Effectiveness of use of phosphogypsum on the solonetzic soils of Siberia and Ural

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Abstract. The problem of rational use of saline soils as applied to the specific region becomes one of the main problems in Russia as well as abroad. The article describes the potential possibility to include these soils for rational land utilization in agro-industrial complex system. This will allow us to broaden the degree of their utilization on ploughed fields, hayfields and pastures in Siberia and Ural. Area of these lands as applied to this territory is more than 10 million ha. Obligatory chemical melioration is required for using of these soils on the level of climatic soil type. Its carrying out using gypsum, phosphogypsum and other ameliorants-coagulants allows us to increase fundamentally the fertility of solonetzic soils with their following implementation as yielding agricultural fields. It’s important to note that influence of ameliorants-coagulants takes place up to 40 and more years and their dose is up to 20 t/ha for perennial grasses and 40 t/ha for crops. The mentioned regions possess mineral, productive and scientific resources for the solution of such an important problem in conditions of Siberia and Ural.

1. Introduction
At present moment the problem of use of saline soils is one of the main in the land utilization system. Saline soils include such soils which contain ready soluble soils in the amounts that are toxic for plants. The salt source for these soils are rock formation, product of volcanic eruption, eolian transport of salts, atmospheric precipitation ground waters, spray-type irrigative ground-waters, vegetation (salt warts). The most widespread among the saline soils are solonetzic soils containing in the occluded state an increased amount of exchangeable sodium in the illuvial horizon (more than 15% of the cation exchange capacity) [10].

Solonetzic soils possess some negative hydrophysical and chemical properties: high dispersion, swelling ability, weak water permeability and filterability, ash structure, slow process of physical maturity of the soil, adhesiveness in wet state, low water mobility, decreased air exchange, strong compression of soil material in case of drying up, solidity and high resistance, alkaline reaction of the media, salts toxicity, deficit of calcium and excess of sodium [1-5].

It’s suffice to note that the area of indicated soils in complex with climatic type soils in Ural and Western Siberia is more than 10 million ha (table 1) [6, 7].

| Region, territory | Total | 10-30 | 30-50 | >50 |
|-------------------|-------|-------|-------|------|
| Orenburg          | 1431  | 720   | 99    | 606  |


Territory including Orenburg, Chelyabinsk, Kurgan, Tyumen, Omsk, Novosibirsk regions and Altai territory is characterized by large heterogeneity of natural conditions. Here there are landscapes of dry steppe with kastanozems (Kulunda village, Orenburg region), landscapes of steppe with south and ordinary chernozems (Omsk, Chelyabinsk, Orenburg, Novosibirsk regions, Altai territory), landscapes of outlier with ordinary and solonetz chernozems (Chelyabinsk, Kurgan, Omsk regions) and landscapes of northern forest-steppe with chernozem-like meadow soils, lixiviated and gray forest soils (Tyumen, Kurgan, Chelyabinsk, Omsk, Novosibirsk regions and Altai territory) [8].

2. Materials and methods

During the ameliorative diagnostics of solonetzic soils a series of important characteristics is taken into account, in particular, soil complexes where among the climate type soils, the solonetzic soils occupy 10-30%, 30-50 and more than 50%. Fertile land with less than 10% of solonetzic soils is not taken into account in the ameliorative fund. In the complex soils with 10-30 to 50% of solonetzic soils, selective chemical amelioration is reasonable (if the solonetzic soils are located as small spots), and above 50% - continuous melioration. Hydrodynamic conditions determine numerous ameliorative properties of solonetzic soils. Type of these conditions are established according to the level of groundwater occurrence taking into account content of soil-forming and basement rocks.

The expedience of amelioration depends on the type of hydrological condition. Character of of solonetz use is determined according to this condition. Meadow solonetzic soils can be masters when the mineralization of ground waters doesn't increase critical values. Melioration of meadow-steppe and steppe solonetzic soils doesn't depend on condition of the ground waters (table 2) [7].

