Barbara FILIPEK-MAZUR[1], Andrzej LEPIARCZYK[2]
and Monika TABAK[1*]

NITROGEN AND SULPHUR FERTILIZATION ON YIELDING AND ZINC CONTENT IN SEEDS OF WINTER RAPE 'BALDUR' CULTIVAR

WPŁYW NAWOŻENIA AZOTEM I SIARKĄ NA PLONOWANIE I ZAWARTOŚĆ CYNKU W NASIONACH RZEPAKU OZIMEGO ODMIANY 'BALDUR'

Abstract: The research was conducted in order to determine the yield of winter rape seeds and zinc content in seeds as a result of fertilization with different doses of nitrogen and sulphur. A three-year field experiment was conducted according to the following scheme (9 treatments): 1. control – without fertilization; 2–4. nitrogen fertilization with doses of 134, 180, and 225 kgN · ha^{-1} in the form of ammonium nitrate (34 % N); 5–7. nitrogen fertilization with doses of 134, 180, and 225 kgN · ha^{-1} in the form of Saletrosan 26 Makro (26 % N and 13 % S); 8. sulphur fertilization with a dose of 60 kgS · ha^{-1} in the form of Saletrosan 26 Makro along with nitrogen complementation with ammonium nitrate to a dose of 180 kgN · ha^{-1}; 9. sulphur fertilization with a dose of 60 kgS · ha^{-1} in the form of Saletrosan 26 Makro along with nitrogen complementation with ammonium nitrate to a dose of 225 kgN · ha^{-1}. Sulphur application led to an increase in the yield of rape seeds and seed zinc content (and, as a result, also in the element uptake with yield), in comparison with the yield and zinc content in seeds collected from treatments without sulphur application.

Keywords: zinc, nitrogen fertilization, sulphur fertilization

Introduction

Optimal growth and development of cultivated plants requires access to indispensable macronutrients and microelements. Winter rape has high nutrient requirements, mainly for nitrogen and sulphur [1, 2]. It is cultivated, above all, as raw material for oil

[1] Department of Agricultural and Environmental Chemistry, University of Agriculture in Krakow, al. A. Mickiewicza 21, 31–120 Kraków, Poland, phone: +48 12 662 4344, fax: +48 12 662 4341, email: rrfilipe@cyf-kr.edu.pl

[2] Department of Agrotechnology and Agricultural Ecology, University of Agriculture in Krakow, al. A. Mickiewicza 21, 31–120 Kraków, Poland, phone: +48 12 662 4364, fax: +48 12 662 4366, email: a.lepiarczyk@ur.krakow.pl

[*] Corresponding author: Monika.Tabak@ur.krakow.pl

production, and the obtained waste products (extracted meal, oil cake, pomace) are used in animal feeding. In connection with the introduction of cultivars of double improved rape to cultivation as well as the introduction of changes in the technological process of acquisition of oil, it is intended to monitor changes in the level of mineral components in seeds of this plant. Zinc, which is a component of many enzymes and which is responsible for forming chelate bonds between enzyme and substrate, is one of microelements indispensable for proper development of plants [3, 4]. What is more, zinc participates in transformations of carbohydrates, proteins and phosphates [4]. Optimum zinc content in rape seeds is important when using them as a seed material, because this element is extremely important for proper plant growth in the first developmental stages [5, 6].

The aim of the research was to evaluate what effect nitrogen and sulphur, used in various doses, have on the yield and zinc content in winter rape, 'Baldur' cultivar, seeds.

Material and methods

The field experiment was conducted in the years 2009–2012 at the Experimental Station of the Department of Agrotechnology and Agricultural Ecology of the University of Agriculture in Krakow-Mydlniki. Brown earth soil, type – Luvisol, subtype – Stagnic Luvisol, textural group – silt, genus – formed from loess, is ranked among good wheat complex. Each year, spring barley was the forecrop for the double improved hybrid (Baldur) cultivar of rape.

