Journal of Crop Nutrition Science
ISSN: 2423-7353 (Print) 2538-2470 (Online)
Vol. 9, No. 4, 2023
https://jcns.ahvaz.iau.ir/ OPEN ACCESS

Response of Crop Production of Wheat Cultivars to Combined Effect of Sulfur and Sulfofertilizer1

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RESEARCH ARTICLE

ARTICLE INFO.
Received Date: *2 Sep. 2023*
Received in revised form: *1 Oct. 2023*
Accepted Date: *4 Nov. 2023*
Available online: *6 Nov. 2023*

To Cite This Article:
Seyedeh Kobra Hatamipor. Response of Crop Production of Wheat Cultivars to Combined Effect of Sulfur and Sulfofertilizer1. ***J. Crop. Nutr. Sci.,*** 9(4): 58-68, 2023.

ABSTRACT

BACKGROUND: Long-term use of fertilizers reduces crop yields. This decrease is due to the acidification of the soil, the reduction of biological activity of the soil and the inappropriate physical properties of the soil. So nutrient management plays an important role for obtaining economic and sustainable yields and increase crop productivity.

OBJECTIVES: This study was carried out to evaluate combined effect of Sulfur and Sulfofertilizer1 of wheat cultivars on seed yield and its components.

METHODS: Current research was done by using a split-plot experiment within randomized complete blocks (RCBD) design with three replications. The experimental treatments consisted of three levels of sulfur fertilizer (control, no consumption; 270g of sulfur fertilizer; and 270g of sulfur fertilizer + 6g of Sulfofertilizer1, biofertilizer) and three wheat cultivars (Mehregan, Chamran 2 and Khalil), which were assigned to the main and sub plots, respectively.

RESULT: Result of analysis of variance revealed effect of different level of fertilizer (instead number of seed per spike at 5%), cultivar (instead number of seed per spike at 5%) and interaction effect of treatments on all studied characteristics (instead number of seed per spike and harvest index was not significant) was significant at 1% probability level. Assessment mean comparison result of different level of fertilizer indicated the maximum amount of grain yield (464.73 $gr.m^{-2}$), number of spike per m^{-2} (416.5), number of seed per spike (40.1) , 1000-seed weight (43.11 gr), biologic yield (1400.8 $gr.m^{-2}$) harvest index (33.17%) were noted for Sulfur + Sulfurfertilizer1 and lowest amount of mentioned traits belonged to control treatment. Compare different level of cultivar showed Khalil was superior to another one and had the highest amount of measured traits.

CONCLUSION: Generally result of studied research revealed using Sulfur + Sulfurfertilizer1 by Khalil cultivar had the highest amount of studied characteristics and it can be advice to farmers.

