SELECTED YIELD COMPONENTS IN WHITE MUSTARD (SINAPIS ALBA) VERSUS SULFUR FERTILIZATION

WYBRANE ELEMENTY PLONOWANIA GORCZYCY BIAŁEJ (SINAPIS ALBA) A NAWOŻENIE SIARKĄ

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ABSTRACT

As shown by the research made based on the four-year field experiment, sulfur fertilization, in general, significantly differentiated the white mustard yield components. Of all the factors (sulfur application method, its form and dose), the greatest effect on the yield structure components was demonstrated for the sulfur dose. The use of 40 kg S·ha^{-1}, regardless of the form applied and the sulfur application method, resulted in significant increases in most of the characters, as compared with the control. The application of sulfur into soil showed a significantly more favorable effect on the seed weigh and number per silique and on the weight of seeds of the entire plant than the foliar application of this nutrient. The white mustard seed yield size was most correlated with the number of siliques per plant, and successively less with the thousand seed weight.

KEYWORDS: white mustard, sulfur, fertilization, yield structure components

STRESZCZENIE

Badania przeprowadzone na podstawie czteroletniego doświadczenia polowego wykazały, że nawożenie siarką na ogół istotnie różnicowało elementy plonowania gorczycy białej. Spośród badanych czynników (sposób aplikacji siarki, jej forma i dawka) największy wpływ na elementy struktury plonu wywierała dawka siarki. Zastosowanie 40 kg S·ha^{-1}, niezależnie od sposobu aplikacji i formy siarki, powodowało istotne przyrosty większości badanych cech w porównaniu z obiektem kontrolnym. Doglebowe stosowanie siarki dla każdej dawki bez względu na jej formę, wyraźnie korzystniej wpływało na masę i liczbę nasion w łuszczynie oraz na masę nasion całej rośliny niż aplikacja dolistna tego składnika. Wielkość plonu nasion gorczycy białej w największym stopniu była skorelowana z liczbą łuszczyn na roślinie, w drugiej kolejności – z masą tysiąca nasion.

SŁOWA KLUCZOWE: gorczyca biała, siarka, nawożenie, elementy struktury plonu

STRESZCZENIE ROZSZERZONE

Badania przeprowadzono w latach 2004-2007 nad gorczycą białą (*Sinapis alba* L.) z rodziny *Brassicaceae,* odmiany Barka, uprawianej w ścisłym doświadczeniu polowym, zlokalizowanym w Stacji Badawczej Uniwersytetu Technologiczno-Przyrodniczego w Wierzchucinku (53°26' N, 17°79' E). Doświadczenie polowe realizowano na glebie płowej właściwej kompleksu żytniego dobrego, klasy bonitacyjnej IIIb, o odczynie kwaśnym oraz o średniej zasobności w przyswajalne formy fosforu, potasu i magnezu, a niskiej - w siarkę. Obiekty doświadczenia rozmieszczono metodą losowanych podbloków (split-plot) w trzech powtórzeniach Celem badań była ocena wpływu nawożenia siarką na kształtowanie zależności pomiędzy plonem nasion gorczycy a najważniejszymi komponentami plonowania.

Badanymi czynnikami doświadczenia polowego były:

- czynnik I rzędu - sposób aplikacji siarki (przedsiewny doglebowy lub dolistny w fazach, w zależności od dawki: przed zawiązywaniem pąków (BBCH 45-50), na początku kwitnienia (BBCH 55-59 oraz 64-67)

- czynnik II rzędu - forma siarki (elementarna w postaci Siarkolu Extra lub jonowa w postaci siarczanu(VI) sodu),

- czynnik III rzędu - dawka siarki w kg S·ha^{-1} - (0, 20, 40 (20+20), 60 (20+20+20)).

