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ORIGINAL PAPER

THE YIELD AND CHEMICAL COMPOSITION OF WINTER OILSEED RAPE SEEDS DEPENDING ON DIFFERENT NITROGEN FERTILIZATION DOSES AND THE PRECEDING CROP*

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Abstract

The aim of this study was to determine the influence of nitrogen fertilization and the preceding crop on the yield and chemical composition of winter oilseed rape. The yield of winter oilseed rape increased significantly in response to a fertilizer dose of 180 kg N ha^{-1}. In our study, significant interactions were observed between the preceding crop and dose of nitrogen fertilizer. The optimal N fertilizer dose for winter oilseed rape grown after peas, narrow-leaved lupine and traditional (indeterminate) faba beans is 120 kg N ha^{-1}. The recommended N fertilizer dose for winter oilseed rape is 60 kg N·ha^{-1} after determinate faba beans and 180 kg N ha^{-1} after spring wheat. Winter oilseed rape was characterized by the highest seed yield when grown after determinate faba beans, and its yield was slightly lower after peas and narrow-leaved lupine. The lowest seed yield was noted when spring wheat was the preceding crop. The micronutrient content (Mn, Zn, Cu and Fe) of winter oilseed rape increased significantly in response to an increase in nitrogen fertilization doses. The seeds of winter oilseed rape were characterized by the highest phosphorus and magnesium content when grown after peas, the highest potassium content was achieved after determinate faba beans, and the highest calcium content occurrd in oilseed ape when grown after spring wheat. A linear regression analysis revealed a significant relationship between total nitrogen concentrations in the seeds of winter oilseed rape growth after spring wheat and nitrogen fertilization dose. An increase in fertilization levels enhanced nitrogen accumulation in seeds. A similar trend was noted when winter oilseed rape was grown after indeterminate faba beans and peas.

Keywords: nitrogen doses, legumes, spring wheat, macronutrients, micronutrients.

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INTRODUCTION

The introduction of new varieties of winter oilseed rape with different responses to environmental and agricultural conditions requires new knowledge in selected areas of agricultural science. Nitrogen fertilization is a farming operation with the greatest impact on the yield of oilseed rape. The responses of the analyzed species to different doses of nitrogen fertilizers have been researched extensively (Budzyński 1986, Fathi et al. 2002, Barłóg, Grzebisz 2004, Kaul 2004, Rathke et al. 2005, Narits 2010, Őzden 2010, Aminpanah 2013, Khorshidi et al. 2014). Oilseed rape has the highest demand for nutrients during stem elongation and at the beginning of inflorescence emergence. Nitrogen taken up by oilseed rape plants in early spring stimulates flowering and fruit development, and nitrogen taken up in later stages prevents a reduction in the number of siliques and the number of seeds per silique (Barłóg, Grzebisz 2004). Researchers are divided over the most effective doses of nitrogen fertilization for winter oilseed rape (Budzyński 1986, Rathke et al. 2005, Őzden 2010, Narits 2010, Aminpanah 2013).

The effectiveness of nitrogen fertilizers is influenced by habitat and agricultural conditions as well as genetic factors. Nitrogen utilization is determined by the yield potential of a given variety, and in years with adverse weather conditions – also by resistance to biotic and abiotic stress. Varieties grown from similar breeding material respond similarly to farming operations. They may differ in their ability to take up and utilize nitrogen, but their responses to nitrogen fertilization are generally similar (Wójtowicz 2013). The optimal dose of nitrogen fertilizer for winter oilseed rape decreases when the preceding crops were abundantly supplied with this nutrient or when nitrogen-rich post-harvest residues were left in the field. Doses higher than 200 kg N ha^{-1} are justified only when the full yield potential of oilseed rape can be expressed (Rathke et al. 2005, Jarecki et al. 2013). In winter oilseed rape, the efficiency of N fertilizer per unit area is highest at low and medium fertilizer doses. When the 150 kg N ha^{-1} threshold is exceeded, fertilizer efficiency per 1 kg of N is visibly reduced. One kilogram of nitrogen fertilizer applied at a dose of up to 150 kg ha^{-1} produces seed yields of 4.3 to 14.5 kg (Budzyński 1986, Jankowski 2007). Higher N fertilizer doses generally reduce seed yield by half (Budzyński 1986, Jankowski 2007).