KEYWORDS: *Fertilizer, Genotype, Harvest index, Nutrition, Seed weight.*

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1. BACKGROUND

Management of balanced fertilizer application according to plant growth requirements and soil testing is one of the strategies for improving the quality and quantity of agricultural products (Singh *et al*., 2015). Chemical fertilizers are significant to succor nutrients in soil. Heavy doses of chemical fertilizers and pesticides are commonly used in order to enhance corn yields. Excessive nitrogen content in soil causes an inappropriate high uptake of this macronutrient by plants, which may result in inadequate growth and development due to the accumulation of nitrogen compounds in plant tissue (Szulc, 2013). Applying ecological principles and concepts, including the management and use of soil microorganisms and the relationships between them, can help us produce food more sustainably. Many researchers believe that one of the basic pillars of sustainable agriculture is the use of biofertilizers in agricultural ecosystems with the aim of eliminating or reducing the use of chemical inputs. The researchers said that the use of growth-promoting bacteria, while reducing the use and increasing the efficiency of chemical fertilizers, increased plant growth by increasing the uptake of nitrogen and phosphorus (Arruda *et al*., 2013). Excessive use of chemical fertilizers destroys the physical and chemical properties of the soil (Kalhapure *et al*., 2013). Research has suggested that integrated nutrient management strategies involving chemical fertilizers and bio-fertilizers enhance the sustainability of crop production. Integrated plant nutrient management is the combined use of mineral fertilizers with organic resources such as cattle manures, crop residues, urban/rural wastes, composts, green manures and bio-fertilizers (Kemal and Abera, 2015). Nadim *et al*. (2021) by examining the effect of using sulfur element and sulfur oxidizing bacteria (applied) stated that the application of one-half of the recommended amount of phosphorus + nitrogen and potassium fertilizer plus sulfur oxidizing bacteria has the greatest effect in increasing studied traits such as seed yield, number of tillers and plant height. Hossein *et al*. (2022) by investigating the effect of absorption and distribution of sulfur on winter wheat crop production reported the application of sulfur fertilizer led to increase seed yield, 1000-seed weight, plant height and protein yield. Azimi *et al*. (2013a) found that application of Super nitroplass bio-fertilizer with Phosphate barvar2 treatment has the highest seed yield (7.6 $t.ha^{-1}$) and non-application of bio-fertilizers treatment has the Pishtaz cultivar has the lowest seed yield (6.3 $t.ha^{-1}$). Azimi *et al*. (2013b) was reported that grain yield and biomass yield increasing with the bio fertilizer application, also which account important benefit, causing decreasing in the inputs of production because of economizing much money to chemical fertilizers and increasing in yield and biological yield.

2. OBJECTIVES

This study was carried out to evaluate combined effect of Sulfur and Sulfofertilizer1 of wheat cultivars on seed yield and its components.

3. MATERIALS AND METHODS

3.1. *Geographical Specifications and Climatic Conditions of the Experimental Site*

This experiment was conducted during the 2022-2023 cropping season on a farm located in Mahshahr County, with geographical coordinates of 49 degrees and 13 minutes east longitude and 30 degrees and 33 minutes north latitude. The site's elevation was 3 meters above sea level. Mahshahr is a coastal city characterized by a warm and humid climate. The temperature in this region varies from 50°C in summer to freezing temperatures in winter. The average annual precipitation in Mahshahr is approximately 233 mm.

3.2. *Experimental design*

The experiment was conducted during the 2022-2023 cropping season in Mahshahr County, utilizing a split-plot design within randomized complete blocks (RCBD) with three replications. The experimental treatments consisted of three levels of sulfur fertilizer [control, no consumption (S_1); 270g of sulfur fertilizer) S2; and 270g of sulfur fertilizer + 6g of Sulfofertilizer1 (S_3)] and three wheat cultivars [Mehregan (C_1), Chamran2 (C_2) and Khalil (C_3)], which were assigned to the main and sub plots, respectively. The soil properties of studied farm were mentioned in table 1.

Table 1. Physiochemical characteristics of field soil

Soil depth (cm)	Soil texture	Clay (%)	Silt (%)	Sand (%)	EC ($dS.m^{-1}$)	pH
0-30	Clay loam	36	39	25	4.54	7.5
Soil depth (cm)	**OM (%)**	**N (%)**	**K (ppm)**	**P (ppm)**	**S (ppm)**	**ρb ($gr.cm^{-3}$)**
0-30	0.71	0.04	190	9.61	45	1.5

3.3. *Implementation Stages of Experiment*

The land preparation operations before planting began in the first half of November and included primary irrigation, plowing with a moldboard plow, two cross-discs harrowing and land leveling. The experiment consisted of 27 plots, each with five planting rows, each row measuring 5m in length and spaced 20 centimeters apart. The plots were positioned 1.5 meters apart from each other, with a 0.5-meter gap between two sub-plots, and a one-meter gap between two main plots. Before planting, the total required phosphorus was supplied from triple superphosphate, based on a net phosphorus consumption of $80kg.ha^{-1}$. Nitrogen fertilizer was sourced from urea (46%) at a rate of 130 $kg.ha^{-1}$, with half of it broadcasted in the field using a disk harrow, and the other half distributed at the beginning of the tillering stage (early stem elongation). Sulfur fertilizer, in the form of granulated organic fertilizer with a composition of 45% organic matter, 45% sulfur, and 10% bentonite, was applied at a rate of 90 $kg.ha^{-1}$ of pure sulfur. Based on the recommendation of

Mehr Asia Biological Technology Company, the biofertilizer Thiobacillus bacteria was applied at a rate of one kilogram per 50 kilograms of sulfur fertilizer, and both were mixed and applied simultaneously before planting.

