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Economic efficiency of the production of spring wheat fertilized with sulfur against the background of various nitrogen doses

[1]Olimpia Klikocka-Wiśniewska, [2]Elżbieta Harasim

[1]District Sanitary and Epidemiological Station in Gdynia, Food and Nutrition Safety Section
Starowiejska 50, 81-356 Gdynia, POLAND
[2]Department of Herbology and Plant Cultivation Techniques, University of Life Sciences,
Akademicka 13. 20-950 Lublin, POLAND

Abstract. The research was carried out on a farm located in Malice (Werbkowice municipality), in the years 2014–2016. The aim of the study was to evaluate the profitability and marginal economic efficiency of sulfur fertilization of spring wheat at various levels of nitrogen fertilization. Production value, direct costs and production profitability were assessed, as well as the marginal economic efficiency. On average, the highest grain yield was achieved on the object fertilized with nitrogen at a dose of 150 kg $\cdot$ ha^{-1} and sulfur in the amount of 40 kg S ha^{-1}. The highest value of direct surplus and, at the same time, the highest profitability of production was obtained after nitrogen application in the dose of 100 kg N ha^{-1}. Increasing the nitrogen dose from 50 to 100 kg ha^{-1} resulted in a significant increase in the grain yield and the achievement of the most favourable marginal economic efficiency index. Among the objects fertilized with nitrogen, the most advantageous in terms of production profitability and marginal economic efficiency was the use of this element in the dose of 100 kg N ha^{-1}. The use of sulfur in the fertilization of spring wheat in the dose of 40 kg S ha^{-1} slightly improved the fertilization efficiency in the objects with 50 and 150 kg ha^{-1}. Among the objects fertilized with nitrogen, the most advantageous in terms of production profitability and marginal economic efficiency was the use of this element in the dose of 100 kg N ha^{-1}.

Keywords: spring wheat, nitrogen and sulfur fertilization, economic efficiency

INTRODUCTION

In agriculture, an important issue is defining the level of production intensification, i.e., determining the optimal effect of applying a particular factor. Production intensification leads to increased labor and production goods outlays (Klepacki, 1997). Thus, the optimal relationship between the applied input and its production or economic effect is sought. Therefore, to optimize inputs, an assessment of both the profitability of production and its marginal efficiency can be carried out (Harasim, 2012; Harasim, Madej, 2018). The ratio of the value of production to the cost of production expresses the profitability of production. On the other hand, input efficiency is measured by the proportion of the incremental value of output to the amount of total input incurred to acquire it.

Marginal economic accounting in crop production is most often adopted to evaluate the level of mineral fertilization and production technology in order to determine the rational level of the studied factor (Harasim, 2012; Harasim, Krasowicz, 1996; Harasim, Madej 2018; Klepacki, 1997; Krasowicz, 1991; Płudowski, 1977). In practice, determining the limits of intensification of fertilization or production technology is of great importance. According to Krasowicz (2009), economic evaluation plays an essential role in making decisions related to choosing a given element (fertilization level or crop production technology on the farm).

Soil sulfur deficiency is becoming a severe concern for crop production. The shortage of component as mentioned above for crops (rape, cereals) was observed in northern areas of Germany (Schnug, Haneklaus, 1998), northern and eastern England (Zhao et al., 1997), Denmark (Eriksen 1997) and other countries (Bloom, 1998). In Poland, symptoms of sulfur deficit in rape cultivation were found by Grzebisz and Fotyma (1996), confirmed by the phenomenon of decreasing average sulfur content in Polish soils between 1995 and 2015 (Siebielec et al., 2017). The least plant-available sulfur is present in soils developed from light loamy sands, poorly loamy sands, and soils formed from strong loamy sands and sandy loams (Lipiński et al., 2003). Nitrogen and sulfur are essential protein components, and the proper N:S ratio significantly affects plant yield and grain quality. Thus, the interaction between sulfur and the most yielding nitrogen is crucial (Boreczek, 2001; Fotyma, 2003). However, the issue of the role and sulfur scarcity in plant fertilization is of interest

Corresponding author:
Elżbieta Harasim
e-mail: elzbieta.harasim@up.lublin.pl
phone: +48 81 4456820

to researchers; there are more and more opinions about the desirability of fertilizing with sulfur under high nitrogen application rates (Boreczek, 2001; Podleśna, 2013; Szulc, 2008).

