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Evaluating the Efficacy of Phosphogypsum as a Soil Amendment for Enhancing Fertility in Compacted Gray-Earth Soils of Kazakhstan During Comprehensive Land Reclamation

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ABSTRACT

The application of phosphogypsum as a bioameliorant for the restoration and rational utilization of compacted gray soils, saline, and degraded lands has gained increasing importance due to the need to mitigate the technogenic impact on the environment caused by industrial waste. This study aimed to investigate the potential of phosphogypsum as an alternative means for restoring compacted gray-earth soils in degraded and saline irrigated lands. Field experiments were conducted to assess the effectiveness of phosphogypsum application from both production and agroecological perspectives. Various doses of chemameliorants were applied to compacted gray-earth degraded and saline soils, and the optimal conditions for restoring soil fertility were determined under experimental field settings. It was observed that the use of phosphogypsum reduced the necessity for mineral fertilizers. Furthermore, phosphogypsum application was found to improve soil structure, resulting in an increase in humus content by 59.0-82.2%. The soil's ability to retain moisture was also enhanced, with an increase in porosity ranging from 20% to 30%. In the root zone, phosphogypsum created conditions conducive to crop production, with salinity levels decreasing by 50-75%. These findings suggest that phosphogypsum can be effectively employed as a soil amendment for enhancing fertility in compacted gray-earth soils during comprehensive land reclamation efforts.

1. INTRODUCTION

Mitigating the technogenic impact of industrial waste on the environment and investigating the potential application of phosphogypsum as a bioameliorant for the restoration and rational use of compacted gray soils, saline, and degraded lands are pressing concerns. The utilization of phosphogypsum holds significance owing to its potential to reduce the environmental impact of industrial waste while also serving as a bioameliorant to restore compacted gray soils, saline, and degraded lands. As a major waste product, phosphogypsum occupies vast areas, contributes to atmospheric pollution, and poses risks to the environment. Given the current agricultural landscape and anthropogenic impacts, it is imperative to implement novel agrotechnical measures that can aid in complex land reclamation. The potential of phosphogypsum, in conjunction with biological fertilizers, remains underexplored and warrants further investigation.

The present agricultural situation necessitates the development of new agrotechnical measures capable of meeting the requirements for complex land reclamation [1]. Anthropogenic impacts, resulting from human activity, give rise to detrimental environmental processes. Such circumstances call for the implementation of additional measures to facilitate the rational use of available water resources and industrial waste, particularly phosphogypsum. The combined use of phosphogypsum with biological fertilizers has been scarcely studied.

In addition to water resource scarcity, another critical issue is the environmental pollution and utilization of accumulated chemical industry waste, specifically phosphogypsum, which amounts to approximately 11 million tons in the territory of the Zhambyl region [1, 2]. Consequently, the existing chemical industry waste (phosphogypsum) can be employed as a biofertilizer and recommended for various types of compacted gray-earth soils, potentially improving their condition and increasing fertility [3-5].

Research has demonstrated that phosphogypsum application reduces the need for mineral fertilizers and enhances the physical and mechanical properties of saline soils, leading to increased humus content and moisture retention capacity. Furthermore, phosphogypsum fosters favorable conditions for crop development by decreasing salinity. The study also developed a technology for the use of organo-mineral fertilizer, which incorporates the application of phosphogypsum. Overall, the research suggests that employing phosphogypsum is an effective strategy to prevent soil degradation and boost fertility in Kazakhstan.

The objective of this study was to evaluate the feasibility of using phosphogypsum as an alternative resource for the restoration of compacted gray-earth soils in degraded and saline irrigated lands. The motivation behind this research is to address the current agricultural challenges and anthropogenic impacts, which demand additional measures to optimize the use of available water resources and industrial waste, specifically phosphogypsum, and to advocate for sustainable and resource-saving technologies in agricultural crop cultivation.

This article comprises several sections, beginning with an Introduction that emphasizes the importance of alleviating the technogenic impact of industrial waste on the environment and the potential application of phosphogypsum as a bioameliorant. The Materials and Methods section details the experiment conducted on solonized lands in Kazakhstan to ascertain the optimal dose of phosphogypsum application. The Results section presents the findings, including the positive impact of phosphogypsum on soil structure, humus content, moisture retention, and salinity reduction. Finally, the Conclusions section encapsulates the benefits of using phosphogypsum and underscores its significance in addressing soil compaction and salinization challenges in Kazakhstan.

2. LITERATURE REVIEW

A review of the scientific literature reveals that the application of phosphogypsum to irrigated lands results in improvements to the soil's water-physical properties, such as increased absorption capacity and porosity [6]. Additionally, changes in the degree of soil super dispersion are observed [7], the acidity of the lower soil layers is reduced, and the rate of water absorption accelerates by 30-35%, consequently creating favorable conditions for the water supply of cultivated crops [8]. The use of phosphogypsum as a fertilizer is reportedly 25 times more cost-effective than concentrated mineral fertilizers. This is attributed to the ability to achieve twice the effect from its usage and the opportunity to dispose of waste (up to 10 tons/ha) while employing it as fertilizer for degraded compacted gray-earth soils in the southern region of the Republic of Kazakhstan [4, 6-10].

