ACTA Acta Sci. Pol. Agricultura, 15(4) 2016, 3-14

ISSN 1644-0625
ISSN 2300-8504 (online)
www.agricultura.acta.utp.edu.pl

SULPHUR AS A FACTOR THAT AFFECTS NITROGEN EFFECTIVENESS IN SPRING RAPESEED AGROTECHNICS
PART II. YIELD OF SEEDS AND PROTEIN

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Abstract. The basis of the study was a three-year long field experiment, carried out on degraded Phaeozems, IIIb soil valuation class, with neutral pH and low richness in assimilable sulphur. Winter rapeseed cultivar Star was grown. The experiment was set up as a split-block design with two factors (n = 2): the first factor was nitrogen dose (in kg·ha^{-1}: 0, 60, 120, and 180), and the second factor was sulphur dose (in kg·ha^{-1}: 0, 20, and 60). An additional study aspect was diversification of methods and dates of sulphur application (pre-sowing: in-soil and top-dressing: as foliar fertilizer). For plants unfertilized with sulphur, dose of 120 kg N·ha^{-1} was the most effective in regards to yield-formation, and for plants unfertilized with nitrogen, dose of 20 kg S·ha^{-1}. In-soil application of sulphur made it possible to obtain higher grain and protein yield than its foliar application. Including sulphur in nitrogen fertilization made it possible to obtain significantly higher yield of spring rapeseed grain, and also protein content and yield, in particular in the conditions of in-soil sulphur application.

Key words: *Brassica napus* L., grain yield, nitrogen and sulphur interaction, protein yield, sulphur fertilization

INTRODUCTION

On a global scale, first of all the spring form of rapeseed is cultivated. It dominates in countries like Canada, China, Russia, Kazakhstan, and Australia. In Poland, spring rapeseed has a decisively lower economic significance than winter rapeseed. Meeting soil and thermal demands of spring rapeseed in Polish conditions is not difficult, although expanding the area of its cultivation is limited by high water demand, which, during intensive growth and grain-formation, is estimated to be 200 mm of precipitation

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[Szot and Rudko 2005]. Water shortage, especially during plant flowering and grain-formation, causes an increase in grain yield and fat content [Mrówczyński and Pruszyński 2008]. Some of the advantages of spring rapeseed are: leaving very good site for cereals, lower nutritional needs, and lower susceptibility to disease than winter cultivars, which generates lower expenditure [Toboła and Muśnicki 2000].

Although spring rapeseed is less prolific than its winter forms (difference by 35--40%), with present stock needs its cultivation may turn out to be perfect and often only complement of economic assumptions made earlier of winter rapeseed [Izdebski et al. 2014]. Spring rapeseed is the most frequently grown successive crop after frozen winter rapeseed, in a situation when in the autumn herbicides that exclude introduction of spring cereals are applied [Mrówczyński and Pruszyński 2008].

In spite of some breeding success in the use of heterosis in the creation of new spring rapeseed cultivars [Bartkowiak-Broda *et al.* 2005], it appears that in the future, the spring form will be no competition in Poland for winter cultivars, despite the risk of freezing of the latter. Lower fruitfulness and unreliableness will be decisive in spring rapeseed cultivation, related to high probability of the occurrence of dry periods in Poland, to which spring rapeseed is particularly sensitive [Szot and Rudko 2005].

In recent years, deepening shortage of sulphur [Morris 2007, Kaczor and Zuzańska 2009, Klikocka 2011, Rathore *et al.* 2015] has caused an increase in the interest in this element in Poland as a component of cultivated plant fertilizers, in particular of species from the *Brassiccaceae* (the mustards) family, which rapeseed is part of. Taking into account systematic limitation of sulphur dioxide emission into the atmosphere and its very important physiological role, as well as present knowledge, which is limited mostly to winter rapeseed, study was carried out, the aim of which was to determine the effect of sulphur application method, its doses and interaction with nitrogen on grain yield size, as well as protein content and yield in the grain of spring rapeseed cultivar Star.

