen had a positive influence not only on leaf dry matter but also on root dry matter.

Yield parameters. Autumn nitrogen fertilization had a statistically significant effect on seed yield of the winter oilseed rape except for the first experimental year (Table 10). This corresponds with the results of Hocking and Stapper (2001). Boyles et al. (2006) and Li et al. (2011). On the other hand, it contradicts the results obtained by Gunstone et al. (2004), and Wright et al. (1988). The highest seeds yield in all three experimental years was reached after the application of 40 kg N/ha with average increase of 10.6% (seeds yield: 5.7–6.5 t/ha). The dose of 80 kg N/ha increased the yield only by 7.4% on average (seeds yield: 5.4–6.3 t/ha). The results indicate that the increased nitrogen doses need not automatically result in higher yield. Measurements of the winter rapeseed oil content did not prove any

Table 9. Growth parameters – dry matter volume

N form (kg N/ha)	Plant sampling 1						Plant sampling 2					
	2013		2014		2015		2014		2015		2016	
	DML	DMR	DML	DMR	DML	DMR	DML	DMR	DML	DMR	DML	DMR
0	15.9^{a}	4.8^{a}	106.5^{a}	27.4^{a}	32.7^{a}	13.13^{a}	28.5^{a}	7.8^{a}	100.1^{a}	35.4^{a}	56.6^{a}	24.5^{a}
40	19.8^{a}	5.2^{a}	148.4^{b}	27.4^{a}	57.3^{b}	16.7^{a}	48.7^{b}	11.4^{a}	168.1^{b}	45.2^{b}	76.0^{a}	29.1^{b}
80	22.7^{a}	5.7^{a}	113.9^{a}	24.1^{a}	69.5^{b}	18.8^{a}	45.7^{b}	8.6^{a}	180.2^{b}	48.0^{b}	98.0^{b}	27.1^{ab}

DML – leaf dry matter from 10 plants (g); DMR – dry root matter from 10 roots (g), n = 3, ANOVA (Tukey's test *HSD* (honestly significant difference)) differences between the mean values are significant (P < 0.05) in case they have a different letter

https://doi.org/10.17221/444/2019-PSE

Table 10. Yield parameters – yield, oil content and weight of one thousand seeds

N form (kg N/ha)	2014			2015			2016		
	Y	OC	W	Y	OC	W	Y	OC	W
0	5.4^{a}	48.2^{a}	3.8^{a}	5.8^{a}	46.3^{a}	3.6^{a}	5.2^{a}	45.2^{a}	3.7^{a}
40	5.9^{a}	48.3^{a}	3.9^{ab}	6.5^{b}	44.6^{a}	3.7^{a}	5.7^{b}	45.0^{a}	3.9^{a}
80	5.9^{a}	47.5^{a}	4.0^{b}	6.3^{b}	45.9^{a}	3.7^{a}	5.4^{ab}	44.9^{a}	3.9^{a}

Y – seeds yield (t/ha); OC – oil content (%); W – weight of one thousand seeds (g), $n = 3$, ANOVA (Tukey's test *HSD* (honestly significant difference)) differences between the mean values are significant ($P < 0.05$) in case they have a different letter

significant impact of autumn fertilization on the oil content change. A negative impact of higher nitrogen doses on oil content was observed by Cheema et al. (2001), Rathke et al. (2005) and Storer et al. (2018). No significant impact of autumn fertilization on one thousand seeds weight was statistically confirmed during the experimental years on average. Only in the year 2013/14, an increase of one thousand seeds weight was observed at the dose of 80 kg N/ha. Weather conditions during the winter rape reproductive phase have the highest impact on the one thousand seeds weight. This was also confirmed by research done by Weyman et al. (2015).

In conclusions, considering the given local and weather conditions and low N_{min} content in the soil, the effect of the autumn fertilization on the winter oilseed rape growth and yield parameters was confirmed as significant. All three experimental years had above-average temperature and normal precipitations course during autumn and winter. The weather course substantially supported the growth itself, winter rape development and mainly the research result. Evaluation of autumn nitrogen fertilization contribution needs to consider rational, ecological and economic aspects. All this indicates that the most suitable nitrogen dose for autumn fertilization is 40 kg N/ha. This dose follows the nitrate directive rules, supports the oilseed rape strengthening before winter and intensifies it for better seed yield. Weaker and medium-strong plants with obvious nitrogen and other nutrient deficiency are recommended to be fertilized in late October. Nutrient deficiency and direct fertilization effects show mainly during warm autumn and winter. It is also desirable to fertilize fields with low N_{min} content in the soil in autumn and leave areas without nitrogen application for straw decomposition. Optimization of the winter rape nutrition in autumn needs to consider its demand for other nutrients, ongoing physiological processes and soil-climatic conditions of the given area.

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Received on August 12, 2019
Accepted on September 3, 2019
Published online on September 18, 2019