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ON THE STUDY OF PHYSICOCHEMICAL PROPERTIES OF SOILS IN THE REGIONS OF THE REPUBLIC

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Abstract: In the case of increasing anthropogenic load and changing climate factors, the study of the physical properties of soils in various regions of the Republic is becoming especially relevant. Particular emphasis is placed on the parameters of water-holding capacity, sorption ability, bulk density, and porosity, as these factors play a decisive role in the productivity of agroecosystems and the stability of land resources. In this study, a detailed analysis of serozem and saline soils was performed using desiccator-based water vapor sorption isotherm techniques, complemented by the application of structure-modifying additives of organic and polymeric nature. Various doses of additives (sulfonyl and carboxymethyl cellulose) were used in varying doses for 50 g of air-dry soil in the experimental part. An increase in specific surface area and porosity is achieved by adding it, but sulfonyl and its composite systems have a more noticeable impact on capillary moisture. The comparative analysis revealed that optimal dosages provide an increase in moisture capacity of up to 20-25% compared to control samples. Therefore, the obtained results contribute not only to a deeper understanding of the physical properties of soils but also provide practical guidance on the application of organic additives aimed at improving agronomic qualities and increasing the efficiency of reclamation measures under the conditions of the Republic.

Keywords: organic additives, soil, aggregate state, soil structure, water retention, specific surface area, volume and pore radius.

Introduction. The relevance of research on physical properties of soils in regions of the Republic is due to a combination of ecological and agricultural problems: degradation of arable aquifers, salinity, reduction of moisture capacity and change of pore structure affect productivity and sustainability of agro-ecosystems. Addressing practical issues related to soil restoration and enhancing their water-retention capacity requires a comprehensive evaluation of physical parameters such as specific surface area, pore volume, pore radius distribution, and sorption potential, along with an assessment of how mineral and polymer additives influence these characteristics.

The inclusion of micronutrients contributes to improved soil productivity and resilience against various environmental stresses. Foliar application helps regulate the soil's water balance, leading to higher uptake of nitrogen, phosphorus, and potassium by crops. Current scientific efforts in this field are directed toward creating and implementing innovative fertilizer types and application technologies, which, combined with optimized water management, result in increased crop yields and better product quality [1].

Natural ores with valuable agrochemical qualities such as swelling and water retention, as well as the presence of valuable macro- and microelements in their composition, can be added to fertilizers to provide controlled properties [2].

Based on literature data, it is known that the different types of soils differ not only in particle size, but also have different mineralogical and chemical compositions, therefore, and the content of nutrients, for example, in the composition of physical clay (<0.01 mm), represented by medium and fine dust, fine lecithin and colloidal fractions, are predominantly secondary aluminosilicate minerals. These fractions contain more aluminum and iron, as well as calcium, magnesium, potassium, sodium, phosphorus and other plant nutrients. Therefore, heavy by granulometric composition clay and clayey soils, in which there are more silty and colloidal particles, richer than sandy and sugestive elements.

This issue is especially pressing in the Karakalpakstan region, where more than 70% of agricultural areas are exposed to arid climatic conditions, poorly developed soil structure, and significant secondary salinity [3]. The decline in water levels of the Amu Darya River and the desiccation of the Aral Sea have disrupted the regional water balance, resulting in a notable reduction in soil fertility and crop productivity. According to data from the Ministry of Agriculture of Uzbekistan, soil degradation on irrigated lands in Karakalpakstan leads to annual yield losses of up to 30% [4]. A detailed understanding of the soil characteristics in this region is therefore crucial for developing targeted measures to mitigate salinization and enhance soil structure through innovative technological and material approaches [5].

Against this background, research focused on enhancing soil moisture retention and sorption characteristics gains particular relevance. These parameters determine the soil's capacity to store and supply water essential for plant development, especially during the vegetation period. In arid regions, where precipitation is scarce and uneven and irrigation resources are limited, optimizing the soil's water regime becomes a decisive factor in achieving sustainable agricultural production.