Crop sequencing plays a very important role in the production of winter oilseed rape. Errors in crop rotation cannot be compensated by other farming operations such as higher seeding dose, higher fertilizer dose or chemical protection against weeds, pathogens and pests . When the optimal preceding crop is selected, the remaining agricultural inputs most effectively contribute to seed yield. Kaul (2004) has demonstrated that legumes are one of the most effective preceding crops for winter oilseed rape. Legume plants are characterized by considerable amounts of post-harvest residues, which are a rich source of nitrogen for rhizobia and which reduce the nitrogen require-

ments of subsequent crops. Due to a relatively narrow C:N ratio in post-harvest residues, nitrogen is not adsorbed and can be effectively utilized by rapeseed plants. Legume plants have a branched root system, which improves soil structure and porosity and enhances the physicochemical properties of soil.

The positive residual effect of legumes on winter oilseed rape has been demonstrated in numerous studies (Kaul 2004, Rathke et al. 2005). However, not all legume plants constitute optimal preceding crops for early sown winter oilseed rape. According to Fordoński et al. (2015), peas and determinate faba beans are the best preceding crops for winter oilseed rape on account of their short growing season.

Winter oilseed rape is generally sown after cereals, mostly winter and spring barley, winter wheat and winter triticale, for environmental and economic reasons (Mączyńska et al. 2012). Cereals are not good preceding crops because they strongly degrade the soil and contribute to the spread of self-sown weeds in oilseed rape stands. According to Mączyńska et al. (2012), intensified use of oilseed rape in crop rotation increases the risk of weeds, pests and pathogens, including fungal diseases.

The objective of this study was to determine the influence of selected legume species and forms and spring wheat as preceding crops, and the effect of different nitrogen fertilization doses on the yield and chemical composition of winter oilseed rape.

MATERIALS AND METHODS

A two-factor field experiment with a randomized block design was carried out in four replications at the Agricultural Experimental Station in Bałcyny in 2012-2014 (53°35′49.7″N, 19°51′17.3″E). The experimental factors were: I. Nitrogen dose: 1. 0 (control); 2. 60 kg N·ha^{-1} (one application in spring before plant growth); 3. 120 kg N ha^{-1} (split into two applications – 60 kg in spring before plant growth, and 60 kg – 2 weeks later); 4. 180 kg N ha^{-1} (split into three applications – 60 kg in spring before plant growth, 60 kg – 2 weeks later, and 60 kg – at the end of bud formation). II. Preceding crop: 1. Narrow-leaved pea cv. Tarchalska; 2. Narrow-leaved lupine cv. Zeus; 3. Indeterminate faba bean cv. Olga; 4. Determinate faba bean cv. Granit; 5. Spring wheat cv. Trappe

The experiment was established on podsolic soil developed on boulder clay with a slightly acidic pH (pH in 1 M KCl: 5.75 - 6.39). The phosphorus content of soil was high to very high (85 - 143 mg P kg^{-1} soil). The experimental soil was moderately abundant in potassium (104 - 133 mg K kg^{-1} soil) and highly abundant in magnesium (51 - 103 mg kg^{-1} soil).

Selected legume species and spring wheat were the preceding crops. The

plot size was 30 m^2. Nitrogen fertilizer was not used in control treatments. In the experimental treatments, nitrogen was applied as 34% ammonium nitrate in line with the adopted methodology. Phosphorus and potassium fertilizers were applied before sowing at 34.88 kg P ha^{-1} (superphosphate – 17.4% P) and 99.6 kg K ha^{-1} (potash – 49.8% K).

In each year of the experiment, winter oilseed rape cv. Californium was sown in the last ten days of August. Farming treatments and protective measures were applied in accordance with good agricultural practices.

Seed yield and the content of macronutrients and micronutrients in the seeds of winter oilseed rape were determined. Phosphorus concentrations were determined by the molybdovanadate method, calcium and potassium levels – by atomic emission spectrometry (AES), magnesium concentrations – by atomic absorption spectrometry (AAS), and total nitrogen content – in the hypochlorite reaction. Micronutrient concentrations were determined in line with analytical procedure PB07 ed. 3 of 3 December 2012 (References). The examined material was mineralized in a mixture of nitric and perchloric acids, and it was analyzed by flame atomic absorption spectroscopy. The analyses were performed on certified reference material OBTL5.