Wykazano, że spośród badanych czynników, w największym stopniu o strukturze plonu gorczycy białej decydowała dawka siarki. Zastosowanie 40 kg S·ha^{-1}, niezależnie od sposobu aplikacji i formy siarki, powodowało istotne przyrosty w porównaniu z obiektem kontrolnym takich elementów struktury plonu jak: masa i liczba nasion w łuszczynie, masa tysiąca nasion oraz masa nasion całej rośliny. Dawka 60 kg S·ha^{-1}, niezależnie od pozostałych badanych czynników, na ogół nie powodowała istotnych zmian wielkości badanych parametrów w porównaniu z dawką 40 kg S·ha^{-1}. Odnotowano istotnie wyższą masę nasion z rośliny z obiektów nawożonych jonową formą siarki w dawkach 20 i 40 kg S·ha^{-1}, niezależnie od sposobu aplikacji, w porównaniu z obiektami, na których stosowano wyłącznie siarkę elementarną. Dla pozostałych elementów struktury plonu gorczycy białej nie wykazano istotnego wpływu formy siarki na kształtowanie ich wielkości. Wykazano jednak istotne współdziałanie tego czynnika oraz dawki siarki w kształtowaniu masy i liczby nasion w łuszczynie, a tym samym na roślinie. Znacznie większy przyrost tych strukturalnych elementów plonu w stosunku do kontroli, niezależnie od sposobu aplikacji siarki, nastąpił po jej zastosowaniu w dawce 40 kg S·ha^{-1} w formie jonowej niż pierwiastkowej. Na masę nasion w łuszczynie oraz ich masę na całej roślinie korzystniej wpływało doglebowe stosowanie siarki niż jej aplikacja dolistna. Wielkość plonu nasion gorczycy białej w największym stopniu był skorelowany z liczbą łuszczyn na roślinie, w drugiej kolejności – z masą tysiąca nasion.

INTRODUCTION

The European agriculture has been facing a new problem of sulfur deficit, getting more and more serious for the last dozen or so years, triggered by a great progress in limiting gas emissions by the industry and motor vehicles as well as changes in the assortment of mineral fertilizers [10, 17]. As forecasted by the Sulfur Institute in Washington, the global sulfur deficit, which in 2003 was evaluated as 9.6 m tones annually, in 2013 will increase up to 11.9 m tones [11]. At present in Poland most soils demonstrate the sulfur content which is insufficient for an adequate plant growth and development [14]. It is estimated that in our country more than half (53%) of the arable land shows low richness in sulfate sulfur (VI). At present the symptoms of sulfur deficit are observed in many plant species, also in cereals [4, 12, 17], but they are most visible in the species with high sulfur requirements, e.g. in white mustard [6, 13]. Its high sulfur requirements come from the fact that white mustard seeds contain secondary metabolites, namely sulfur-rich glucosinolates as well as a high content of protein the synthesis of which is limited by methionine containing it.

Although the problem of sulfur yield-forming effectiveness in agrotechnical practices of plants representing *Brassicaceae* has been, for some time already, investigated [3, 5, 9, 16,19], however, the problem of the effect of sulfur fertilization on respective yield components has not been covered by many reports so far. As for mustard, the seed size is affected by three basic yield structure components: the number of plants per area unit, the number of seeds per silique and the thousand seed weight [7, 18]. It seems that the research into the role of sulfur as a fertilization factor determining structural yield components of plants representing *Brassicaceae* can be of great importance in programming their cultivation technology.

The objective of the present research was thus to determine the effect of the supply of white mustard with sulfur on the yield structure components and on the relationship between its seed yield and the most important yield components.

MATERIALS AND METHODS

The present research was based on a field experiment under strict conditions carried out over 2004-2007 at the Experiment Station at Wierzchucinek (53°26' N, 17°79' E), of the Faculty of Agriculture, the University of Technology and Life Sciences. The experiment was set up in three reps, with the randomized split plot design, on Haplic Luvisol, produced from loam, of the heavy loamy sand composition, representing the agronomic category of light soil. It was the soil representing the good rye complex, soil valuation class IIIb; it demonstrated acid reaction and an average richness in available forms of phosphorus, potassium and magnesium (tab. 1). Interestingly the content of sulfate forms (VI) $S\text{-}SO_4^{2-}$ in the soil where the field experiment was performed qualifies it as soil of low sulfur richness [8].

Table 1 Chemical properties of soil humus horizon (0-25 cm) prior to the establishment of the field experiment in 2004.
Tabela 1 Właściwości chemiczne gleby w poziomie próchnicznym (0-25 cm) przed założeniem doświadczenia polowego w 2004 roku

pHKCl	Hh	Corg.	Nog./ Ntotal	Sog./ Stotal	N-NH4+	N-NO3-	P	K	Mg	S-SO42-
	mmol(+)·kg1		mg·kg-1				g ·kg-1			
5.3	18.55	6.33	0.71	0.259	18.9	2.06	67.4	207.4	51.2	9.4

In the field experiment the following factors were considered:

- 1st order factor – the application method of substances containing sulfur: into soil pre-sowing and foliar application

- 2nd order factor – the sulfur form: elementary sulfur in a form of Siarkol Extra and ionic sulfur in a form of sodium sulfate (VI),

- 3rd order factor – sulfur dose in kg $S·ha^{-1}$: 0, 20, 40 (20+20), 60 (20+20+20).

