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Effects of various nitrogen fertilisers applied in autumn on growth parameters, yield and quality of winter oilseed rape

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Abstract: The aim of this trial was to verify the influence of various autumn-applied nitrogen fertilisers on the growth, yield and quality of winter oilseed rape. In the three years, small-plot field trials were carried out at the Research Station Červený Újezd (50.0697044N, 14.1659086E). The hybrid cultivar DK Exstorm was chosen, with a sowing rate of 50 seeds/m^2. Five fertilisation regimes were tested: (1) nitrogen-free control; (2) CAN (calcium ammonium nitrate); (3) ANU (ammonium nitrate urea); (4) U (urea), and (5) US (urea with N-(n-butyl)thiophosphoric acid triamide (NBPT) inhibitor). A uniform dose of 40 kg N/ha was applied at the end of October. Fertilisers U (leaf length, root collar diameter, leaf and root dry weight) and US (number of leaves and root length) had the best growth outcomes. The highest seed yields were obtained with US (5.83 t/ha) and ANU (5.82 t/ha) applications, which outperformed the unfertilised control by 0.65 and 0.64 t/ha, respectively. CAN fertiliser appears to be unsuitable for autumn fertilisation in terms of yield. There were no statistically significant differences in oil content (%) or thousand seed weight (g) between the treatments in any of the experimental years.

Keywords: *Brassica napus* L.; oilseed crop; mineral nutrient; autumn nitrogen fertilisation; dry matter

With a global production of 33.29 million tonnes of oil, oilseed rape is the third most important oilseed crop in the world, following palm oil (79.46 million tonnes) and soybean oil (61.91 million tonnes). Oilseed rape is also the most important oilseed crop in the European Union, with a production of 10.25 million tonnes of rapeseed oil (USDA 2024).

Nitrogen (N) is the most abundant mineral nutrient in plants, making up 2–4% of plant dry matter, a component of chlorophyll and an essential component of all proteins. Nitrogen is responsible for the dark green colour of stems and leaves, vigorous and prolonged growth, leaf set and yield formation (Schott 2001, Roy et al. 2006).

The nitrogen stock in the soil consists of mineral nitrogen in the root zone at the beginning of the growing season (N_{min} content, kg N/ha) and the amount of nitrogen mineralised during the growing season. Before the growing season, the N_{min} content in the 0 to 100 cm soil layer varies from 20 to 300 kg N/ha depending on the preceding crop (cereals, sugar beet and vegetables) (Wehrmann and Scharpf 1979). As Carter and Schipanski (2022) reported, about half of the N in plants comes from the decomposition of soil organic matter (SOM). Trial results showed that under high SOM and simultaneously high N fertilisation, plants obtained 64% of their N from SOM. Whereas, at high SOM and low nitrogen fertilisation, plants' nitrogen uptake from SOM was significantly higher, at 89%. This is confirmed by results with nitrogen fertilisation on soils with low fertility (Tian et al. 2023). High nitrogen fertiliser

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rates and low nitrogen utilisation from fertilisers not only increase the cost of field crops but also cause serious ecological problems, especially leaching and atmospheric nitrogen leakage (Ceccon et al. 1995, Freney 2005, Czyzyk and Rajmund 2013, Cantarella et al. 2018, Zhan et al. 2023). As reported by Wiesler (1998), the efficiency of nitrogen fertilisers is usually poor. The crop often uses less than 50% of the nitrogen applied to fertilisers. A comparison of nitrogen fertilisers shows that they act differently due to their chemical composition (Rathke et al. 2006).