Pre-sowing phosphorus fertilization in the form of superphosphate (40 % P_2O_5) amounted to 100 kg$P_2O_5 \cdot ha^{-1}$, and potassium fertilization in the form of potassium salt (60 % K_2O) amounted to 198 kg$K_2O \cdot ha^{-1}$. Doses of nitrogenous fertilizers, including the ones containing sulphur, were used according to the experiment scheme that included the following treatments: 1. control – without fertilization; 2–4. nitrogen fertilization in doses 134, 180, and 225 kgN $\cdot$ ha^{-1} in the form of ammonium nitrate (34 % N); 5–7 nitrogen fertilization in doses 134, 180, and 225 kgN $\cdot$ ha^{-1} in the form of Saletrosan 26 Makro (26 % N and 13 % S; this fertilizer is a mixture of ammonium nitrate and ammonium sulphate); 8. sulphur fertilization in a dose of 60 kgS $\cdot$ ha^{-1} in the form of Saletrosan 26 Makro complemented with nitrogen (ammonium nitrate) to a dose of 180 kgN $\cdot$ ha^{-1}; 9. sulphur fertilization in a dose of 60 kgS $\cdot$ ha^{-1} in the form of Saletrosan 26 Makro complemented with nitrogen (ammonium nitrate) to a dose of 225 kgN $\cdot$ ha^{-1}. Nitrogen in doses 134 kgN $\cdot$ ha^{-1} and 180 kgN $\cdot$ ha^{-1} was used three times, and in a dose of 225 kgN $\cdot$ ha^{-1} it was used four times. Each year in autumn, a starting dose of 30 kgN $\cdot$ ha^{-1} was applied to all the fertilization treatments, except the control (without fertilization).

The experiment was set up using the method of random blocks in 4 replications, and the area of each plot was 28 m^2 (15 m^2 for harvest).

Total precipitation in the period from sowing to inhibition of vegetation (VIII–XI) was between 119 mm in the season 2011/2012 and 281 mm in the season 2010/2011 (Table 1), and it was higher than the optimal total precipitation for rape in this period [7].

During the period of winter rest (XII–III), total precipitation was less diversified and it was between 93 mm in the season 2010/2011 and 143 mm in the season 2009/2010.

Table 1

Total precipitation in research years compared to multi-annual period 1977–2008 [mm]

Year	Month											
	VIII	IX	X	XI	XII	I	II	III	IV	V	VI	VII
Season 2009/2010	53.3	61.5	42.7	27.6	36.2	44.2	31.5	31.0	39.9	299.0	135.1	105.2
Season 2010/2011	127.5	112.8	14.0	26.6	43.4	25.9	8.1	15.2	77.7	48.0	33.0	186.4
Season 2011/2012	73.1	14.4	31.5	0.3	38.1	51.6	27.9	17.3	49.0	17.5	143.8	70.6
Multi-annual period 1977–2008	61.9	87.9	49.2	32.6	41.1	27.6	19.0	53.5	42.7	46.4	53.0	108.0
Optimum amount of precipitation acc. to Klatt									50	70	75	30

Particularly in the season 2010/2011 precipitation was lower than optimal precipitation in the period when rape rests [7]. From the beginning of vegetation to harvest, total precipitation exceeded the water requirements and was between 281 mm (season 2011/2012) and 579 mm (season 2009/2010). Cumulative water requirements during winter rape vegetation are approximately 400–525 mm [7]. Sums of precipitation, particularly in seasons 2009/2010 and 2010/2011, were higher. When comparing the data for the period of conducting the research with the data for the multi-annual period 1977–2008, it was established that the greatest differences occurred in May, June and August 2010, as well as in June 2012 (sums of precipitation were higher than the ones determined for the multi-annual period), and also in October 2010, March, September and November 2011, as well as in March 2012 (sums of precipitation were considerably lower).

During time of conducting the experiment, air temperature was generally lower than the mean temperature from the multi-annual period 1977–2008 (temperature higher than mean was found in August and April in all years of the research as well as in November 2009, July 2010, June 2011, and also in May and July 2012) (Table 2).