MATERIAL AND METHODS

Three-year long field experiment was carried out in Kazimierzewo (Mrocza commune, Kuyavian-Pomeranian Voivodeship), on degraded Phaeozems, defective wheat complex, IIIb soil valuation class. According to the international classification FAO-UNESCO, it was *Albic Luvisols.* The soil was of regulated water and air regime, neutral pH (pH_{KCl} within the range of 6.45-7.11). Richness in the assimilable forms of phosphorus and potassium was high (230-246 $mg \cdot kg^{-1}$ and 125-225 $mg \cdot kg^{-1}$, respectively), average in assimilable magnesium (35-38 $mg \cdot kg^{-1}$) and low in sulphur (19.0-19.6 $mg \cdot kg^{-1}$). Plot area was 18 m^2. Spring rapeseed cultivar Star was grown after sugar beet. In the subsequent years, sowing was carried out on April 7th, 15th, and 8th, and harvest on August 12th, 17th and 2nd. Density was marked at the proper leaf stage, by counting seedlings in a row at the length of 833 cm, which corresponds to the area of 1 m^2. Plant density in the subsequent years amounted to 100, 100, and 99 $plants \cdot m^{-2}$ on average.

The subject of the study was nitrogen fertilization at four levels (first factor, n = 4, in $kg \cdot ha^{-1}$: 0, 60, 120, and 180) and sulphur fertilization at three levels (second factor, n = 3, in $kg \cdot ha^{-1}$: 0, 20, and 60).

Two identical field experiments, differing in the method of sulphur application, were located next to each other on one plot in such a way as for the plot with no nitrogen and sulphur (control plot), situated between them, to be common for both experiments. In one experiment, sulphur was applied pre-sowing (in-soil) and in the second one top-dressing (foliar). They were set up in a split-block design in four repetitions. Plot area for harvest amounted to 18 m^2.

In the experiment with pre-sowing (in-soil) sulphur application, both doses were applied at the same time, after field smoothing. Top-dressing (foliar) application was carried out during growth at full emergence on all the plots fertilized with sulphur at the dose of 20 $kg \cdot ha^{-1}$, and on plots with the dose of 60 $kg\ S \cdot ha^{-1}$, additional 20 $kg\ S \cdot ha^{-1}$ was applied after stem formation and 20 $kg \cdot ha^{-1}$ at the beginning of flowering. The studied component was applied in the form of sodium sulphate. In addition to the described sulphur doses, all the remaining agrotechnical elements were identical for both experiments.

Nitrogen doses were applied in the amount of 60 $kg \cdot ha^{-1}$. The first dose was applied before rapeseed sowing in the form of ammonium nitrate and borated salpetere (1:1). Subsequent doses were applied exclusively in the form of ammonium nitrate, the first one 3-4 weeks between flowering, the second one at the beginning of flowering). Before winter ploughing, phosphorus-potassium-magnesium fertilization was applied in the form of multiple fertilizer, through introducing 120 kg $K_2O \cdot ha^{-1}$ (100 kg $K \cdot ha^{-1}$), 60 kg $P_2O_5 \cdot ha^{-1}$ (26 kg $P \cdot ha^{-1}$), and 48 kg $MgO \cdot ha^{-1}$ (29 kg $Mg \cdot ha^{-1}$).

Relatively favourable weather conditions for spring rapeseed growth occurred in the first study year. Systematic showers after sowing, both in April and May (21 rainy days), as well as favourable precipitation distribution in June and high precipitation in July (Table 1), were conducive to plant growth and development. In May of the second study year, precipitation sum was high, but its distribution was unfavourable. After rainy first ten days of the month, nearly four-week-long dry period occurred, which fell on the rosette-formation stage. On the other hand, abundant precipitation in late July contributed to plant lodging, particularly on the plots with the highest nitrogen fertilization. The highest temperatures in the period from April to June were present in the second study year (Table 1). In the third study year, from May to July, shortage in precipitation became visible (cumulative precipitation sum from those months amounted only to 136.0 mm, which is 72% of the many-years' average), which was accompanied by temperatures higher than the many-years' average.