3.4. *Planting and Crop Management*

After preparing the planting rows, manual planting was carried out on November 28, 2022, at a depth of 3cm, with a density of 400 seeds $.m^{-2}$. The first irrigation was performed one day after planting.

3.5. *Sampling Method and Experimental Traits Estimation*

The final harvest took place on May 18, 2023. For each plot, a two-square-meter area was harvested, and the borders were manually removed before conducting the harvest.

3.6. *Measurement of studied traits*

The final harvest was done on May 15, 1401 when the seeds were almost hard and their moisture content reached about 14%. At the end, in the seed physiological growth stage, the area of 1.5 square meters from the four middle lines of each plot was measured after removing the margins for the final harvest and the following traits. In order to determine yield and yield components, two side rows and half a meter from the beginning and end of the plot were removed as marginal effects, and finally, the final harvest was done from an area equal to 1.5 square meters from the four middle lines of each plot. To determine the number of spikes per unit area, the total number of spikes harvested in the area of 1.5 square meters (from the four middle lines) was counted and considered as the number of spikes per unit area. In order to calculate the number of seeds per spike, 20 spikes were completely randomly separated from the total harvested spikes of each plot (from the four middle lines) and after separating the seeds from the spike, the number of seeds was counted. The number of seeds per spike was calculated by dividing the number of seeds by the number of spikes. For this purpose, 2 samples of 500 seeds from the produced seeds of each plot were randomly separated and weighed. If the difference in the weight of two samples was less than 5%, their total weight was considered as the weight of a thousand seeds. In order to determine the seed yield, in the ripening stage and after removing 0.5 meters from the beginning and end of the four middle lines, a surface equivalent to 1.5 square meters was harvested. After threshing, the seeds were separated from the straw and after weighing the seeds, the seed yield was calculated in grams per square meter. To calculate the height of the plant, the height of about 20 plants was randomly calculated from the soil surface to the end of the stems at the time of harvesting and their average was considered as the plant height. At the time of harvesting, all the plants in an area of 1.5 square meters were harvested from each plot (from the four middle lines by removing half a meter from the beginning and end of each line). In order to determine the biological yield, about 500 grams of the harvested plants were separated and after transferring the samples to the laboratory, they were placed in a ventilated oven at a temperature of 75 degrees Celsius for 48 hours, and after drying, their weight was weighed. Calculation to be calculated through the proportion of dry weight per unit area. The harvest index was calculated by dividing the seed yield by the biological yield, as a percentage (Gardner *et al*., 1985).

3.7. *Statistical Analysis*

The data analysis and result calculations were conducted by using the SAS software (Ver.8). Mean comparisons were performed using the LSD method at a 5% significance level, and relevant graphs were created using Microsoft Excel software (Ver.2010).

