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Effect of sulfur-containing fertilizers on the chemical properties of soil and winter wheat yield

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Abstract

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The researches were conducted at studying the effectiveness and development of practical methods of using fertilizers containing micronized sulfur (monoammonium phosphate (MAP): P_2O_5 – 40%, N – 11%, S – 11%, Zn – 1%, sulfur particles size from 5 to 200 micron) under winter wheat in the conditions of South Kazakhstan. The yield of grain in the control variant (without fertilizers) was 14.3 q.ha^{-1}. When using sulfur-containing phosphorus fertilizer ($N_{60}P_{(2)60}K_{30}$) (MAP + S) the addition to yield is significant, and amounted to 4.5 q.ha^{-1} or 31.5%. The maximum yield addition was obtained in the variant when phosphorus fertilizers contained sulfur and zinc ($N_{60}P_{(3)60}K_{30}$) – 5.5 q.ha^{-1} (38.4%). According to the test results, the possibility of using Kazakhstani elemental sulfur by mixing with ammophos of the domestic company “KazFosfat” for wide application in agricultural was revealed.

Keywords: sulfur-containing fertilizers; winter wheat; yield; sulfur

Introduction

The guarantee of ensuring high fertility of soils, increasing the productivity of crops and environmental safety of the components of environment is balanced in all elements of mineral nutrition, taking into account the content, distribution and transformation of them in the soil. Along with elements such as nitrogen, phosphorus and potassium, there is sulfur – the second after nitrogen proteinogen (Maslova, 1993).

Sulfur is an important macronutrient that is essential for metabolic processes in plants, including block synthesis. Sulfur, like a nitrogen cycle, goes through a cycle of oxidation in the soil and restoration in the plant. Both elements are retained in organic compounds by covalent bonds with carbon. They are inaccessible to plants in elemental form, and they are assimilated by them only in the stage of the highest oxidation (SO^{2-}_4, NO^-_3) (Slyusarev, 2007).

The lack of sulfur, like nitrogen, reduces the synthesis of proteins, while the external manifestation of sulfur starvation of plants almost completely coincides with the signs of a lack of nitrogen nutrition (Skwierawska et al., 2016). Reduction of atmospheric deposition of sulfur in recent years can lead to a sulfur deficit, especially on coarse textured (sandy) with a low content of organic substances (< 2%) of soils. Yellowing of leaves is one of the main symptoms of sulfur deficiency in soil. In such cases it is necessary to consider the use of sulfur-containing fertilizers, such as ammonium thiosulfate, potassium-magnesium sulfate, ammonium sulfate, or gypsum (Killian et al., 2011).

The problem of the use of sulfur-containing fertilizers became urgent in the agriculture of Latvia (Malle, 2005), Moldova (Vitkalenko, 1981), Volgograd Region (Khala, 2001), Far East (Golov and Bakhova, 1996) and other countries. Xu et al. (2004) researched that in China, about 25% of the soils have a deficit of available sulfur and about 42% have a potential deficit.

Despite the obvious efficiency of use, elemental sulfur was not widely used in agriculture as a fertilizer. Norton et al. (2013) have found that the use of elemental sulfur can enhance the absorption of heavy metals (Cu, Mn, Zn, Fe and Ni) by plants as a result of acidification of the rhizosphere during sulfur oxidation. It is more commonly known as a contact fungicide protective action against a number of plant diseases. The studies of Jędryczka et al. (2002) and Figas et al. (2008) have shown that sulfur-containing fertilizers improve plant resistance to disease. The studies of Kurowski and Jankowski (2003) have shown that elevated glucosinolate content in plants enriched with sulfur stimulates natural resistance to fungal infections. Therefore, there is a need to produce new, highly effective complex fertilizers or use alternative types of sulfur-containing fertilizers, as well as cheap meliorants, for example, loesslike loam (Majchrzak et al., 2010). For sustainable crop yields and the proper quality of the products, adequate nutrition of plants with sulfur is required. Therefore, in each specific case, a careful check of the presence and distribution of sulfur forms in soils, the provision of this element of plants, its influence on fertility and ecology of soils in general is necessary.