Directly after plant harvest, the size of spring rapeseed grain yield was determined. In the grain, the content of total nitrogen was marked with the Kjeldahl method, and protein content ($6.25xN_{total}$) and yield were calculated.

The obtained study results were statistically processed and underwent analysis of variance according to a model compatible with the design of the experiment. Honest significant differences were estimated according to the Tukey's test at the significance level of p = 0.05.

RESULTS AND DISCUSSION

In the subsequent study years, high variability in spring rapeseed yield was found, which probably resulted from strongly diversified hydro-thermal conditions (Table 1). The most favourable weather conditions for spring rapeseed yield occurred in the first study year, in which average grain yield for both study variants was 3.34 $Mg \cdot ha^{-1}$. Second study year was characterized by unfavourable precipitation distribution, and the third year, exceptionally unfavourable for rapeseed growth, was dry. As a consequence, lower grain yield was obtained, on average 2.29 and 1.79 $Mg \cdot ha^{-1}$. Rapeseed water demands determine to the greatest extent the profitability of the cultivation of its spring form. The factor that limits the yield is insufficient precipitation amount in the spring. Spring rapeseed yield depends to a significantly higher extent than that of its winter cultivars on the sum and proper distribution of precipitation during flower bud formation, flowering, and ripening [Szot and Rudko 2005]. Lowering potential yield caused by bud and capsule dropping, as a result of retaining dry periods, may amount even to 46% [Kuchtova and Vašak 1998].

Table 1. Precipitation and temperature distribution throughout the field experiment

Year	Month				
	April	May	June	July	
	Precipitation, mm				Sum
I	28.7	80.1	85.9	110.7	305.4
II	29.5	57.8	83.0	100.6	270.9
III	83.5	45.6	53.6	36.8	219.5
Long-term average	32.0	49.0	68.0	71.0	220.0
	Temperature, °C				Mean
I	5.7	12.9	17.4	18.7	13.7
II	10.0	15.2	18.9	17.9	15.5
III	9.8	14.0	17.7	21.5	15.8
Long-term average	7.2	13.0	16.1	18.0	12.5

In every study year, positive response of spring rapeseed was found to nitrogen fertilization (Table 2). Doses of 60 and 120 $kg \cdot ha^{-1}$ on the plots on which sulphur was not used, caused statistically proven increase in grain yield in relation to the control group. The differences in the subsequent study years amounted to: 30.4% and 45.4% (first year), 32.5% and 43.0% (second year), 29.0% and 36.6% (third year), respectively. Dose of 180 $kg \cdot ha^{-1}$ in comparison with 120 $kg \cdot ha^{-1}$ did not increase significantly rapeseed grain yield. Including nitrogen fertilization in rapeseed agrotechnics is considered to be a very important yield-forming factor [Toboła and Muśnicki 2000, Lošák and Richter 2003, Wielebski 2011]. Its shortage inhibits the growth of plants, which are then poorly branched and have smaller, light green, quickly yellowing leaves. Small leaf number and area with low chlorophyll content and premature grain maturation as a result of shortened growth period make it impossible to form high yield [Toboła and Muśnicki 2000]. Insufficient nitrogen supply also caused an increase in plant susceptibility to pathogens and lowering of natural resistance to stress factors, which also, as a consequence, may contribute to lowering yield size.