Plants intake nitrogen from applied fertilisers in the form of nitrate (NO_3^--N), ammonium (NH_4^+-N), urea and amino acids. Thus, the uptake and assimilation of different nitrogen forms change the forms of nitrogen delivery from roots to shoots (Liu et al. 2003). However, in oilseed rape, the uptake rate of urea, as the sole nitrogen form, is up to ten times lower than that of nitrate or ammonium (Arkoun et al. 2012). Urea and fertilisers containing urea are rapidly hydrolysed to ammonium carbonate by the enzyme urease (Wiesler 1998). To prevent nitrogen loss, inhibitors are added to nitrogen fertilisers (Bailey 1990, Freney 2005, Lana et al. 2018). The most commonly used urease inhibitor is N-(n-butyl) thiophosphoric acid triamide (NBPT) (Cantarella et al. 2018). According to Zerulla et al. (2001), nitrapyrin (2-chloro-6-(trichloromethyl)-pyridine) and DCD (dicyandiamide) are the most commonly used commercially as nitrification inhibitors. Nitrapyrin is the most commonly used in the USA, whereas DCD is used in Europe. Another inhibitor on the market is DMPP (2,4-dimethylpyrazole-phosphate), which is more environmentally friendly (Subbarao et al. 2006).

For good growth and high seed yields, oilseed rape needs a sufficient and, above all, well-timed supply of nutrients. In relation to seed yield, oilseed rape has particularly high requirements for nitrogen fertilisation (Rathke et al. 2006, Roy et al. 2006, Berry et al. 2010). The total nitrogen intake by the plant at a yield of 4.5 t/ha is between 300–350 kg N/ha (Roy et al. 2006). According to Geisler and Kullman (1991), oilseed rape reacts positively to nitrogen fertilisation and requires 150–210 kg N/ha for a seed yield of 3 t/ha. Nitrogen fertilisation in oilseed rape stimulates growth and increases biomass nitrogen accumulation and yield. The results of Rathke et al. (2005) show that the level of nitrogen fertilisation is the main determinant of winter oilseed rape productivity, followed by other factors such as the effect of the pre-crop, the type of fertiliser used and/or the interaction of these factors.

Oilseed rape is characterised by its nitrogen uptake in autumn (Vazquez-Carrasquer et al. 2021). During the autumn, oilseed rape stands can accumulate 40–80 kg of nitrogen per hectare. This amount can be reduced to 20 kg N/ha during winter due to loss of foliage (Diepenbrock and Grosse 1995). According to Roy et al. (2006), of the total N uptake, about 20% is absorbed by plants before winter and about 50% in spring before flowering. According to Béreš et al. (2019), autumn nitrogen fertilisation of oilseed rape has statistically significant effects on aboveground and root biomass growth and seed yield. The 40 kg N/ha rate was the best, increasing yield by 10.6%, while the higher rate of 80 kg N/ha increased yield, but only by 7.4%. In contrast, Varényiová and Ducsay (2016) reported that autumn nitrogen had no significant effect on seed yield in winter oilseed rape. Studies by Zhang et al. (2010) and Ulas et al. (2012) confirm that the effective use of nitrogen fertilisation applied in autumn depends on several factors, including the type of fertiliser, the timing of application, and the course of weather conditions after application. According to other authors (Walker and Booth 2001), under European conditions, the yield response of winter rape to autumn nitrogen fertilisation is low because autumn N-mineralisation is relatively high. Therefore, if nitrogen is applied in autumn, it is mainly at low rates.

The aim of the experiment was to find out which nitrogen fertilisers are the most suitable for autumn fertilisation of winter oilseed rape stands in terms of growth parameters, root and aboveground biomass, yield and quality of harvested seeds.

Table 1. Chosen soil characteristics of the experimental site, Mehlich III

Season	pH_{CaCl_2}	C_{ox} (%)	P	K	Ca	Mg
			(mg/kg)			
2013–14	7.1	1.7	67	138	2 400	92
2014–15	6.5	2.0	76	182	2 030	123
2015–16	6.8	2.0	66	172	2 310	114

Sampling one week before sowing. C_{ox} – chemical oxidation, according to Tjurin

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Table 2. Soil sampling results – determination of mineral nitrogen (mg/kg) before autumn fertilisation

	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

MATERIAL AND METHODS

Small plot trials were established at the Research Station of the Czech University of Life Sciences in Červený Újezd during the growing years 2013–14, 2014–15 and 2015–16. The research station is located in the central part of the Czech Republic 50.0697044N, 14.1659086E, at an altitude of 398 m a.s.l. The experimental site is in a region which is moderately warm and moderately dry. The average annual rainfall is 495.1 mm, the average annual air temperature is 9.0 °C, and the growing season for winter oilseed rape is 330–340 days. The prevailing soil type is haplic luvisol–clay loam. Soil characteristics are described in Tables 1 and 2. The harvested area of each plot was 11.875 m^2 (1.25 × 9.5 m). The experiments were located in one levelled block of a six-year rotation with winter wheat, spring barley and sown peas as compensatory crops.

