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**COMPARATIVE AMELIORATIVE EFFICIENCY  
OF PHOSPHOGYPSUM AND SULFUR IN SEMI-TERRESTRIAL  
MODERATELY ALKALINE SULPHATE SALINE SOLONETS  
OF THE LIGHT GRAY EARTH SUBZONE**

**Abstract.** The article presents the data from field tests for determining the relative ameliorative efficiency of equivalent dosages of phosphogypsum and elemental sulfur on the alkaline saline semi-terrestrial solonetz. Based on the analyses of soils water extract, higher ameliorative efficiency of elemental sulfur and fast amelioration of alkali-saline soils with the use of sulfur have been detected. Ten-month incubation of phosphogypsum and elemental sulfur in the semi-terrestrial alkali-sulfate moderately saline high-sodium medium solonetz from the area of light gray earth had significant influence on the content and composition of salts, by altering their ionic composition, increasing the amount of salts and reducing pH. Flushing initial primary and the newly formed secondary salts from the root zone of the soil had little effect on salt removal (only 0.032%) in the variant with phosphogypsum from 0.527% to 0.543%, while in the variant with elemental sulfur, considerable desalination with salt content decreasing from 0.527% to 0.354% was observed. Moreover, after flushing salts in the variants with phosphogypsum became more toxic due to the "peak" of alkalinity.

**Keywords:** alkali-saline soil, fertility, amelioration, sulfur, phosphogypsum.

**Introduction.** Soda-saline (alkaline) soils have been widely distributed in the two regions of the Republic of Kazakhstan: in the grain belt of chernozems and chestnut soils in the form of solonets and solonchak-solonetsous soils (more than 25 million hectares) and in the southern part, among the most fertile soils of the foothill plain of the Northern Tien Shan meadow-chestnut and meadow-gray soils (7.09 million hectares) [1]. The main method of melioration is the introduction of gypsum and phosphogypsum. However, recent studies have found low profitability of traditional meliorants of gypsum and phosphogypsum on soda-saline soils due to a rapid decrease in their initial efficiency, due to the coating of the crystal surface with an insoluble calcium carbonate layer, which isolates them from the environment [2, 3].

Among the meliorants, sulfur is the most effective. Therefore, it was practically not applied and the problem of increasing its reclamation efficiency was almost not dealt with. However, the recent rapid growth in the volume of oil and gas production in the republic led to a sharp increase in the volume of their processing and accumulation, its byproduct - elemental sulfur, its volume in the republic exceeded more than 8 million tons. The country became the largest in the world (second place after Iran) by the sulfur storage [4], in connection with which the problems of its utilization increased. Our research resulted in 2009-2012. It is established that in the first year only 25% of the added sulfur passes into its oxide forms, samples of sulfuric acid. Hence, it takes four years to obtain a full meliorative effect [5].

Thus, the above-mentioned circumstances prevailing in the republic, i.e. the presence of a large area of alkaline saline soils in areas of intensive farming, the low economic efficiency of the currently used ameliorant of phosphogypsum and the huge amount of accumulated sulfur requires the development of technologies for reclamation of alkaline saline soils using sulfur. In our opinion, the solution of this

problem can be achieved by accelerating the oxidation of elemental sulfur, which is possible with high dispersity of its particles.

**Program and methodology.** The studies were conducted in 2015 and 2016 on the territories of LLP "Amiran" of Talgar district of Almaty region.

To establish the comparative meliorative efficiency of phosphogypsum and elemental sulfur on soda-saline soils, we selected a site of 0.5 ha. Soil soil is a soda-sulfate-solonchak semihydromorphic salt. The field experiment was carried out by applying calculated equivalent doses of ameliorants. The doses of meliorants were calculated to a depth of 0.5 m according to the formula of B.M. Agaeva Phosphogypsum of the Zhambyl plant of phosphorus fertilizers and micronized sulfur of the Atrau refinery were used as ameliorants (1966). [6]. The scheme of the field experiment is as follows:

#	Variant of experience	Doses of meliorants, t/ha
1	Control	–
2	Phosphogypsum	15
3	Elemental sulfur	5

The plot area is (3×5) 15 m<sup>2</sup>, replication of the experiment is 3-fold. Samples of soils were selected in the spring before the introduction of meliorants (26.06.2015), in the autumn after 4.5 month incubation of ameliorants (07.11.2015), next year in spring and summer before (26.03.2016) after (28.04.2016) washing. Correction of ameliorants into the soil was carried out by plowing to a depth of 29 cm, followed by disking. The depth of sampling of samples is 0-20, 20-40 and 40-60 cm. In them, the composition of the ions of the water extract of Arinushkin was determined [7]. The field experiment was conducted according to the generally accepted method [8, 9].

