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Problems of Regulation of Structure Formation in Soil Using Water-Soluble Polymers

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ABSTRACT: This article draws attention to the relevance of using water-soluble polymers to regulate soil structure. The practical importance of water-soluble polymers in various industries such as medicine, food production and environmental protection is introduced. The focus of the article is on the application of these polymers to improve soil quality and reduce erosion. The article emphasizes the importance of: enhancing soil stability and fertility, mechanisms to improve soil aggregation through polymer integration, the use of water-soluble polymers to optimize soil structure.

In conclusion, the urgency of the problems associated with the efficient use of water-soluble polymers is emphasized. Among these problems are the determination of optimal doses, methods of application and the assessment of environmental consequences. The article highlights the need for further research to fully unlock the potential of water-soluble polymers in agriculture and environmental protection.

KEYWORDS: water-soluble polymers, soil structure, improvement of soil aggregation, soil stability, polyacrylamide, structure formation, polymer emulsion.

I.INTRODUCTION

Water-soluble polymers (WP) have found wide practical importance in the branches of modern industry [1–3] and the national economy, such as the food, pharmaceutical, paint and varnish, textile, paper industries, in the production of adhesives and protective coatings, and in the purification of natural and waste waters [4, 5].

Water-soluble polymers are used in the manufacture of dosage forms such as tablets, capsules, injections, etc. They can be used as coatings on tablets to protect them from the effects of stomach acid and also to regulate the rate of drug release. VP can be used as thickeners, stabilizers, emulsifiers and gel formers in food products. They can also be used to improve the texture and taste of foods.

Some VPs are used to make films and bags such as hygiene bags, biohazard bags, and detergent bags. They can be used to create biodegradable materials, which is an important step in reducing the impact of plastic on the environment [6-8].

These are just a few examples of water soluble polymers, their use can be found in many other industries.

II. SIGNIFICANCE OF THE SYSTEM

This article draws attention to the relevance of using water-soluble polymers to regulate soil structure. The study of methodology is explained in section III, section IV covers the experimental results of the study, and section V discusses the future study and conclusion.

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III. METHODOLOGY

Today's social impact has led to a violation of the natural balance in the biosphere, resulting in an active decrease in soil fertility and intensification of their degradation processes, especially on a global scale. Nearly 2 billion hectares of arable and pasture land have already suffered from moderate to severe degradation, with more than half of the damage caused by water erosion and about a third by wind erosion. In this regard, the use of polymeric materials to improve soil characteristics, fix mobile sands and increase the stability of soil aggregates is one of the possible ways to solve this problem.

To combat soil erosion and improve its sustainability, scientific research is being carried out aimed at finding solutions [8, 9]. One of the key criteria for preventing erosion is the structural stability of the soil. To improve it, phytomelioration, additives of natural and chemical origin are used, which contribute to the formation of a strong structure of aggregates [10, 11]. Polymers are considered an effective material for preventing erosion and improving soil fertility [12, 13]. Especially water-soluble polymers (WP) show excellent results in protecting soil and water, maintaining moisture and loose soil structure [14]. It follows that more and more countries and researchers are joining research on the use of polymeric materials to prevent sand erosion [15].

Among the widely available water-soluble polymers, the most common are polyacrylamide, polyethylene glycol, polyvinyl alcohol, and polyvinylpyrrolidone, which are widely used in various sectors of the national economy, including soil cultivation [16–18].

The stability of soil aggregates depends on their composition and structural features. Water-soluble polymers used as structurants have a strong effect on soil structure due to their ability to adsorb water in excess of more than 400 times their weight. This affects the rate of infiltration and evaporation of moisture, density and porosity, as well as the structure of the soil system [19].

IV. EXPERIMENTAL RESULTS

Soil Aggregate Stabilization Mechanism Using Polymers. The mechanism of soil structure stabilization with the help of synthetic polymers is based on the adsorption of macromolecules on soil particles [20–23].

Possible benefits from the use of polymers for structure formation depend on factors such as molecular weight, macromolecular structure, and charge density [23-25]. Studies have shown that soil treatment with polymer solutions leads to a change in the shape, size, and bonds between its aggregates. The interaction of structure-forming macromolecules and soil particles occurs on their surface; therefore, a significant factor is the surface area of the soil disperse system [26]. However, the amount of polymers associated with large soil particles such as sand and silt is negligible compared to the amount associated with finer clays [27]. Therefore, a greater change in soils with a high content of adsorption-active clays is expected than in sands.