Studies on the fertilization of crops with sulfur most often include aspects of crop yield and quality and the balance of the above element under different levels of nitrogen fertilization (Barczak, 2010; Boreczek, 2001; Podleśna 2013). However, there is a lack of studies on sulfur application's profitability and economic (marginal) efficiency, particularly under intensive nitrogen fertilization.

The study aimed to determine the optimal level of spring wheat fertilization with nitrogen under conditions of sulfur application and without this compound.

MATERIALS AND METHODS

The research was carried out on a farm located in Malice (50°42'N, 23°15'E), Werbkowice municipality (Lubelskie voivodeship), in the years 2014–2016. The field experiment was conducted on medium brown soil, formed from medium sandy loam classified as good rye complex, with a slightly acid reaction. Spring wheat has high water (especially in June) and thermal requirements and demands fertile soils – wheat and very good rye complexes. (Jończyk, Kuś, 2011). The results of soil chemical composition measurements before the establishment of the experiment in individual years were similar (Table 1). It provides evidence of a slight variation in soil quality. The experimental object was spring wheat of Kandela cultivar, grown in a stand after potato fertilized with cattle farmyard manure at 30 t ha^{-1}. The experiment was established using the split-plot method in 4 replications. The plot area was 30 m^2 at the beginning and 20 m^2 for harvesting. Spring wheat grain sowing was performed between 25 March and 5 April, depending on the year, at 200 kg ha^{-1}, i.e., 500 grains m^{-2}.

Table 1. Soil properties before to setting up the field experiment.

Specification	Unit	Year of research		
		2014	2015	2016
pH in 0.01 M $CaCl_2$	-	5.7	5.6	5.8
Total C	g kg^{-1}	9.2	8.9	8.5
Total N	g kg^{-1}	0.9	0.9	0.8
N mineral	kg ha^{-1}	70.8	69.4	67.9
Available P	mg kg^{-1}	53.5	55.5	50.3
Available K	mg kg^{-1}	87.6	86.2	80.6
Available Mg	mg kg^{-1}	35.8	34.7	35.3
Total S	mg kg^{-1}	98.8	89.3	82.0
Available S-SO_4	mg kg^{-1}	5.4	13.6	12.3

In the study, two factors were considered as follows:

I. nitrogen fertilization: 0, 50, 100 and 150 kg N ha^{-1}.

II. sulfur fertilization: 0 and 40 kg N ha^{-1}.

Plant protection consisted of controlling weeds, stem base diseases, leaf and ear diseases, and pests. Moreover, the plants were prevented from lodging. In total, five chemical plant protection treatments were performed according to the recommendations of Institute of Plant Protection – National Research Institute (IOR-PIB) in Poznań. Before wheat sowing (except for objects without N and S), the following treatments were applied: nitrogen at 50 kg ha^{-1} in the form of ammonium nitrate and sulfur at 40 kg ha^{-1} in the form of kieserite. The dose of 100 kg N ha^{-1} was treated at two dates (before sowing and with top dressing at the stage of stem shooting – BBCH 30–31), while the dose of 150 kg N ha^{-1} was applied at three terms (before sowing, with top dressing at the stage of stem shooting – BBCH 30-31 and with top dressing at the stage between mid and full earing – BBCH 55-59) at 50 kg N ha^{-1} each. Besides, the whole experimental area was fertilized presowing with phosphorus at a rate of 90 kg P_2O_5 ha^{-1} and potassium – 100 kg K_2O ha^{-1}.

During the study period, the growing seasons varied in terms of individual agrometeorological indices (Table 2). However, the growing seasons were very similar in terms of mean daily air temperature. Based on the Sielianinov hydrothermal index, combining thermal and precipitation elements, the respective seasons can be assessed the following: 2014 was quite wet (especially in May and July), 2015 – dry/relatively dry, and 2016 – quite humid and near the optimum.

Table 2. Characteristics of agrometeorological conditions during the growing season.

Index	Month				
	IV	V	VI	VII	IV–VII
			2014		
Total rainfall [mm]	32.9	141.6	91.3	146.1	411.9
Mean air temperature [°C]	10.3	14.2	16.3	20.7	15.4
Hydrothermic index	1.06	3.19	1.87	2.27	2.10
			2015		
Total rainfall [mm]	26.7	91.1	36.2	60.4	214.4
Mean air temperature [°C]	8.6	13.6	17.7	21.1	15.3
Hydrothermic index	1.03	2.16	0.68	0.92	1.20
			2016		
Total rainfall [mm]	51.7	49.9	116.8	115.3	333.7
Mean air temperature [°C]	10.2	14.3	18.9	19.7	15.8
Hydrothermic index	1.70	1.12	2.06	1.88	1.69

