Original Paper

Fertilization of oilseed rape with and without autumn nitrogen dose

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Investigation of the effect of autumn nitrogen dose, in comparison to nitrogen fertilization without autumn dose, on rapeseed yield, oil content and oil production was the main aim of the experiment. The plot scale experiment was conducted during three experimental years 2013–2016 in terms of agricultural cooperative in Mojmírovce. The experiment consisted of three treatments of nitrogen fertilization. The block method of experimental plot size of 600 m^2 was used in this experiment. It was tested in triplicate. The total dose of nitrogen was 240 kg ha^{-1}. Both treatments were fertilized during spring in phonological growth stages BBCH 20, 30 and 51. There was applied autumn nitrogen dose in BBCH 15 at treatment 2. Considering the weather conditions of the previous year, a significant effect of autumn nitrogen dose was not expected in this experiment. Results were predictably, significantly influenced by different weather conditions. The experimental year 2013/2014 was wetter and warmer than the other two experimental years. The highest average yield of seed, 3.63 t ha^{-1} was reached at treatment 3 without any autumn nitrogen application. The average oil content fluctuated from 44.36% to 45.09%. The highest average oil content 46.72% was observed in weather more favourable the experimental year 2013/2014. Although the highest average oil production of treatment 3 reached 1625.04 kg ha^{-1}, the difference in oil production between treatments with and without an autumn dose of nitrogen was not statistically significant, similarly as yield. The highest average oil production was statistically significant in the experimental year 2013/2014.

Keywords: oilseed rape, the yield of seed, oil content, oil production, autumn nitrogen dose

1 Introduction

Oilseed rape is one of the most important dicotyledonous field crops in the world, where it plays a key role in productive cereal crop rotations (Stahl et al., 2019). Nitrogen is an important essential nutrient for rape growth and development, of which demand is large (Xing et al., 2021). Finally, nitrogen use efficiency (NUE) can also be seen as a trait that improves the protein content of rapeseed oilcake and, therefore, increases its value compared to competing sources of protein (Charbonnier et al., 2019). Increasing N rates reduced seed oil percentages and consequently increased oil yield per unit area (Zheljazkov et al., 2009). There is also sulphur nutrition important to reach quantity and quality yield, in the nutrition system of crops. Application of sulphur can increase the nitrogen use efficiency, seed yield and stabilize or increase the oil content of oilseed crops (Hřivna et al., 2002; Šípalová et al., 2011).

In agricultural plant production, nitrate, ammonium, and urea are the major fertilized nitrogen forms, which differ in root uptake (Heuermann et al., 2021). The suitable nitrogen fertilizer and its doses and application timing is an important mover for reaching high parameters of yield (López-Bellido & López-Bellido, 2001). Oilseed rape is characterized as a plant with a good ability to absorb nitrogen from soil during autumn (Vazquez-Carrasquer et al., 2021). Autumn nitrogen dose often increased yield and oiliness of rapeseed. However, autumn N should be critically discussed from an environmental point of view,

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since NUE is low and the pathway(s) of autumn N on yield is/are still unidentified (Sieling et al., 2017).

The hypothesis of realized experiment was that the yield, oil content and oil production is non-significant affected by autumn nitrogen dose. Monitoring of weather conditions and soil analyses was necessary to confirm or refute the hypothesis. The goal was to compare the effect of nitrogen fertilization with and without autumn nitrogen dose on yield of seed, oil content and oil production of oilseed rape in given climatic conditions. Any significant effect of autumn nitrogen dose on monitored yield parameters was not assumed.

2 Material and methods

The plot scale experiments were established on 02 September 2013, 22 August 2014 and on 02 September in Mojmírovce (48° 11´ 283.6″ N, 17° 59´ 32.1″ W; 48° 12´ 22″ N,18° 02´ 19.2″ W and 48° 09´ 53.4″, 18° 00´ 35.0″ W). There was used block method of experimental plots with a plot size of 600 m^2 tested in 3 repetitions. Hybrid Artoga was seeded. The quantity of seeds was 0.45 million germinable seeds per 1 ha. The winter wheat (*Triticum aestivum* L.) was a previous crop in all experimental years. Mojmírovce belongs to the maize growing region at an altitude of 140 m a.s.l. The climatic region is very warm, dry with mild winters. The average annual temperature during the growing season is 11.9 °C. The average annual rainfall is 436.7 mm. More detailed characteristics of weather conditions are stated in Tables 1, 2, 3 and 4. The weather conditions were evaluated according to Kožnárová and Klabzuba (2002). Can be concluded, that experimental year 2014/2015 and 2015/2016 were colder and drier than the year 2013/2014.