The removal of the tertiary salts formed as a result of the interaction of phosphogypsum and sulfur in 2016 led to soil washing. The calculated norm of washing water per plot was submitted in 2 stages (6.04 and 14.04.2016) in the volume of 6900 liters or 4600 m<sup>3</sup> / ha. During the entire meliorative period, optimum soil moisture was maintained.

**Results and discussion.** The analysis of the water extract on the initial salt composition of the trial options shows the average degree of salinity (the amount of salts is 0.5-0.7%). Salts are represented by soda-sulphate chemistry (table 1).

Table 1 – Initial composition of aqueous extract of medium-sulphatesolonchak high-sodium hemihydromorphicsolonetz subzone of light gray soils, (mg-eqv) / %

Variant	Depth, cm	HCO <sub>3</sub> <sup>-</sup>	CO <sub>3</sub> <sup>2-</sup>	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Na <sup>+</sup> + K	Total salts, %	pH
1. Control	0-20	<u>1.44</u> 0,087	<u>Her</u> Her	<u>0.65</u> 0,022	<u>8.25</u> 0,39	<u>4.37</u> 0,087	<u>2.50</u> 0,03	<u>3.34</u> 0,076	0,692	8,0
	20-40	<u>1.62</u> 0,098	<u>Her</u> Her	<u>0.55</u> 0,019	<u>8.38</u> 0,40	<u>4.75</u> 0,095	<u>2.75</u> 0,03	<u>3.05</u> 0,070	0,715	8,2
	40-60	<u>1.70</u> 0,103	<u>0.37</u> 0,011	<u>0.60</u> 0,021	<u>8.88</u> 0,42	<u>5.00</u> 0,1	<u>2.88</u> 0,034	<u>3.70</u> 0,085	0,774	8,2
2. Phospho-gypsum	0-20	<u>1.12</u> 0,068	<u>Her</u> Her	<u>0.75</u> 0,026	<u>8.63</u> 0,41	<u>4.25</u> 0,085	<u>2.88</u> 0,034	<u>3.37</u> 0,077	0,777	8,1
	20-40	<u>1.56</u> 0,095	<u>Her</u> Her	<u>0.70</u> 0,024	<u>4.25</u> 0,20	<u>1.75</u> 0,035	<u>1.38</u> 0,016	<u>3.69</u> 0,084	0,454	8,2
	40-60	<u>1.64</u> 0,100	<u>0.48</u> 0,014	<u>0.60</u> 0,021	<u>4.13</u> 0,19	<u>2.25</u> 0,045	<u>1.50</u> 0,018	<u>3.10</u> 0,071	0,459	8,3
3. Sulfur	0-20	<u>1.48</u> 0,090	<u>Her</u> Her	<u>0.65</u> 0,022	<u>7.75</u> 0,37	<u>4.00</u> 0,08	<u>2.88</u> 0,034	<u>2.75</u> 0,063	0,659	8,1
	20-40	<u>1.92</u> 0,117	<u>Her</u> Her	<u>0.75</u> 0,026	<u>5.38</u> 0,25	<u>2.5</u> 0,05	<u>1.75</u> 0,021	<u>2.29</u> 0,052	0,516	8,2
	40-60	<u>2.32</u> 0,141	<u>0.60</u> 0,018	<u>0.75</u> 0,026	<u>4.38</u> 0,21	<u>2.00</u> 0,04	<u>1.25</u> 0,015	<u>4.80</u> 0,110	0,560	8,5

In the soils there are all the ions in quantities, which adversely affect the growth and development of plants. But the greatest damage is noted from solonchakness and high alkalinity. The soda of the soil of the section is indicated by the presence of an appreciable amount of  $[\text{HCO}]_3^-$  - exceeding its threshold concentration of 0.8 meq per 100 g of soil). Its content, as a rule, increases with depth, reaching up to 2 and more mg-eq per 100 g of soil. It should be noted that only at this depth (40-60 cm) there are normal carbonates ( $\text{CO}_3^{2-}$ ), also significantly exceeding the threshold concentration (0.03 meq per 100 g of soil) in connection with which the lower horizon has a higher alkalinity (pH 8.2-8.5).

The content and distribution of the chlorine ion along the soil profile is uniform and almost identical (0.60-0.75 meq per 100 g soil) in calorific values twice exceeding its threshold toxicity (0.35 meq per 100 g soil). This distribution of chlorine ion indicates the absence in the soil profile of both the wash and water effluent regime. Of the anions, the highest concentration differs, sulfate ions (7-8 meq per 100 g soil), exceeding the threshold concentration (1.7 meq) more than 4 times. They decrease with depth to 4-5 mg-eq per 100 g of soil. The anionic composition noted that the soils of the experimental site are represented by soda-sulfate type of salinity.