An overview of all agronomic practices for site maintenance, including their timing each year, is presented in Table 3. The trials were carried out following a winter wheat pre-crop. Wheat harvest was followed by ploughing (22 cm). The day before sowing, the experimental plot was prepared with a compactor. The sowing date of the trials was between the 21st and the 22nd of August, using the cultivar DK Exstorm at a sowing rate of 50 seeds/m^2 in 12.5 cm rows and a depth of 1.5 cm. The sown areas were treated with preemergent herbicides, and graminicide was applied postemergently (Table 3). No foliar fertiliser, fungicide, growth regulator or stimulator treatments were applied during the growing season. The trials were treated as needed for both autumn and spring pests (Table 3). No fertilisers were applied before sowing. The trials were fertilised in autumn according to the methodology (Table 4) with a uniform dose of 40 kg N/ha. Spring nitrogen was applied for a total of 180 kg N/ha, divided into four doses using CAN fertiliser. Harvesting was done with a Wintersteiger

Table 3. Agricultural practices of the trials in 2013–14, 2014–15, and 2015–16

	2013	2014	2015
Autumn			
Pre-crop harvest (winter wheat)	17 August	10 August	4 August
Drill ploughing (22 cm)	21 August	19 August	21 August
Pre-sowing soil preparation (compactor)	22 August	20 August	22 August
Sowing (50 seeds/m^2)	22 August	21 August	22 August
Herbicide (metazachlor + clomazone)	23 August	22 August	24 August
Graminicide (quizalofop-P-ethyl) + insecticide (cypermethrin + chlorpyrifos)	27 September	5 September	16 September
Autumn fertilisation (40 kg N/ha)	26 October	29 October	27 October
	2014	2015	2016
Spring			
1a. Nitrogen dose (40 kg N/ha) in CAN	13 February	13 February	19 February
1b. Nitrogen dose (50 kg N/ha) in CAN	11 March	26 February	8 March
Insecticide (deltamethrin + thiacloprid)	21 March	24 March	25 March
2. Nitrogen dose (60 kg N/ha) in CAN	31 March	23 March	21 March
Insecticide (cypermethrin + chlorpyrifos)	4 April	11 April	13 April
3. Nitrogen dose (30 kg N/ha) in CAN	10 April	13 April	11 April
Insecticide (thiacloprid)	25 April	5 May	28 April
Harvest	23 July	24 July	26 July

CAN – calcium ammonium nitrate

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Table 4. Overview of experimental treatments, dose rate 40 kg N/ha

Variant	Fertiliser	Chemical composition	Fertiliser description
1	control (C)		
2	calcium ammonium nitrate (CAN)	$NH_4NO_3 + CaCO_3$	20% $CaCO_3$, granular fertiliser 2–5 mm
3	ammonium nitrate urea (ANU)	$NH_4NO_3 + CO(NH_2)_2$	liquid fertiliser
4	urea (U)	$CO(NH_2)_2$	prilled fertiliser 1–4 mm
5	ureastabil (US)	$CO(NH_2)_2$ + urease inhibitor (NBPT)	prilled fertiliser 1–4 mm

NBPT – N-(n-butyl)thiophosphoric acid triamide

small-plot combine harvester. Seed oil content was determined by nuclear magnetic resonance (NMR) on a Bruker-minispec mq-one series.