The Luvic Chernozem on loess is predominant soil type (Societas pedologica slovaca, 2014). Soil analyses were performed by routine analytical methods. N_{an} - N_{min} (N_{an} = N inorganic, N_{min} = N mineral) was calculated as the sum of N-NH_4^+ and N-NO_3^-. The colourimetric method with Nessler's reagent was used for the determination of N-NH_4^+ and phenol acid 2.4-sulphonic for N-NO_3^-. By the method, Mehlich III was determined P, K, Mg and Ca-available. Sulphur was given with ammonium acetate solution. After extraction by 1 mol per dm^{-3} KCl was found pH/KCl. The results of agrochemical soil analysis before setting the experiment on 26 August 2013, 15 August 2014 and 26 August 2015 are stated in Table 5. From Table 5, it follows that nitrogen content in experimental years 2013/2014 and 2015/2016 was good and there was an appropriate nitrogen level in the experimental year 2014/2015.

In a plot scale experiment was studied the effect of three- and four-times divided dose of nitrogen on rapeseed yield, oil content and oil production. The experiment consisted of three treatments of fertilization. The first treatment was unfertilized

Table 1 The average monthly precipitation in years 2013 and 2014 (the evaluation of month precipitation normality according to the long-term average) in Mojmírovce

Month	Long-term average	2013		2014	
		precipitation (mm)	evaluation of normality	precipitation (mm)	evaluation of normality
I.	32.90	67.30	very wet	38.20	normal
II.	29.20	70.10	very wet	39.50	normal
III.	31.90	71.00	very wet	19.50	normal
IV.	36.90	45.50	normal	51.50	wet
V.	60.50	104.20	wet	84.70	wet
VI.	59.00	21.50	very dry	34.60	dry
VII.	55.30	0.00	extraordinary dry	56.20	normal
VIII.	48.70	56.50	normal	116.10	extraordinary wet
IX.	46.10	59.50	normal	107.20	very wet
X.	35.90	31.40	normal	38.00	normal
XI.	45.40	89.50	very wet	21.50	dry
XII.	42.30	8.50	very dry	67.50	wet
			long-term average	precipitation (mm)	
∑ of months II.–VI.			217.50	229.80	
∑ of months III.–V.			129.30	155.70	

Table 2 The average monthly precipitation in years 2015 and 2016 (the evaluation of month precipitation normality according to the long-term average) in Mojmírovce

Month	Long-term average	2015		2016	
		precipitation (mm)	evaluation of normality	precipitation (mm)	evaluation of normality
I.	32.90	82.00	extraordinary wet	11.00	very dry
II.	29.20	18.50	normal	97.00	extraordinary wet
III.	31.90	31.50	normal	26.00	normal
IV.	36.90	19.50	dry	19.00	dry
V.	60.50	74.50	normal	73.50	normal
VI.	59.00	8.00	extraordinary dry	62.50	normal
VII.	55.30	19.00	very dry	196.50	extraordinary wet
VIII.	48.70	74.40	wet	75.50	wet
IX.	46.10	63.50	normal	60.00	normal
X.	35.90	67.00	dry	96.00	very wet
XI.	45.40	38.00	extraordinary dry	42.50	normal
XII.	42.30	14.60	extraordinary dry	6.00	extraordinary dry
			long-term average	precipitation (mm)	
∑ of months II.–VI.			152.00	215.50	
∑ of months III.–V.			125.50	118.50	

Table 3 The average monthly temperatures in years 2013 and 2014 in Mojmírovce (the evaluation of month air temperature normality according to the long-term average)

Month	Long-term average	2013		2014	
		temperature (°C)	evaluation of normality	temperature (°C)	evaluation of normality
I.	0.90	-0.70	normal	-0.50	normal
II.	0.50	2.30	normal	2.50	normal
III.	5.00	3.60	normal	3.60	normal
IV.	10.90	11.70	normal	7.60	very cold
V.	15.90	17.20	normal	11.20	extraordinary cold
VI.	18.70	20.70	warm	14.20	extraordinary cold
VII.	20.90	23.60	extraordinary warm	17.20	extraordinary cold
VIII.	20.50	23.90	extraordinary warm	16.20	extraordinary cold
IX.	1.60	17.50	warm	12.80	very cold
X.	10.30	13.70	extraordinary warm	9.30	normal
XI.	4.80	7.00	very warm	5.50	normal
XII.	0.30	3.40	very warm	0.60	normal
			long-term average	temperature (°C)	
Average of months II.–VI.			10.20	10.70	
Average of months III.–V.			10.60	7.50	