Nitrogen effectiveness depends, among others, on the stand on which rapeseed is grown. In the present study, sugar beet was the forecrop for spring rapeseed, grown with no manure. Asare and Scarisbrick [1995] demonstrated that spring rapeseed on a stand after cereals responded positively to nitrogen up to the dose of 120 $kg \cdot ha^{-1}$. Toboła and Muśnicki [2000] found that in years abundant in precipitation, on a stand after frozen winter rapeseed, nitrogen fertilization of the spring cultivar was unprofitable, and in the conditions of low precipitation, after harvest, the optimum dose was 70 $kg \cdot ha^{-1}$. On the other hand, in the studies by Kotecki *et al.* [1999] rapeseed grown after sugar beet on manure did not respond with yield increase after the application of doses from 90 to 150 kg N·ha^{-1}.

Proper nitrogen metabolism and its yield-forming properties are not possible without correct plant supply with sulphur, which is a necessary element for plant and animal life and plays specific physiological functions [Ahmad *et al*. 2007, Jamal *et al*. 2010, Szulc 2010, Gaj and Klikocka 2011]. As demonstrated by the conducted research, sole sulphur application (without nitrogen) at the dose of 20 kg·ha^{-1}, regardless of its application method, in all the study years, caused a significant increase in spring rapeseed grain yield in comparison with the control group. Slightly higher effectiveness was demonstrated in the experiment with in-soil sulphur application. Respective differences in the subsequent study years for this form of application at 20 kg·ha^{-1} amounted to 32.2%, 40.4%, and 30.5%, and for the foliar variant to 29.1%, 37.1%, and 22.9%. In both variants of the experiment, dose of 60 kg S·ha^{-1} was more effective in the area of yield-forming in comparison with the control group, but in relation to the dose of 20 kg S·ha^{-1} in the first and second study year, it significantly decreased rapeseed grain yield.

There are significant discrepancies in literature regarding the effects of foliar plant additional feeding with sulphur. Foliar sulphur application turned out to be more favourable in comparison with in-soil application, in relation to grain and straw yield, as well as the formation of yield elements of blue lupine [Barczak *et al*. 2013] and grain yield of blueweed [Król and Wiśniewski 2014]. On the other hand, Barczak [2010] in the research on spring barley and white mustard, found that foliar sulphur application gave slightly lower yield-forming effects in relation to its in-soil application. Also studies by Krauze and Bowszys [2001], as well as Podleśna [2009], on winter rapeseed confirmed higher yield-forming effectiveness of the traditional sulphur fertilization method. Sulphur components found in working liquid may cause leaf burning, which limits photosynthesis and negatively affects yield size [Phillips and Mullins 2004]. Many authors [Szewczuk and Sugier 2009, Jarecki and Bobrecka-Jamro 2011] point out to higher dependency of the effects of foliar additional feeding on the weather conditions. This cause is also indicated by Podleśna [2009] when justifying the fact that foliar magnesium sulphate (VI) in winter rapeseed agrotechnics made it possible to obtain only 73% of the yield produced as a result of in-soil application of this fertilizer.

The conducted research demonstrated usually significant interaction between nitrogen and sulphur in forming the yield size of spring rapeseed grain. Its growth under the effect of 120 kg N·ha^{-1} applied without sulphur in relation to the control group amounted to, on average, 42.4%. On the other hand, the difference for the doses of 120 kg N·ha^{-1} and, respectively, 20 and 60 kg S·ha^{-1}, on average for the three study years, amounted to 60.6% and 68.2% (in the conditions of in-soil sulphur application) and 67.1% and 64.1% (as a result of its foliar application).

Insufficient amount of sulphur in the soil limits nitrogen effectiveness, and intensive fertilization with this element at sulphur shortages deepens its deficiency [Bilsborrow *et al*. 1995, Lošak *et al*. 2000]. Many studies confirm that the use of nitrogen from fertilizers and its effectiveness is higher in the conditions of optimum plant supply in sulphur [Lošak *et al*. 2000, Jamal *et al*. 2010, Wielebski 2011, Podleśna 2013].