NO_3^--N, NH_4^+-N and total N_{min} were measured three times per growing season (Table 5). The initial soil sampling (SS1) was completed prior to autumn fertilisation. The second sampling (SS2) took place approximately 1–1.5 months after autumn fertilisation, depending on weather conditions, followed by a third sampling (SS3) before the first spring fertilisation. Samples were taken to a depth of 30 cm by soil probe punctures. From each plot, 5 subsamples were collected. After collection, the subsamples were combined for a composite sample and immediately taken to an accredited laboratory for analysis. From each sample, 20 g of fresh soil was extracted through a 1:5 solution of KCl (1 mol/L) for 45 min. The soil extract was filtered and analysed using AutoAnalyser 3 (Norderstedt, Germany) using a standard colourimetric method. The results of soil analysis are presented in Table 6.

For each experimental treatment, two plots were identified – a harvesting plot and a sampling plot. Plant collection took place only in the sampling plots. Harvest plots were used exclusively for yield and quality parameters. In the middle row, 10 plants were sampled consecutively. A spade was used for sampling. The collection took place on two dates: BBCH 16–18 (PS1) and BBCH 18–23 (PS2) (Table 5). After collection, the plants were washed gently but thoroughly, and the roots were separated from the above-ground part. The following parameters were measured for roots: root length (cm), root collar diameter (mm) and dry weight (g/10 plants). The number of leaves (pcs), leaf length (cm) and dry weight (g/10 plants) were observed for the above-ground biomass. The sample drying was carried out at 105 °C for 24 h. After cooling, the dry weight of roots and above-ground biomass were weighed. Figures 1 and 2 summarise the site's weather conditions from sowing to spring revegetation.

Statistical evaluation. The obtained results were statistically evaluated by analysis of variance (ANOVA). Differences between means were evaluated by Tukey's *HSD* (honestly significant difference) test at α = 0.05 level of significance (statistically significant difference) using the Statgraphics Plus program, version 4.0 (Statgraphics, Warrenton, USA).

RESULTS AND DISCUSSION

Growth parameters. Plant emergence was influenced by the amount of rainfall after sowing in all experimental years. The sowing rate was set at 50 germinating seeds per m^2, but the resulting number of emerging plants per m^2 was lower. Field emergence in experimental years was 85% (2013–14), 88% (2014–15) and 82% (2015–16). Rainfall and temperatures from September to March (Figures 1 and 2) affected growth parameters, root dry weight and above-ground biomass formation.

The first collecting date (PS1) was characterised by statistically significant differences in leaf length (LL) in all experimental years (2013–2015). There were statistically significant differences in leaf number (LN) in 2014 and 2015 and in root collar width (RCT) only

Table 5. Dates of soil and plant sampling

Season	Soil sampling 1	Soil sampling 2	Soil sampling 3	Plant sampling 1	Plant sampling 2
2013–14	21 October	25 November	14 February	9 December	19 March
2014–15	16 October	15 December	10 February	17 December	5 March
2015–16	19 October	7 December	15 February	14 December	22 March

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Table 6. Results of soil sampling – determination of mineral nitrogen (N_{min}, mg/kg) following autumn fertilisation

		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	C	1.5	7.1	8.6	41.9	4.9	46.8	1.5	14.3	15.8
	CAN	1.4	7.5	8.9	26.4	8.3	34.7	2.4	18.5	20.9
	ANU	3	6.8	9.8	32.5	5.1	37.6	1.4	15.6	17.0
	U	3.4	5.8	9.2	44.9	8.3	53.2	1.6	16.3	17.9
	US	12.0	11.1	23.1	47.9	9.0	56.9	2.5	18.1	20.6
		2014			2015			2016		
		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 3	C	1.9	7.3	9.2	3.4	5.4	8.8	1.8	6.5	8.3
	CAN	1.5	6.9	8.4	21.3	4.9	26.2	1.4	6.1	7.5
	ANU	1.5	6.1	7.6	19.6	5.1	24.7	1.4	5.9	7.3
	U	1.5	6.9	8.4	23.4	5.6	29.0	1.4	6.1	7.5
	US	1.5	8.6	10.1	3.5	5.9	9.4	1.5	6.1	7.6