Table 2. Critical mineralization of ground waters depending on the depth of their occurrence and rock composition.

| Depth of groundwater occurrence, m | gault clay, light loam | Medium loam | medium clay, heavy loam | Mineralization, g/l |
|-----------------------------------|-----------------------|-------------|-------------------------|---------------------|
| <1.0                              | <1.2                  | <1.5        | <1.5                    |
| 1.0-1.2                           | 1.2-1.5               | 1.5-2.0     | 1.5-3.0                 |
| 1.2-1.5                           | 1.5-2.0               | 2.0-2.5     | 3.0-5.0                 |
| 1.5-2.0                           | 2.0-2.5               | 2.5-3.0     | 5.0-10.0                |
| 2.0-2.5                           | 2.5-3.0               | 3.0-3.5     | >10.0                   |
| >2.5                              | >3.0                  | >3.5        | -                       |

Salinization character of solonetz is depth of salt horizon occurrence, chemism and salinization degree. The most laborious solonetzic soils in a view of amelioration are those with high level of location of maximum of salts and with increased soda content.

Degree of solonetzicity of soils depends on exchangeable sodium and plays crucial role in calculation of chemical ameliorant dose. By the content of exchangeable sodium, solonetzic soils are divided into residual (less than 10% of base exchange capacity), soils with low sodium content (10-20%), soils with medium sodium content (20-40%) and soils with high sodium content (more than 40%). Methods of
solonetzic soils amelioration should be strictly differentiated in connection with quality and quantity variety [4].

During the amelioration of solonetzic soils (improvement of physical properties, creation of thick fertile layer, change of exchangeable sodium with calcium, removal of excess of water-soluble salts of root habitable layer) for the increasing of productiveness of growing cultures it's recommended to apply two main methods: chemical and self-amelioration method. Chemical amelioration method provides for introduction of chemical ameliorants from the outside. This method is the only way to increase the fertility of solonetzic soils with deep occurrence of carbonates and gypsum (deeper than 40-50 cm). It's reasonable to combine gypsuming with watering. In case of high occurrence of deep plantage plowing and step processing [7].

Texts carried out in Western Siberia and in Ural have proved high efficiency of chemical amelioration. Term of aftereffect continues more than 40-50 years [1-3, 5, 7, 8, 10].

Local gypsum deposits are located in Altai territory where there were found about 20 deposits. The most perspective for using is Zhira deposit (Zhira lake of Kuludinsk region), reserves of which are enough for complete amelioration of all solonetzic soils of Altai territory and neighboring regions of other territories. Its efficiency is checked and proved on the territory of West-Siberian region of Ural and Republic of Kazakhstan [4].

Enormous reserves of natural gypsum are located in Perm territory (Kungur town), carnallite deposit is near Solikamsk town. Carnallite has proved itself as good coagulant.

However, it's worth noting that waste of chemical industry – phosphogypsum is rather promising as ameliorant. Beside gypsum, it contains 0,5-1,5% of labile phosphorus (P$_2$O$_5$). Its enormous reserves are in Sverdlovsk region in Revda town.

Similar effect on soil is made by green vitriol – waste of paint and coatings industry. It's applied in Chelyabinsk region and is small grain powder with good flowability and weak caking ability, its dose should be increased in comparison with gypsum by 1.6 times.

As applied to Tyumen region, natural reserves of diatomite, zeolite and mud from the cleaning of Velijansk water intake artesian waters can be considered as important reserves of ameliorant-coagulant. It's worth noting that diatomite reserves in northern regions amounts to billions of tons. Preliminary laboratory tests show that the largest efficiency is demonstrated by heat-treated diatomite. The effectiveness of ordinary diatomite is very low. Zeolite and surface and artesian waters cleaning mud wastes influence selectively, taking into account chemism of soil salinization. This proves the necessity of industrial tests on their solonetzic soils of neutral and soda salinization.

It's important to note that the theoretical and practical issues connected with mastering of solonetzic soils received basis in the works by scientists from Siberia and other regions. However, taking into account genetic features of solonetzic soils in different zones and even within the limits of certain region, the constant improvement of applied methods of chemical and agrobiological amelioration and their complex use as applied to specific agro-ameliorative conditions is required.