The discussed studies were carried out on soil with low richness in the assimilable forms of sulphur (19.0-19.6 mg S-SO_4^{2-}·kg^{-1}). Literature data indicates that high yield-forming effectiveness of sulphur may be reached only in the conditions of its shortage [Malhi and Gill 2006, Wielebski 2011, Rathore *et al*. 2015]. On soils with average or high richness in sulphate sulphur (VI), many authors demonstrate lack of yield-forming effect or even yield lowering [Świderska-Ostapiak and Stankowski 2002, Hassan *et al.* 2007].

Protein content in spring rapeseed grain in all the study years was similar. On average, for the variant with in-soil sulphur fertilization, it oscillated between 216 and 219 g·kg^{-1}, and for the variant with foliar application, proper range oscillated between 206 and 219 g·kg^{-1} (Table 3). Factors applied in the studies usually significantly increased protein content in rapeseed grains. Doses of 60, 120, and 180 kg N·ha^{-1} without sulphur application caused on average its growth in relation to the control group by 1.5%, 2.5%, and 6.5%, respectively. Grain of plants with in-soil sulphur fertilization without nitrogen under the effect of 60 kg S·ha^{-1} accumulated in every study year significantly more protein than the grain of plants with no fertilization (on average by 11.0%). Foliar application of 20 kg S·ha^{-1}, in relation to the control group, to a greater extent increased protein content (on average by 3.0%) than the dose of 60 kg S·ha^{-1} (by 0.5%). Effect of sulphur fertilization on protein biosynthesis results from the fact that it is a component of important protein amino acids, such as cysteine, cystine, and methionine. It activates numerous enzymes and takes part in enzymatic and redox reactions, by stimulating photosynthetic activity and affecting the increase in the contents of protein, as well as sugar and fat in the plant [Scherer 2001, Brodowska 2004, Gaj and Klikocka 2011].

In-soil application of nitrogen and sulphur caused, on average for the three study years and for the subsequent nitrogen doses, protein content increase in the amount of 1.9%, 2.8%, and 7.6%, and in the foliar variant in the amount of 7.4%, 9.4%, and 12.9%. In the case of in-soil sulphur application, the most favourable fertilizer combination in all the study years was 180 kg N·ha^{-1} and 20 kg S·ha^{-1}. In the variant with foliar sulphur application, the highest amount of protein was found in the grain of plants fertilized with the highest doses of the studied nutrients (180 kg N·ha^{-1} and 60 kg S·ha^{-1}), but the differences in comparison with the combination of 180 kg N·ha^{-1} and 20 kg S·ha^{-1}, and 120 kg N·ha^{-1} and 60 kg S·ha^{-1} were not confirmed statistically.

Relation between good supply of the species from the *Brassicaceae* family in nitrogen and sulphur and the increase in protein content, both in their vegetative parts and grain, was confirmed, among others, by the studies of Lošak et al. [2000], Kotecki *et al.* [2001], and Brodowska [2004]. Sulphur takes part in protein biosynthesis, and at the same time, thanks to the ability to form lasting disulfides -S-S-, the element is responsible for secondary and tertiary protein structures, as well as for sustaining its conformational isomerism.

A consequence of nitrogen and sulphur effect on the yield size of spring rapeseed grain and protein content was a significant increase, in comparison with the control group, of protein yield on all the experimental plots (Table 4). Sole application of nitrogen (without sulphur) and sulphur (without nitrogen) caused the highest increase in protein yield in the second study year. For the dose of 180 kg·ha^{-1}, the difference in comparison with the control group amounted to 76.6%. It was demonstrated, similarly to Barczak [2010] in the studies on spring barley, blue lupine, and white mustard, that sulphur had the greatest effect on protein yield size in the year with less favourable weather conditions. In the first study year, which was characterized by favourable precipitation distribution in June and high precipitation in July, and also favourable thermal conditions for spring rapeseed (Table 1), sulphur effectiveness was lower.