The cation composition of the aqueous extract of soils is characterized by an increased content of calcium and sodium, somewhat less than magnesium. An increased concentration of sodium can be explained by the presence of considerable salinity in the soil.

Thus, the initial state of the meliorated soil is characterized by an average alkalinity due to the increased bicarbonate ion content throughout the profile and the presence of normal carbonates in its lower part, as well as a high content of sulfate ion, which, with an increased content of  $\text{Ca}^{2+}$  and  $\text{Na}^+$ , form toxic salts with a predominance of sodium salts  $\text{NaHCO}_3$ ,  $\text{Na}_2\text{SO}_4$ .

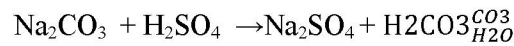
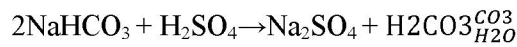
Table 2 – Effect of equivalent doses of phosphogypsum and elemental sulfur on the composition of the aqueous extract of the medium-sulphate solonchak high-sodium hemihydromorphic solonetz of the subzone of light gray soils, (mg-eq) / %

Variant	Depth, cm	$\text{HCO}_3^-$	$\text{CO}_3^{2-}$	Cl	$\text{SO}_4^{2-}$	$\text{Ca}^{2+}$	$\text{Mg}^{2+}$	$\text{Na}^+ + \text{K}$	Total salts, %	pH
Control	0-20	<u>1.52</u> 0,092	Следы Следы	<u>0.60</u> 0,021	<u>6.50</u> 0,31	<u>3.50</u> 0,07	<u>2.50</u> 0,03	<u>2.62</u> 0,060	0,583	8,3
	20-40	<u>2.36</u> 0,143	Следы Следы	<u>0.40</u> 0,014	<u>5.00</u> 0,24	<u>1.63</u> 0,03	<u>0.86</u> 0,01	<u>5.06</u> 0,116	0,553	8,5
	40-60	<u>2.56</u> 0,156	Следы Следы	<u>0.40</u> 0,019	<u>3.63</u> 0,17	<u>1.50</u> 0,03	<u>0.75</u> 0,009	<u>3.70</u> 0,085	0,739	8,6
Phospho-gypsum	0-20	<u>1.56</u> 0,095	Нет Нет	<u>0.55</u> 0,019	<u>7.13</u> 0,34	<u>3.63</u> 0,07	<u>2.38</u> 0,028	<u>2.24</u> 0,051	0,603	8,2
	20-40	<u>1.56</u> 0,095	<u>0.12</u> 0,003	<u>0.50</u> 0,017	<u>8.75</u> 0,42	<u>1.75</u> 0,03	<u>1.25</u> 0,025	<u>7.92</u> 0,182	0,772	8,5
	40-60	<u>2.56</u> 0,156	<u>0.24</u> 0,007	<u>0.60</u> 0,021	<u>8.00</u> 0,38	<u>1.88</u> 0,03	<u>1.13</u> 0,013	<u>8.40</u> 0,193	0,804	8,8
Sulfur	0-20	<u>0.80</u> 0,048	Нет Нет	<u>0.60</u> 0,021	<u>13.25</u> 0,636	<u>5.00</u> 0,1	<u>2.88</u> 0,034	<u>6.63</u> 0,156	0,995	7,4
	20-40	<u>1.00</u> 0,061	Нет Нет	<u>0.60</u> 0,021	<u>13.00</u> 0,620	<u>4.00</u> 0,08	<u>2.50</u> 0,03	<u>8.10</u> 0,186	0,998	7,4
	40-60	<u>1.14</u> 0,069	Нет Нет	<u>0.60</u> 0,021	<u>8.75</u> 0,420	<u>4.00</u> 0,08	<u>2.63</u> 0,031	<u>3.87</u> 0,089	0,710	7,4

The results of this analysis of the water extract of soil samples (Table 2) taken after the beginning of the experiment for 4.5 months after the control variant show that there are noticeable changes in concentrations as in the composition of anions: (an increase of  $[\text{HCO}]_3^-$  - in the lower horizons from 1.65 mg-eq to 2.45 meq, disappeared  $[\text{CO}]_3^{2-}$  (2-), decreased  $\text{SO}_4^{2-}$  (2-) (from 8.0 meq to 4.00 meq), and cations: a sharp decline  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  in the lower horizons (respectively, from 4.9 meq to 1.55 meq and from 2.8 meq to 0.80 meq) and a slight increase in  $\text{Na}^+$  concentrations in the underlaid horizon with 3.05 mg-eq to 5.06 mg-eq per 100 g of These changes in the concentration of ions in the liquid phase of the soil of the control variant cause the proportion of more toxic sodium salts ( $\text{NaHCO}_3$  and  $\text{Na}_2\text{CO}_3$ ) to increase in the solution composition and to reduce the proportion of less toxic (especially  $\text{Na}_2\text{SO}_4$ ) and nontoxic ( $\text{CaSO}_4 \cdot \text{Ca}(\text{HCO}_3)_2$ ) salts, significantly increasing its value from 8.1, 8.3.