The goal of studies is to reveal long-term consequence of calciferous ameliorants for hydrophysical and physical and chemical properties of solonetzic soils, their efficiency as applied to West-Siberian region.

Study objectives: to give theoretical and practical underpinning of dose of introduced ameliorant, taking into account the rate of exchange reactions outflow; to track the change of quantity and quality content of salts in soil under the influence of gypsuming with different doses, to establish possibilities of exchangeable sodium displacement from the absorbing complex for the long ameliorative period, to determine the response of crops-phytoameliorants to the long-term consequence of chemical amelioration.

Soil cover of test station in the northern forest-steppe (state farm "Vagayskiy" of Omutinskiy region) consists of long-fallow crusted and fine solonetz. According to the classification, it belongs to the meadow multisodium, high-carbonate, deep-gypsum and heavy-loam soils. An amount of exchangeable sodium in solonetzic horizon is 40-72% of exchange capacity. Maximal content of water-soluble salts (0,6%) is related to 10-40 cm layer.
Study methods: experiments were conducted on hydromorphic chernozem-meadow solonchak sulfate-soda medium-saline deep-carbonate deep-gypsum crusted multisodium column solonetz of the Tyumen region. Experiments on chemical amelioration were started in 1972, the area of plots is 400 m², repetition - 4 times. Exchange sodium was determined by the Gedroyts method. Analysis of the aqueous extract was carried out according to the following methods: alkalinity from soluble carbonates - potentiometrically, chloride ions - complexometricly, potassium and sodium by difference.

The studies have shown that during observational years, the level of weakly-mineralized ground waters varied from 1.2 to 2.4 m, its maximum was reached after complete snow melting. As control, long-fallow solonetz was used. Salt condition of long-fallow solonetz has shown that total content of salts in meter layer varied within the limits of 48-58 t/ha and their largest amount was reached during dry years. In the composition of salts, soda dominated - 28.2 t/ha, chlorides accounted for up to 7 t/ha, sulphates - 5.3 t/ha. The dominance of soda in solonetz gave them sulphate-soda salinization, which led to an increase in their alkalinity and toxicity. The introduction of phosphogypsum in 1972 significantly changed the qualitative and quantitative composition of the aqueous extract over the entire soil profile (Table 3).

| Layer, cm | CO$_3^{2-}$+HCO$_3^-$ | Cl$^-$ | SO$_4^{2-}$ | Σ anions |
|-----------|------------------------|-------|-------------|----------|
| Control, without ameliorant | | | | |
| 0-10      | 1.1                    | 0.6   | 0.5         | 2.2      |
| 0-40      | 5.7                    | 2.9   | 2.5         | 11.1     |
| 0-100     | 28.2                   | 7.0   | 5.3         | 40.5     |
| Phosphogypsum, 21 t/ha | | | | |
| 0-10      | 0.3                    | 0.2   | 1.0         | 1.5      |
| 0-40      | 1.9                    | 1.1   | 5.0         | 8.0      |
| 0-100     | 7.9                    | 4.6   | 16.7        | 29.2     |
| Phosphogypsum, 43 t/ha | | | | |
| 0-10      | 0.1                    | 0.1   | 0.9         | 1.1      |
| 0-40      | 0.7                    | 0.7   | 4.9         | 6.3      |
| 0-100     | 5.2                    | 3.1   | 17.2        | 25.5     |

With a full dose of phosphogypsum, the removal of soda from the soil profile was more intense, while the content of products of exchange reactions in the form of sulfates increased by 2 times. This phenomenon did not lead to an increase in the intensity of the salt regime, since the toxicity of sulfates is several orders of magnitude lower than that of soda. Thus, the amount of salts in meter layer has decreased in comparison with control variant by 15-20 t/ha. At the same time the essential decrease was noted at the expense of soda decrease. For the study years its content in this layer has dropped by 3.6-5.4 times. Under the complete dose of phosphogypsum, soda removal from the soil profile took place more intensive, at the same time content of products of the exchange reactions in a form of sulphates has increased by 2 times. This phenomenon didn't lead to the strengthening of salt condition intensity, since toxicity of sulphates is few times lower of that of soda.