Addressing this issue necessitates conducting additional research to identify suitable agro-reclamation measures for implementing complex land reclamation, using resource-saving technologies in the cultivation of agricultural crops [4]. Numerous studies have emphasized that proposed agrotechnical measures should resolve not only plant nutrition issues but also consider the unique characteristics of the environment [11] and the creation of favorable conditions for the agricultural landscape [1].

In light of this, optimal methods for liberating lands from phosphorus-containing waste have been identified in the literature [6, 9, 12]. Under the prevailing circumstances, it is essential to reevaluate existing approaches, technical and design solutions, and plan for their future implementation. The adoption of specific measures for performing complex land reclamation can improve the condition of irrigated lands prone to compaction, salinization, and soil solonetization. Additionally, the implementation of complex land reclamation procedures is necessary following recultivation on sandy and sandy loam land territories.

The research gap lies in the scarcity of detailed studies examining the optimal application rates and methods for utilizing phosphogypsum as a bioameliorant and fertilizer across various soil types and crops. While some references highlight the benefits of phosphogypsum, such as the enhancement of soil water-physical properties and the reduction of soil acidity, limited information exists regarding its potential impact on crop yield, soil structure, and other soil properties.

3. MATERIALS AND METHODS

On the territory of Kazakhstan, there are solonized lands, and it is recommended to use chemical reclamation in order to improve conditions of irrigated lands and during cultivating technical, fodder, vegetable and various crops in arid regions of the republic. In this regard, for the use of waste from the chemical industry - about 92% of gypsum is not used by-product of phosphoric acid production, where only 2.0% of phosphogypsum was used. Therefore, it leads to that authors have the necessary reserves of this chemical ameliorant in sufficient quantities.

In order to achieve the goal and solve the task, it is necessary to carry out gypsum plastering, i.e., to reduce the alkalinity of the soil on degraded lands and increase the fertility of irrigated lands. At the same time, the volume oof phosphogypsum usage is produced according to the standard of ST RK 2208-2012 as a source of calcium and phosphorus. Ways of optimal use of phosphogypsum were proposed during the experiment, which allows increasing soil fertility.

The principal difference and feature of this research is an integrated approach for solving the issue and implementing the technology of phosphogypsum application on compacted gray-earth soils and saline soils on irrigated lands with the determination of its optimal dose. Therefore, for this purpose there several variants of application and determination of the soil properties processes were used by regulating the physico-chemical properties and nutritional regimes when applying different doses of phosphogypsum.

Experimental field surveys were conducted in accordance with the current regulatory documents and approved methods and techniques, norms and rules of technological and environmental safety with the most effective and acceptable methods such as: effectivness assessment of phosphogypsum application from the point of view of production (yield, land use, etc.) or agroecological (soil fertility, changes in agricultural landscapes) features. Based on the conducted research results an economic assessment of adapted farming systems (in particular for the Zhambyl region) is carried out, the influence of various doses of phosphogypsum on the water-physical and physico-chemical properties of compacted gray soils is determined, after that there will be developed scientifically-based, ecological and meliorative methods of regulating the fertility of irrigated soils and crop yields [13-16].

Field studies were conducted at experimental sites where optimal norms for the phosphogypsum application on compacted gray-earth soils were established and will be carried out in subsequent variants using the necessary methodology for determining the main indicators of changes in the properties of degraded soils with the following options [7]:

- without apply of phosphogypsum (control);
- with apply of phosphogypsum (norm of 2 tons/ha);
- with apply of phosphogypsum (norm of 4 tons/ha);
- with apply of phosphogypsum (norm of 6 tons/ha).

The degree of salinity is reduced by applying different doses of phosphogypsum step by step during conducting experiments on compacted gray-earth soils [9, 17, 18]. The effect of phosphogypsum in a humid environment was determined during experiments. The sequence of experiments necessary to begin with the application of phosphogypsum at a dose calculated for compacted gray soils. If there are more than 50% spots in saline areas, then the estimated application rate of phosphogypsum per 1 hectare of irrigated land is used. The dose of phosphogypsum directly depends on the depth of saline layers. Phosphogypsum is applied during the plowing process in compacted gray earth soils. At the same time, in accordance with agrotechnical requirements the application of phosphogypsum is carried out using tractor trailers-spreaders RUM-8 and 1RMG-4. In this regard, the applied dose of phosphogypsum should correspond to the required moisture content, which is necessary to maintain and ensure the content of humus at the normative soil moisture [9, 17].

4. RESULTS

The way that section titles and other headings are displayed in Currently, a large amount of stale phosphogypsum have been accumulated on the territory (location of waste dumps) of LLP "Kazphosphate" (Figure 1).

Figure 1. Existing storage facilities of stale phosphogypsum near the city Taraz

This meliorant-phosphogypsum is an excellent tool for restoring the salt balance in saline and degraded agricultural soils. Currently, a roadmap has been prepared and approved, where issues related to the realization of waste from the phosphorus industry used for agricultural needs, in general, to solve ecological problems of Zhambyl region.

From the scientists' researches of the globe, it is known that when applying phosphogypsum to cultivated areas, it is possible to regulate the degree of salinity of soils. The conducted studies on phosphogypsum dumps allowed making the following conclusions, i.e., the existing stale phosphogypsum has large volumes. Based on the analysis, it was found that the composition of phosphogypsum included elements of the periodic table, such as: oxides of calcium-gypsum, sulfur and silicon with some impurities of iron oxides, aluminum, magnesium, phosphorus, sodium, etc. And phosphogypsum consists of gypsum and an admixture of quartz according to the mineralogical composition.