The plants were sprayed with the solutions of Siarkol Extra and sodium sulfate (VI) at the concentration of 3.3% at the following vegetation stages, marked compliant with the applicable EU codes using the BBCH scale [1]:

- the dose of 20 kg $S·ha^{-1}$ was applied once prior to bud-setting (BBCH: 45-50) (20 kg $S·ha^{-1}$),

- the dose of 40 kg $S·ha^{-1}$ was applied at two stages: prior to bud-setting (BBCH: 45-50) (20 kg $S·ha^{-1}$) and at the beginning of flowering (BBCH: 53-59) (20 kg $S·ha^{-1}$),

- the dose of 60 kg $S·ha^{-1}$ was applied at three stages: prior to bud-setting (BBCH: 45-50) (20 kg $S·ha^{-1}$), at the beginning of flowering (BBCH: 53-59) (20 kg $S·ha^{-1}$) and over full flowering (BBCH: 64-67) (20 kg $S·ha^{-1}$).

The experiment involved the cultivation of white mustard (*Sinapis alba* L.) representing *Brassicaceae, var.* 'Barka'. The forecrop in each research year was made up by spring barley. There was applied homogenous pre-sowing fertilization with nitrogen, phosphorus and potassium: nitrogen was applied at the dose of 70 kg $N·ha^{-1}$ in a form of ammonium nitrate, phosphorus – at the dose of 32 kg $P·ha^{-1}$ in a form of 40% triple superphosphate, and potassium – at the dose of 63 kg $K·ha^{-1}$ as 60% potassium salt. The second dose of nitrogen (70 kg $N·ha^{-1}$) was provided as top fertilization at the beginning of budding. The area of plots for harvest was 15 m^2. The harvest was made at full mustard seed maturity. The following were determined: the yield structure components: the number of yielding plants per area unit, the number of siliques and seed weight per plant, the number and weight of seeds per silique and the thousand seed weight and the seed yield.

RESULTS AND DISCUSSION

The synthesis of three-year research results demonstrated that the sulfur application method and its form, in general, did not have a significant effect on the yield structure components in white mustard (Table 2), except for seed weight per silique and their weight per plant, which were significantly higher for the treatments which involved sulfur fertilization pre-sowing into soil or as applied as foliar fertilizer. The following respective differences were recorded: 8.4% and 13.5%. A greater effect of soil sulfur application, as compared with its foliar application, must have been due to the dependence of the spraying effectiveness on weather conditions which were not always favorable. Besides, this is the way, in general, to introduce only an inconsiderable amount of nutrients as compared with the plant requirements. According to Booth et al. [2], only 2% of sulfur can be directly uptaken by leaves. Its remaining part reaches soil where it is transformed by microorganisms and gradually launched.

Of all the factors studied, the sulfur form differentiated the mustard yield structure components least considerably. In general, slightly higher values of the components researched were possible to obtain for the ionic than for the elementary form, however the differences were not significant.

The greatest effect on the mustard yield components was recorded for sulfur. There was shown a significant effect of this factor on all the yield components, except for the plant density and the number of siliques per plant. Having applied 40 kg $S \cdot ha^{-1}$, regardless of the application method and the sulfur form, there were found significant increases in the characters studied as compared with the control. As for the seed weight and the number per silique, the thousand seed weight and the seed weight per plant, the differences were 13.1%, 10.1%, 3.6% and 18.8%, respectively (Table 2). As for the thousand seed weight, already the dose of 20 kg $S \cdot ha^{-1}$ resulted in its significant increase. Interestingly, the dose of 60 kg $S \cdot ha^{-1}$, regardless of the factors studied, as compared with the dose of 40 kg $S \cdot ha^{-1}$, did not cause significant quantitative changes. A positive effect of sulfur on the yield structure components in *Brassicaceae* species was reported by numerous authors. Cyna and Grzebisz [5] demonstrated that the winter rape yield was determined by the number of siliques per main stem and increasing doses of sulfur resulted in, similarly as reported by Wielebski and Muśnicki [16] and Wielebski [15], an increase in its number. A more favorable effect of sulfur than magnesium on the thousand seed weight in white mustard as well as on the plant density is reported by Budzyński and Jankowski [3], at the same time not showing its significant effect on the number of siliques and the number of seeds per silique.

Interestingly, the present research points to a significant interaction between the second and the third factors (forms and doses) for the seed weight and the number per silique as well as for the seed weight per plant. For each of those components there was recorded a considerably higher increase, as compared with the control, regardless of the application method following the application of sulfur at the dose of 40 kg $S \cdot ha^{-1}$ in a ionic form than in the elementary form. Respective differences for the seed weight per silique were as follows: 9.7% and 17.3%, for the seed number per silique: 5.9% and 14.5%, for seed weight per plant: 12.3% and 25.5% (Table 2).