In this respect, the gray-brown soils of the South Kazakhstan region are poorly studied. The aim of the research is to develop the theoretical foundations and methods of application of sulfur-containing fertilizers for winter wheat in conditions of gray-brown soils of the South Kazakhstan, and to study and summarize the information about the content of sulfur compounds, total and mobile forms of macronutrients (N, P, K) in the soil, and the effect of sulfur-containing fertilizers on the physical and physic-chemical properties of the soil on the growth, development and yield of winter wheat.

Materials and Methods

The experience is conducted in the Kazygurt region of the South Kazakhstan region on gray-brown soils. The site lies at longitude 41°39′39.27″C and latitude 69°28′44.69″B. The humus content in the surface layer is 2-3-3.5%, nitrogen 0.15-0.20% with a gradual decrease in depth. A low amount of carbonates (1-2%) in the upper part of the profile indicates a washing regime for the formation of these soils under natural conditions. The carbonate content in the carbonate-illuvial horizon reaches significant values (25% or more). The reaction of the soil solution is slightly alkaline, increasing with depth. Soils are well provided with mobile forms of potassium, medium-mobile nitrogen and exhibit an unstable supply of mobile phosphorus.

The climate of the Kazygurt district of the South Kazakhstan region is characterized by sharply continental conditions, with a small amount of precipitation associated with it. From October 2015 to July 2016 (from sowing to harvesting) the average air temperature was 14.7°C, the relative humidity was 68.4% and the total precipitation was 379.2 mm. Monthly average temperatures were measured in January (+5.0°C) and July (+28.3°C).

Winter wheat, variety Krasnovodopadskaya-210, was sown in November 12-13, 2014. Krasnovodopadskaya-210 variety has selected in Krasnovodopad selective experimental station (Kazakhstan) by the hybridization method "Krasnovodopadskaya 49 x Bima 1 (China) x Bezostaya 1". *Variety:* erythrospermum. The ear is prismatic, small or medium-sized (6-8 cm), medium-dense. The grain is red, large, barrel-shaped, and slightly hunchbacked, the furrow is shallow. The stem is of medium height (72-106 cm), it is resistant to lodging (4-5 points). The variety is early maturing. The duration of the growing season is 153-160 days. Winter hardiness is average. The susceptibility to yellow and brown rust, the hard smut is weak. The average yield is 28.6-31.7 $q.ha^{-1}$.

Applied fertilizers: ammonium nitrate (N-34%), urea (N-46%), (2 experiments), ammophos (P-46%, N-11%), potassium chloride (K-60%) and monoammonium phosphate (MAP) (P-40%, N-11%) with sulfur content (S-10%) and zinc (Zn-1%), ammonium sulfate (N-21%, S-24%).

During the vegetation period soil samples were selected on layers 0–20; 20–40; 40–60 cm.

According to the scheme of experience NPK; MAP+S and MAP+S, Zn was introduced.

Scheme of experience: 1/ Control (no fertilizers); 2/ $N_{60}K_{30}$; 3/ $N_{60}P(1)_{60}K_{30}$ – MAP; 4/ $N_{60}P(2)_{60}K_{30}$ – MAP+S; 5/ $N_{60}P(3)_{60}K_{30}$ – MAP+S, Zn.

Chemical analyzes of soil were carried out according to the following methods: determination of organic matter according to GOST 26213-91; mobile compounds of phosphorus and potassium by the method of Machigin in the modification of CINAO GOST 26205-91; easily hydrolyzable nitrogen according to Tyurin-Kononova; cation-anionic composition of aqueous extract in accordance with GOST 264-85-GOST 26428-85, the granulometric composition of the soil with a solution of sodium pyrophosphate; pH by potentiometric method; CO_2 with a calcimeter using the Golubev method; mobile forms of sulfur by the method of CINAO, GOST 26490-85; content of total sulfur in accordance with GOST 32599.2-2013, determination of mobile sulfur by extracting a solution of potassium chloride from the soil according to GOST 26490-85 according to the method of CINAO.