In the follow up message of the President to the people of Kazakhstan as of September 1st 2021, the head of State emphasized the necessity for additionally development of degraded lands up to 40%, which are currently in poor condition and it is necessary to manage the irrigated lands to 3.0 million hectares. Based on the above, it is possible to determine the main leading directions that allow increasing the yield of agricultural crops using modern methods and land cultivation technologies. However, in order to increase the volume of food production it is necessary to use available land resources rationally and cost-effectively. Based on monitoring, it was identified that in the present 1.7 million hectares of irrigated lands were under the threat of degradation. Land degradation is accompanied by intense soil salinization, which ultimately leads to the territory increase of compacted and saline desert regions in water basins in the south and southeast part of the republic. Currently about 30% of lands used for irrigation in agriculture, which are located in the South of the republic do not meet required quality and these lands were subject to compaction and salinization, alkanization and thus have significant losses of nutrients in the region. Such created anthropogenic and ecological conditions of lands require to find out additional opportunities and measures for the rational use of natural resource reserves, to improve existing methods with the essential technological solutions for the increase of land fertility properties [1, 2]. The process of increasing the productivity and stability of soils requires the improvement and implementation of innovative technologies using the most optimal variants of technical solutions.

It is known that the soil environment is a dynamic environment that evolves when the conditions of plant development change through additional plant nutrition, fertilization, climatic fluctuations and the influence of anthropogenic effects on increasing crop yields with the correction of soil properties, i.e., carrying out complex land reclamation. In modern conditions, when the acute issue is to provide lands with water resources and the possible solution of this problem is to use water-saving technologies with the correct implementation of agro-reclamation measures.

The proposed optimal technology for applying phosphogypsum will improve soil properties (water-physical, agrochemical) and the ecological condition of the environment, increases both the fertility of irrigated lands and the productivity of agricultural crops. The proposed option is economically justified and water-saving and most effective ways developed in order to preserve the fertility of land and thereby prevent the negative consequences resulting from irrigation [15, 16, 19]. Based on the experimental results, the following conclusions can be drawn: to improve efficiency with various options for applying phosphogypsum (different doses), it provides the needs of cultivated crops for Ca and the required sulfur [6]. In the structure of phosphogypsum applied to the soil as a fertilizer, the ameliorant consists of the following constituent elements such as calcium and phosphorus, which make it possible to increase the yield of agricultural crops cultivated on irrigated lands. The presented and applied biomeliorant - phosphogypsum does not require additional cleansing works, since phosphorus is in a molecular state, the ion is easily absorbed by cultures [3, 11]:

$$N = 0.08(Mg - 0.3E)*h*d \quad (1)$$

where, N is the required volume of phosphogypsum, t/ha; Mg is exchangeable magnesium in mg-eq per 100 g of soil; E is the exchange capacity in mg-eq per 100 g of soil; h is the thickness of the soil layer used for melioration, cm; d is the soil density, g/cm^3.

According to the data obtained from field experiments, the following conclusions can be drawn: when processing between rows, it is necessary to use phosphogypsum in a volume of 3-6 t/ha. Based on the calculations the main payback indicators were determined, the expenditure costs used for reclamation measures were determined and justified. On compacted saline and solonetzics soils depending on the zone location of arid regions and applied reclamation measures the expected pay off period within two or three years (Figure 2).

Soil characteristics indexes were obtained at the experimental site (Figures 2-3), where the thickness of humus layer consisted 25-37 cm, the humus content has changed within 0.35%, and this indicator decreased to 0.2% at a depth of 150 cm, total nitrogen has changed in the range of 0.15-0.178%, gross phosphorus changed up to 0.29%, mobile varied within 20-22 mg/kg of soil, gross potassium changed 1.5-2.0%, pH varied between 4.8-6.0. In the soil, the following indicators change as: this is the content of physical clay 70-75%, the density of the soil is 1.51 g/cm3, the specific gravity of soil's solid phase is 2.62 g/cm3, their porosity has changed within 40-50%, the content of physical clay (less<0.01mm) in the arable layer reached to 65.9%; silt content changed to 22.8%; the volume of sand reached up to 10.3%. Based on the received calculated data it can be said that the distribution of the above indicators throughout the field is evenly, as well as the distribution of fractions along the profile is uniform. From the analysis it can be observed that dehumanization and the reduction of humus layer process, which must be restored by applying ameliorants.