Agrotechnical factors, as well as sulfur fertilization, affects the plant yield by a direct effect on its structure components [18]. The analysis of the value of coefficients of correlation shows, similarly as reported by Jankowski and Budzyński [7] and Wielebski [15], that the dominant role in forming the white mustard seed and straw yields was played by the number of siliques per plant (Table 2). For all the sulfur levels researched, the coefficients of correlation between the characters were significant and assumed the highest values, as compared with the coefficients for the other components. The second most important factor which significantly affected the white mustard seed yield size was the thousand seed weight, which is seen from only slightly lower values of respective coefficients of correlation. Interestingly, however, the higher the sulfur doses, the lower the values of the coefficients of correlation between the seed yield and the thousand seed yield, which suggests that an enhanced sulfur supply weakens that dependence.

The present research performed, as exposed to sulfur deficit in soil, showed, irrespective of its application method and form, a significance of that nutrient for the mustard seed yield structure components. One can, therefore, claim that sulfur, next to NPK and Mg, should be an indispensable component of mineral fertilization of *Brassicaceae* plant species and, as such, it should be considered in agrotechnical practices.

CONCLUSIONS

Of all the factors studied, the white mustard yield structure components were mostly determined by the sulfur dose. As compared with the control, the application of 40 kg $S \cdot ha^{-1}$ resulted in significant increases in most of the characters studied.

The seed weight per silique and their weight per plant were enhanced by sulfur application into soil more than by its foliar application.

The seed weight and number per silique and the seed weight per plant were demonstrated to increase much more considerably, as compared with the control, following the application of sulfur at the dose of 40 kg $S \cdot ha^{-1}$ in a ionic form than the elementary form.

The white mustard seed yield size was most correlated with the number of siliques per plant, and then, respectively, with the thousand seed weight.

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Table 2. Yield structure components in white mustard – mean for 2004-07 years
Tabela 2. Elementy struktury plonu gorczycy białej – średnie z lat 2004-07