Aggregate composition characterizes the ratio of structural units of different sizes present in the soil. The soil structure reflects the way particles are bound into aggregates that can break apart under external forces. These aggregates consist of fine mechanical particles and smaller structural units interconnected through physical and chemical bonds. Depending on their size, structural units are divided into microaggregates (<0.25 mm), mesoaggregates (0.25–10 mm), and macroaggregates (>10 mm). Aggregates with a diameter of 1–5 mm are considered the most favorable for maintaining soil fertility. Soils with a well-developed structure demonstrate superior water and air permeability, better temperature regulation, high erosion resistance, and create optimal conditions for seed germination and root system development. In quantitative terms, well-structured soils contain more than 80% aggregates of 1–5 mm, medium-structured soils — 30–80%, and poorly structured — below 30% [6].

The role of soil structure in agricultural production is of great importance, as it directly influences the soil's physical properties, water–air balance, and overall fertility [7]. The stability of soil aggregates against mechanical stress and their resistance to disintegration during wetting depend on maintaining favorable structural conditions through systematic tillage and irrigation. When these factors are not ensured, soil structure deteriorates rapidly under the effects of cultivation, rainfall, or irrigation, leading to the formation of structureless soils. In a wet state, such soils tend to become waterlogged, whereas upon drying, they form a dense surface crust [8, 9].

It is essential to recognize that not all soil structures are of agronomic value. A favorable structure is one in which aggregates are loosely packed, well-porous, and capable of absorbing water easily, providing access for microorganisms and plant root hairs. The agronomic importance of soil structure is determined by its considerable effect on physical properties, water–air balance, temperature regulation, redox and microbiological activity, nutrient availability, and erosion resistance [10].

The ability of soil to retain moisture plays a fundamental role in maintaining its water regime and supplying plants with the necessary amount of water. This capacity depends on the texture, organic matter content, and stratification of the soil profile. Soil moisture, defined as the volume of water the soil retains against gravity, is one of the key parameters influencing plant growth and overall soil health. The current research analyzed the adsorption and water-retention behavior of different soil samples [5].

Materials and Methods. Soil samples were collected from various genetic horizons to investigate their agrochemical, chemical, and agrophysical characteristics under laboratory conditions. Samples intended for the assessment of biological activity were taken from depths of 0–30, 30–50, and 50–70 cm, placed in sterile containers, and collected during different seasons. The principal soil properties were determined using established analytical methods and standard procedures [11]. The following parameters were evaluated: specific gravity of the soil in air (ϱ_{air}), in water (ϱ_{wat}), in benzene (ϱ_{ben}), and in mercury (ϱ_{P}). These density values characterize distinct physical aspects of the soil. The air (or dry) density represents the ratio of the oven-dried soil mass to its total volume. To determine this parameter, soil samples were dried to constant weight at 105 °C and the corresponding volume was measured.

Results and Discussion. Research involves obtaining samples of salted soil from regions with depths of 0-30, 30-50, and 50-70 cm in sterile containers.

Table 1 presents the structural-porous characteristics for two soil samples with different parameters of density and porosity. The total soil density, including pores and air spaces, is determined by the density of soil through air (ρ_{air}). The air density values for sol and salted soil are 1.71 g/cm³ and 1.56 g/cm³ respectively. The soil in mesothelial areas is more compacted than the soil in salted areas, as per this explanation.

Table 1. The properties of soil samples that are both structural and porous

Sample	ρ_{air}, g/cm³	ρ_{wat}, g/cm³	ρ_{benz}, g/cm³	ρ_p, g/cm³	Λ_1, %	Λ_2, %
serozem soil	1,71	2,56	2,71	1,96	33,2	27,7
saline soil	1,56	2,48	2,53	1,57	37,1	37,9