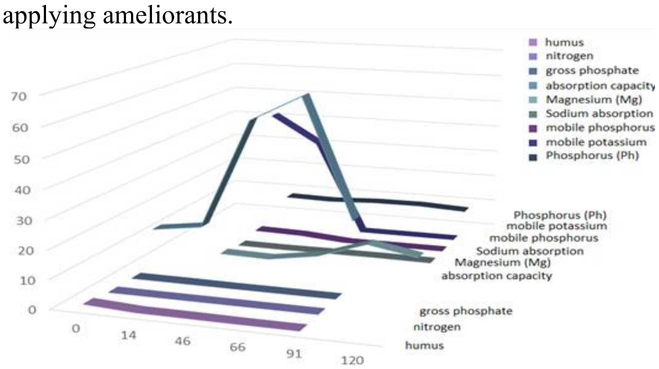

Figure 2. Index of soil sample analysis results of investigated area

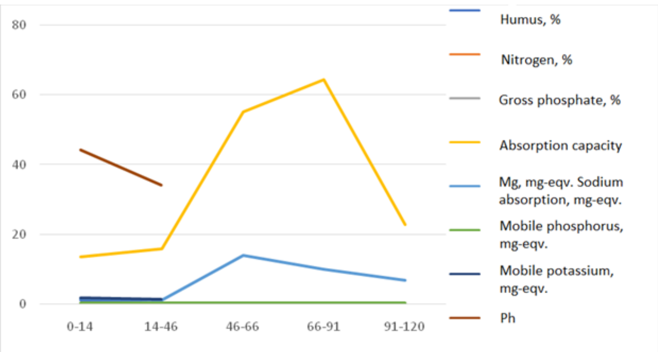

Figure 3. Results of water extraction analysis

The soil moisture content on irrigated lands increases when conducting experiments with various options (plots without phosphogypsum and plots with different doses of phosphogypsum) of applying phosphogypsum, also occurs reduction of irrigation water loss for evaporation and dumping more than 2 times, provides uniformly plant development, meanwhile the following results were determined: this is an increase in alfalfa yield by 3.9-7.2 t/ha, it follows that these indicators change from 40 to 80%, and the proportion of alfalfa hay produced varied within the range of 1.00-1.88 t/ha or equaled to 35-65%. When comparing various experimental options, good yield indicators were shown when applying fertilizer in the form of phosphogypsum in the amount of 6 t/ha.

From obtained results it can be seen that an increase in soil activity when applied phosphogypsum during meliorants are applied to the upper layer of the soil. In case of phosphorus is applied at 8-5 mg/kg, generally it improves the growth and development of industrial crops such as beets and increases yields on average from 24-25 t/ha to 30-36 t/ha (Figure 4) [15, 16].

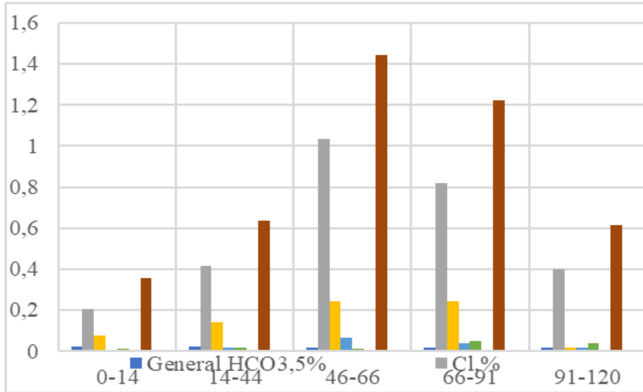

Figure 4. Results of soil samples analyses with determination of cations and humus content

Most of the resulting mineral salts dissolve during water exposures to the soil and pass into an aqueous extract, in which they can be determined by appropriate methods. Consequently, according to the analysis of water extraction from the soil, it is possible to judge the sanitary condition of the soil, i.e., the nature and degree of soil contamination with organic substances, the intensity of their mineralization and the completeness of the process of self-purification of the soil (Figure 5).

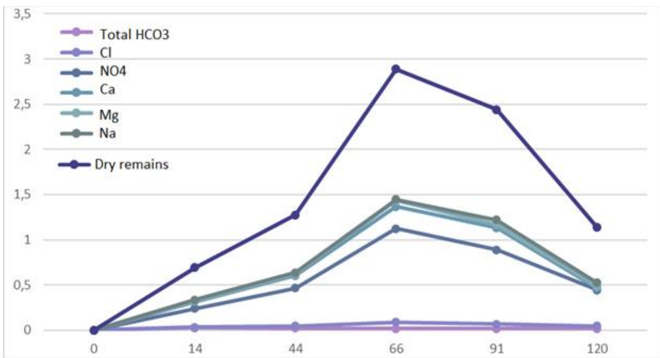

Figure 5. Results of water extract analysis

There is the humus layer is presented in a small form of about 20-40 cm, in which contains no more than 1.19% of humus, the soil belongs to low-humic, also called poor soil. In dry conditions occurs enhanced mineralization of humus and organic matter, which leads to a slight accumulation of humus. Hence, the peculiarity of the soil formation zone is weakly expressed processes of humus formation and redistribution according to the profile of water-soluble salts. The zone occupies over 2.0 thousand hectares, of which about 30% are alkali soils and solonetzic soils, 36% are sandy soils.

The climate of the zone is extremely arid, the average annual temperature is over +18°C, the average temperature in July is up to +35-45oC, and the soil temperature is up to +80°C. Precipitation falls 70-150 mm, mainly in winter and early spring. They are blown away into negative topography forms. Zonal soil types are gray-brown soils, takyrs and desert-sandy soils. There are also meadow and meadow-marsh saline soils.