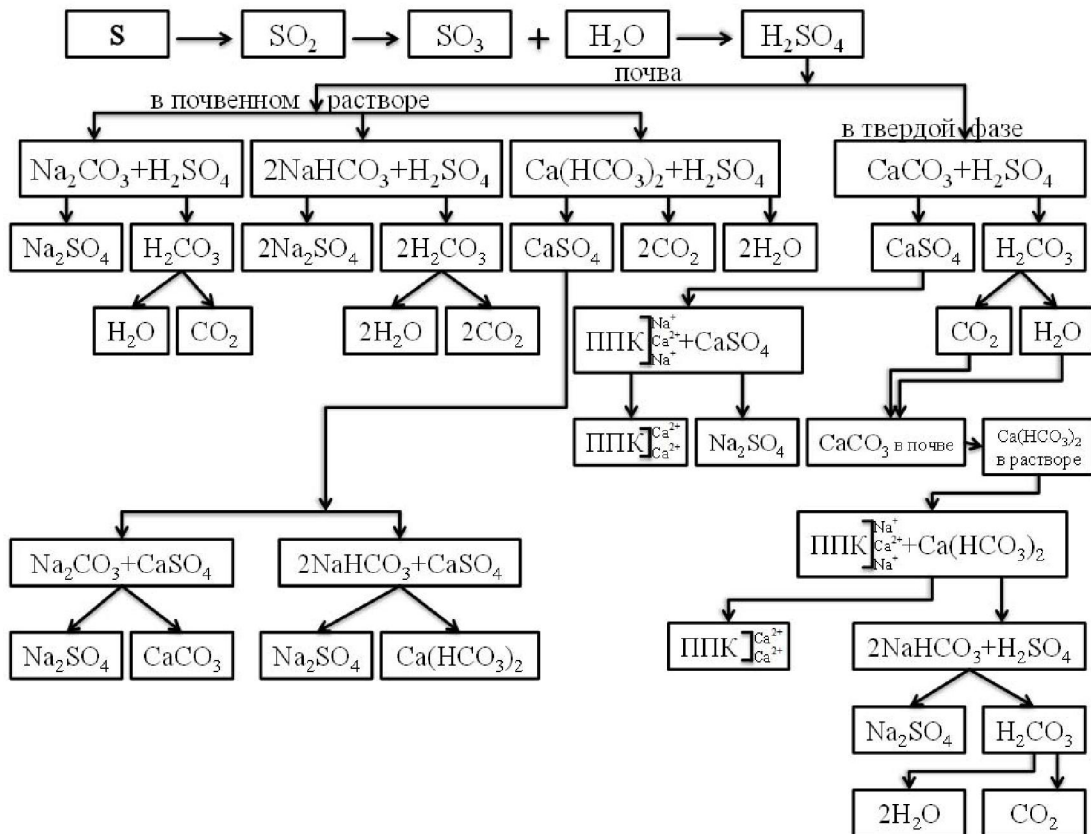
The introduction of phosphogypsum significantly increased the content of  $\text{SO}_4^{2-}$  and  $\text{Na}^+$  ions corresponding to 4.20 to 8.40 and from 3.40 to 8.20 meq per 100 g of soil and slightly reducing their concentrations in the 0-20 cm layer, as well as  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  in this layer. At the same time, an increase in the content of the sulfate ion occurs due to the release of  $\text{SO}_4^{2-}$  contained in the phosphogypsum into the solution, and sodium is displaced from the PPC by calcium phosphorus ions. Thus, a 4.5 month incubation of phosphogypsum in a soda-saline semihydromorphicsolonetz had a significant effect on the composition of aqueous extracts, increasing the content of sulfate and sodium ions in it, leaving without significant changes the remaining ions.