Table 4 The average monthly temperatures in years 2015 and 2016 in Mojmírovce (the evaluation of month air temperature normality according to the long-term average)

Month	Long-term average	2015		2016	
		temperature (°C)	evaluation of normality	temperature (°C)	evaluation of normality
I.	0.90	-0.60	normal	-0.80	normal
II.	0.50	-0.60	cold	1.90	normal
III.	5.00	2.50	cold	3.00	normal
IV.	10.90	4.2	extraordinary cold	7.40	very cold
V.	15.90	10.20	extraordinary cold	11.20	extraordinary cold
VI.	18.70	14.90	extraordinary cold	16.40	very cold
VII.	20.90	17.40	extraordinary cold	15.90	extraordinary cold
VIII.	20.50	18.20	cold	15.20	extraordinary cold
IX.	1.60	13.10	cold	12.40	very cold
X.	10.30	7.40	very cold	6.10	extraordinary cold
XI.	4.80	2.60	very cold	7.00	extraordinary warm
XII.	0.30	1.30	normal	3.40	extraordinary warm
			long-term average	temperature (°C)	
Average of months II.–VI.			10.20	8.10	8.00
Average of months III.–V.			10.60	5.20	7.20

Table 5 Agrochemical characteristics of the soil to a depth of 0.3 m before setting the experiment with oilseed rape in experimental years 2013/2014, 2014/2015 and 2015/2016 in Mojmírovce

Experimental year	Content of available nutrients in mg kg-1								pH/KCl
	N_{an} - N_{min}	N-NH_4^+	N-NO_3^-	P	K	Mg	Ca	S	
2013/2014	11.40	4.80	6.60	17.50	165.00	393.00	5450.00	2.50	6.60
2014/2015	7.00	3.80	3.20	27.50	232.50	352.60	2170.00	1.30	6.80
2015/2016	18.40	12.10	6.30	47.80	395.00	406.20	7100.00	0.00	7.30

Table 6 Treatments of oilseed rape fertilization in experimental years 2013/2014, 2014/2015 and 2015/2016 in Mojmírovce

Treatment	Fertilization level				The total dose of N (kg ha^{-1})
	BBCH 15	BBCH 20	BBCH 30	BBCH 51	
	N (kg ha^{-1})				
1	0	0	0	0	0
2	46	84	80	30	240
3	0	120	90	30	240

control. Treatments 2 and 3 were fertilized by the total dose of nitrogen 240 kg ha^{-1} at growth stages BBCH 20 (rosette stage), 30 (beginning of stem elongation) and 51 (bud formation). Dolomite-ammonium nitrate (DAN, 27% N) was applied at both treatments in the growth stage BBCH 20. Nitrogen was used in the liquid form of urea ammonium nitrate (UAN, 39% N) used at other growth stages BBCH 30 and 51 at both treatments. Treatment 2 was fertilized by autumn (BBCH 15) dose of nitrogen in the form of urea (46% N). Doses of nitrogen are stated in Table 6.

The effect of autumn nitrogen doses on yield, oil content and oil production was monitored after the harvesting. It was done on 25 June 2014, 07 July 2015 and on 03 July 2016 by harvester Claas Lexion 770.

The oil content was performed according to the standard STN 4610111-28 (Slovak technical standard).

The determination was realized by the extraction for assistance to petroleum ether (50/70). The apparatus DET-GRAS N (P Selecta) was used for this determination. A superfluous extractant was distilled after the extraction. The obtained oil was drained and weighed. Oil content was calculated according to the following equation:

$$W = (m_1/m_2) \times 100$$

where:
m_1 – amount of extracted oil (g); m_2 – mass of the test sample (g)

Oil production was expressed as the conversion of oil content to kg ha^{-1} according to the formula:

$$\text{Oil production} = (\text{yield} * \text{oil content})/100$$

The yield of seed in kg per hectare. Oil content in %.

Achievable yields, oil content and oil production were evaluated statistically by analysis of variance. Differences among treatments and years were analysed by the least significant difference (LSD) test in the program Statgraphics Plus 5.1.