Suspensions of polymer and clay particles were used to study the mechanism of steric stabilization in soils [28, 29]. The results of the study showed that when clay particles approach a distance exceeding the thickness of the adsorption layer on their surface, the polymer chains of both surfaces begin to block each other, as a result of which the value of the Gibbs free energy of the system increases, and the system tends to a more energetically favorable state, remaining at a certain distance between the contacting particles.

Aggregates of mineral disperse systems treated with polymer structurants are more stable than particles treated with electrolytes. This occurs due to bridging flocculation, which occurs due to the binding of one macromolecule of several soil aggregates [30]. At the same time, high rates of bridge flocculation are achieved depending on the amount of polymer, which leads to an increase in the strength of aggregates, or to an excess of the saturation capacity of the polymer, which contributes to the detection of lubricating characteristics and sliding of soil particles over each other [31].

The commercial liquid polymer SS299 was used to increase the strength of the residual soil in Malaysia [32]. A study of the effect of SS299 and ductility on time-dependent compressive strength showed that the addition of 6% polymer additive significantly increased compressive strength after 7 days of curing. Micrographs of the treated samples indicate that the polymer treatment changes the structure of the system and lighter layers are formed on the soil surface.

One of the functions of the soil is the size distribution of particles, which affects the hydraulic conductivity of the soil [33]. Soil treatment with a polymer solution can change the soil structure and hydraulic conductivity of soils, which can lead to an increase in water absorption [34, 35]. Studies [36-38] show that soils treated with polymers have a lower level of moisture release compared to untreated ones, which indicates a change in the structure of the system after treatment with polymers.

Water-soluble polymers for structure formation in soil. Polyacrylamide is a class of water-soluble polymers with unique properties that are widely used in various fields such as oil production, chemical industry and water treatment [39-41]. However, conventional polyacrylamide has low temperature, salt and shear resistance, so its use is limited.

Since the early 1950s, polyacrylamide has been used to control soil erosion [42]. This is due to the fact that it effectively improves the structure of aggregates and their stability at low costs for tillage of the soil surface [43, 44]. A flocculant such as PAA is able to bind soil particles, which reduces negative physicochemical effects and increases porosity between contacting particles, which accelerates water infiltration and improves the stability of soil aggregates [45, 46].

The cationic form of polyacrylamide showed the best results in increasing the stability of soil aggregates by 17–18% and increasing the infiltration rate by more than 2 times [47]. The positive effect of PAA treatment on plant growth and survival in arid soils has been confirmed [48], and it is widely used in agriculture as a soil stabilizer, as well as a structurant to retain water in the soil system in fields and for wastewater treatment [49].

From the studies carried out, it becomes clear that in order to maintain soil stability, it is not necessary to apply polymer solutions throughout the entire growing season. To evaluate the effect of various polymers on maintaining irrigation, studies were conducted of distilled water rainfall on Arlington sandy soil treated with solutions of polymers T-4141, CP-14, cationic polysaccharide, and anionic PAA [20]. The maximum impact of various classes of polymers applied at a concentration of 10 g/m^3 on maintaining irrigation is reduced in the order: T-4141>CP-14>PAA. Based on the data obtained, it can be assumed that cationic and nonionic polymers are adsorbed on the surface of soil particles, increasing interactions between particles, contributing to stable aggregation of the system. The effectiveness of treatment with T-4141 and CP-14 in subsequent showers of distilled water is lower than the first, and in the case of treatment with PAA and the first and second showers, the protective characteristics were preserved.

In addition, the scientific basis for the effect of acrylic polymers on soil microbiocenosis has been developed. In laboratory experiments, PAA hydrogels showed a slight stimulation of the growth of bacteria of the genus Pseudomonas, as studies have shown [50, 51].

In addition to traditional industrial polymer materials, polymer emulsion has been introduced. In [52], the goal was to study the effectiveness of lateritic soil stabilization using liquid soil stabilizers Canlite and Probase. A study of these polymers has shown that the addition of Canlite and Probase improves the physical properties of the lateritic soil, such as yield strength and unconstrained compressive strength (UCS), while the latter's ability is significantly higher.