In contrast to phosphogypsum, sulfur had a more significant change in the water extract hose. The most noticeable change is manifested in the content of the  $\text{HCO}_3^-$  ion, where its initial content in the 0-20, 20-40 and 40-60 cm layers, respectively, amounting to 1.48, 1.92 and 2.32 meq per 100 g of soil decreased to 0, 80, 1.00 and 1.14 meq. Moreover, the content of  $\text{CO}_3^{2-}$  in its original soil (0.60 meq per 100 g of soil) has disappeared. The noted indicate a fairly high efficiency of elemental sulfur to reduce the increased alkalinity of soda-greasy soils compared to phosphogypsum. They are explained by neutralization reactions proceeding according to the following scheme:



The occurrence of such reactions is confirmed by the increase in the concentrations of the sulfate ion. Thus, before the addition of elemental sulfur, the  $\text{SO}_4^{2-}$  content in the 0-20, 20-40, 40-60 cm layers, respectively, was 7.75, 5.38, 4.38 meq / 100 g of soil, then after 4.5 month incubation of elemental sulfur in the soil, its content increased to 13.25, 13.00, 8.75 meq per 100 g of soil or 171, 242, 200%, respectively.

It is known that sulfuric acid formed during the oxidation of elemental sulfur, along with the liquid phase of the soil, also reacts with the solid phase (figure).



Hypothetical block diagram of the effect of sulfur on the composition of soda-saline soils

It follows from the presented scheme [10] that during the interaction of sulfuric acid with calcium carbonates and partly magnesium, they are destroyed, as a result of which new bicarbonates are formed in the solution. They are captured in the analysis of aqueous extract, the data of which show the significance of the growth of the concentrations of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  in the layers of 20-40 and 40-60 cm, respectively, of the content of 160, 200% and 143, 210% compared to their values prior to the introduction of elemental sulfur. The addition of sulfur further increases the concentration of sodium compared with phosphogypsum. This can be explained by the sodium ion displaced from the PPK. It appears in the layers 0-20 and 20-40 cm. If before the introduction of sulfur the sodium content in the aqueous extract was respectively 2.75 and 2.29 meq, then after 4.5 months incubation its content increased to 6.63 and 8.10 meq per 100 g of soil or 241 and 354%. It follows that elemental sulfur, along with greater neutralization of alkaline salts, is also most actively involved in the desalinization of the soil compared with phosphogypsum.

To determine the influence of autumn-winter climatic conditions on the meliorative state of soils in early spring (6.03.2016), an examination of the experimental plots was carried out. It turned out that the surface of the soil with ameliorants was fluffier than in the control variants. Somewhat later, (March 26, 2016) sampled soil samples, to determine the influence of autumn-early spring climatic conditions on the salt composition of soils of the variants of the experiment (table 3).

Table 3 – Influence of autumn and spring climatic conditions on the composition of water extracts of the experimental variants, (mg-equiv) %

Variant	Depth, cm	$\text{HCO}_3^-$	$\text{CO}_3^{2-}$	$\text{Cl}^-$	$\text{SO}_4^{2-}$	$\text{Ca}^{2+}$	$\text{Mg}^{2+}$	$\text{Na}^+$	Total salts, %	pH
Control	0-20	<u>1.70</u> 0,104	нет	<u>0.50</u> 0,018	<u>4.25</u> 0,204	<u>3.15</u> 0,063	<u>0.80</u> 0,059	<u>2.60</u> 0,059	0,457	8,1
	20-40	<u>1.60</u> 0,098	нет	<u>0.50</u> 0,018	<u>4.75</u> 0,228	<u>3.25</u> 0,065	<u>0.90</u> 0,011	<u>2.70</u> 0,062	0,482	8,1
	40-60	<u>0.52</u> 0,032	нет	<u>0.40</u> 0,014	<u>5.00</u> 0,246	<u>1.50</u> 0,030	<u>0.30</u> 0,004	<u>4.12</u> 0,095	0,421	7,8
Phospho-gypsum	0-20	<u>0.88</u> 0,054	нет	<u>0.30</u> 0,011	<u>6.00</u> 0,288	<u>5.08</u> 0,102	<u>0.83</u> 0,011	<u>1.26</u> 0,029	0,495	7,8
	20-40	<u>1.38</u> 0,084	сл.	<u>0.23</u> 0,008	<u>6.25</u> 0,300	<u>2.92</u> 0,058	<u>0.53</u> 0,006	<u>4.42</u> 0,102	0,558	8,1
	40-60	<u>1.26</u> 0,077	<u>0.56</u> 0,59	<u>0.33</u> 0,019	<u>6.25</u> 0,300	<u>2.83</u> 0,057	<u>0.56</u> 0,007	<u>4.72</u> 0,109	0,585	8,2
Sulfur	0-20	<u>0.73</u> 0,045	нет	<u>0.23</u> 0,008	<u>5.92</u> 0,284	<u>4.25</u> 0,085	<u>0.96</u> 0,012	<u>1.66</u> 0,038	0,472	7,2
	20-40	<u>0.90</u> 0,055	нет	<u>0.27</u> 0,009	<u>7.17</u> 0,344	<u>3.25</u> 0,065	<u>0.83</u> 0,011	<u>4.25</u> 0,098	0,582	7,6
	40-60	<u>1.77</u> 0,108	<u>0.56</u> 0,59	<u>0.26</u> 0,009	<u>6.67</u> 0,320	<u>3.50</u> 0,070	<u>0.70</u> 0,008	<u>5.06</u> 0,116	0,647	7,8