4. RESULT AND DISCUSSION

4.1. *Grain Yield*

The results of the analysis of variance indicated effect of fertilizer, cultivar and interaction effect of treatment on grain yield was significant at 1% probability level (Table 2). As observed from the mean comparison table (Table 3), the highest grain yield was obtained from the combined application of sulfur and sulfofertilizer1 (with an average of 464.73 $g.m^{-2}$), while the lowest grain yield was recorded in the non-fertilized control treatment (with an average of 352.04 $g.m^{-2}$). Among the wheat cultivars, the highest grain yield was associated with the Khalil cultivar (with an average of 477.43 $g.m^{-2}$) and the lowest was attributed to the Mehregan cultivar (with an average of 370.82 $g.m^{-2}$) (Table 3). Additionally, the interaction effect of sulfur fertilizer and wheat cultivars showed that the highest grain yield was achieved with the combined application of sulfur and biofertilizer in the Khalil cultivar (with an average of 490.1 $g.m^{-2}$) (which did not differ significantly from the sulfur fertilizer treatment), while the lowest grain yield was obtained in the non-fertilized treatment (control) with the Mehregan cultivar (with an average of 346.88 $g.m^{-2}$) (Table 4). The higher grain yield observed in the high-yielding Khalil cultivar can be attributed to its genotype characteristics, environmental factors and the accumulation of higher dry matter in this cultivar compared to others, which is consistent with the findings of Asadalahzadeh *et al*. (2019) in wheat plants. It can also be noted that improved wheat cultivars usually have higher grain yield due to a larger number of spikes per unit area, as well as a greater number of grains per spike and higher 1000-grain weight, as reported by Mokhtari *et al*. (2015). In this regard, Zahedian *et al*. (2015) stated that selecting suitable cultivars for the region can significantly affect growth, yield and yield components in wheat, leading to increased production and economic yield, which is in line with the results of this study. Furthermore, it appears that the combined application of sulfur and sulfofertilizer1 resulted in a decrease in soil pH, which in turn enhanced the uptake of essential nutrients, especially nitrogen, phosphorus and trace elements such as iron. The increased phosphorus uptake improved energy use and storage in the plant, ultimately leading to higher grain yield (Yadav and Yuosepur, 2015).

Table 2. Results of analysis of variance of studied traits

S.O.V	df	Grain yield	No. spike per m^{-2}	No. seed per spike	1000-seed weight	Biologic yield	Harvest index
Replication (R)	2	59.2	10.26^{ns}	0.02^{ns}	2.32^{ns}	183.1^{ns}	0.33^{ns}
Fertilizer (F)	2	87731**	11385**	192.36*	265.1**	165743**	400.5**
Ea	4	3028.5	1144.2	24.1	16.02	10335	13.07
Cultivar (C)	2	64751**	22658.1**	115.2*	188.4**	18246.1**	190.1**
C × F	4	102371**	10035.7**	1.4^{ns}	229.32**	99613**	0.44^{ns}
Eb	12	2116.4	1066.3	18.5	13.86	9541.02	11
CV (%)		11	8.4	11.6	9.39	7.18	10.75

ns, * and **: non-significant, significant at 5% and 1% of probability level, respectively.

Consistent with this, Orman and Kaplan (2007) in their reports mentioned that the consumption of Thiobacillus bacteria (sulfur-containing fertilizer) and sulfur-oxidizing bacteria results in both direct sulfur nutrition effects on plants and a decrease in soil pH, leading to improved access to necessary plant nutrients and having a positive effect on plant growth and yield. According to the findings of Nadeem *et al*. (2021), the use of sulfur and sulfur-oxidizing bacteria had the most significant effect on increasing grain yield-related traits and the number of wheat spikes. Moreover, Hussain *et al*. (2022) stated that sulfur fertilizer application led to an increase in grain yield and 1000-grain weight in the Hiwanto cultivar compared to the Kurdoo cultivar. The results of Hasanpour *et al*. (2018) also indicated that the bio-gypsum (sulfur-containing fertilizer) had a significant effect on grain yield and quantitative growth components of wheat. The consumption of sulfur in soil, in addition to improving soil properties, resulted in an increase in wheat yield, which is consistent with the findings of this study (Erdem *et al*., 2016).

4.2. *Number of spike per m^{-2}*

According results of the analysis of variance the effect of fertilizer, cultivar and interaction effect of treatment on number of spike per m^{-2} was significant at 1% probability level (Table 2). Mean comparison result of different level of fertilizer indicated that maximum number of spike per m^{-2} (416.5) was noted for sulfur and sulfofertilizer1 and minimum of that (340.1) belonged to control treatment (Table 3). As for Duncan classification made with respect to different level of cultivar maximum and minimum amount of number of spike per m^{-2} belonged to Khalil (410.8) and Mehregan cultivar (365.92) (Table 3).