The determination of soil density using water as a dispersing medium provides a measure of the soil's density relative to water. Based on the obtained data, both serozem and saline soil samples exhibit a relatively high solid-phase density—2.56 g/cm³ for serozem and 2.48 g/cm³ for saline soil. The parameters ϱ_{ben} and ϱ_p were employed to refine the evaluation of soil porosity, as benzene and mercury interact differently with the soil matrix, allowing for a more detailed characterization of its pore system. Variations in porosity and pore structure between these soil types are reflected in the measured values. The porosity coefficients Λ_1 and Λ_2 were found to be 33.2% and 27.7% for serozem, and 37.1% and 37.9% for saline soil, respectively. These results indicate that serozem soil possesses a more developed pore structure and greater aeration capacity compared to saline soil. Below is a qualitative and quantitative generalization of the effect of the studied additives on key physical parameters of soils (results obtained under laboratory conditions, 1% solutions, volumes 4, 6 and 8 ml per 50 g dry air mass (table 2)). The table uses nouns: «↑» - increase compared to control; «↓» - decrease; «≈» - minor change; «±» - dose-dependent (non-linear effect).

Table 2. Effect of additives on specific surface area (Ssp), pore volume (Vp) and moisture capacity (W) for sub-clay soil (serozem) and sub-sand soaked (saline) soils

Sample	Additive (volume, ml per 50 g)	Ssp (specific area)	Vp (pore volume)	W (moisture capacity)
sub-clay soil (serozem, control)	—	base	base	base
sub-clay soil	Sulfonyl 4	↑	↑	↑
sub-clay soil	Sulfonyl 6	↑↑	↑↑	↑↑
sub-clay soil	Sulfonyl 8	↑ (sometimes ±)	↑ (stabilization possible)	↑ (possible saturation)
sub-clay soil	CMC 4	↑	↑	↑↑
sub-clay soil	CMC 6	↑↑	↑↑	↑↑↑
sub-clay soil	CMC 8	↑↑ (film formation)	↓ (partial occlusion of small pores)	↑ (significantly)
sub-sand soaked (saline soil, control)	—	low	low	low
sub-sand-soaked soil	Sulfonyl 4–8	↑ (less pronounced)	↑	↑
sub-sand-soaked soil	CMC 4–8	↑ (moderately)	↑↑	↑↑

As shown in table 2 for loamy soils, sulphonyl and carboxymethyl cellulose (CMC) additives have the most pronounced effect of increasing moisture content and surface area; Carboxymethylcellulose has a strong effect on water retention due to gelation and film formation on soil particles. At high volumes (8 ml per 50 g), there is a tendency to partial «filling» of interpolar spaces (decrease in fine volume) in some samples. Sulfonyl as a surfactant changes the pore radius distribution, contributes to an increase in the available sorption surface and can improve the adsorption of benzene along with water. In sub-sand samples, the effects are smaller in absolute value, but the relative gains are significant - the addition of polymers increases fineness and overall moisture content. CMC contribute to the growth of small and medium pores due to the binding of particles and the formation of thin water-conducting films. This explains the increase in moisture content and slow evaporation during dessication.

Conclusion. Based on the above data, it can be concluded that the values for soil from the serozem and saline soils are 2,56 g/cm^3 and 2,48 g/cm^3, which indicate a high density of the solid phase of the soil for both samples. The values for sol and salinity vary, indicating different degrees of porosity and pore structure in these soils.

The results are in line with current understanding of the influence of polymer additives and surfactants on soil structure and sorption: polymers increase fine particle aggregation, increase water retention by forming hydrophilic molecular layers and creating additional fine polymers, while surfactants (sulfonyl) modify interphase interactions and improve the availability of sorption surfaces for non-polar solvents (benzene) and water.

Practical interpretation of the indicators Sp and Vp allows to assume optimal dosages: for loamy soils effective volumes were 4-6 ml/ 50 g at 1% solution concentration (the balance between increasing moisture capacity and maintaining permeability, and for sub-sandy soils the recommended ratio is 6 ml/50 g as a compromise between economic and technical effect. Further increase the volume (8 ml) gives an increase in moisture capacity, but risks to break permeability and lead to partial blockage of small pores, which is especially important for strip application into deep horizons.

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