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Применение почвенных кондиционеров для контроля эрозии: научный обзор

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Аннотация. Эрозия почвы наиболее важная экологическая проблема в сельскохозяйственном производстве. Известно, что почва является одним из важных и ограниченных стратегических природных ресурсов. Земельный фонд необходим для обеспечения экономической и продовольственной безопасности государства. В тоже время почва подвержена деградации от эрозионных процессов. Эрозия почвы представляет собой серьезную экологическую угрозу для сельского хозяйства и социально-экономического развития страны. По мнению различных исследователей, почвенные кондиционеры (почвоулучшители) являются одним из методов предотвращения и уменьшения эрозии почвы. Целью данного научного обзора было изучение данных об использовании почвенных кондиционеров для контроля и уменьшения водной эрозии в сельском хозяйстве. В ходе исследования был проведен обзор литературных источников по проблеме применения почвенных мелиорантов для борьбы с эрозией почв. Анализ и охват литературы составил 44 года (1976–2020 гг.). Почвенные кондиционеры используют для уменьшения поверхностного стока и капельной эрозии, улучшению инфильтрации и стабилизации почвенных агрегатов. Почвенные кондиционеры используют в жидком или сухом виде. Приведены данные о концентрации почвенных кондиционеров, рекомендованные разными исследователями.

Ключевые слова. Почва, эрозия, почвенный кондиционер, почвоулучшитель, полиакриламид, гипс, фосфогипс.

Erosion control by application of soil conditioners: scientific review

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Abstract. Soil erosion is the most important environmental problem for rural lands. It is well known, that soil is one of the important and limited strategic natural resource for ensuring the economic and food security of the country. At the same time, the soil is subject to degradation from erosion processes. Soil erosion is a major environmental threat to the sustainability and productivity of agriculture and socio-economic sustainable development of the country. According to various researchers, the soil conditioners (soil improvers) are one of the methods to prevent and reduce soil erosion. The purpose of this scientific review was the study of data in use of soil conditioners to control and reduce water erosion in agriculture. During this study, a review of the literature aimed on the problem of using of soil ameliorants to combat soil erosion was carried out. The retrospective of the literature search was within 44 years (1976–2020). Soil conditioners are used to reduce surface runoff and splash erosion; they are increase infiltration and stabilize soil aggregates. Soil conditioners are used in liquid or dry forms. The data on the concentration of soil conditioners recommended by various scientists are given.

Keywords. Soil, erosion, soil conditioner, soil improver, polyacrylamide, gypsum, phosphogypsum.

Introduction. Soil erosion is the most important environmental problem for rural lands. As it is known, that soil is one of the important and limited strategic natural resource for ensuring the economic and food security of the country. It is easily to subject for degradation by erosion. Soil erosion is a major environmental threat to the sustainability and productivity of agriculture [1] and socio-economic sustainable development [2–3].

According to various researchers, the soil conditioners (soil improvers) are one of the methods to prevent and reduce soil erosion. These substances are well known in their effect on soil structure. The most important aspect of using soil conditioners is their aggregating and stabilizing effect on the soil. This property of soil conditioners has been widely used since the invention of the first soil conditioner in the 1950s [4]. Also, conditioners improve the soil fertility and reduce erosion [5].

The soil conditioners are used in the form of organic substances, polyvalent salts and various synthetic polymers. Polyvalent salts, such as gypsum or phosphogypsum, cause a flocculation of clay particles; organic substances and synthetic polymers bind soil particles into aggregates. The effect of soil amendments (conditioners) can be divided into two groups: 1) increasing soil hydrophobicity to decrease infiltration and increase runoff; 2) increasing soil hydrophilicity to increase infiltration and decrease runoff [6]. Hydrophobic conditioners are not widely used for erosion control. In addition, it is necessary to note, that the size of soil aggregates should be at least 2 mm, and preferably more than 5 mm for increasing infiltration and decrease erosion by hydrophobic conditioners [6–7].

The purpose of this scientific review is analyzing of data and literature related with topic: the using of soil conditioners into control and reducing of water erosion in agriculture.

Material and methods. The review of literary sources on the problem of application of soil conditioners and its effect on soil erosion were performed during this study. The retrospective of the literature search was 44 years (1976–2020).

Results and discussion. Below are the results of some studies by various researchers on the effectiveness of the use of some soil amendments and conditioners to control and decrease erosion. It should be noted that soil conditioners such as synthetic polymers are effective in increasing hydraulic conductivity, porosity, improving water holding capacity, and decreasing erosion and crust strength [5].

Terry et al. [8] studied the changes of the soil physical properties during irrigation (flooding and sprinkling) and addition of the polyacrylamide (PAM). The formation of a crust contributed to an increase in soil density to 25.5 kg per m^2 in the variant without PAM and under flooding with water. The use of PAM reduced soil density to 2.2 kg per m^2, and only sprinkling irrigation – to 4.6 kg per m^2. The irrigation method had no effect on the stability of the aggregates, but the PAM treatment increased it by 3…4 times.