Results and Discussion

In the soil, sulfur is mainly found in the composition of organic matter. It occurs in two forms: mineral and organic. In the form of inorganic compounds, sulfur in the soil is oxidized (sulfates, polythionates), reduced (sulphides), and rarely – molecular. Sulphates are readily soluble in water and are found in soil solution of most soil types. This is the main source of sulfur for plants. Sulphates are mainly represented by $CaSO_4$*$2H_2O$, Na_2SO_4, K_2SO_4, $(NH_4)_2SO_4$. The polythionates are represented by the salt of tetrathionic acid ($H_2S_4O_6$) – sodium tetrathionate ($Na_2S_4O_6$). Sulphides are present in the soil more often with pyrite (FeS_2) and sphalerite (ZnS). Gypsum and anhydrite are basic sulphates, and pyrite and sphalerite are the main sulphides of the soil. Gypsum is a source of sulfur for winter wheat and this leads to an increase in yield. In six of the 14 studies in the eastern part of Oklahoma, USA, from 1996 to 2002, sulfur was used as $CaSO_4$, and this significantly increased the yield of cereals (Girma et al., 2005). For its development winter wheat requires sulfur in sufficient quantities. Deficiency of sulfur in soils has become a big problem in the issues of soil fertility all over the world. Sen et al. (2016) reported that this deficit occurs due to reducing sulfur deposits from the air in the soil according to the laws and increasing yields removal.

The soil of the investigated experimental section is gray-brown, with medium-loamy texture. In Table 1 the initial soil state data are presented, which shows the reliability of the mean data obtained by the Student's t-test. So the total humus content in 0-20 cm is very low (1.5 ± 0.04%), easily hydrolyzable nitrogen – very low (26.3 ± 2.60 mg/kg), mobile phosphorus – low (14.4 ± 1,08 mg/kg), exchange potassium – medium (278 ± 3,74 mg/kg) and mobile sulfur – low (0,9 ± 0,20 mg/kg). The statistical data confirm that the content of the main elements decreases in the soil depth from 0-20 to 40-60 cm. Thus, it can be said that the results obtained are statistically reliable.

There are many examples showing that sufficient plant nutrition, both nitrogen and sulfur, is necessary to obtain the planned crop. Norton et al. (2013) have established that with a lack of sulfur in legumes, the number of nodules on the roots of plants decreases and, accordingly, the intensity of fixation of atmospheric nitrogen decreases. According to the research of Skwierawska et al. (2008), the use of sulfur-containing fertilizers in pastures, the soils of which are sufficiently provided with mobile sulfur, promotes yield growth and increases the efficiency of nitrogen use from fertilizers by plants. The loss of nitrogen from the soil decreases.

As shown in Table 2, the chemical properties of the soil at the end of the growing season, where various min-

Table 1
Average indicators of the initial state of gray-brown soils

Depth, cm	Humus, %	Total forms, %			Mobile forms, mg/kg			Sulfur	
		N	P_2O_5	K_2O	N	P_2O_5	K_2O	Total, %	Mobile, mg/kg
0-20	1.5±0.04	0.1±0.01	0.7±0.08	1.7±0.08	26.3±2.60	14.4±1.08	278±3.74	0.007± 0.001	0.011
20-40	1.1±0.09	0.1±0.01	0.6±0.10	1.8±0.08	21.8±1.63	9.8±0.92	208±3.74	-	-
40-60	0.8±0.16	0.1±0.00	0.5±0.14	1.5±0.15	19.6±2.17	6.4±1.57	174±9.80	-	-

Table 2
Chemical properties of gray-brown soils at the end of vegetation

Treatment	Depth, cm	Humus, %	Total forms, %			Mobile forms, mg/kg			CO_2 %	pH
			N	P_2O_5	K_2O	P_2O_6	K_2O	S		
No fertilizers	0-20	1.66	0.098	0.62	1.69	10	190	1.5	2.77	7.99
	20-40	1.15	0.084	0.5	1.69	10	180	1.63	4.13	8.09
$N_{60}K_{30}$	0-20	1.52	0.098	0.5	1.87	11	210	0.73	2.4	8.03
	20-40	1.42	0.112	0.5	1.69	10	180	0.24	3.86	8.04
$N_{60}P_{(1^*)60}K_{30}$	0-20	1.76	0.112	0.5	1.87	24	250	1.22	1.01	7.9
	20-40	1.72	0.112	0.56	1.87	16	200	2.05	1.05	7.96
$N_{60}P_{(2^*)60}K_{30}$	0-20	2.03	0.126	0.32	2.25	23	390	0.96	0	7.79
	20-40	1.76	0.098	0.32	2.25	22	310	1.25	0	7.74
$N_{60}P_{(3^*)60}K_{30}$	0-20	1.96	0.14	0.28	2.25	16	350	2.75	0.14	7.75
	20-40	1.66	0.112	0.26	2.25	10	310	2.71	0.1	7.77