Serozems are characterized by a relatively low content of humic substances - from 1 to 4%. In addition, they are distinguished by an increased level of carbonates. These are alkaline soils with insignificant indexes of absorptive capacity. In their composition contain a certain amount of gypsum and easily soluble salts. One of the properties of serozems is the biological accumulation of potassium and phosphorus. Soils of this type contain quite large amount of easily hydrolyzable nitrogen compounds. The soil formation process, i.e., humus formation and mineralization of organic substances proceeds in the spring season. Therefore, the content of humus is 1-1.19%, Cation Exchange Capacity (CEC) = 13.6-64.4 meq/100g. Humus is often distributed throughout the profile. At a depth of 60-90 cm lies a layer of gypsum. Serozems are characterized by microporosity, i.e., very high microbiological activity. The high alkalinity and carbonate content of the soil increases from the depth 46 cm and deeper.

Light gray soils develop on foothill plains, low mountains and deserts. They are formed on loess-type loamy, loess, sandy and fine-earth structures. The profile of light gray soils is represented by the following horizons:

- turf (thickness from 4 to 14 cm);
- humus (no more than 65 cm thick);
- transitional (thickness from 65 to 90 cm);
- carbonate illuvial with inclusions of fine-grained gypsum (up to 120 cm thick).

In this case, in the upper layers of light gray soils it contains from 1% to 1.19% of humic substances, among the components of which fulvic acids dominate, but has a low absorption capacity.

The generally accepted fundamental scheme of the genesis and evolution of saline soil is the sequence “solonchak - solonetz - licorice” proposed by K.K. Gedroits. From this scheme follows the task of solonetz soil melioration - to replace the illuvial horizon (15-30 cm: the depth of the illuvial horizon varies for different soil objects) of solonetz sodium to calcium, which contain in the soil absorption complex (SAC). This improves the structure, increases the water permeability of the soil, ensures the leaching of easily soluble salts, optimizes conditions for the development of the root system, plant nutrition and soil biota, accordingly, increases the biological productivity of agricultural plants [3, 4, 11].

Moreover, there is the application of biomeliorant (soil treatment product), which contains of calcium. The dose of the biomeliorant is determined by calculating the amount of calcium in the soil equivalent to the sodium content in the SAC in the calculated soil layer (Lyubimova; Baibekova; Semendyaeva, Goss). The scheme of K.K. Gedroits over the last century has been successfully widely tested in the world [15, 17]. In order to improve the quality of gray-earth soils located in the lands of Akkol village in Talas region, beside irrigation processes it is recommended to apply the proposed bioameliorant, which aimed to prevent secondary salinization. When phosphogypsum is used separately as a fertilizer, it simply spreads to the top of the earth and does not provide soil desalination. In each case it is necessary to choose the appropriate horizon for phosphogypsum application.

To resolve the issue of improving fertility and reducing the salinity degree of gray-earth soils, a technology for obtaining and applying organomineral fertilizer based on cattle manure, camel thorn and phosphogypsum was developed, at a small installation for the production of biomeliorant, which reduces the loss of nitrogen and organic matter and increases the phosphorus content.

Applications of a new biomeliorant made from cattle manure with the supplementation of crushed camel thorn and phosphogypsum, which is a source of gypsum, calcium and sulfur. According to calculations this method allows reducing the loss of nitrogen and organic matter up to 40%. This method is simple, energy-efficient, allows obtaining a highly effective fertilizer that improves the physical, chemical and biological properties of the soil, which helps to increase the yield of crops, for a short time.

The conducted researches showed that the use of the biomeliorant as an organic fertilizer gave several positive aspects:

1. The organic-mineral biomeliorant contains a fairly large amount of nitrogen, lignin and sulfur, which is both like a slow-acting source of mineral nutrition elements, and as a source for the formation of humus, an environmental place for the development of microorganisms, which means a reliable source of nutrients for plants.
2. The calcium contained in the organic-mineral biomeliorant provides favorable conditions for the formation of optimal water-physical properties of the soil.
3. The organo-mineral biomeliorant contains a certain amount of mobile nutrients, macro - and microelements, which are necessary for plants.
4. The use of the organo-mineral biomeliorant, which contains up to 6% organic carbon, allows solving one of the most important problems of modern agricultural production - ensuring a deficiency-free balance of humus in degraded soil.
5. The obtained mixture can be used as a universal land reclamation component applicable for introduction on solonetzic soils and which allows achieving an acidified mixture containing of $CaSO_4$, and if on acidic soils, then, respectively, slightly alkaline, saturated $CaCO_3$.

Conducted research studies on agricultural crops (winter wheat, lettuce, fodder beet), both in laboratory, vegetation experiments, and in the field, everywhere statistically reasonably showed an increase in yield. Also, experiments were conducted in an intensive garden, where significant positive changes were recorded in the development of dwarf apple trees [20].

The study of the obtained organic-mineral biomeliorant effect on the environment shows their effectiveness from an ecological point of view. The usage of these kind of fertilizers reduces the removal of nitrate ions that are particularly dangerous in relation to pollution of water sources. The ammonium ion is completely trapped in the upper layers of the meter-thick soil. Apparently, this is mainly due to the content of lignin (30-50%) in organic-mineral fertilizers, which fixes mobile ammonium.