From the analysis of the water extract it follows that the effect of climatic conditions on the salt composition of soils of the control variant does not have any appreciable changes, whereas in the variants with ameliorants, the concentration of  $[\text{HCO}_3^-]$  in the 0-40 cm layer on the phosphogypsum variant is reduced 1.5 times (from 1.65 mEq to 1.13 mEq) and in the variant with sulfur in 2 times (from 1.65 mEq to 0.82 mEq).

These changes indicate the continuing chemical and physico-chemical processes that took place in the soil with the products of decomposition of the dissolved part of phosphogypsum ( $\text{Ca}^{2+}$  and  $\text{SO}_4^{2-}$ ) and formed sulfuric acid during the oxidation of some part of the elemental sulfur. They are manifested in marked increases in the content of  $\text{SO}_4^{2-}$  in comparison with the control variant. So, if on the control its content in the 0-40 cm layer of the soil was 4.50 meq, then in the variants with phosphogypsum and elemental sulfur, respectively, were 6.13 and 6.55 meq per 100 g. Soil content. The content of  $\text{Ca}^{2+}$  up to 4.0 meq or 0.80 meq is more compared to the control (3.20 meq) in the variant with phosphogypsum should be attributed to the part of phosphogypsum released into the solution, and its growth up to 3.75 meq-equivalents on a variant with elemental sulfur-account for the calcium of its carbonate, released into

the liquid phase of the soil as a result of its decomposition by sulfuric acid. It should also be noted here that a higher concentration of  $Mg^{2+}$  (0.90 meq per 100 g soil) in the sulfur variant is compared to phosphogypsum (0.68 meq), which can only be explained by the magnesium of its carbonate, which also appeared in solution as a result of its decomposition with sulfuric acid

The content of sodium ion in the water extract of the soil by spring is slightly less in comparison with the autumn one, which can be explained by washing it with autumn-early spring precipitation.

The effect of the ameliorant content of sodium ion turned out to be different. The effect of phosphogypsum on the content of sodium ion in the solution is manifested by the amount of calcium formed when dissolving gypsum phosphogypsum, providing for the displacement of an equivalent amount of absorbed sodium from the AUC into the solution, and elemental sulfur by the amount of  $Ca^{2+}$  formed by decomposition of calcium carbonate with sulfuric acid.

Thus, a ten-month incubation (26.06.15g to 26.03.16g) of phosphogypsum and elemental sulfur in the semihydromorphic soda-sulphate mid-solonchak high-sodium mean solonetz of the serozem zone had a significant effect on the content and composition of the salts, reconstructing their ionic composition, increasing the amount of salts and lowering the pH of the soil medium. Some reduction, especially on the variant with sulfur, requires the next stage of work on land reclamation washing from the original primary and newly formed secondary salts from the root layer of soils.

Before washing, the soil was plowed up to a depth of 25 cm. The soils of the control variants were not washed out due to extremely low water permeability, but were moistened with water of 1000 liters per plot or 667 m<sup>3</sup> / ha. Washing of soil with ameliorants was carried out in two stages (6.04.16 and 14.04.16) by submitting design standards for washing water in four cycles (two for each stage). The total volume of supplied washing water per plots amounted to 6900 liters or 4600 m<sup>3</sup> / ha. The water supplied by the last fourth cycle (1500 liters) to the plots with phosphogypsum was absorbed significantly slower (5 days) than in the cases with elemental sulfur, due to low soil permeability, (2 days). The noted indicate a weak meliorative efficiency of phosphogypsum on soil water permeability.

To determine the effectiveness of soil washing two weeks later (28.04.2016) sampled soil samples and determined the ion composition, their sums and pH of aqueous extract (table 4).