Table 2

Mean air temperature in research years compared to multi-annual period 1977–2008 [^{o}C]

Year	Month											
	VIII	IX	X	XI	XII	I	II	III	IV	V	VI	VII
Season 2009/2010	18.6	12.9	9.8	5.7	–1.2	–6.3	–2.2	3.3	9.0	12.8	17.5	20.7
Season 2010/2011	18.4	12.3	8.7	3.1	–2.3	–1.2	–2.6	3.6	10.3	13.5	18.2	17.7
Season 2011/2012	19.0	14.1	8.6	2.1	1.6	–1.2	–6.6	4.4	9.4	15.0	17.4	20.3
Multi-annual period 1977–2008	18.2	13.1	10.0	3.9	0.2	–0.2	1.1	3.9	8.3	13.9	17.6	18.8

A temperature of over 20 ^{o}C [8] is the best for plant germination, and a temperature of 15–16 ^{o}C, which should drop gradually to 0 ^{o}C, is sufficient for growth and development before the winter rest. After recommencement of vegetation, air temperature should not be lower than 7–10 ^{o}C; 14.2 ^{o}C is optimal for the flowering stage, and 16.8 ^{o}C for seed filling.

During rape vegetation, plant protection measures were taken in accordance with agrotechnical recommendations. 10 days before rape harvesting, the plantation was dessicated with Reglone 200 SL in a dose of 2 $dm^3 \cdot ha^{-1}$.

Rape harvesting was carried out using a plot combine. Results regarding the seed yield were elaborated statistically, conducting an analysis of variance, and significance of the differences between treatments was verified by the Tukey's test at a significance level of α = 0.05, using Statistica 10 software (StatSoft, Inc.).

Zinc content in rape seeds was determined in two replications, in average samples from each treatment, adding a sample of reference material to the series of analyses. The determination was carried out with inductively coupled plasma atomic emission spectrometry (ICP-AES) on JY 238 Ultrace apparatus. Preparing the samples for determination consisted in dry mineralization of the material (8 hours, 450 ^{o}C), evaporation with hydrochloric acid, and dilution of the remains in nitric acid solution [9].

Results and discussion

Dry matter yield from winter rape seeds in the research years is presented in Table 3. The data suggest that the highest yields of winter rape seeds in all the experimental treatments were obtained in 2012 (between 2.63 and 3.53 t of d.m. $\cdot$ ha^{-1}). However, they were lower than yields which can be obtained in optimal conditions according to many authors [10, 11].

Table 3

Rape seed yield [t of d.m. $\cdot$ ha^{-1}]

Treatment no.	Fertilization	2010	2011	2012	Mean
1	Control – without fertilization	1.74a*	1.85a	2.63a	2.07a
2	134 kgN $\cdot$ ha^{-1} ammonium nitrate	2.14b	2.38b	3.22bc	2.58b
3	180 kgN $\cdot$ ha^{-1} ammonium nitrate	2.31b	2.63c	3.14b	2.69bc
4	225 kgN $\cdot$ ha^{-1} ammonium nitrate	2.39b	2.86c	3.53c	2.93d
5	134 kgN $\cdot$ ha^{-1} Saletrosan 26 Makro	2.44c	3.20d	3.24bc	2.96d
6	180 kgN $\cdot$ ha^{-1} Saletrosan 26 Makro	2.52d	2.68c	3.25bc	2.82cd
7	225 kgN $\cdot$ ha^{-1} Saletrosan 26 Makro	2.50cd	3.32d	3.49c	3.10d
8	60 kgS $\cdot$ ha^{-1} Saletrosan 26 Makro + up to 180 kgN $\cdot$ ha^{-1} ammonium nitrate	2.50cd	2.79c	3.36bc	2.88d
9	60 kgS $\cdot$ ha^{-1} Saletrosan 26 Makro + up to 225 kgN $\cdot$ ha^{-1} ammonium nitrate	2.51d	2.51bc	3.33bc	2.78c

* Mean values in columns marked with the same letters do not differ statistically significantly at α = 0.05, according to the Tukey's test.

Lower yields are caused mainly by the course of weather conditions during winter rape vegetation. It can be inferred from the amount and distribution of precipitation (Table 1) as well as the height of temperature (Table 2) during vegetation, which were most favorable for development of this species in the season 2011/2012 in comparison to the season 2009/2010 that was the least suitable.