The calculation of biomeliorant doses containing phosphogypsum, which is necessary for the land reclamation of compacted gray - earth soils is carried out according to the following formula:

$$Pt/ha = 0.086(Na - 0.05CEC)*h*d = 0.086\ (5.1-0.075\cdot 55.2)*22*1.47 = 5.5\ tn \quad (2)$$

where, P - dose of phosphogypsum; Na - content of absorbed sodium (mg/eq per 100 g of soil); 0.086 - converting mg/eq to grams; CEC - cation-exchange capacity; h - reclaimed layer thickness capacity; d - soil density.

The application of the proposed biomeliorant into the soil leads to a noticeable improvement in its structure and physical properties. Thus, pH = 7.0-7.2 or soil pH becomes close to neutral. Humates, which are introduced into the soil by the biomeliorant, are in a stable calcium form, in contrast to the predominantly sodium humates contained in the soil environment. This contributes to the fixation of organic matter in the soil and thereby improves the soil structure. The improvement of the water-physical and agrochemical properties of the soil largely occurs as a result of the structure formation of compacted gray-earth soils.

Thus, when making applications, the economic effect increases received income by 300-500 dollars per hectare. From the gained experience it can be said that the usage of phosphogypsum on fused soils allows to consume water rationally. After the application of phosphogypsum 2.5-4.5 t/ha, the volume of absorbed water in furrows varies from 350-600 m^3/ha to 600-900 m^3/ha per day.

5. DISCUSSION

Wei and Deng [21] also researched the effectiveness of using phosphogypsum to improve soil conditions. He established that a fairly common and promising approach to the use of the above-mentioned element was its processing into complex mineral, as well as organo-mineral fertilizers and composts. Thus, he supports using phosphogypsum, but in a modified form. In addition, the researcher emphasizes that composting makes it possible to dispose of waste, which helps to clean the environment and increase soil fertility. Revealing its features, he claims that composted phosphogypsum, which got into the soil, is decomposed by living organisms in the process of vital activity. Thus, decomposition and assimilation of nutrients occurs, which in turn contributes to the neutralization of organic toxicants, in particular phosphorus compounds. The given position is completely relevant, as it meets and satisfies several interests at once, namely the processing of harmful elements and increasing soil fertility. This indicates the priority of spreading this method of using phosphogypsum in the future.

Similar opinions are expressed by Outbakat et al. [22], who analyzed the periodicity of the use of phosphogypsum in order to improve the condition of the soil. Their research showed that phosphogypsum should be applied to the soil in the fall, as well as to the frozen soil in the spring. He came to this conclusion as a result of studying statistical data, as well as indicators of a specific area, namely plowing at 23-25 cm. Therefore, according to the study of Outbakat et al. [22], the specifics of using phosphogypsum in the specified terms are determined by certain features. They consist in the fact that in autumn, as well as in early spring, under conditions determined by a water-saving irrigation regime, as well as, regardless of the method and tools of the main tillage, the quantity and quality of the harvest changes, namely increases. Thus, he proves that due to this approach, the affinity of the soil, which is expressed in the harvest, is clearly increased. The expressed position might be partially true, as the scholar draws attention to the fact that the researcher studied the processes of growing soybeans. This factor cannot indicate the effectiveness of applying phosphogypsum to the soil in autumn and spring in Kazakhstan, which requires additional measurements and research.

Wang [23] paid special attention to the fertility of directly compacted soils. He managed to determine how the above concepts relate to each other. Thus, he established that soil compaction is usually equated with the concept of “soil structure degradation”. This process is negative in the context of the impact on the quality and condition of the land, as it consists in an increase in bulk density, as well as a decrease in soil porosity. It is important that soil compaction can occur due to both natural and mechanical factors. Wang [23] established that at the moment the degradation of the soil structure occurred to a greater extent as a result of the action of large agricultural machines. The researcher noted that compaction negatively affected the complex of soil properties, which included physical, chemical and biological indicators. Based on this, he came to the conclusion about the low fertility of compacted soils, which causes an urgent need to increase it. Because of this, he proposed a number of measures aimed at avoiding and reducing the dynamics of land compaction. These include drainage, liming, covering the soil with vegetation, ensuring the supply of organic elements from plant residues, proper processing, and the use of special compositions. In this case, the author fully agrees with the above ideas. He believes that the obtained conclusions justify the possibility and effectiveness of using phosphogypsum as a fertilizer.

In turn, Silva et al. [24] investigated this issue with the aim of describing phosphogypsum as a tool for reducing the negative impact of external and natural factors on the condition and fertility of the soil. They established that the effectiveness of using the above-mentioned compound is high provided that it is neutralized, which provokes a decrease in its acidity level. Thus, it has been proven that phosphogypsum is introduced into the soil in order to increase its fertility, when it has lost its physico-chemical, as well as marketable properties. Thus, the views of this scholar are similar to the first, as he also justifies the feasibility of using processed phosphogypsum in the form of a complex fertilizer. This process of modifying a chemical compound consists in treating it with a phosphate solution, filtering and drying the finished element. The disclosed approach is correct, as it is believed that the processing of phosphogypsum contributes to the production of complex mineral fertilizer.

Bouray et al. [25] paid special attention to the process of applying fertilizers, in particular phosphogypsum, to the soil. The noted that during the implementation of any technological procedures, especially in relation to grey-earth compacted soils, it was necessary to conduct field research. The researchers justifie this approach by the fact that effective use of mineral fertilizers and other chemical compounds designed to increase soil fertility is possible only if the required dose is accurately calculated. As for phosphogypsum, Bouray et al. [25] note that it contains a number of impurities, which in turn can be toxic to plants, and therefore can affect the harvest. This above statement is relevant, as the urgent need for a careful approach to the use of various compounds and their application to the soil is emphasized.