C – control; CAN – calcium ammonium nitrate; ANU – ammonium nitrate urea; U – urea; US – ureastabil

in 2015 (Table 7). In 2014, suitable weather conditions (Figures 1 and 2) led to leaf overgrowth (Table 7). The highest number of leaves was found in treatments with US (2014) and U (2015). Leaf length was positively affected by fertilisers, with all treatments different from the control in 2013 and 2015, but only US different from the control in 2014 (Table 7). The root collar width at the first sampling date was insignificant in 2013 or 2014. It was only in 2015 that fertiliser treatments ANU, U and US had wider root collar widths than the nontreated control. Overall, however, there were less differences between the treatments in the PS1 term than in the second term (PS2). This was due to the fact there was a short period for the corresponding effect after fertilisation, which is more noticeable in the spring or at harvest.

In the second sampling date, the effect of the applied fertilisers on the observed parameters was more evident (Table 7), and this can be seen in the three-year average (Table 8). In most measured parameters, all fertiliser treatments were different from the non-fertilised control, except in root length (RL) and root dry matter (RDM) (Table 8). Differences among treatments can only be seen in leaf number, where US was 1.3 leaves more than ANU, and dry leaf matter (LDM), where U had 2 g more roots than ANU (Table 8). These trends can be seen in individual years, as well (Table 7). Except for root

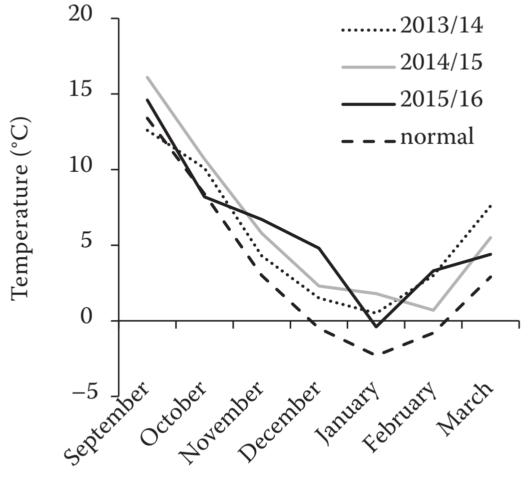

Figure 1. Average temperatures, monitored period September–March. Normal – standard climatological normal (1991–2020)

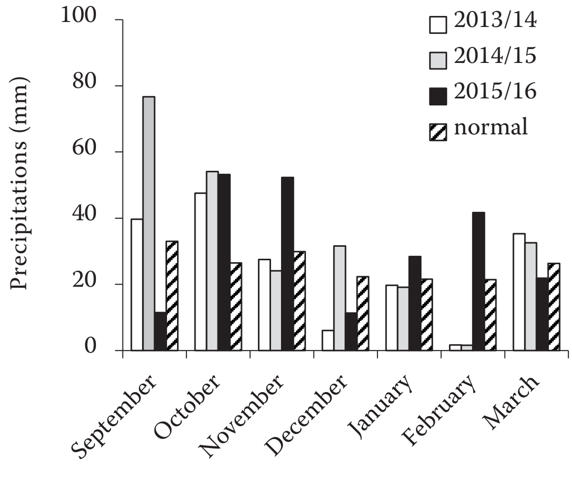

Figure 2. Precipitations, monitored period September–March. Normal – standard climatological normal (1991–2020)

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Table 7. Growth parameters – leaves and root measurements