The results of chemical analyses and yield were verified statistically. Differences between means were regarded as statistically significant at $p < 0.05$ and $p < 0.01$ respectively. All calculations were performed in the Statistica v. 10 program.

Temperature and total precipitation levels during the growing season supported the growth, wintering and yielding of winter oilseed rape in all years of the experiment. Low temperatures in winter and early spring did not cause significant losses due to considerably thick snow cover. Precipitation levels in spring and summer exceeded the water requirements of crops. High temperature and moderate precipitation in late July and early August had a positive influence on ripening and seed yield.

RESULTS AND DISCUSSION

The seed yield of winter oilseed rape was very high in all years of the experiment, ranging from 5.50 t ha^{-1} in 2012 and 2013 to 5.72 t ha^{-1} in 2014 (data from years of the investigation).

The seed yield of winter oilseed rape was significantly higher in plots fertilized with nitrogen than in control treatments (Table 1). Seed yield increased significantly in response to higher doses of N fertilizer. The highest seed yield was noted in treatments where winter oilseed rape was grown after determinate faba beans and fertilized at 180 kg N ha^{-1} (Figure 1).

In a study conducted by Aminpanah (2013), the optimal spring doses of N fertilization for winter oilseed rape grown after cereals ranged from 140 to

Table 1

Effect of nitrogen fertilization dose on yield of winter rape seeds in t ha $^{-1}$ (mean from 2012-2014)

Preceding crop	N rate (kg ha^{-1})				Mean
	0	60	120	180	
A*	4.97	5.55	6.08	6.35	5.74
B	4.41	5.24	6.00	6.45	5.53
C	4.43	5.25	5.83	6.15	5.41
D	5.09	6.07	6.38	6.76	6.07
E	4.12	4.63	5.53	6.19	5.11
HSD ($p \leq 0.05$)	0.47				0.27
Mean	4.60	5.35	5.96	6.38	

A* – pea, B – blue lupine, C – indeterminate cultivar of field bean, D – determinate cultivar of field bean, E – spring wheat

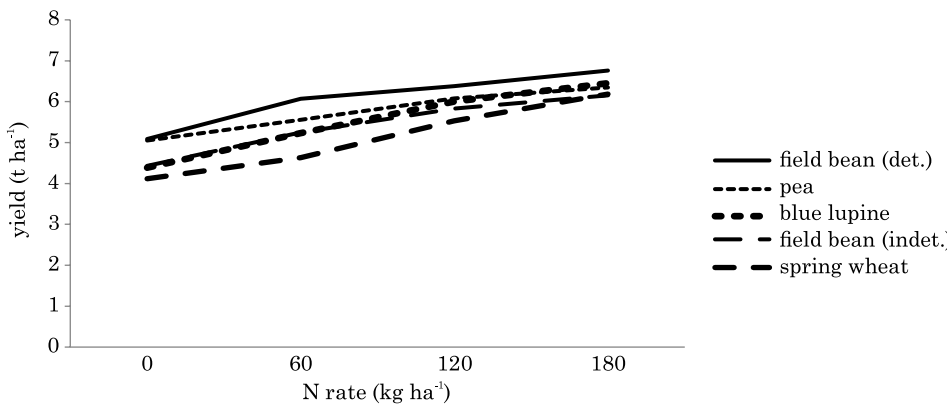

Fig. 1. Effect of preceding crop and nitrogen fertilization dose on yield winter rape seeds

200 kg N ha^{-1}. Nartis (2010) reported the highest yield when winter oilseed rape was fertilized at 120 kg N ha^{-1} after fallow. Fathi et al. (2002) observed a significant increase in yield in response to very high fertilization doses of 225 - 240 kg N ha^{-1}. In an experiment performed by Zhao et al. (1993), an increase in N fertilizer dose from 150 kg ha^{-1} to 200 kg ha^{-1} increased the yield by 20%-22% and 15%, respectively. The yield-promoting effect of nitrogen fertilization was inhibited at doses higher than 250 kg ha^{-1}, and a decrease in seed yield was observed when N fertilizer was applied in excess of 300 kg ha^{-1} (Zhao et al. 1993). In a study by Őzden (2010), a decrease in seed yield was noted already at the fertilization dose of 200 kg N ha^{-1}.