*1 – MAP, 2 – MAP+S, 3 – MAP+S, Z

eral fertilizers were applied, provide a reliable increase in nutrients, compared with the control (Table 2). The content of mobile forms of sulfur in the control treatment (no fertilizers) was 1.5 mg/kg in the 0-20 cm layer. Comparatively high contents of mobile sulfur are observed in the variant $N_{60}P_{(3)60}K_{30}$, where the increase is almost 2 times.

During the vegetation period phenological observations of the growth and development of winter wheat were conducted. The height of the stem, the number of leaves and grain were determined monthly. According to the results of the experiments in the tillering phase the density of plants per 1 m^2 in the control treatment is 69%, and in the fertilizers treatments is 75-83%, i.e., 6-14% higher compared to the control variant (Table 3). Phenological data show that the use of various fertilizers improves the growth and development of winter wheat.

Table 4 shows the data of the phenological observations carried out before winter wheat harvesting. The data of the variational-statistical processing, which were estimated by the t-criterion of the Student, show the reliability of the obtained average data (t_{fact}.> t_{tab}.). The established average values of plant heights are basically statistically stable, as indicated by an analysis of the degree of variability of this indicator in the variants of the experiment. This is confirmed by the values of their coefficients of variation, which on the gradation scale vary mainly from a small (10.39) to a medium (21.17).

As shown by the average statistical data, treatment $N_{60}P_{(2)60}K_{30}$ and $N_{60}P_{(3)60}K_{30}$ were the best in terms of the effect on plant height, the plant height was 79.1 ± 1.24 and 81.7 ± 1.09 cm (by 19.8 and 22.4 cm higher than the control). In other treatments the difference in plant height in comparison with the control varies from 12.36 to 15.53 cm (Figure 1).

Table 3.
Phenological observations of the growth and development of winter wheat

Treatments	March				April	May		
	Density of plants per m^2		Amount of leaves per plant		Height, cm	Amount		Height, cm
						Leaves	Grain	
	pcs.	%	pcs.	average		per plant, pcs.		
Control	220	69	2	3-4	22	4.1±0.09	15.4±0.91	59.3±1.69
$N_{60}K_{30}$	240	75	2	3-4	23	4.3±0.08	18.9±0.78	71.6±1.31
$N_{60}P_{(1^*)60}K_{30}$	265	83	2	4-5	26	4.5±0.08	21.2±0.80	74.8±1.41
$N_{60}P_{(2^*)60}K_{30}$	257	80	2	4-5	25	4.5±0.08	23.2±0.76	79.1±1.25
$N_{60}P_{(3^*)60}K_{30}$	263	82	2	5	26	5.3±0.14	25.4±0.87	81.7±1.09

*1 – MAP, 2 – MAP+S, 3 – MAP+S, Zn

Table 4
Formation of productivity of winter wheat

Treatments	n	M±m	Limits of oscillations between min and max	t-test		Level of reliability ±t0,05 * m,	V, %
				t-fact	t 0,05		
Height of plants, cm							
Control	55	59.3±1.69	30÷83	35	2	3.39	21.17
$N_{60}K_{30}$	55	71.6±1.31	50÷96	55	2	2.63	13.59
$N_{60}P_{(1^*)60}K_{30}$	55	74.8±1.41	50÷92	53	2	2.84	14.01
$N_{60}P_{(2^*)60}K_{30}$	60	79.1±1.24	55÷97	63	2	2.5	12.21
$N_{60}P_{(3^*)60}K_{30}$	60	81.7±1.09	64÷100	75	2	2.19	10.39
Amount of grains in ear, pcs							
Control	55	15.4±0.91	6÷32	17	2	1.82	43.71
$N_{60}K_{30}$	55	18.9±0.78	6÷30	24	2	1.56	30.42
$N_{60}P_{(1^*)60}K_{30}$	55	21.2±0.80	8÷35	27	2	1.6	27.89
$N_{60}P_{(2^*)60}K_{30}$	60	23.2±0.76	12÷34	30	2	1.53	25.51
$N_{60}P_{(3^*)60}K_{30}$	55	25.4±0.87	10÷36	29	2	1.75	25.5