The data of table 4 shows that introduction of ameliorants in full and half doses led to the significant weakening of solonetzicizity. Thus, initially the content of exchangeable sodium in crusted solonetz (0-40 cm layer) was on the level of medium-sodium to multi-sodium (28.8-53.4% of exchange capacity), then after the gypsuming in the mentioned doses the level of solonetzicizity decreased to the residual and low-sodium level, i.e, 2.2-19%. Accepted earlier provision on the short duration or total absence of ameliorative process in conditions of close location of the ground waters wasn’t confirmed. It’s important to note that phosphogypsum dose for 0-15 cm layer (21 t/ha) could be compared well with full calculated dose of a layer for 0-30 cm (43 t/ha) by its duration. Amount of exchangeable sodium maintained in 0-20 cm layer was on the equal layer under the half as well full dose of ameliorant.
Table 4. Content of exchange cations in meadow solonetz of sulphate-soda salinization for the ameliorative period of 1972-2006.

| Depth, cm | %, of exchange capacity |
|-----------|-------------------------|
|           | Na | K | Ca | Mg |
| Control, without ameliorant | | | | |
| 0-10      | 28.8 | 8.5 | 8.6 | 24.6 |
| 10-20     | 45.9 | 5.4 | 7.4 | 23.9 |
| 20-40     | 53.4 | 7.2 | 4.8 | 24.6 |
| Phosphogypsum, 21 t/ha | | | | |
| 0-10      | 4.4 | 7.2 | 18.3 | 18.4 |
| 10-20     | 4.4 | 3.4 | 16.4 | 16.4 |
| 20-40     | 19.0 | 5.8 | 26.3 | 26.3 |
| Phosphogypsum, 43 t/ha | | | | |
| 0-10      | 2.2 | 5.9 | 28.2 | 20.2 |
| 10-20     | 3.9 | 4.6 | 29.7 | 18.9 |
| 20-40     | 16.6 | 5.1 | 22.4 | 21.5 |

The efficiency of dry mass of perennial grass herbage during the study years by half-dose, was 21.2 centner/ha, in case of full dose – 24.7 centner/ha. It didn’t exceed 3.2 centner/ha on the long-fallow land (control).

3. Conclusion

Use of chemical industry waste – phosphogypsum on the crusted solonetzic soils allows us to obtain stable efficiency of perennial grasses for more than 34 years under the significant improvement of the main chemical properties of these soils. For the meadow formation on the ameliorated solonetz, it's enough to introduce full dose of phosphogypsum for 0-15 cm layer, calculated according to Gedroyts method. In the field crop rotation the dose of ameliorant should be calculated for the layer of 0-30 cm.

References

[1] Fedotkin V 1993 Solonetzic soils of Siberia and the Urals (Novosibirsk: Science)
[2] Kovda V 1937 Solonchak and solonetzic (Moscow: USSR Academy of Sciences)
[3] Berezin L 2006 Amelioration and the use of solonetzic soils in Siberia: monograph (Omsk: FGOU VPO OmGAU)
[4] Semendyaeva N 2014 Dynamics of salt composition of Baraba solonettes during the 27–32-year-old action of gypsum (Novosibirsk: NGAU)
[5] Novikova A 2004 Saline soils, their distribution in the world, the improvement of land and environmental issues (Kharkov: HNAU)
[6] Yeremchenko O 1997 Natural-anthropogenic changes in solonetzic soils in the Southern Trans-Urals (Perm: Perm University)
[7] Skipin L 2000 Siberian solonetzic soils: environmental aspects of development (Yalutorovsk)
[8] Khusainov A 2012 Opportunities for reclamation and development of solonetzic soils of Western Siberia
[9] Reclamation of solonetz of the Southern Urals and Western Siberia 1976
[10] Oborin A 1958 On melioration and development of solonettes in conditions of irrigated agriculture of the chernozem strip of Western Siberia Problems of melioration of solonettes (Moscow: USSR Academy of Sciences)