Trout et al. [9] in studying of the effectiveness of PAM in furrow (surface) irrigation noted, that water-applied PAM provided the additional advantage of flocculation of sediments in running water, which reduced its transportability and increased its tendency to accumulate in the bottom of furrow.

The improvement of erosion-preventive stability of soil in irrigation furrows was studied by Kouznetsov et al. [10]. The application of hydrolyzed polyacrylonitrile created a membrane on the surface in the irrigation furrows, led to decrease a water turbidity and the amount of suspended sediment, and increase the roughness of the furrows. This made it possible to increase of the water discharge in the irrigation furrows and to reduce erosion.

Wallace et al. [11] in lysimetric experiments studied the effect of PAM on the water-physical properties of sandy loam, loamy and clay soils. According to the experiment variants, the following polymer doses were applied: 0, 7.5, 15, 22.5 kg per ha. It was found that the polymer in all variants improved the soil infiltration.

Sepaskhah et al. [12] investigated the use of PAM at concentrations of 0, 0.1, 0.2, 0.4 and 0.6 g per m^2 on runoff plots with slopes of 2.5, 5 and 7.5%. It was found that the maximum concentration of PAM (0.6 g per m^2) is effective on a slope of 7.5%, and PAM in an amount of 0.4 g per m^2 reduced erosion at slopes of 5 and 7.5% effectively.

Suleimanov et al. [13] investigated the effect of surface application of phosphogypsum and turkey litter on the erodibility of clay-illuvial agrochernozems in the Southern Urals (Russia). Surface slopes of 1°, 3° and 7° with artificial heavy rainfall (360…420 mm per hour for 30 min) were modeled under the laboratory conditions. Soil losses were maximum and amounted to 28.9 t per ha in the variant without treatments. It was found that the introduction of phosphogypsum, turkey litter and their combination reduced erosion processes significantly.

Scientists from Iran have studied the effect of PAM during sprinkling on marly soils. Borogani M. et al. [14] concluded that the use of PAM at concentrations of 0.2, 0.4 and 0.6 g per m^2 can reduce splash erosion during irrigation with an intensity of 65…120 mm per hour, but no statistical differences were found between the results of experiments with the polymer. In variant with rain intensity of 120 mm per hour and the PAM amount of 0.4 g per m^2 is effective in the splash erosion control. It reduces the amount of soil erosion by about 40%.

Lei et al. [15] simulated rainfall on soil surfaces with various slopes and PAM concentrations. The researchers reported that PAM was effective in decreasing of soil loss.

In the Moldavian Department of Ukrainian Research Institute of Hydraulic Engineering and Land Reclamation the method of sprinkling with PAM had been developed to decrease the size (diameter) of artificial rain drops. Gavrilica et al. [16] recommended polymer concentration – 0.1…0.5 g per L. As a result, the drop diameters were decreased, and rates of water infiltration into the soil were increased.

Peterson et al. [17] studied the method of using the soil conditioner PAM (60 kg per ha) in liquid or granular form in combination with gypsum-containing materials (gypsum dose 5 t per ha in field experiments on 12 runoff plots (length 9.1 m, width 3 m) with slope about 20%. The use of PAM in liquid form followed by drying on the soil surface reduced the volume of liquid and solid runoff. The most effectively variants are: 62…76% and 93…98% respectively compared with the control (without treatment). The use of PAM in liquid form prevented erosion much better than in granular form. Erodibility after spraying of the PAM solution over the soil surface decreased significantly compared to the control. The use of PAM in dry form (granules) reduced the soil erodibility compared to control too, but to a much lesser extent than in liquid form. It is recommended to use spraying of PAM solutions for better protection of initially dry soil from erosion under heavy rainfall.

Nishimura et al. [18] studied the effects of gypsum and PAM application on infiltration and erodibility of a Japanese acid soil. They used 2.5 t per ha of gypsum and/or 15 kg per ha of non-ionic or anionic PAM for soil treatments. Rainfall with intensity rate 40 mm per hour was simulated. Researchers noted that gypsum enhanced surface runoff, PAM improve soil infiltration and reduce it loss.

Teo et al. [19] simulated erosive rainfall with varying intensities (5…8.5 cm per hour) on soil samples. They used doses of PAM both in dry and solution forms with different rates in the laboratory. They found that PAM was very effective and significantly reduced sediment runoff and soil splash, increased soil infiltration rates and aggregate stability.

Shengqiang et al. [20] in China studied the synergistic effect of rock fragments covering by applying PAM on erosion of irrigated slope. The studies shown that in variants with PAM, the infiltration rates (rain absorbency) increased significantly (significance level $p < 0.05$), the increase of PAM dose from 0.4 to 1 g per kg reduced the infiltration and the amount of sediments in the runoff. Researches recommended the optimal PAM dose at the level of 0.4 g per kg.

Lentz et al. [21] noted that PAM in anionic form is more effective than cationic forms for decreasing furrow erosion of U.S. Portneuf silt loam soils. In addition, in laboratory experiments, Ben-Hur et al. [22] demonstrated that the application of a cationic polymer to soil can increase soil erosion sometimes. It was pointed, that although the polymer stimulated a flocculation, which prevented the formation of fine particles that compact the soil surface and reduce the infiltration rate, the formed aggregates are more susceptible to transport even by thin layers of water.