Variant	Plant sampling 1											
	2013				2014				2015			
	LN	LL	RCT	RL	LN	LL	RCT	RL	LN	LL	RCT	RL
C	7.0	10.7^{c}	5.9	18.1	7.5^{b}	40.8^{b}	9.7	19.6	6.1^{b}	14.8^{c}	6.7^{b}	20.2
CAN	7.6	12.8^{ab}	5.6	17.8	7.6^{b}	42.1^{b}	9.5	20.4	7.1^{a}	16.4^{bc}	7.3^{ab}	19.0
ANU	7.4	13.9^{a}	6.3	19.0	7.9^{ab}	40.6^{b}	9.6	20.7	7.8^{a}	18.8^{a}	8.1^{a}	20.2
U	7.0	12.7^{ab}	5.9	18.5	8.8^{a}	43.4^{ab}	9.5	21.7	7.1^{a}	19.1^{a}	8.1^{a}	20.3
US	7.1	12.4^{b}	5.5	18.7	7.9^{ab}	46.9^{a}	9.6	20.9	7.3^{a}	17.9^{ab}	7.9^{a}	19.5
P-value	0.4332	0.0000	0.2041	0.6170	0.0016	0.0004	0.9958	0.2907	0.0000	0.0000	0.0014	0.4952
Variant	Plant sampling 2											
	2014				2015				2016			
	LN	LL	RCT	RL	LN	LL	RCT	RL	LN	LL	RCT	RL
C	9.0^{b}	12.2^{c}	7.5	18.2^{b}	9.5^{b}	37.1^{b}	11.3^{c}	24.3^{b}	9.3^{b}	12.3^{b}	8.6^{b}	21.3
CAN	12.6^{a}	14.1^{ab}	8.1	18.0^{b}	9.7^{b}	42.3^{a}	11.8^{bc}	24.6^{ab}	11.8^{a}	17.2^{a}	10.6^{a}	21.3
ANU	11.4^{a}	14.8^{ab}	8.7	20.1^{ab}	9.6^{b}	40.6^{ab}	12.3^{abc}	23.6^{b}	10.3^{ab}	16.5^{a}	9.8^{a}	22.5
U	12.2^{a}	15.3^{a}	8.9	21.0^{a}	10.1^{ab}	43.2^{a}	13.0^{a}	24.8^{ab}	11.9^{a}	17.3^{a}	10.3^{a}	21.9
US	12.9^{a}	13.5^{bc}	8.0	20.2^{ab}	10.7^{a}	42.5^{a}	12.7^{ab}	26.5^{a}	11.6^{a}	16.4^{a}	9.9^{a}	23.2
P-value	0.0000	0.0000	0.951	0.0010	0.0001	0.0001	0.0007	0.0044	0.0002	0.0000	0.0001	0.2223

LN – leaf number (pieces); LL – leaf length (cm); RCT – root collar thickness (mm); RL – root length (cm); $n = 40$, 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. C – control; CAN – calcium ammonium nitrate; ANU – ammonium nitrate urea; U – urea; US – ureastabil

collar in 2014 and root length in 2015, there were statistically significant differences between the treatments for all other parameters each year. In 2014, leaf number was higher in all treatments compared to the control, where the longest leaf only longer than the control in CAN, ANU, and U. The root length was only longer than the control when applied with U. The results are not entirely consistent with those of Heuermann et al. (2021), who analysed nitrogen allocation to stems, leaves, and siliques after different nitrogen fertilisers, but found no significant differences between plants fertilised with ammonium nitrate and urea.

Dry leaf matter of the fertilised treatments was higher than the control in the three-year average (Table 8), but not all treatments were higher than

Table 8. Growth parameters, seed yield and quality parameters – three years results (2014–2016)

Parameter	Plant sampling						Yield and quality		
	LN	LL	RCT	RL	LDM	RDM	SY	OC	TSW
C	9.3^{c}	20.5^{b}	9.1^{b}	21.3^{b}	59.0^{c}	21.6^{b}	5.18^{b}	45.8	3.763
CAN	11.3^{ab}	24.5^{a}	10.2^{a}	21.3^{b}	105.6^{ab}	24.5^{ab}	5.57^{ab}	45.4	3.873
ANU	10.4^{b}	24.0^{a}	10.3^{a}	22.1^{ab}	93.5^{b}	24.2^{ab}	5.82^{a}	46.5	3.768
U	11.4^{ab}	25.2^{a}	10.7^{a}	22.6^{ab}	117.2^{a}	29.9^{a}	5.70^{ab}	46.2	3.859
US	11.7^{a}	24.1^{a}	10.2^{a}	23.3^{a}	98.6^{ab}	27.2^{ab}	5.83^{a}	46.1	3.818
P-value	0.0000	0.0000	0.0000	0.0001	0.0000	0.0051	0.0108	0.1685	0.2870