Table 2. Yield of spring rapeseed grain, $Mg \cdot ha^{-1}$

$kg\ N \cdot ha^{-1}$ A	Years of study												Mean from years			
	I year				II year				III year							
	$kg\ S \cdot ha^{-1}$ – B			x	$kg\ S \cdot ha^{-1}$ – B			x	$kg\ S \cdot ha^{-1}$ – B			x	$kg\ S \cdot ha^{-1}$			x
	0	20	60		0	20	60		0	20	60		0	20	60	
In-soil sulphur fertiliser																
0	2.27	3.00	2.78	2.68	1.51	2.12	1.89	1.84	1.31	1.71	1.65	1.56	1.70	2.28	2.11	2.03
60	2.96	3.39	3.67	3.34	2.00	2.37	2.57	2.31	1.69	1.77	1.88	1.78	2.22	2.51	2.71	2.48
120	3.30	3.88	4.00	3.73	2.16	2.44	2.59	2.40	1.79	1.86	2.00	1.88	2.42	2.73	2.86	2.67
180	3.47	3.70	3.91	3.69	2.51	2.64	2.66	2.60	1.78	1.89	2.10	1.92	2.59	2.74	2.89	2.74
Mean	3.00	3.49	3.59	3.36	2.04	2.39	2.43	2.29	1.64	1.81	1.91	1.79	2.23	2.56	2.64	2.48
$LSD_{0.05}$	A 0.16 A × B 0.18	B 0.10 B × A 0.18			A 0.15 A × B 0.21	B 0.13 B × A 0.19			A 0.07 A × B 0.17	B 0.09 B × A 0.14			A 0.08 A × B 0.13	B 0.07 B × A 0.12		
Foliar sulphur fertiliser																
0	2.27	2.93	2.57	2.59	1.51	2.07	1.74	1.77	1.31	1.61	1.42	1.45	1.70	2.20	1.91	1.94
60	2.96	3.34	3.68	3.33	2.00	2.55	2.37	2.31	1.69	2.01	1.69	1.80	2.22	2.63	2.58	2.48
120	3.30	3.47	4.06	3.61	2.16	2.88	2.43	2.49	1.79	2.17	1.86	1.94	2.42	2.84	2.78	2.68
180	3.47	3.80	3.86	3.71	2.51	2.74	2.61	2.62	1.78	2.04	1.89	1.90	2.59	2.86	2.79	2.74
Mean	3.00	3.39	3.54	3.31	2.04	2.56	2.29	2.30	1.64	1.96	1.72	1.77	2.23	2.64	2.52	2.46
$LSD_{0.05}$	A 0.15 A × B 0.37	B 0.17 B × A 0.36			A 0.15 A × B 0.26	B 0.20 B × A 0.20			A 0.09 A × B ns	B 0.06 B × A ns			A 0.09 A × B 0.19	B 0.11 B × A 0.17		

ns – non-significant differences

Table 3. Content of total protein in spring rapeseed grain, $g \cdot kg^{-1}$

kg N·ha⁻¹	Years of study												Mean from years			
	I year				II year				III year							
	kg S·ha⁻¹ – B			x	kg S·ha⁻¹ – B			x	kg S·ha⁻¹ – B			x	kg S·ha⁻¹			x
A	0	20	60		0	20	60		0	20	60		0	20	60	
In-soil sulphur fertiliser																
0	199	210	220	210	201	211	222	211	200	213	224	212	200	211	222	211
60	202	211	228	214	204	213	229	215	204	216	230	217	203	213	229	215
120	203	213	228	215	205	216	230	217	206	217	231	218	205	215	230	217
180	209	236	228	224	214	238	230	227	215	239	231	228	213	238	230	226
Mean	203	218	226	216	206	220	228	218	206	221	229	219	205	220	228	218
$LSD_{0.05}$	A 19.0 B 15.2 A × B ns B × A ns				A 18.3 B 14.1 A × B ns B × A ns				A 19.3 B 16.6 A × B ns B × A ns				A 8.2 B 9.3 A × B 11.2 B × A 10.9			
Foliar sulphur fertiliser																
0	199	206	200	202	201	207	202	203	200	204	202	203	200	206	201	203
60	202	216	227	215	204	218	229	217	204	221	230	218	203	218	228	217
120	203	224	230	219	205	226	233	221	206	226	236	223	204	225	233	221
180	209	230	239	226	214	231	239	228	215	233	242	230	213	231	240	228
Mean	203	219	224	215	206	221	226	217	206	221	228	219	205	220	226	217
$LSD_{0.05}$	A 0.15 B 0.17 A × B 0.37 B × A 0.36				A 0.15 B 0.20 A × B 0.26 B × A 0.20				A 0.09 B 0.06 A × B ns B × A ns				A 0.09 B 0.11 A × B 0.19 B × A 0.17			