In our study, significant interactions were observed between the preceding crop and the dose of N fertilizer (Table 1). The yield of winter oilseed rape grown after peas, narrow-leaved lupine and indeterminate cultivar faba beans increased significantly in response to the N fertilizer dose of up to

120 kg N ha^{-1}. In treatments where determinate faba beans were used as the preceding crop, a similar increase in seed yield was noted already at the N dose of 60 kg ha^{-1}. Seed yield increased significantly in response to the fertilizer dose of 180 kg N ha^{-1}. When grown after spring wheat, the yield of winter oilseed rape increased significantly when nitrogen was applied at 180 kg ha^{-1}.

The results presented in Figure 2 point to a positive relationship between the total nitrogen content of soil after the harvest of preceding crops and the seed yield of winter oilseed rape. The correlation coefficient was determined at $r = 0.50$ with a p-value of 0.61, which indicates a lack of statistical significance. Similar relationships were also reported by KAUL (2004) and FORDOŃSKI et al. (2015).

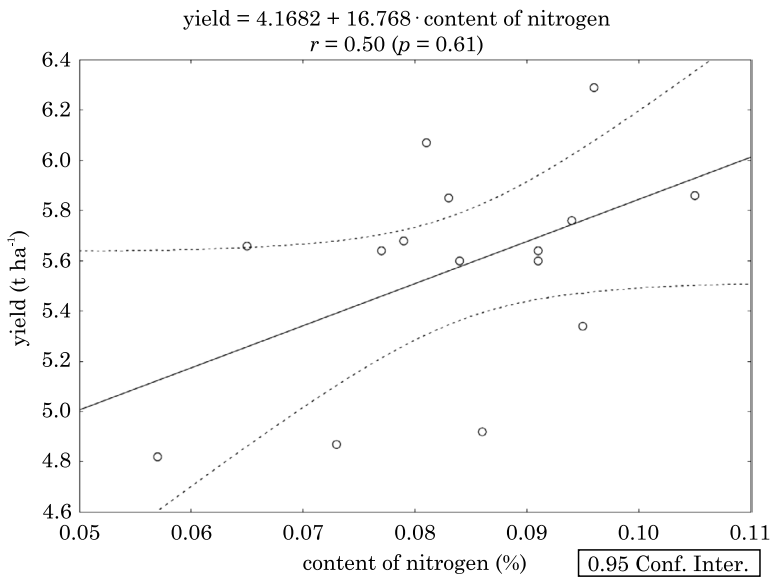

Fig. 2. Scatterplot of the relationship between the content of nitrogen and yield winter rape seeds (t ha^{-1})

The preceding crop significantly influenced seed yield (Table 1). The yield of winter oilseed rape sown after different crops without nitrogen fertilization was discussed by FORDOŃSKI et al. (2015). Determinate faba beans were the optimal preceding crop (Table 1). Peas and narrow-leaved lupine were less effective preceding crops, and the lowest seed yield was noted when winter oilseed rape was grown after spring wheat.

KAUL (2004) analyzed the yield of winter oilseed rape sown after various crops and reported the best results for peas and faba beans. The yield of winter oilseed rape reached 5.36 t ha^{-1} after peas, 4.81 t ha^{-1} after faba beans, 2.27 t ha^{-1} after flax, and only 1.33 t ha^{-1} after white lupine (KAUL 2004). According to MĄCZYŃSKA et al. (2012), the yield of winter oilseed rape grown after cereals increases with adequate protection against pests and pathogens, including fungal diseases.

The analyzed variables induced significant variations in macronutrient and micronutrient concentrations in winter oilseed rape (Tables 2, 3, 4 and 5).

Table 2

Effect of nitrogen fertilization dose on the content of macronutrients in winter oilseed rape seeds (g kg^{-1} d.m.)

N rate (kg ha^{-1})	P	K	Mg	Ca
0	6.06	7.16	3.14	4.06
60	5.94	7.16	3.16	4.00
120	6.04	7.20	3.18	4.02
180	6.12	7.44	3.08	4.06
HSD ($p \leq 0.01$)	0.01	0.01	0.01	0.01

Table 3

Effect of preceding crop on the content of macronutriens in winter oilsed rape seeds (g kg^{-1} d.m.)