Table 3. Mean comparison effect of treatments on measured traits

Treatment	Grain yield ($gr.m^{-2}$)	No. spike per m^{-2}	No. seed per spike	1000-seed weight (gr)	Biologic yield ($gr.m^{-2}$)	Harvest index (%)
Fertilizer						
Non-applying (Control)	352.04	340.1	32.81	34.48	1287.41	27.34
Sulfur	445.1	408.72	38.43	41.29	1391.22	32
Sulfur + Sulfurfertilizer1	464.73	416.5	40.01	43.11	1400.8	33.17
LSD (5%)	10.2	4.31	1.25	0.92	6.53	0.81
Cultivar						
Mehregan	370.82	365.92	33.26	36.8	1304.11	28.43
Chamran2	413.64	388.6	36.19	39.47	1357.31	30.47
Khalil	477.43	410.8	41.8	42.61	1418.01	33.66
LSD (5%)	15.33	9.54	1.86	1.70	8.74	1.17

Means followed by similar letters in each column show non- significant difference according to LSD tests at 5% level.

Evaluation mean comparison result of interaction effect of treatments indicated maximum number of spike per m^{-2} (433.5) was noted for Sulfur + Sulfofertilizer1 with Khalil cultivar and lowest one (345.5) belonged to control treatment with Mehregan cultivar (Table 4). Asifa *et al.* (2021) evaluated the response of bread wheat to sulfur (0, 15 and 30 $kg.ha^{-1}$) and phosphorus (0, 11, 22 and 44 $kg.ha^{-1}$) fertilizers and stated and reported that the application of 15 and 44 $kg.ha^{-1}$ sulfur and phosphorus fertilizers increased grain yield, number of spikes per square meter, starch yield and harvest index compared to the control treatment.

4.3. *Number of seed per spike*

The results of the analysis of variance indicated effect of fertilizer and cultivar on number of seed per spike was significant at 5% probability level but interaction effect of treatment was not significant (Table 2). Assessment mean comparison result indicated in different level of fertilizer the maximum number of seed per spike (40.1) was noted for sulfur and sulfofertilizer1 and minimum of that (32.81) belonged to control treatment (Table 3). Compare different level of cultivar showed that the maximum and the minimum amount of number of seed per spike belonged to Khalil cultivar (41.8) and Mehregan cultivar (33.26) treatments (Table 3). It seems that the increase in the number of spikes per unit area due to the application of sulfur fertilizer is related to the local acidification of the soil and the increase in the ability to dissolve nutrients and, as a result, the increase in the absorption efficiency of nutrients. Momen *et al.* (2011) was reported same result.

Table 4. Mean comparison interaction effect of treatment on measured traits

Fertilizer	Cultivar	Grain yield ($gr.m^{-2}$)	No. spike per m^{-2}	1000-seed weight (gr)	Biologic yield ($gr.m^{-2}$)
Non-application	Mehregan	346.8*	345.5*	35.6	1263.5
	Chamran2	365.2	353.24	36.3	1290.1
	Khalil	391.4	367.55	37.01	1320.4
Sulfur application	Mehregan	408.3	375.48	37.5	1354.2
	Chamran2	429.7	397.6	40.74	1383.1
	Khalil	482.3	426.2	43.4	1422.3
Sulfur + Sulfoferti-lizer1	Mehregan	417.5	386.8	38.8	1372.6
	Chamran2	455.1	410.1	42.5	1397.05
	Khalil	490.1	433.5	44.8	1435.12
LSD (5%)		2.37	4.69	0.01	6.82

*Means followed by similar letters in each column show non- significant difference according to LSD tests at 5% level.

4.4. *1000-seed weight*

According results of the analysis of variance the effect of fertilizer, cultivar and interaction effect of treatment on 1000-seed weight was significant at 1% probability level (Table 2). Evaluation mean comparison result revealed in different level of fertilizer the maximum 1000-seed weight (43.11 gr) was noted for sulfur and sulfofertilizer1 and minimum of that (34.48 gr) belonged to control treatment (Table 3). Between different levels of cultivar the maximum 1000-seed weight (42.61 gr) was observed in Khalil cultivar and the lowest one (36.8 gr) was found in Mehregan cultivar (Table 3). Assessment mean comparison result of interaction effect of treatments indicated maximum 1000-seed weight (44.8 gr) was noted for Sulfur + Sulfofertilizer1 with Khalil cultivar and lowest one (35.6 gr) belonged to control treatment with Mehregan cultivar (Table 4). Mousavi *et al.* (2018) studied the effect of sulfur sulfate (0, 250 and 500 $kg.ha^{-1}$) and Thiobacillus fertilizer (0, 5 and 10 $kg.ha^{-1}$) on wheat crop production and reported the combined use of sulfur fertilizer and Thiobacillus fertilizer in agricultural lands with high soil acidity led to improve the physiological and morphological characteristics of wheat such as grain weight, plant height, total dry matter, leaf surface index, crop growth rate and net assimilation rate.