In all years of the research, the lowest, significantly proven yields of rape seeds were found in the treatment without fertilization. On the other hand, fertilization of winter rape with various doses of nitrogen without sulphur in 2010 did not cause significant diversification of dry matter yield of seeds, whereas in the years 2011–2012 a tendency to a higher yield in the treatments with a higher nitrogen dose was found. In comparison with the yield from treatments fertilized with nitrogen without sulphur, introduction of this element along with Saletrosan 26 Makro resulted in an increase in mass of rape seeds, particularly in the years 2010 and 2011. Based on the amount of dry matter yield of rape seeds it was established that in order to satisfy plant demand for nitrogen it is better to use Saletrosan 26 Makro than ammonium nitrate.

There is no uniform position in the available literature regarding the effect of nitrogen and sulphur doses on the amount of rape seed yield. Wielebski and Wojtowicz [12] did not show that increase in sulphur doses had an effect on rape seed yield, whereas Sattar et al [13] established that the amount of yield increased along with the increase in nitrogen and sulphur doses. Wielebski [14] determined that rape seed yield increases under the influence of sulphur fertilization only in the case of a low content of the element in soil, whereas in conditions where plants have optimum supply of this element there is no effect of yield increase. On the basis of the own research it can be stated that nitrogen together with sulphur had a beneficial effect on the mean yield of dry matter from rape seeds from 3 years of the research, although differences among the treatments were not always statistically significant (Table 3). The seed yield from plants fertilized with Saletrosan 26 Makro in the smallest dose (134 kgN $\cdot$ ha^{-1} and 67 kgS $\cdot$ ha^{-1}) was by 15 % higher than the seed yield from plants fertilized only with ammonium nitrate in which the same dose of nitrogen was introduced. At the same time, this yield, at a dose of 225 kgN $\cdot$ ha^{-1} in the form of ammonium nitrate was in the same homogenous group as in the case of fertilization with 134 and 225 N $\cdot$ ha^{-1} applied in the form of Saletrosan 26 Makro, as well as with 60 kgS in the form of Saletrosan 26 Makro + 180 kgN in the form of ammonium nitrate.

Depending on the fertilization treatment, weighted mean of zinc content was within a range from 37.4 to 42.9 mgZn $\cdot$ kg^{-1} of d.m. (Table 4). These values are in accordance with the ones given by Banaszkiewicz [15] and Filipek and Harasim [16].

The zinc content in rape seeds in no treatment exceed the permissible value for rape intended for consumption or fodder, which is, respectively 50 mgZn and 100 mgZn $\cdot$ kg^{-1} of d.m. [17]. In own research, the highest zinc contents were found in rape seeds from treatments in which nitrogen and sulphur fertilization was used in doses 180 and 225 kgN $\cdot$ ha^{-1}, as well as 90 and 112.5 kgS $\cdot$ ha^{-1}. Such dependence occurred particularly in 2010 and 2011 (moreover, in 2011, sulphur fertilization in a dose of 60 kgS $\cdot$ ha^{-1} and nitrogen fertilization in a dose of 180 and 225 kgN $\cdot$ ha^{-1} had similar effect), and also in the case of mean values from 3 years.

Table 4

Zinc content in dry matter of rape seeds [mgZn · kg^{-1} of d.m.]

Treatment no.	Fertilization	2010	2011	2012	Weighted mean
1	Control – without fertilization	49.9	24.8	38.9	37.78
2	134 kgN · ha^{-1} ammonium nitrate	48.5	28.0	37.0	37.41
3	180 kgN · ha^{-1} ammonium nitrate	53.4	30.4	38.9	40.28
4	225 kgN · ha^{-1} ammonium nitrate	53.2	31.5	37.3	39.74
5	134 kgN · ha^{-1} Saletrosan 26 Makro	50.9	30.0	38.6	38.88
6	180 kgN · ha^{-1} Saletrosan 26 Makro	56.9	34.2	36.2	41.74
7	225 kgN · ha^{-1} Saletrosan 26 Makro	58.0	35.5	39.2	42.93
8	60 kgS · ha^{-1} Saletrosan 26 Makro + up to 180 kgN · ha^{-1} ammonium nitrate	51.9	34.1	37.3	40.49
9	60 kgS · ha^{-1} Saletrosan 26 Makro + up to 225 kgN · ha^{-1} ammonium nitrate	51.8	35.7	38.0	41.46

Similarly to own research, Kozlowska-Strawska [18] showed that rape plants fertilized with sulphur, particularly in sulphatic form, had the highest zinc content. In own research, sulphur was introduced to soil along with the Saletrosan 26 Makro fertilizer in the form of ammonium sulphate. In this context, the significance of soil reaction in the uptake of zinc by rape cannot be excluded.