ns – non-significant differences

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Table 4. Yield of protein of spring rapeseed grain, kg·ha^{-1}

kg N·ha^{-1}	Years of study												Mean from years			
	I year				II year				III year							
	kg S·ha^{-1} – B			x	kg S·ha^{-1} – B			x	kg S·ha^{-1} – B			x	kg S·ha^{-1}			x
A	0	20	60		0	20	60		0	20	60		0	20	60	
	In-soil sulphur fertiliser															
0	452	630	612	565	304	447	420	390	262	364	370	332	339	480	467	429
60	598	715	837	717	408	505	589	501	345	382	432	386	450	534	619	535
120	670	826	912	803	443	527	596	522	369	404	462	412	494	586	657	579
180	725	873	892	830	537	612	629	593	383	452	485	440	548	646	669	621
Mean	611	761	813	729	423	523	559	502	340	401	437	393	458	562	603	541
$LSD_{0.05}$	A 60.8 B 31.2 A × B 73.1 B × A 67.4				A 45.9 B 30.7 A × B 51.4 B × A 4.90				A 32.2 B 30.3 A × B 39.8 B × A 36.6				A 28.1 B 34.3 A × B 32.1 B × A 34.7			
	Foliar sulphur fertiliser															
0	452	604	514	523	304	429	352	362	262	328	287	292	339	454	384	392
60	598	721	835	718	408	556	543	502	345	444	389	393	450	574	589	538
120	670	777	934	794	443	651	566	553	369	490	439	433	494	639	646	593
180	725	874	923	841	537	633	624	598	383	475	457	438	548	661	668	626
Mean	611	744	802	719	423	567	521	504	340	434	393	389	458	582	572	537
$LSD_{0.05}$	A 54.9 B 43.9 A × B 52.1 B × A 60.2				A 42.4 B 33.8 A × B 53.4 B × A 50.2				A 38.3 B 31.2 A × B 48.9 B × A 44.9				A 29.3 B 27.9 A × B 34.8 B × A 36.7			

In all the study years, higher increase in the yield of protein from spring rapeseed grain as a result of in-soil sulphur application was demonstrated than after its foliar application. Difference between the dose of 20 kg S·ha^{-1} and the control group, on average for the study years, for the in-soil variant amounted to 45.7%, and for the foliar – amounted to 33.2%. For the dose of 60 kg S·ha^{-1}, the disproportion was even higher. Sulphur is an element that moves from the leaves to the other plant organs with difficulties [Scherer 2001]. Studies by Schnug *et al.* [1998] demonstrated that winter rapeseed uses only up to 3% of magnesium sulphate (VI) in foliar application and 33--35% of elemental sulphur. On the other hand, Booth *et al.* [1995] talk about 2% effectiveness of sulphur uptake by leaves. The remaining part goes to the soil, where it is gradually released and uptaken by the root system.