*1 – MAP, 2 – MAP+S, 3 – MAP+S, Zn

Fig. 1. Winter wheat sheaves

1. Control; 2. $N_{60}K_{30}$; 3. $N_{60}P_{(1)60}K_{30}$ – MAP; 4. $N_{60}P_{(2)60}K_{30}$ – MAP+S; 5. $N_{60}P_{(3)60}K_{30}$ – MAP+S, Zn

Table 5
Influence of the fertilizers on winter wheat yield of grain

Treatments	Yield of grain, q.ha^{-1}	Addition from fertilizers		Weight of 1000 grains, g
		q.ha^{-1}	%	
Control	14.3	-	-	30.7
$N_{60}K_{30}$	15.5	1.2	8.6	32.3
$N_{60}P_{(1^*)60}K_{30}$	18.4	4.1	29.0	33.1
$N_{60}P_{(2^*)60}K_{30}$	18,8	4.5	31.5	33.6
$N_{60}P_{(3^*)60}K_{30}$	19,8	5.5	38.4	33.7
LSD_{05} = 0,52 q.ha^{-1}; P, % = 1,80				

*1 – MAP, 2 – MAP+S, 3 – MAP+S, Zn

Integral indicator of soil fertility, as it is known is the yield. The harvest of the grain of winter wheat is determined by the following values: the number of ears on one plant; number of spikelets and flowers in one ear, grains filling, which is usually measured by a mass of 1000 grains per gram.

The results of the studies showed that the average amount of grains in the treatment $N_{60}P_{60}K_{30}$ was 21.2 ± 0.80, the lowest and highest values were in the control (15.4 ± 0.91) and $N_{60}P_{(3)60}K_{30}$ (25.4 ± 0.87) (Table 4).

The grain yield in the control (no fertilizers) was 14.3 q.ha^{-1} (Table 5). Mineral fertilizers significantly influenced crop productivity. The addition to yield from their use reached 1.2-5.5 q.ha^{-1} or 8.6-38.4%. The lowest indicator (1.2 q.ha^{-1}) was on the treatment $N_{60}K_{30}$. In case use of $N_{60}P_{60}K_{30}$ the yield reached 18.4 q.ha^{-1}, the addition is 4.1

q.ha^{-1}, or 29.0%. When using sulfur-containing phosphate fertilizers ($N_{60}P_{(2)60}K_{30}$), the addition to yield was significant and amounted to 4.5 q.ha^{-1} or 31.5%. The most effective treatment of phosphorus fertilizers with the content of sulfur and zinc ($N_{60}P_{(3)60}K_{30}$) allowed to obtain an addition to yield by 5.5 q.ha^{-1} (38.4%). The mass of 1000 grains on the treatments where mineral fertilizers were applied was greater in comparison with the control (30.7 g).

Conclusion

On the basis of the conducted studies, it has been established that the chemical properties of soil at the end of vegetation, where sulfur-containing fertilizers are used, in comparison with the control (without fertilizers) provide a reliable increase in nutrients. The yield of winter wheat increases significantly on the treatments of $N_{60}P_{(2)60}K_{30}$ (MAP, S) and $N_{60}P_{(3)60}K_{30}$ (MAP, S, Zn). The additions to yield on these treatments were 31.5% or 38.4%. Thus, the results of the conducted studies have shown that the effectiveness of the application of sulfur-containing fertilizers for winter wheat is quite high and indicates the profitability of the use of sulfur-containing fertilizers (MAP, S) for cereals in conditions of gray-brown soils.

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