Zinc amount uptaken along with dry matter yield from rape seeds is presented in Fig. 1. Since this amount is a product of seed yield mass and zinc content in it, the

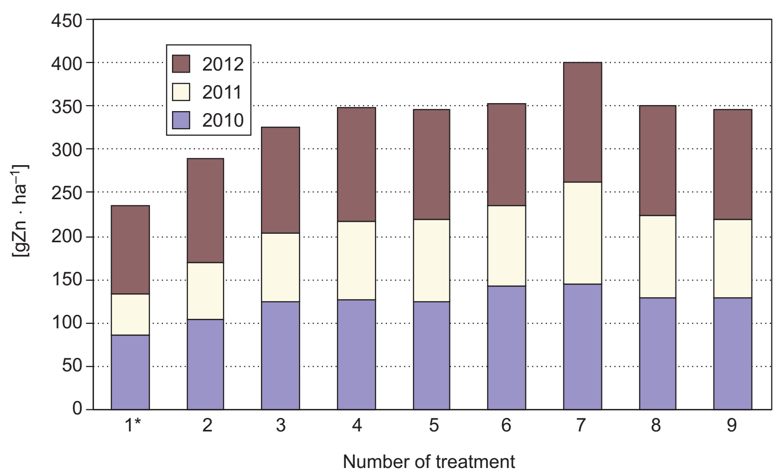

Fig. 1. Zinc amount [g Zn · ha^{-1}] uptaken along with dry matter yield from rape seeds: * 1. Control – without fertilization; 2–4. 134, 180 and 225 kgN · ha^{-1} in the form of ammonium nitrate, respectively; 5–7. 134, 180 and 225 kgN · ha^{-1} in the form of Saletrosan 26 Makro, respectively; 8. 60 kgS · ha^{-1} in the form of Saletrosan 26 Makro complemented with nitrogen (ammonium nitrate) to a dose of 180 kgN · ha^{-1}; 9. 60 kgS · ha^{-1} in the form of Saletrosan 26 Makro complemented with nitrogen (ammonium nitrate) to a dose of 225 kgN · ha^{-1}

differences among the research years are in accordance with the diversity in yielding and in the content of the component in yield. In the period of the experiment, rape from the non-fertilized soil took up the least zinc. At the same time, uptake of zinc with seed yield from plants fertilized with nitrogen with an addition of sulphur was higher than from plants fertilized only with nitrogen.

Rape is a plant that is relatively tolerant to zinc deficiency, but for proper growth and development this element is indispensable. Physiological role of zinc is connected with its function as an enzyme activator, particularly the ones participating in carbohydrate transformations and in synthesis of proteins. What is more, zinc guarantees a high level of protein in rape seeds [19], which is particularly important when the plants are intended for consumption or fodder.

Conclusions

1. The yields of rape seeds varied between the research years due to differences in weather conditions.
2. Application of sulphur in the fertilization contributed to an increase in the rape seed yields in comparison to yields from treatments without sulphur participation.
3. As a rule, the highest sulphur contents were determined in rape seeds from treatments where nitrogen and sulphur fertilization was used.
4. Uptake of zinc with seed yield from plants fertilized with nitrogen with an addition of sulphur was higher than from plants fertilized only with nitrogen.