Preceding crop	P	K	Mg	Ca
A*	6.25	7.25	3.17	4.05
B	5.97	7.15	3.17	3.85
C	6.02	7.20	3.12	4.12
D	5.85	7.35	3.10	4.00
E	6.10	7.25	3.12	4.15
HSD ($p \leq 0.01$)	0.01	0.01	0.01	0.01

* Explanations under Table 1

Table 4

Effect of nitrogen fertilization dose on the content of micronutrients in winter oilseed rape seeds (mg kg^{-1} d.m.)

N rate (kg ha^{-1})	Mn	Zn	Cu	Fe
0	31.1	32.0	3.08	72.4
60	32.7	33.1	3.72	78.0
120	34.6	35.5	3.72	81.5
180	36.7	36.5	3.88	86.2
HSD ($p \leq 0.01$)	0.34	0.42	0.05	0.82

Table 5

Effect of preceding crop on the content of micronutriens in winter oilsed rape seeds (mg kg^{-1} d.m.)

Preceding crop	Mn	Zn	Cu	Fe
A*	33.1	34.8	4.12	87.8
B	34.6	34.1	4.04	77.0
C	32.2	33.8	3.21	78.9
D	34.0	33.6	3.65	78.5
E	34.0	34.2	3.06	75.5
HSD ($p \leq 0.01$)	0.39	0.56	0.07	0.89