Grain yields were evaluated in terms of direct profitability and the marginal efficiency of production. The assessment of production profitability was carried out according to the methodology of Institute of Agricultural and Food Economics – National Research Institute (IERiGŻ-PIB), taking into account the category of direct surplus (Augustyńska, 2018; Skarżyńska et al., 2017). Direct surplus is the difference between the value of production (yield) and direct (material) production costs. The direct surplus allows a simplified economic evaluation of the production of agricultural goods, depending on the fluctuation (level) of yields, variations in agricultural products, and means prices (Harasim, 2012). Direct costs included the value of consumed materials, i.e., grain (seed), mineral fertilizers, and plant protection products. In addition, the immediate profitability index (without subsidies) was calculated. The direct profitability index expresses the relation of production value to the direct costs incurred. On the other hand, the marginal effectiveness index determines the limits of intensification of inputs (fertilization level).

The marginal efficiency of production (Ee) was calculated according to the formula:

$$Ee = \frac{W_N - W_{N-1}}{K_N - K_{N-1}} = \frac{\Delta W}{\Delta K}$$

W – grain yield value (PLN ha^{-1})
K – the cost of nitrogen fertilizer (PLN ha^{-1})
ΔW – the increase in grain yield value (PLN ha^{-1})
ΔK – the cost increment of nitrogen fertilizer (PLN ha^{-1})
Marks in subscript:
N – nitrogen application rate, the efficiency of which is calculated
N-1 – nitrogen application rate, against which the change in efficiency is calculated (including zero application rate)

The marginal efficiency expresses the ratio of yield value increment to the increase of fertilization cost, determining the optimal level of mineral fertilization (Harasim, 2012; Klepacki, 1997).

In the calculations, purchase prices of inputs (materials) and grain sales from 2016 were taken into consideration, the sources of which were studies by CSO (Statistical Yearbook ..., 2017), IERiGŻ-PIB (Zalewski, 2017), and LODR (Jakimiak, 2016).

RESULTS

Grain yield

The analysis of variance revealed significant variation in grain yield depending on the amount of nitrogen and sulfur fertilization (Table 3). No fertilization interaction between nitrogen and sulfur was found. However, grain yields on both objects without sulfur and those fertilized with S in 40 kg S ha^{-1} did not differ significantly. Nitrogen fertilization in each variant of sulfur application (40 kg S ha^{-1}) had no significant effect on grain yield. There was only a tendency to increase grain yield under the influence of all nitrogen doses, irrespective of sulfur application (Table 2). The average grain yield was similar in 2014 – 6.21 and 2015 – 6.13 t ha^{-1}, and significantly higher under optimal weather conditions in 2016 – 6.44 t ha^{-1} (Table 2).

Profitability of production

Tables 4 and 5 present the value, direct costs, and direct profitability of spring wheat production in two approaches – depending on the nitrogen fertilization level and the version with nitrogen and sulfur fertilization. On average, the highest grain yield was obtained on the object fertilized with nitrogen in the dose of 150 kg N ha^{-1} with sulfur (Table 3). There was a slight increase in grain yield revealed with an increasing level of nitrogen fertilization. The value of production (grain yield × marketing price) was similar. The costs of applied mineral fertilizers determined the direct production costs because the costs of grain (seed) and plant protection chemicals were the same for all treatments. The highest direct costs were characteristic for the object fertilized with the highest dose of nitrogen – 150 kg ha^{-1}, whereas the highest value of direct surplus was obtained under conditions of spring wheat fertilization with nitrogen in the dose of 100 kg N ha^{-1}. The lowest direct costs of treatment without nitrogen resulted in the

Table 3. Grain yield (t·ha^{-1}) of spring wheat (mean of years 2014–2016).

N dose [kg ha^{-1}] (N)	S dose [kg ha^{-1}] (S)		Mean
	0	40	
0	5.57 a	5.66 a	5.61 d
50	5.67 a	5.88 a	5.77 c
100	6.60 a	6.80 a	6.70 b
150	6.84 a	7.06 a	6.95 a
Mean	6.17 B	6.35 A	
Years (L)	2014	2015	2016
Grain yield [t·ha^{-1}]	6.21 A	6.13 A	6.44 B
LSD(0.05): N = 0.097; S = 0.069; L = 0.084; N × S = n.s.; N × L = 0.169. S × L = n.s.			