4.5. *Biologic yield*

The results of the analysis of variance indicated effect of fertilizer, cultivar and interaction effect of treatment on biologic yield was significant at 1% probability level (Table 2). Mean comparison result of different level of fertilizer indicated the maximum and the minimum amount of biologic yield belonged to Sulfur + Sulfofertilizer1 (1400.8 $gr.m^{-2}$) and control treatment

(1287.41 $gr.m^{-2}$) (Table 3). Among different level of cultivar maximum biologic yield (1418.01 $gr.m^{-2}$) was obtained for Khalil cultivar and minimum of that (1304.11 $gr.m^{-2}$) was for Mehregan cultivar (Table 3). Evaluation mean comparison result of interaction effect of treatments indicated maximum biologic yield (1435.12 $gr.m^{-2}$) was noted for Sulfur with Sulfofertilizer1 with Khalil cultivar and lowest one (1263.5 $gr.m^{-2}$) belonged to control treatment with Mehregan cultivar (Table 4). Hojattipor *et al*. (2014) reported that the maximum total dry weight was obtained in wheat with increasing nitrogen fertilizer up to 225 $kg.ha^{-1}$, along with biological nitrogen fertilizer of nitrokara. Dehghan *et al*. (2018) by study on the effect of biosulfur (fertilizer containing Thiobacillus) and foliar spraying of zinc on wheat crop production reported that the highest seed yield and its components was obtained from the treatment of 500 $kg.ha^{-1}$ sulfur along with zinc foliar spraying at 1% concentration.

4.6. *Harvest index*

The results of the analysis of variance indicated effect of fertilizer and cultivar on harvest index was significant at 1% probability level but interaction effect of treatment was not significant (Table 2). Mean comparison result of different level of fertilizer indicated that maximum harvest index (33.17%) was noted for sulfur and sulfofertilizer1 and minimum of that (27.34%) belonged to control treatment (Table 3). The variability of the harvest index in the plants depends on the difference in the production of the assimilates during the seed filling and re-transplantation of the assimilates before the pollination of each genotype and the strength of the reservoir. Increase in corn harvest index in bio-fertilizer treatment to better absorb nutrients. Because the plant with better absorption of nutrients and increasing leaf area index can use better solar radiation and send more photosynthetic materials to seed and thus increase dry matter (Han and Lee, 2006). Hosseini *et al*. (2013) reported the maximum and the minimum amount of nitrogen harvest index belonged to control (66.41%) and 270 $kg.ha^{-1}$ (58.52%) treatments, respectively. Application of high levels of nitrogen fertilizer than to lower levels resulted in a significant decrease in this index. The reason for this trend can be stated that with increasing nitrogen application, a certain range of nitrogen transfer to the seed will be stopped, similar to the absorption of more nitrogen from the soil, although application of 270 $kg.ha^{-1}$ nitrogen did not lead to further increase in seed yield. Delogu *et al.* (1998) in their study of wheat and barley cultivars founded that increasing nitrogen application led to significant decrease in nitrogen harvest index, and there was a significant difference for all studied levels in their experiments. As for Duncan classification made with respect to different level of cultivar maximum and minimum amount of harvest index belonged to Khalil (33.66%) and Mehregan cultivar (28.43%) (Table 3).

5. CONCLUSION

Generally result of studied research revealed using Sulfur + Sulfurfertilizer1 by Khalil cultivar had the highest amount of studied characteristics and it can be advice to farmers.

ACKNOWLEDGMENT

The authors thank all colleagues and other participants, who took part in the study.

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