3 Results and discussion

The statistically significant effect of nitrogen fertilization, its dose and timing on the growth and yield of rapeseed was confirmed by a lot of studies. As Belete et al. (2018) stated, for optimum yields and improving nitrogen recovery is important to split nitrogen into several doses. Wright et al. (1988) found the highest yield of rapeseed at treatment where nitrogen was applied at sowing. This high rate of nitrogen application at sowing led to more raped leaf area development and higher maximum leaf area index (LAI) compared to treatments supplied with the split application of the same amount of N at sowing and rosette stages. Higher maximum leaf area indexes were associated with greater numbers of pods per plant, which combined with longer leaf area duration led to higher final seed yields. On the other hand, as it is generally known, a large nitrogen amount can reduce frost resistance and the ability to overwinter. Therefore is, according to Varga and Ducsay (2011), nitrogen fertilization realized before sowing and during October only rarely.

The highest average rapeseed yield, 3.63 t ha^{-1}, was reached at treatment 3 without autumn nitrogen dose (Table 7). It means a statistically non-significant increase by 13.22% compared to treatment 2, where autumn nitrogen dose was applied. Autumn dose of nitrogen had no significant effect on the yield of seed, in another experiment in Mojmírovce (Varényiová & Ducsay, 2016). The highest average yield, 3.69 t ha^{-1}, was also reached at treatment without autumn nitrogen application. On the contrary, results of similar experiments indicated a statistically significant effect of autumn dose of nitrogen on seed yield of the winter oilseed rape (Li et al., 2011; Béreš et al., 2019). This corresponds with the results of Kwiatkowski (2012), where the autumn foliar dose of nitrogen significantly increased yield by 9–13%.

Dose of nitrogen could increase seed and also oil yield by affecting several growth parameters such as a number of pods per plant, a number of seeds per pod and seed weight, on the contrary, high doses of nitrogen reduce oil percentage. So, there was an assumption that the divided total nitrogen rate into autumn and spring dose is not a crucial factor affecting the yield of oil. It was confirmed in this experiment. There was found the highest average oil content was 45.09% at unfertilized control treatment 1 (Table 8). The difference among treatments was statistically non-significant. On the other hand, in the study by Kwiatkowski (2012), autumn fertilization increased the oil content of oilseed rape by 16–29 kg ha^{-1} DM. The results of the experiment realized by Béreš et al. (2019) did not prove any significant effect of autumn fertilization on the oil content change of the winter rapeseed. There was found, that the crucial factor influencing the oil content of rapeseed is not timing and

Table 7 Reached yield of rapeseed in experimental years 2013 – 2016 in Mojmírovce

Treatment	Yield of rapeseed (t ha^{-1})			
	2013/2014	2014/2015	2015/2016	average of years
1	3.41	1.35	2.68	2.48aA
2	3.24	2.67	3.55	3.15 bAB
3	4.62	2.75	3.53	3.63 bB
LSD treatment 0.05	–	–	–	0.51
LSD treatment 0.01	–	–	–	0.71

small letters – the least significant difference at the level α = 0.05; capital letters – the least significant difference at the level α = 0.01

Table 8 Reached oil content in experimental years 2013 – 2016 in Mojmírovce

Treatment	Oil content (%)			
	2013/2014	2014/2015	2015/2016	average of years
1	47.41	43.32	44.54	45.09 aA
2	45.99	43.48	43.95	44.47 aA
3	46.77	42.60	43.70	44.36 aA
LSD treatment 0.05	–	–	–	0.83
LSD treatment 0.01	–	–	–	1.16

small letters – the least significant difference at the level α = 0.05; capital letters – the least significant difference at the level α = 0.01

Table 9 Reached oil production in experimental years 2013 – 2016 in Mojmírovce

Treatment	Oil production (kg ha^{-1})			
	2013/2014	2014/2015	2015/2016	average of years
1	1617.04	584.49	1192.04	1131.19 aA
2	1489.82	1161.07	1560.91	1403.93 bAB
3	2160.59	1172.85	1541.69	1625.04 bB
LSD treatment 0.05	–	–	–	246.15
LSD treatment 0.01	–	–	–	343.22

small letters – the least significant difference at the level α = 0.05; capital letters – the least significant difference at the level α = 0.01

Table 10 Reached yield, oil content and oil production of rapeseed in experimental years 2013–2016 in Mojmírovce as the average of treatments

	Year			LSD test$_{0.05}$	LSD test$_{0.01}$
	2013/2014	2014/2015	2015/2016		
Yield (t ha^{-1})	3.76bB	2.26aA	3.25bB	0.51	0.71
Oil content (%)	46.72cB	43.13aA	44.06bA	0.83	1.16
Oil production (kg ha^{-1})	1755.81cB	972.80aA	1431.55bB	246.15	343.22

small letters – the least significant difference at the level α = 0.05; capital letters – the least significant difference at the level α = 0.01

number of nitrogen doses, but total nitrogen rate, in the experiment conducted by Cheema et al. (2001). A non-significant negative effect of higher nitrogen doses on oil content was confirmed in this experiment. Similar results were proven by Rathke et al. (2005) and Storer et al. (2018).