Values with different letters within the same column or row are significantly different
n.s – not significant

Table 4. Value, direct costs and profitability of spring wheat grain production depending on the level of nitrogen fertilization (averaged over 2014–2016).

Specification	N dose [kg ha^{-1}]			
	0	50	100	150
Grain yield [t ha^{-1}]	5.57	5.67	6.60	6.84
Sell price [PLN t^{-1}]	650	650	650	650
Production value [PLN ha^{-1}]	3621	3686	4290	4446
Direct costs [PLN ha^{-1}] including:	1422	1602	1782	1962
grains	380	380	380	380
mineral fertilizers	602	782	962	1142
plant protection products	440	440	440	440
Direct surplus [PLN ha^{-1}]	2199	2084	2508	2484
Direct profitability index [%]	255	230	241	227

highest immediate profitability index. Among the objects fertilized with nitrogen, the highest production profitability was obtained after applying the nitrogen dose of 100 kg N ha^{-1} (Table 4).

Nitrogen fertilization under conditions of sulfur application at the rate of 40 kg S ha^{-1} favorably affected the yield of spring wheat, although the increase in grain yield was relatively poor (Table 5). Similarly, as in the case of nitrogen application without sulfur, the relations of production values and direct costs between the objects studied were analogous. Only the cost of mineral fertilizers was higher due to sulfur application. The direct surplus in treatments fertilized with nitrogen was slightly higher than in conditions without sulfur application (Tables 4 and 5). The direct profitability index was very similar to those found under nitrogen-only fertilization conditions. Thus, sulfur application in spring wheat fertilization did not give the expected productive and economic effects. Sulfur fertilization likely affected the quality of the obtained grain yield.

Table 5. Value, direct costs and profitability of spring wheat grain production depending on the level of nitrogen fertilization and the use of sulfur (averaged over 2014–2016).

Specification	N and S dose [kg ha^{-1}]			
	0 N+40 S	50 N+40 S	100 N+40 S	150 N+40 S
Grain yield [t ha^{-1}]	5.66	5.88	6.80	7.06
Sell price [PLN t^{-1}]	650	650	650	650
Production value [PLN ha^{-1}]	3679	3822	4420	4589
Direct costs [PLN ha^{-1}] including:	1485	1665	1845	2025
grains	380	380	380	380
mineral fertilizers	665	845	1025	1205
plant protection products	440	440	440	440
Direct surplus [PLN ha^{-1}]	2194	2157	2575	2564
Direct profitability index [%]	248	230	240	227

Table 6. Marginal efficiency of spring wheat grain production depending on the level of nitrogen fertilization.

Specification	N dose [kg ha^{-1}]			
	0	50	100	150
Grain yield [t ha^{-1}]	5.57	5.67	6.60	6.84
Yield grain [kg ha^{-1}]	-	100	930	240
Increase in fertilization [kg N]	-	50	50	50
Yield increment value [PLN ha^{-1}]	-	65.0	604.5	156.0
The cost of increasing N fertilization [PLN ha^{-1}]	-	180	180	180
Marginal efficiency [PLN PLN]	-	0.36	3.36	0.87

Table 7. Marginal efficiency of spring wheat grain production depending on the level of nitrogen fertilization and the use of sulfur.

Specification	N and S dose [kg ha^{-1}]			
	0 N +40 S	50 N +40 S	100 N +40 S	150 N +40 S
Grain yield [t ha^{-1}]	5.66	5.88	6.80	7.06
Yield grain [kg ha^{-1}]	-	220	920	260
Increase in fertilization [kg N]	-	50	50	50
Yield increment value [PLN ha^{-1}]	-	143.0	598.0	169.0
The cost of increasing N fertilization [PLN ha^{-1}]	-	180	180	180
Marginal efficiency [PLN PLN]	-	0.79	3.32	0.94

Economic efficiency

The optimal level of spring wheat fertilization with nitrogen under the cultivation conditions without sulfur applying and with S treatment at 40 kg S ha^{-1} was calculated using the marginal economic efficiency index (Tables 6 and 7). The index mentioned above expresses the ratio of the grain yield value increase to the rise in the component cost. Among the evaluated effects of nitrogen fertilization without sulfur application, the nitrogen dose of 50 kg N ha^{-1} resulted in a slight enlargement in grain yield and value compared to the outcomes obtained in the control plot without nitrogen fertilization (Table 5). Extending the dose from 50 to 100 N ha^{-1} led to a significant increase in grain yield and, as a result, to the most favorable marginal economic efficiency index (3.36). For 1 PLN of the nitrogen applied cost accounted for 3.36 PLN of the yield value increment. On the other hand, an increase in the nitrogen rate from 100 to 150 kg ha^{-1} significantly reduced the effectiveness of fertilization since as the nitrogen rate increased, the economic efficiency of this factor decreased (Table 6).