Table 4 – Результаты анализа водной вытяжки образцов почв, взятые после промывки,  $\frac{мг-экв}{\%}$

Variant	Depth, cm	HCO <sub>3</sub> <sup>-</sup>	CO <sub>3</sub> <sup>2-</sup>	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Na <sup>+</sup>	Total salts, %	pH
Control	0-20	<u>3.04</u>	<u>0.75</u>	<u>0.25</u>	<u>3.17</u>	<u>1.75</u>	<u>0.33</u>	<u>5.40</u>	0,738	8,6
		0,185	0,022	0,009	0,152	0,035	0,004	0,124		
	20-40	<u>3.04</u>	<u>0.64</u>	<u>0.36</u>	<u>3.42</u>	<u>1.58</u>	<u>0.33</u>	<u>5.55</u>	0,545	8,6
		0,185	0,019	0,013	0,164	0,032	0,004	0,128		
	40-60	<u>2.37</u>	<u>0.43</u>	<u>0.50</u>	<u>3.66</u>	<u>1.42</u>	<u>0.26</u>	<u>5.28</u>	0,503	8,6
		0,145	0,012	0,018	0,176	0,028	0,003	0,121		
Phospho-gypsum	0-20	<u>5.73</u>	<u>0.32</u>	<u>0.35</u>	<u>2.75</u>	<u>1.50</u>	<u>0.30</u>	<u>3.50</u>	0,617	8,5
		0,349	0,009	0,012	0,132	0,030	0,004	0,081		
	20-40	<u>3.00</u>	<u>0.40</u>	<u>0.35</u>	<u>2.75</u>	<u>1.92</u>	<u>0.33</u>	<u>3.83</u>	0,469	8,4
		0,183	0,012	0,012	0,132	0,038	0,004	0,088		
	40-60	<u>2.31</u>	<u>0.24</u>	<u>0.30</u>	<u>3.37</u>	<u>1.75</u>	<u>0.40</u>	<u>4.07</u>	0,455	8,3
		0,141	0,007	0,011	0,168	0,035	0,005	0,094		
Sulfur	0-20	<u>1.98</u>	<u>0.40</u>	<u>0.30</u>	<u>1.75</u>	<u>2.37</u>	<u>0.30</u>	<u>1.60</u>	0,315	8,2
		0,121	0,012	0,011	0,084	0,047	0,003	0,037		
	20-40	<u>2.01</u>	<u>0.36</u>	<u>0.20</u>	<u>3.33</u>	<u>3.62</u>	<u>0.63</u>	<u>0.55</u>	0,393	8,2
		0,123	0,011	0,007	0,159	0,072	0,008	0,013		
	40-60	<u>2.82</u>	<u>0.35</u>	<u>0.25</u>	<u>2.66</u>	<u>2.33</u>	<u>0.57</u>	<u>4.22</u>	0,471	8,3
		0,172	0,011	0,009	0,128	0,047	0,007	0,097		

From the analysis of the water extract, it follows that irrigation and washing of the soil promoted a sharp increase in the content of the ions  $[HCO]_{3}^{-}$  and the appearance of  $[CO]_{3}^{2-}$ , i.e. "flash" a sharp increase in alkalinity, especially on the control and on the variant with phosphogypsum.

For example, in the soils of the control variant before irrigation, the average content of HCOO in the 0-40 cm layer of soil HCO] <sub>3</sub> was 1.65 meq, and [CO] <sub>3</sub> (2-) was absent, after irrigation, the content of [HCO] <sub>3</sub>-grown to 3.04 meq and appeared [CO] <sub>3</sub> ^ (2-) in a significant amount (0.70 meq). Irrigation of the soils of the control variant contributed to a marked decrease in the concentration of the sulfate ion (from 4.50 to 3.30 meq), calcium (from 3.20 to 1.67 meq), magnesium (from 0.85 to 0.33 mg-eq) and sodium growth (from 2.65 to 5.47 meq), which resulted in a significant increase in the amount of salts (from 0.467 to 0.642%) and alkalinity (pH from 8.1 to 8.6) .

The results of the conducted washing of soils with meliorants proved to be ambiguous. If the soil washing on the variant with phosphogypsum resulted in a significant increase in the content of [HCO] <sub>3</sub> - - from 1.13 to 4.36 meq and [CO] <sub>3</sub> ^ (2-) to 0.37 meq (not before washing ), then on the variant with elementary sulfur, respectively, an increase in the contents of [HCO] <sub>3</sub>--from 0.81 to 2.00 and [CO] <sub>3</sub> ^ (2-) from 0.00 to 0.38 meq, ie . the latter created more favorable soil conditions for plants. The washing also had a positive effect on the content of SO<sub>4</sub> ^ (2-) in the soil, substantially reducing its concentration from 6.13 to 2.75 mEq for the variant with phosphogypsum and from 6.55 to 2.54 meq for version with sulfur. The effect of washing on the content of Ca<sup>2+</sup> in the soil solution manifested itself in significant decreases from 4.00 to 1.71 meq / eq in the variant with phosphogypsum and an insignificant decrease from 3.75 to 3.00 meq per variant with elemental sulfur. The same pattern is observed in the Mg<sup>2+</sup> contents, although its concentration is much lower than that of Ca<sup>2+</sup>. The flushing led to a decrease in Mg<sup>2+</sup> from 0.68 to 0.32 meq for the variant with phosphogypsum and from 0.90 to 0.46 meq for the variant with elemental sulfur.