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References

[1] Hołubowicz-Kliza G. Technologia uprawy rzepaku. Instrukcja upowszechnieniowa nr 171. Puławy: Wyd IUNG-PIB; 2010.
[2] Pepó P. Acta Agron Hung. 2013;61(3):195-205. DOI: 10.1556/AAgr.61.2013.3.3.
[3] Andreini C, Bertini I. J Inorg Biochem. 2012;111:150-156. DOI: 10.1016/j.jinorgbio.2011.11.020.
[4] Kopcewicz J, Lewak S. Fizjologia roślin. Warszawa: Wyd Nauk PWN; 2002.
[5] Grewal HS, Graham RD. Plant Soil. 1997;192:191-197.
[6] Pandey N, Pathak GCh, Sharma ChP. J Trace Elem Med Biol. 2006;20:89-96. DOI: 10.1016/j.jtemb.2005.09.006.
[7] Dzieżyc J, Nowak L, Panek K. Zesz Probl Post Nauk Roln. 1987;314:11-33.
[8] Budzyński W, Zając T. Rośliny oleiste. Uprawa i zastosowanie. Poznań: PWRiL; 2010.
[9] Ostrowska A, Gawliński S, Szczubiałka Z. Metody analizy i oceny właściwości gleb i roślin. Katalog. Warszawa: Instytut Ochrony Środowiska; 1991.
[10] Rathke GW, Behrens YT, Diepenbrock W. Agric Ecosyst Environ. 2006;117:80-108. DOI: 10.1016/j.agee.2006.04.006.
[11] Rathke GW, Christen O, Diepenbrock W. Field Crops Res. 2005;94:103-113. DOI: 10.1016/j.fcr.2004.11.010.
[12] Wielebski F, Wojtowicz M. Rośliny Oleiste. 2003;24(1):109-120.
[13] Sattar A, Cheema MA, Wahid MA, Saleem MF, Hassan M. Crop Environ. 2011;2(1):32-37.

[14] Wielebski F. Rośliny Oleiste. 2008;29(1):91-104.
[15] Banaszkiewicz T. Ecol Chem Eng A. 2008;15(1-2):9-13.
[16] Filipek T, Harasim P. Acta Agrophys 2007;9(3):591-602.
[17] Kabata-Pendias A, Motowicka-Terelak T, Piotrowska M, Terelak H, Witek T. Ocena stopnia zanieczyszczenia roślin metalami ciężkimi i siarką. Ramowe wytyczne dla rolnictwa. Puławy: IUNG; 1993.
[18] Kozłowska-Strawska J. Ochr Środow Zasob Natur. 2009;40:254-261.
[19] Orlovius K. Fertilizing for high yield and quality. Oilseed rape. International Potash Institute; 2003. http://ipipotash.org/udocs/No%2016%20Oilseed%20rape.pdf [08.01.2014].

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[1] Katedra Chemii Rolnej i Środowiskowej
[2] Katedra Agrotechniki i Ekologii Rolniczej
Uniwersytet Rolniczy im. Hugona Kołłątaja w Krakowie

Abstrakt: Badania wykonano w celu określenia wielkości plonu nasion rzepaku ozimego oraz zawartości w nich cynku w efekcie nawożenia zróżnicowanymi dawkami azotu i siarki. Doświadczenie polowe prowadzone w latach 2009–2012 obejmowało 9 obiektów: 1. kontrola – bez nawożenia; 2–4. nawożenie azotem w dawkach 134, 180 i 225 kgN $\cdot$ ha^{-1} w postaci saletry amonowej (34 % N); 5–7. nawożenie azotem w dawkach 134, 180 i 225 kgN $\cdot$ ha^{-1} w postaci Saletrosanu 26 Makro (26 % N i 13 % S); 8. nawożenie siarką w dawce 60 kgS $\cdot$ ha^{-1} w postaci Saletrosanu 26 Makro uzupełnione azotem (saletra amonowa) do dawki 180 kgN $\cdot$ ha^{-1}; 9. nawożenie siarką w dawce 60 kgS $\cdot$ ha^{-1} w postaci Saletrosanu 26 Makro uzupełnione azotem (saletra amonowa) do dawki 225 kgN $\cdot$ ha^{-1}. Wykazano, że zastosowanie siarki prowadziło do zwiększenia masy nasion rzepaku i zawartości w nich cynku (a w rezultacie także pobrania tego składnika z plonem), w porównaniu z plonem i zawartością cynku w nasionach zebranych z obiektów bez siarki.

Słowa kluczowe: cynk, nawożenie azotem, nawożenie siarką