* Explanations under Table 2

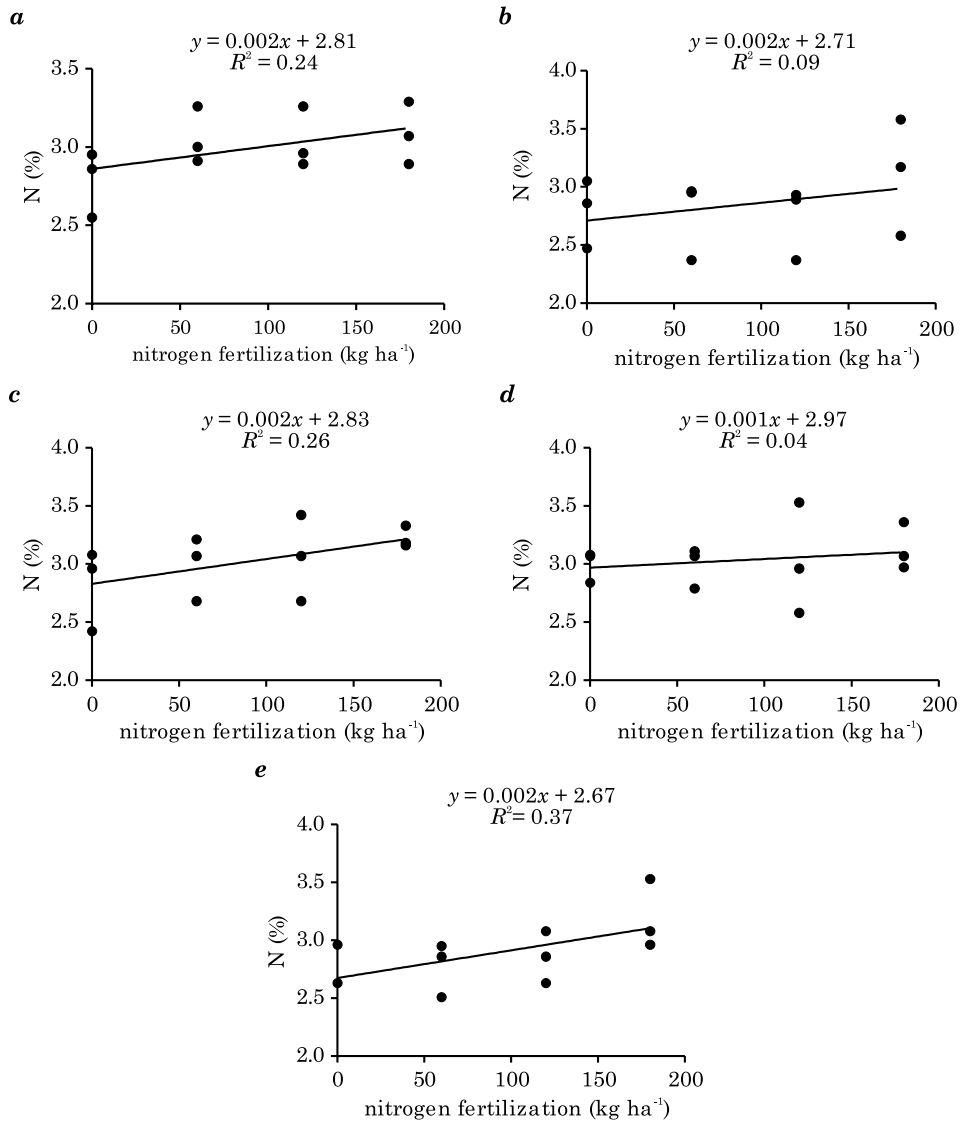

Fig. 3. Linear regression between doses of nitrogen fertilization and nitrogen content in winter rape seeds depending on different preceding crops: *a* – pea, *b* – lupine, *c* – indeterminate cultivar of field bean, *d* – determinate cultivar of field bean, *e* – spring wheat

The phosphorus and magnesium content of seeds was highest when winter oilseed rape was grown after peas, potassium content – when winter oilseed rape was grown after determinate faba beans, and calcium content – when it was grown after spring wheat (Table 3).

The seeds of winter oilseed rape fertilized with nitrogen at 180 kg ha^{-1} were characterized by the highest phosphorus and potassium content and

the lowest magnesium levels. Calcium concentrations in seeds were not significantly depended on the dose of N fertilizer (Table 2).

A linear regression analysis revealed a significant relationship between total nitrogen concentrations in the seeds of winter oilseed rape grown after spring wheat and N fertilization dose. An increase in fertilization levels enhanced nitrogen accumulation in seeds ($y = 0.02x + 2.67$; $R^2 = 0.37$) – Figure 3. A similar trend was noted when winter oilseed rape was grown after indeterminate faba beans ($y = 0.02x + 2.83$; $R^2 = 0.26$) and peas ($y = 0.02x + 2.81$; $R^2 = 0.24$).

The manganese, zinc, copper and iron content of the evaluated seeds increased significantly in response to higher N doses (Table 4).

The seeds of winter oilseed rape grown after peas were characterized by a significantly higher content of iron, copper and zinc (Table 5). The lowest manganese concentrations were noted in winter oilseed rape grown after traditional faba beans (Table 5).

Fordoński et al. (2015) observed that the macronutrient content of winter oilseed rape varied subject to preceding crop. The N, P and C content of seeds clearly increased when winter oilseed rape was grown after determinate faba beans. The differences in the Mg content of seeds from various treatments were not statistically significant. The seeds of winter oilseed rape grown after determinate faba beans were also characterized by the highest concentrations of Cu, Fe and Zn. The seeds of oilseed rape grown after determinate faba beans and narrow-leaved lupine were a rich source of manganese. Seeds from plants grown after spring wheat were least abundant in macronutrients and micronutrients. The positive effect of soybean and pea as preceding crops on the content macronutrients and micronutrients in spring wheat grain was confirmed also by Woźniak, Makarski (2013).

CONCLUSIONS

1. The seed yield of winter oilseed rape increased significantly in response to the N fertilizer dose from 60 to 180 kg N ha^{-1}.

2. The economically optimal N fertilizer dose for winter oilseed rape grown after peas, narrow-leaved lupine and traditional faba beans is 120 kg N ha^{-1}.

3. The recommended N fertilizer dose for winter oilseed rape is 60 kg N ha^{-1} after determinate faba beans and 180 kg N ha^{-1} after spring wheat.

4. Winter oilseed rape was characterized by the highest seed yield when grown after determinate faba beans, and its yield was slightly lower after peas and narrow-leaved lupine. The lowest seed yield was noted when spring wheat was the preceding crop.

5. The micronutrient content of winter oilseed rape increased significantly in response to an increase in nitrogen fertilization doses.

6. The seeds of winter oilseed rape were characterized by the highest phosphorus and magnesium content when grown after peas, the highest potassium content when grown after determinate faba beans, and the highest calcium content when grown after spring wheat.

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