From a different point of view, this issue was considered by Dyck et al. [26] who studied the process of increasing the fertility of gray earth soil in the context of its reclamation. In this case, it was based on an approach that consisted in using phosphogypsum to clean the soil of contamination. Mostly, this state of the land is caused by oil getting into it, which is a frequent phenomenon in agricultural activities. This approach corresponds to the present study, as it also applies to the improvement of the condition of soils, in particular compacted gray soils. However, it is emphasized that the rate of introduction of meliorants must necessarily correspond to the volume of the spilled chemical substance, in particular oil.

The discussion made it possible to assess the expediency of using phosphogypsum in soil preparation processes. The views of the researchers coincide to a greater extent, which indicates the priority of such an approach, including for gray earth compacted soils of Kazakhstan. At the same time, the main condition is high-quality preparation of phosphogypsum for its rational use and corresponding increase in soil fertility.

6. CONCLUSIONS

Application of phosphogypsum significantly reduces the use of mineral fertilizers. The use of phosphogypsum fundamentally improves the physical and mechanical properties of both saline and saline soils. Improves the structure of the soil, which ultimately leads to an increase in the content of humus in the soil to 59.0-82.2%. Increases the ability to retain moisture with an increase in porosity from 20% to 30%. Phosphogypsum creates in the root zone favorable conditions for the development of crop production with a 50-75% decrease in salinity.

In addition, the priority of using phosphogypsum directly in Kazakhstan was characterized, as it was established that about 1.7 million hectares of irrigated land are under threat of soil compaction and salinization. It certainly affects the fertility and, accordingly, the amount of harvest in these territories. It was important to reveal the peculiarities of the composition of phosphogypsum, since these elements affect the condition of the lands to which it is applied. It was determined that it consists of calcium and phosphorus. These components are responsible for the development of agricultural crops.

In addition, calculations related to the indicators of gray earth compacted soils in Kazakhstan were made. Based on their analysis, the technology of formation and use of organo-mineral fertilizer was developed and described, namely phosphogypsum on the usual mechanism for the production of biomeliorant. The implications for managers and policymakers are the following. The use of phosphogypsum can improve soil quality and increase crop yields, particularly in areas facing soil degradation and salinization. The study provides a potential solution for improving agricultural productivity and addressing food security challenges in Kazakhstan. The development of organo-mineral fertilizers, particularly phosphogypsum-based biomeliorants, offers a promising approach to addressing soil degradation challenges. The contribution of this study lies in its focus on the specific application of phosphogypsum in Kazakhstan and the development of an effective approach for using it as a biomeliorant. The study's findings enrich the study of soil improvement approaches and provide valuable insights into the benefits of using phosphogypsum. The study's emphasis on the need for further research on reducing the negative impact of agricultural machinery on soil compaction is a useful area for future research. Overall, the study highlights the importance of sustainable agriculture practices and offers practical recommendations for improving soil quality and increasing agricultural productivity.

REFERENCES

[1] Shmelev, S.E., Salnikov, V., Turulina, G., Polyakova, S., Tazhibayeva, T., Schnitzler, T., Shmeleva, I.A. (2021). Climate change and food security: The impact of some key variables on wheat yield in Kazakhstan. Sustainability, 13(15): 8583. https://doi.org/10.3390/su13158583

[2] Department of Industrial and Innovative Development of Zhambyl region. (2022). https://www.gov.kz/memleket/entities/zhambyl-kasipkerlik.

[3] Khozhanov, N.N., Musabekov, K.K., Seitkaziev, A.S., Esengeldieva, P.N., Estayev, K.A., Khozhanova, G.N., Tursunbaev, K.I. (2017). Comprehensive reclamation - the basis of the green economy in agriculture. International Scientific Review, 5(36): 1-6. https://cyberleninka.ru/article/n/kompleksnaya-melioratsiya-osnova-zelenoy-ekonomiki-v-zemledelii.

[4] Zhilenko, S., Akanova, N., Vinnichek, L. (2016). Agro-economic effectiveness of application of new forms of fertilizers based on phosphogypsum in maize crops. Mezhdunarodnyĭ Sel'skokhozyaĭstvennyĭ Zhurnal, (2): 55-59.

[5] Maazoun, H., Bouassida, M. (2019). Phosphogypsum management perspectives. Massive valorization or massive storage. Acta Scientific Agriculture, 8: 184-189. http://dx.doi.org/10.31080/ASAG.2019.03.0584

[6] Karpenko, N.P., Egemberdiev, D.K., Glazunova, I.V. (2022). Biomeliorant for the restoration of saline and degraded soils in the arid zone. In IOP Conference Series: Earth and Environmental Science, 1010(1): 012044. https://doi.org/10.1088/1755-1315/1010/1/012044

[7] Ponomareva, Y.V., Belichenko, I.S. (2005). Effect of phosphogypsum on soil properties germination of winter wheat seeds. Ekologicheskie Problem Kubani, 27: 184-192.