LN – leaf number (pieces); LL – leaf length (cm); RCT – root collar thickness (mm); RL – root length (cm); $n = 120$; LDM – leaf dry mass from 10 plants (g); RDM – root dry mass from 10 roots (g); SY – seeds yield (t/ha); OC – oil content (% dry matter); TSW – thousand seeds weight (g); $n = 12$, Multifactor 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

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Table 9. Growth parameters – dry matter weight

Parameter	Plant sampling 1						Plant sampling 2					
	2013		2014		2015		2014		2015		2016	
	LDM	RDM	LDM	RDM	LDM	RDM	LDM	RDM	LDM	RDM	LDM	RDM
C	14.6[c]	4.7[a]	95.3[b]	27.8	35.4[b]	13.5[b]	22.8[b]	7.4[b]	95.6[c]	36.9	53.7[c]	20.6
CAN	22.5[ab]	5.8[a]	124.4[ab]	24.8	51.2[ab]	14.7[ab]	45.0[a]	9.9[ab]	146.6[ab]	39.0	125.2[a]	24.5
ANU	28.1[a]	6.8[a]	123.6[ab]	27.5	70.6[a]	20.1[a]	44.7[a]	11.3[ab]	135.6[b]	39.6	100.2[ab]	21.8
U	24.3[ab]	6.1[a]	146.3[a]	31.7	69.7[a]	19.4[a]	54.7[a]	11.9[a]	180.0[a]	52.0	117.0[ab]	25.9
US	18.5[bc]	4.8[a]	142.9[ab]	28.0	62.0[a]	17.8[a]	46.2[a]	10.3[ab]	163.4[ab]	46.1	86.2[b]	25.2
P-value	0.0009	0.0354	0.0464	0.4945	0.0040	0.0998	0.0009	0.0478	0.0001	0.1028	0.0000	0.2224

LDM – leaf dry mass from 10 plants (g); RDM – root dry mass from 10 roots (g); *n* = 4, 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. C – control; CAN – calcium ammonium nitrate; ANU – ammonium nitrate urea; U – urea; US – ureastabil

the control in all years (Table 9). ANU fertiliser had a positive effect on LDM and RDM in years when weather conditions were not conducive to growth (2013–2014 and 2015–2016) (Figures 1 and 2, Table 9). In the favourable year 2014, the fertiliser U was the only fertiliser with higher LDM than the control at PS1, and at PS2 had higher LDM than ANU, while in this year, there was no statistically significant influence of fertilisers on RDM in any treatment (Table 9). In 2016, fertiliser CAN had higher LDM at PS2 than the control and US but was similar to ANU and U and was the only fertiliser not different from the control at PS1 (Table 9). For the trait RDM, no differences were seen amongst treatments at PS1 and PS2 only in the first year (2013–2014) (Table 9). When averaging across the three years at the PS2 (Table 8), all fertilisers differed from the control; however, the fertiliser U was the only one different from ANU (Table 8). Differences from the unfertilised control are especially evident for LDM (+ 58.2 g/10 plants) and less so for RDM (+ 8.3 g/10 plants). Also, the effect of the NBPT inhibitor in fertiliser US on growth parameters was not fully confirmed.

Yield and quality parameters. There was a statistically significant effect of the growing season on seed yield in 2014–15 and 2015–16, but no differences in quality in any year (Table 10). No statistical significance (*P*-value = 0.5514) was achieved in seed yield (SY) in the first year (2013–14) (Table 10). For 2014–15, fertiliser US (6.45 t/ha) was the only treatment which was statistically significant (0.62 t/ha) from the nitrogen-free control (5.83 t/ha) (Table 10). In 2015–2016, both US (5.76 t/ha) and ANU (5.91 t/ha) were different from the control (5.22 t/ha), but ANU was also different from U (5.39 t/ha) applied alone (Table 10). These findings match the results of Rathke et al. (2005). The difference between the highest yield and the nitrogen-free control ranged from 0.62 (2014–15) to 0.94 t/ha (2013–14). With an oilseed rape