Smith et al. [23] noted that the formation of a soil crust is usually associated with the impact of raindrops or drip irrigation on the soil surface. The studies were carried out with artificial sprinkling of sandy-loamy soils in Israel after treatment with anionic PAM and phosphogypsum (PG). Soil tillage with PAM (20 kg per ha) in combination with PG improves infiltration, reduces runoff and erosion at different levels of rain kinetic energy. The proposed measures showed a significant reducing of soil crust formation and improve the water-physical properties of the soil.

Wallace et al. [24] studied the effect of soil improver PAM on soil infiltration properties and erosion losses at the University of California. It was found that soil losses decreased from 101 t per ha (control, without polymer treatment) to 2.3 (dry polyacrylamide treatment) and to 4.5...6.7 t per ha (solution treatment). PAM addition improved the water infiltration into soil.

Agassi et al. [25] found that products such as phosphogypsurm and polyacrylamide were very efficient in erosion control on a wide range of soil types and denuded slopes, but vegetation cover was considered the most effective in the long term conditions.

Wallace et al. [26] studied the effect of Krillium (polymer for improvement of soil structure) and PAM on the physical properties of saline soils and the germination of tomato seeds in laboratory experiments performed at California University. The effectiveness of PAM was ten times higher than that of Krillium depending on the degree and type of soil salinity. The addition of PAM in a mixture with a polysaccharide accelerated the process of structure formation, increased the size of soil particles and the pore volume in the soil.

Levin et al. [27] studied the influence of the kinetic energy of rain and soil improvers on the infiltration rate and erosion. PG alone or in combination with PAM served as soil improvers (conditioners). The rates of rain energy varied depending on the drop height (0.4, 1 and 1.6 m) with same size – 3 mm. The rate of erosion is much lower in the variant with the application of PAM+PG than in the control and PG alone.

Yonter et al. [3] used a polyvinylalcohol (PVA) and polyacrylamide (PAM) at different doses (0, 6.70, 13.40 and 26.80 kg per ha) to investigate its effects on erosion caused by runoff and by splash under laboratory conditions with simulated rainfall (60 mm per hour) for 1 hour. Researchers found that increases in PVA and PAM doses are reduced runoff, erosion by runoff and splash significantly ($p < 0.05$ and 0.01 respectively). Also authors analyzed an effect of sprayed polyvinylalcohol (PVA) and PAM (doses 1 and 5 g per L respectively) on six soil samples placed in erosion trays (30 x 45 cm; slope 9%). Soil samples were irrigated by simulated precipitation (64 mm per hour) for 24 hours. They found that PVA and PAM were effective in reducing runoff and soil loss.

Kasyanov A.E. et al. [28] studied the effect of PAM (0.4 g per m^2) on splash erosion of soil. Studies shown, that there was no particle splashing under the impact of 1.73 mm drop. The distances of particles splashing were 0.7...1.2 cm and 4.4 ... 5.3 cm under the impact of 2.73 mm drop from height of 1.0 m and 2.5 m respectively. The mass of splashed particles were 0.004...0.006 g after the single impact of 2.73 mm drop.

Chang et al. [29] in China studied the effect of raindrops diameter and PAM addition on the runoff, soil and nitrogen losses during soil splashing. In the laboratory conditions, the impact of drops with diameters of 1.52, 2.45 and 3.59 mm and PAM addition with concentration 0, 1.0, and 2.0 g per m^2 were simulated. Studies showed that then the diameter of the raindrop increased, the rate of runoff and nitrogen loss increased too. Addition of polymer and increasing the PAM concentration reduced runoff, erosion and nitrogen losses significantly.

Kebede et al. [30] studied the effectiveness of PAM in reducing runoff and soil loss under consecutive rainfall storms. The used acidic clay red soil one of the widely abundant soils in Japan. Runoff plotes (50 cm length, 30 cm width, and 7 cm depth) were filled with soil. The anionic granular PAM with rates: 0 (control), 20, 40, 60 kg per ha are used. The effectiveness of the these PAM rates were tested by applying it in a mixture with gypsum (4 t per ha) or lime (2 t per ha). The rate of PAM 40 t per ha was selected as the most effective for reducing runoff and soil loss under rainfall storms (fall-height of 12 m, raindrop diameter of 3 mm, and rain kinetic energy of 29 J^{-1} m^{-2} mm^{-1}). Scientists also noted that application of PAM with lime could reduce soil erosion and improve land productivity especially in acidic soils. PAM with gypsum or lime increased infiltration rate through improving soil solution viscosity.

Conclusions

Soil conditioners are used to reduce erosion, reduce splash erosion, increase infiltration, reduce surface runoff, and stabilize soil aggregates. Soil conditioners are used in liquid or dry forms. The data on the concentration of soil conditioners recommended by various scientists are given.

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Дополнительная информация

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