Dose Dawka kg S·ha⁻¹	Application method-Sposób aplikacji						Form-Forma		
	Soil fertiliser Doglebowe nawożenie			Foliar fertiliser Dolistne nawożenie			S elementary S elementarna	Na_2SO_4	Mean Średnio
	S elementary S elementarna	Na_2SO_4	Mean Średnio	S elementary S elementarna	Na_2SO_4	Mean Średnio			
The number of yielding plants per area unit-Liczba roślin plonujących [szt./m2]									
0	98,6	102,4	100,5	106,5	107,5	107,0	101,9	104,9	103,9
20	107,1	99,2	103,5	104,9	109,0	106,7	105,8	104,4	105,1
40	99,6	81,7	92,1	103,0	115,3	108,9	101,3	95,7	98,8
60	95,2	101,5	99,6	104,3	111,3	107,9	99,6	107,5	103,6
x	99,6	95,2	98,4	104,6	110,8	107,0	102,2	103,0	103,1
LSD-NIR: Icz.-n.s./n.i. IIcz.-n.s./n.i. IIIcz.-n.s./n.i. IxII –n.s./n.i. IIxI-n.s./n.i.. IxIII-n.s./n.i. IIxIII-n.s./n.i. IIIxI-n.s./n.i. IxIIxIII-n.s./n.i.									
The number of siliques per plant-Liczba łuszczyn na roślinie									
0	66,4	64,4	65,4	64,1	63,4	63,8	65,3	63,9	64,6
20	63,6	65,6	64,6	64,6	65,9	65,2	64,1	65,7	64,9
40	68,2	71,3	69,7	66,6	64,3	65,4	67,4	67,8	67,6
60	71,0	66,6	68,8	64,7	64,8	64,8	67,8	65,7	66,8
x	67,3	66,9	67,1	65,0	64,6	64,8	66,1	65,8	66,0
LSD-NIR: Icz.-n.s./n.i. IIcz.-n.s./n.i. IIIcz.-n.s./n.i. IxII-n.s./n.i. IIxI- n.s./n.i. IxIII-n.s./n.i. IIxIII-n.s./n.i. IxIIxIII-n.s./n.i.									
The number of seeds per silique-Liczba nasion w łuszczynie									
0	4,34	4,22	4,28	4,21	4,20	4,21	4,27	4,21	4,24
20	4,34	4,42	4,38	4,14	4,35	4,25	4,24	4,38	4,31
40	4,55	5,01	4,78	4,49	4,64	4,56	4,52	4,82	4,67
60	4,74	4,73	4,74	4,65	4,51	4,58	4,70	4,62	4,66
x	4,49	4,59	4,54	4,37	4,42	4,40	4,43	4,51	4,47
LSD-NIR: Icz.- n.s./n.i IIcz.- n.s./n.i IIIcz.-0,209 IxII – n.s./n.i. IIxI- n.s./n.i. IxIII-n.s./ n.i. IIxIII-0,146 IIIxI-0,181 IxIIxIII-n.s./n.i.									
The weight of seeds per silique-Masa nasion w łuszczynie [mg]									
0	32,9	32,4	32,7	31,4	31,3	31,3	32,1	31,8	32,0
20	33,2	36,4	37,8	31,3	32,4	31,9	32,3	34,4	33,4
40	35,2	40,8	38,0	35,1	33,8	34,4	35,2	37,3	36,2
60	37,8	39,1	38,5	36,3	34,2	35,2	37,0	36,7	36,9
x	34,8	37,2	36,0	33,6	32,9	33,2	34,2	35,1	34,6
LSD-NIR: Icz.-n.s./n.i. IIcz.-n.s./n.i. IIIcz.-1,82 IxII-3,72 IIxI-1,74 IxIII-n.s./n.i. IIxIII-n.s./n.i. IIIxII-n.s./n.i. IxIIxIII- n.s./n.i.									
The seed weight per plant-Masa nasion z rośliny [g]									
0	2,20	2,09	2,14	2,01	1,99	2,00	2,11	2,04	2,07
20	2,12	2,39	2,26	2,04	2,12	2,08	2,08	2,26	2,17
40	2,40	2,95	2,67	2,34	2,16	2,25	2,37	2,56	2,46
60	2,72	2,61	2,66	2,35	2,21	2,28	2,53	2,41	2,47
x	2,36	2,51	2,44	2,19	2,12	2,15	2,27	2,32	2,29
LSD-NIR: Icz.-n.s./n.i. IIcz.-0,041 IIIcz.-0,238 IxII-0,431 IIxI-0,138 IxIII-n.s./n.i. IIxIII-0,114 IIIxII-0,163 IxIIxIII- n.s./n.i									
The thousand seed weight - Masa tysiąca nasion [g]									
0	7,59	7,66	7,62	7,45	7,38	7,42	7,52	7,52	7,52
20	7,66	8,25	7,96	7,61	7,43	7,52	7,63	7,84	7,74
40	7,75	8,15	7,95	7,84	7,44	7,64	7,79	7,79	7,79
60	7,96	8,26	8,11	7,80	7,65	7,72	7,88	7,95	7,92
x	7,74	8,08	7,91	7,67	7,47	7,57	7,71	7,78	7,74

Table 3. Value of correlation coefficients between white mustard seeds and straw yield and yield components depending on sulphur fertilization
Tabela 3. Wartości współczynników korelacji między plonem nasion i słomy a elementami struktury plonu gorczycy białej w zależności od nawożenia siarką

kg S·ha-1	Variable Zmienna	1000 seeds weight Masa 1000 nasion (1)	The seeds weight per plant Masa nasion w łuszczynie (2)	The seeds weight per plant Masa nasion z rośliny (3)	The number of siliques per plant Liczba łuszczyn z rośliny (4)	Seeds yield Plon nasion (5)	Straw yield Plon słomy (6)
0	1	0,490	-0,390	-0,218	0,737	0,682	-0,939
	2		-0,226	-0,245	0,560	0,764	-0,501
	3			0,977	-0,882	-0,782	0,581
	4				-0,810	-0,747	0,541
	5					0,959	-0,920
	6						-0,848
20	1	-0,396	-0,813	-0,838	0,131	-0,052	-0,634
	2		0,020	-0,053	0,322	0,395	-0,140
	3			0,987	-0,674	-0,529	0,965
	4				-0,597	-0,446	0,935
	5					0,820	-0,840
	6						-0,729
40	1	-0,819	-0,322	-0,308	-0,769	-0,860	0,666
	2		0,055	0,178	0,781	0,652	-0,771
	3			0,970	-0,358	-0,129	0,482
	4				0,970	-0,198	0,443
	5					0,929	-0,985
	6						-0,856
60	1	0,266	0,819	0,986	-0,595	-0,665	-0,203
	2		0,230	0,141	0,613	0,543	-0,998
	3			0,743	-0,523	-0,531	-0,171
	4				-0,678	0,750	-0,079
	5					0,992	-0,663
	6						-0,596