Table 10. Yield and quality parameters

Parameter	2013–2014			2014–2015			2015–2016		
	SY	OC	TSW	SY	OC	TSW	SY	OC	TSW
C	4.48	48.0	3.850	5.83[b]	44.9	3.634	5.22[c]	44.5	3.807
CAN	5.07	47.4	4.024	6.08[ab]	43.1	3.726	5.58[abc]	45.6	3.868
ANU	5.26	47.9	3.893	6.28[ab]	45.7	3.643	5.91[a]	46.0	3.769
U	5.42	48.0	3.981	6.28[ab]	44.7	3.711	5.39[bc]	45.8	3.885
US	5.29	48.2	3.954	6.45[a]	45.4	3.676	5.76[ab]	44.8	3.822
P-value	0.5514	0.7528	0.6781	0.0133	0.1432	0.8838	0.0008	0.2026	0.8480

SY – seeds yield (t/ha); OC – oil content (% dry matter); TSW – thousand seeds weight (g); *n* = 4, 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. C – control; CAN – calcium ammonium nitrate; ANU – ammonium nitrate urea; U – urea; US – ureastabil

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price of 436.5 Euro/t (MATIF 2024), these yield differences were economically interesting, covering the cost of fertiliser and application each year. Averaging the three-year results of the trials (Table 8), the highest yields were achieved by the US (5.83 t/ha) and ANU (5.82 t/ha) fertiliser treatments, which statistically significantly outperformed the unfertilised variant C by 0.66 and 0.65 t/ha, respectively. This supports the results of Béreš et al. (2019), where 40 kg N/ha of urea + NBPT fertiliser in autumn application increased oilseed rape yield by 0.3 to 0.7 t/ha. CAN fertiliser (5.57 t/ha) appeared unsuitable for autumn N fertilisation, as it was not statistically different from the control in any year. This is contrary to the results of Heuermann et al. (2021), who found significantly higher seed yield under ammonium nitrate supply compared to nitrogen in the form of urea. No statistically significant differences in growth parameters and yield between fertiliser treatment U and US with the NBPT inhibitor exist. Cantarella et al. (2018) reported that urea improved by the NBPT inhibitor reduced NH_3 emissions by about 53% and increased yield by an average of 6%; however, the results were not always positive, and the effect on yield varied from –0.8% to +10.2% depending on the crop species. Lana et al. (2018) reported a decline in nitrogen emissions after 11 days by 75% when NBPT was added to urea.

Cheema et al. (2001) state that the crucial factor influencing the oil content of rapeseed is not timing and number of nitrogen applications but the total nitrogen rate. In our results, oil content (OC) and thousand seed weight (TSW) were not affected by treatment in any of the experimental years (Table 10). This contrasts with the results of Rathke et al. (2005), who concluded that the highest oil content was obtained with the unfertilised control. However, in their experiments, the control was not fertilised with nitrogen throughout the entire growing season, whereas in our experiments, the control only had nitrogen fertiliser withheld in autumn. The results of Zaluszniewska and Nogalska (2020) indicated that the lowest TSW was achieved in the non-nitrogen fertilised variant, as well as in our experiments. When years were combined, there were still no statistically significant differences between treatments (Table 8).

Based on the cumulative results, it can be concluded that autumn nitrogen fertilisation has a positive effect on growth parameters and subsequent yield of winter rape, but no conclusion can be made on the effect of fall fertiliser type on oil content or thousand seed weight. At the first sampling date at BBCH 16–18, there were no major differences in growth parameters between the treatments in any year. Differences were quantifiable at the second sampling date, with the highest growth observed in treatments fertilised with U (LL, RCT, LDM and RDM) and US (LN, RL). The seed yield from US (5.83 t/ha) and ANU (5.82 t/ha) were the highest-yielding treatments and significantly higher than the unfertilised control by 0.66 and 0.65 t/ha, respectively.

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