For rapeseed plants with joint nitrogen and sulphur fertilization, significantly higher grain protein yield was found than for plants fertilized with only one of the studied elements. In the first study year, which turned out to be the most conducive to spring rapeseed yield, regardless of the sulphur application method, significantly higher protein yield was obtained as a result of the application of 120 kg N·ha^{-1} and 60 kg S·ha^{-1}. In the subsequent years (second and third), in the conditions of in-soil sulphur application, the highest protein yield was reached with the help of the combination of doses 180 kg N·ha^{-1} and 60 kg S·ha^{-1}, and in the variant with its foliar application, the most favourable turned out to be joint application of 120 kg N·ha^{-1} and 20 kg S·ha^{-1}.

CONCLUSIONS

1. Applied fertilization elements significantly determined spring rapeseed yield. For the plots fertilized solely with nitrogen, the highest rapeseed grain yield was obtained, depending on the growth season, as a result of the application of 120 or 180 kg N·ha^{-1}. In the conditions of sole sulphur application, the most effective in yield-forming was the dose of 20 kg S·ha^{-1}.
2. Regardless of the sulphur application method, its use in combination with nitrogen made it possible to obtain significantly higher grain yield than the sole use of the studied elements.
3. In every study year, in the conditions of in-soil sulphur application, the highest protein content in rapeseed grain was obtained after the application of 180 kg N·ha^{-1} and 20 kg S·ha^{-1}, and in the foliar variant of fertilization with this element, the optimum combination turned out to be the application of 180 kg N·ha^{-1} and 60 kg S·ha^{-1}.
4. Higher grain and protein yield increase of spring rapeseed was obtained as a result of in-soil sulphur application than after its foliar application.
5. Demonstrated yield-forming effects of sulphur used solely and in combination with nitrogen, as well as its positive effect on the content and yield of protein in spring rapeseed grain, justify the necessity to take sulphur into account in the agrotechnics of this species.

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SIARKA JAKO CZYNNIK KSZTAŁTUJĄCY EFEKTYWNOŚĆ AZOTU W AGROTECHNICE RZEPAKU JAREGO. CZĘŚĆ II. PLON NASION I BIAŁKA

Streszczenie. Podstawę badań stanowiły wyniki trzyletniego doświadczenia, realizowanego na czarnej ziemi zdegradowanej, klasy bonitacyjnej IIIb, o odczynie obojętnym i niskiej zasobności w przyswajalną siarkę. Uprawiano rzepak jary odmiany populacyjnej Star. Doświadczenie założono w układzie równoważnych bloków z dwoma czynnikami (n = 2): czynnikiem I rzędu były dawki azotu (w kg·ha^{-1}: 0, 60, 120, 180), czynnikiem II rzędu – dawki siarki (w kg·ha^{-1}: 0, 20, 60). Dodatkowym aspektem badań było zróżnicowanie sposobów i terminów stosowania siarki (przedsiewnie – doglebowo oraz pogłównie – dolistnie). Dla roślin nienawożonych siarką najbardziej efektywna plonotwórczo była dawka 120 kg N·ha^{-1}, a dla roślin nienawożonych azotem – 20 kg S·ha^{-1}. Aplikacja doglebowa siarki pozwoliła uzyskać wyższe przyrosty plonu nasion i białka niż jej zastosowanie dolistne. Uwzględnienie siarki w nawożeniu azotem pozwalało uzyskać istotnie wyższy plon nasion rzepaku jarego, a także zawartość i plon białka, zwłaszcza w warunkach doglebowego stosowania siarki.

Słowa kluczowe: *Brassica napus* L., nawożenie siarką, plon białka, plon nasion, współdziałanie azotu i siarki

Accepted for print – Zaakceptowano do druku: 01.09.2016

For citation – Do cytowania:

Barczak, B., Skinder, Z., Piotrowski, R. (2016). Sulphur as a factor that affects nitrogen effectiveness in spring rapeseed agrotechnics. Part II. Yield of seeds and protein. Acta Sci. Pol. Agricultura, 15(4), 3-14.