The average oil production ranged from 1131.19 kg ha^{-1} to 1625.04 kg ha^{-1} (Table 9). The difference among treatments was not statistically significant. The average oil production of treatment 3 was statistically highly significant compared to treatment 1.

Differences among experimental years in yield, oil content and oil production were significantly influenced by different weather conditions. The yield of rapeseed in 2013/2014 was higher by 39.90% and 13.57% than yield in years 2014/2015 and 2015/2016 (Table 10). Similarly, the difference in oil production among all experimental years was statistically significant. There was found the highest average oil content 46.72% in the experimental year 2013/2014 in Mojmírovce. The difference was statistically highly significant, in comparison to the years 2014/2015 and 2015/2016. In comparison to experimental years 2014/2015 and 2015/2016, the average oil production in the year 2013/2014 was statistically highly significant higher by 44.60% and 18.47%. The negative effect of a lack of precipitation on a number of pods, yield and oiliness of rapeseed was also confirmed by Istanbulluoglu et al., 2010; Ahmadi and Bahrani, 2009.

Results of some studies have proven the high sensitivity of oilseed rape to weather conditions during the growing season (Oleksy, 2018; Stankowski et al., 2019). There was confirmed the importance of the effect of water availability on nitrogen response and water use efficiency of oilseed rape, in some experiments (Sinclair & Ruffy, 2012; Pan et al., 2016). So, this is one possible cause of the ineffectiveness of the autumn nitrogen dose on yield and oil content in the experiment realized in Mojmírovce. Hocking and Stapper (2001) found that nitrogen fertilizer could not compensate for the yield reduction in oilseed rape due to sowing late, under dry weather conditions. Early sowing is essential to achieve also high oil level. So, there is an assumption, that for reach high yield and oil content is not so important nitrogen dose and autumn nitrogen fertilization, but the date of sowing, under dry weather conditions. Whereas the precipitation decrease is expected in the following years, it would be appropriate to consider the earlier date of oilseed rape sowing. On the contrary, Riar et al. (2020) stated, that, compared to crops, where the timing of nitrogen fertilization is the main crop yield-limiting factor, correct nitrogen rate should be the main consideration for oilseed rape.

There is a possibility, that autumn nitrogen dose could significantly increase yield, oil content and oil production under low soil nitrogen level conditions. To determine more accurately causes, further research is needed. However, based on results obtained from this experiment is possible to recommend fertilization without an autumn dose of nitrogen. From the point of view of yield and oiliness, probably application of urea with nitrification inhibitors could be effective whereas nitrification inhibitors reduce nitrogen losses. It means that nitrogen is more available during the spring. However, there would be appropriate to evaluate the economic efficiency of autumn nitrogen dose, in practice. Comparison of profit achieved by non-significant yield increase at treatment fertilized by autumn nitrogen dose and fertilization costs such as fertilizer costs, labour costs and application costs, is needed.

4 Conclusions

The effect of the autumn dose of nitrogen, compared to nitrogen fertilization without the autumn dose, on yield, oil content and oil production of rapeseed, was observed in an experiment established in experimental years 2013/2014, 2014/2015 and 2015/2016 in terms of agricultural cooperative in Mojmírovce. Although there was not found a significant difference between treatments 2 and 3 in this experiment, the highest average yield and oil production was reached at treatment 3, where any autumn nitrogen dose was not used. As for oil content, there was not found a statistically significant difference among treatments. All in all, the positive significant effect of autumn dose of nitrogen on yield, oil content and oil production of rapeseed was not proven, and the hypothesis was confirmed in this experiment. On the other hand, the strong effect of unequal weather conditions during all experimental years on yield and oiliness of seed of oilseed rape was confirmed in this experiment. Considering the fertilization costs, the omission of autumn nitrogen dose could be recommended in practice, based on obtained results.

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