The effect of washing on the content of Na<sup>+</sup> in the soil of the variants of the experiment also turned out to be ambiguous. On the variant with phosphogypsum it is noted that it increases from 2.84 meq to 3.66 meq, whereas on the variant with elemental sulfur, it decreases significantly (from 2.96 to 1.08 meq per 100 g soil) , which explains the high water permeability.

The results of quantitative changes in the ion composition of the liquid phase of soils from the introduced ameliorants, as well as the conducted washing of soils, had an ambiguous effect on the amount of salt. So, if the introduction of ameliorants led to an increase in the amount of salts in both phosphogypsum and elemental sulfur (with some advantage in the latter), the washing had an insignificant effect on the removal of salts (total 0.032%) in the variant with phosphogypsum from 0.527 to 0.543 %, and on the variant with elemental sulfur to significant desalination, where the salt content decreased from 0.527% to 0.354%. Moreover, after washing the salt on the variants with phosphogypsum became more toxic due to the "flash" of alkalinity.

**Conclusion.** The above factual materials obtained on the basis of the field experiment on the determination of the comparative meliorative efficiency of phosphogypsum and elemental sulfur on the medium-sulfate solonchak high-sodium semihydromorphic solonetz subzone of light serezems testify to the considerable advantage of elemental sulfur over phosphogypsum, which makes it possible to shorten the melioration period to one year.

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**АШЫҚСҰР ТОПЫРАҚ АЙМАҒЫНДАҒЫ ЖАРТЫЛАЙ ГИДРОМОРФТЫ  
ОРТАША СОДАЛЫ-СУЛЬФАТТЫ СОРТАНДАНҒАН КЕБІРДЕ ФОСФОГИПС ПЕН  
ЭЛЕМЕНТАРЛЫ КҮКІРТТІ САЛЫСТЫРМАЛЫ МЕЛИОРАТИВТІК ТИІМДІЛІГІ**

**Аннотация.** Жоғарыда келтірген ашық сұр топырақтар аймақшасының орта содалысульфатты сортаңдаған жоғары натрийлі жартылай гидроморфты кебірде фосфогипс пен элементарлы, күкірттің салыстырмалы мелиоративтік тиімділіктерін анықтау бойынша далалық тәжірибе негізінде алынған деректі материалдар элементарлы күкірттің фосфогипспен айтарлықтай артықшылығын растайды, сөйтіп мелиоративтік кезеңнің ұзақтығын бір жылға дейін қысқартуға мүмкіндік береді.

**Түйін сөздер:** alkali-saline soil, fertility, amelioration, sulfur, phosphogypsum.

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**СРАВНИТЕЛЬНАЯ МЕЛИОРАТИВНАЯ ЭФФЕКТИВНОСТЬ ФОСФОГИПСА И СЕРЫ  
НА ПОЛУГИДРОМОРФНОМ СРЕДНЕСОДОВО-СУЛЬФАТНОСОЛОНЧАКОВОМ  
СОЛОНЦЕ ПОДЗОНЫ СВЕТЛЫХ СЕРОЗЕМОВ**

**Абстракт.** В статье приведены данные полевых испытаний определения сравнительной мелиоративной эффективности эквивалентных доз фосфогипса и элементарной серы на содово-засоленном полугидроморфном солонце. На основании анализов водной вытяжки почв установлена более высокая мелиоративная эффективность элементарной серы и возможность ускоренной мелиорации содово-засоленных почв, с ее применением серы. Десятидневная инкубация фосфогипса и элементарной серы в полугидроморфном содово-сульфатном среднесолончаковом высоконатриевом среднем солонце зоны светлых сероземов оказали существенное влияние на содержание и состав солей, перестроив их ионный состав, росту суммы солей и снижению pH. Некоторое снижение, особенно на варианте с серой, требует проведения работ по мелиорации почвего промывки от исходных первичных и вновь образовавшихся вторичных солей из корнеобитаемого слоя почвы. Результаты количественных изменений в ионном составе жидкой фазы почв от внесенных мелиорантов, а так же проведенной промывки почв оказали неоднозначное влияние и на суммы солей.

**Ключевые слова:** содово-засоленная почва, плодородие, мелиорация, сера, фосфогипс.

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