Sulfur fertilization at a rate of 40 kg S ha^{-1} improved the efficiency of spring wheat fertilization with nitrogen applied at 50 and 150 kg N ha^{-1}; however, it was not economically justified (index <1.0); (Tables 6 and 7). On the treatment with 100 kg N ha^{-1}, the economic efficiency index remained at comparable level as under conditions without sulfur (3.32 and 3.36 PLN PLN^{-1}). For both nitrogen fertilization variants (with and without sulfur), only the dose of 100 kg N ha^{-1} appeared to be the most effective and financially reasonable (Tables 6 and 7).

DISCUSSION

Fertilization of spring wheat with nitrogen and sulfur is a subject of growing interest of researchers (Barczak, 2010; Boreczek, 2001; Fotyma, 2003; Klikocka, Cybulska 2020; Podleśna, Cacak-Pietrzak, 2006; Szulc, 2008). Most often, the highest grain yields were reached after application of 120–160 kg N ha^{-1}. The research conducted by Podleśna and Cacak-Pietrzak (2006) revealed that sulfur applied at each nitrogen fertilization level led to a slight (on average by 0.3 t ha^{-1}) increase in spring wheat grain yield and had a favorable effect on the baking properties of dough. Beneficial modification of grain milling and baking properties was noticed, particularly under low soil sulfur content. In own research, the increase in grain yield under sulfur fertilization averaged to 0.18 t ha^{-1} (Table 3). Higher grain yields could have been attributed to spring wheat's more effective mineral nitrogen consumption (Fotyma, 2003).

Nitrogen fertilization combined with sulfur had a beneficial effect on the yield of spring wheat (Klikocka, Cybulska, 2020; Podleśna, Cacak-Pietrzak, 2006), but increasing N level resulted in lower productivity of 1 kg N and utilization of mentioned nutrient (Fotyma, 1997; Gąsiorowska et al., 2006). According to Boreczek (2001), Fotyma (2003), and Podleśna (2009), sulfur fertilization enhances nitrogen utilization by crops. While, under conditions of soil sulfur deficiency, the nitrogen yield-forming efficiency is reduced, and intensification of fertilization with N inhibits nitrogen uptake by plants (Barczak, 2010). However, Boreczek (2000) research in a 4-field crop rotation does not confirm the yield-forming effect of sulfur fertilization.

In general, spring wheat grain yields increased with the intensity of nitrogen fertilization. Depending on habitat conditions and the range of tested nitrogen doses, the highest grain yields were obtained after applying high N doses. Different maximum nitrogen rates for spring wheat were assumed in the study: 100 (Fotyma, 1997), 120 (Klikocka, Cybulska, 2020; Wróbel, 1999), 125 (Boreczek, 2001; Fotyma, 2003; Podleśna, Cacak-Pietrzak, 2006), 160 (Gąsiorowska et al., 2006) and 180 kg N ha^{-1} (Sułek, Podolska, 2008), while sulphur was applied at: 40 (Boreczek, 2001; Fotyma, 2003), 50 (Klikocka, Cybulska, 2020; Podleśna, Cacak-Pietrzak, 2006) and 60 kg S ha^{-1} (Fotyma, 2003). In our study, the highest nitrogen dose amounted to 150 kg N ha^{-1}, whereas a lower dose – 100 kg N ha^{-1} seemed economically justified. The results of other authors' research do not include an economic evaluation of nitrogen doses applied with sulfur in spring wheat cultivation.

The scarcity of publications on production profitability and economic efficiency of spring wheat fertilization with nitrogen and sulfur complicates direct confrontation of own research results with literature data.

CONCLUSIONS

1. Spring wheat grain yield depended significantly on the nitrogen dose and sulfur application. A rise in grain yield accompanied an increase in the nitrogen dose.
2. Among the objects fertilized with nitrogen, the most advantageous, in terms of production profitability and economic efficiency, was the N application at the rate of 100 kg ha^{-1}.
3. Fertilization with sulfur contributed to higher economic efficiency of 50 and 150 kg ha^{-1} nitrogen doses.
4. Sulfur fertilization of spring wheat may be justified by improving grain quality parameters crucial for its suitability for consumption purposes.

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Author	ORCID
Elżbieta Harasim	0000-0002-7893-7958

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