The PAA-based polymer can improve soil quality, especially when tilled at planting time, as it prevents crust formation before plant emergence and increases soil resistance to water and wind erosion. This polymer also contributes to the formation of water stable aggregates, which improves soil filtration and permeability [53]. Previous studies on the use of polymers to prevent soil erosion have been performed under laboratory and mild field conditions. However, little is known about the effect of polymers on soil aggregates under extreme rainfall conditions. One study compared PAA and polyvinyl alcohol (PVA) to prevent soil erosion. The results showed that PAA was more effective than PVA in reducing total runoff during the first precipitation. In addition, the efficiency of polymer treatment also depends on the dispersity of the initial soil, and the best results are achieved with the stabilization of aggregates with a diameter of 6.4 mm.

The use of polymers that create artificial structures in the soil, especially in combination with fertilizers, can reduce the harmful effects of human activities on the soil, maintain its fertility and increase crop yields [54, 55].

The article [56] presented the results of a study of a complex consisting of a biopolymer of chitosan and a synthetic polymer of polyacrylic acid, which was used for soil structure formation in the East Kazakhstan region. The complex consisted of equal proportions of different polymers, and was optimized for best results, where the ratio of chitosan to polyacrylic acid was 1:9. Mixing these two polymers resulted in higher mechanical strength of the films compared to using only one of the polymers. The use of this solution to stabilize the strength of soil aggregates improved the structure of the soil and increased its anti-deflation resistance. Soil treatment with a mixture of polymers led to a decrease in soil water erosion and an increase in its resistance to this type of erosion up to 99%. The results of the study recommend the use of a mixture of bio- and synthetic polymers for structure formation and improvement of the anti-erosion properties of degraded soils.

The limitation of the wide use of synthetic water-soluble polymers as structurants is associated with their high cost, according to [57]. However, research aimed at the synthesis of polymers with organomineral fillers, such as sawdust, is promising due to cost reduction and rapid biodegradation, which provides an additional source of nutrition of trace elements and organic carbon. Polyacrylamide gel can also serve as a good carrier for most fertilizers, pesticides, fungicides, herbicides and insecticides, as mentioned in [58].

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Natural biopolymers are renewable raw materials for soil structuring. Hydrogels based on natural and/or synthetic biopolymers can retain large amounts of water and nutrients and release them slowly. The use of natural biopolymers, together with synthetic polymers, has distinctive features, such as biodegradability and high functional characteristics [59].

The use of synthetic polymer materials and mixtures based on industrial waste often leads to contamination of soil and groundwater, as well as a change in its pH level. However, there are methods of tillage that are environmentally friendly. For example, the use of a biopolymer based on xanthan gum for the structure formation of soil dispersions has been investigated. The results showed that increasing the concentration of the biopolymer leads to an improvement in the adhesion and strength of the treated sand, as well as a decrease in its permeability. The higher the concentration of the biopolymer, the greater the number of bonds per unit surface of the treated sand [60].

V. CONCLUSION AND FUTURE WORK

Thus, the article draws attention to the problems associated with the regulation of structure formation in the soil when using water-soluble polymers. In the context of agriculture and agricultural production, the use of water-soluble polymers to improve the structural properties of the soil and increase its fertility is an urgent task.

One of the main problems is to determine the optimal doses and conditions for the use of water-soluble polymers in different types of soils and agricultural systems. This requires an integrated approach, taking into account the specifics of the soil, climatic conditions, cultural practices and requirements for end products. Much attention is paid to studies aimed at determining the optimal physicochemical properties of water-soluble polymers, their interaction with soil particles and microorganisms, as well as assessing their effect on structural changes in the soil.

In general, the problems of regulating structure formation in soil using water-soluble polymers require further research and development. It is necessary to deepen the understanding of the interaction of polymers with soil, develop optimal methods and conditions for their application, identify optimal doses and application regimes, and conduct an environmental assessment of their impact on the soil ecosystem. Further research in this area will lead to the development of new technologies and recommendations that promote a more efficient and sustainable use of water-soluble polymers in agriculture and other areas related to soil structure formation.

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