[8] Khozhanov, N.N., Seitkaziev, A.S., Tursunbaev, Kh. I. (2019). Energy of intensive farming system. Problems of Science, 36: 1-12

[9] Khozhanov, N.N., Tursunbaev, Kh., Masatbayev, M., Nurabayev, D., Assis, P. (2019). Empirical relationships of humus formation in soils in the arid zone of Kazakhstan. Repositorio Institucional Da UFOP, 8(12): 1739-1743 https://doi.org/10.21275/ART20203498

[10] Moalla, R., Gargouri, M., Khmiri, F., Kamoun, L., Zairi, M. (2018). Phosphogypsum purification for plaster production: A process optimization using full factorial design. Environmental Engineering Research. https://doi.org/10.4491/eer.2017.05512

[11] Shoba, S., Yakovlev, A., Rybalsky, N. (2013). Standardization and Regulation of Environmental and Soils Quality and Land Management. Moscow: NIA-Priroda.

[12] Saadaoui, E., Ghazel, N., Romdhane, C., Massoudi, N. (2017). Phosphogypsum: potential uses and problems - a review. International Journal of Environmental Studies, 74(4): 558-567. http://dx.doi.org/10.1080/00207233.2017.1330582

[13] Tleshpaeva, D.I., Auesbekov, N.R., Ermekbaev, B.K. (2021). Efficiency of agricultural land use in Kazakhstan. Moscow Economic Journal, 7: 134-146.

[14] Fisher, J. (2014). Global Agriculture Trends: Are We Actually Using Less Land? Cool Green Science. https://blog.nature.org/science/2014/06/18/global-agriculture-land-sustainability-deforestation-foodsecurity/.

[15] Pismennaya, E.V., Stukalo, V.A., Volters, I.A., Azarova, M.Y., Perederieva, V.M., Faizova, V.I. (2019). Optimization of Agriculture Land Use Development Basing on Natural-resource Potential (On the Example of

the Stavropol Territory). KnE Life Sciences, pp. 448-457. https://doi.org/10.18502/kls.v4i14.5632

[16] Sayer, J., Cassman, K.G. (2013). Agricultural innovation to protect the environment. Proceedings of the National Academy of Sciences, 110(21): 8345-8348. http://dx.doi.org/10.1073/pnas.120805411020

[17] Tleshpaeva, D.I., Auesbekov, N.R., Ermekbaev, B.K. (2021). Efficiency of agricultural land use in Kazakhstan. Moscow Economic Journal, 7: 134-146. https://cyberleninka.ru/article/n/effektivnost-ispolzovaniya-selskohozyaystvennyh-zemel-v-kazahstane.

[18] Khozhanov, N.N., Tursunbaev, Kh.I., Masatbaev, M.K., Khozhanova, G.N. (2019). Evaluation of empirical relationships between humus formation and energy factors in the arid zone of Kazakhstan. Series of Agricultural Sciences, 1(49): 40-45. https://doi.org/10.32014/2019.2224-526X.5

[19] Musaev, A.I., Khozhanov, N.N., Tursunbaev, Kh.I. (2019). Fundamentals of energy efficiency of wastewater irrigation in Kazakhstan. Ways to Improve the Efficiency of Irrigated Agriculture, 4(76): 88-94. https://elibrary.ru/item.asp?id=41506312.

[20] Essengeldiyeva, P.N., Mussabekov, K.K., Nurabaev, D.M. (2020). Water Consumption by a Young Apple Orchard of Intensive Type. Journal of Environmental Management and Tourism, 5(45): 1176-1183. https://doi.org/10.14505//jemt.11.5(45).1525

[21] Wei, Z., Deng, Z. (2022). Research hotspots and trends of comprehensive utilization of phosphogypsum: Bibliometric analysis. Journal of Environmental Radioactivity, 242: 106778. https://doi.org/10.1016/j.jenvrad.2021.106778

[22] Outbakat, M.B., El Mejahed, K., El Gharous, M., El Omari, K., Beniaich, A. (2022). Effect of phosphogypsum on soil physical properties in Moroccan salt-affected soils. Sustainability, 14(20): 1-17. http://dx.doi.org/10.3390/su142013087

[23] Wang, J. (2020). Retracted: Utilization effects and environmental risks of phosphogypsum in agriculture: A review. Journal of Cleaner Production, 276: 1-14. http://dx.doi.org/10.1016/j.jclepro.2020.123337

[24] Silva, L.F., Oliveira, M.L., Crissien, T.J., Santosh, M., Bolivar, J., Shao, L., Schindler, M. (2022). A review on the environmental impact of phosphogypsum and potential health impacts through the release of nanoparticles. Chemosphere, 286: 131-135. http://dx.doi.org/10.1016/j.chemosphere.2021.131513

[25] Bouray, M., Moir, J., Condron, L., Lehto, N. (2020). Impacts of phosphogypsum, soluble fertilizer and lime amendment of acid soils on the bioavailability of phosphorus and sulphur under lucerne. Plants, 9(7): 883. http://dx.doi.org/10.3390/plants9070883

[26] Dyck, M., Sorenson, P.T., Lejoly, J.D., Quideau, S.A. (2022). Gray Luvisols are polygenetic. Canadian Journal of Soil Science, 1: 1-45. http://dx.doi.org/10.1139/CJSS-2022-0035