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DEVELOPMENT OF WATER-RETAINING CARTRIDGES WITH POLYMER-MINERAL MATERIAL

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Abstract

To ensure the normal functioning of plants, light, heat, water, nutrients and air are necessary. Increasing the yield and quality of cultivated crops can be achieved with the help of

systems for monitoring and controlling the processes of growing plants and environment (soil and atmosphere), applied fertilizers and missing irrigation water. The addition of polymer-mineral material (PMM) to the soil, a new innovative material, created at Moscow State University (Research Institute of Mechanics), by mixing them as well as the installation of water-retaining cartridges of various shapes with a predetermined amount of PMM in it, increase its moisture capacity, allow saving an additional volume of water for plant nutrition accumulated from precipitation or artificial irrigation. Standard designs of cartridges of various shapes, pre-designed and manufactured using additive technologies, installed in containers with soil or in the open ground, allow for the accumulation of additional moisture for plants, reduce the metered consumption of irrigation water by 2 times and when used in the open ground in rain-filled conditions of the middle zone of Russia, practically eliminate it, by increasing the moisture capacity of the soil by 20–30 % (PMM dissolved in water increases its viscosity tenfold).

Keywords: polymer-mineral material; soil moisture capacity; hydroaccumulator; biodegradation; zeolite; meliorant; viscosity of the liquid; 3D printers.

Introduction

The gold reserve of the XXI century will be fresh water, which determines the presence of life on Earth, including for cultivated plants. The technological fork of modernity can be the saving of fresh water through the ecological use of PMM introduced in a certain dose into the soil to increase its moisture capacity.

The quantity and quality of seeds, fertilizers and irrigation water, the temperature of the soil and the surrounding air, their physical and chemical properties, as well as climatic conditions significantly affect the viability and yield of cultivated plants. Therefore, it is necessary to regularly monitor the soil, the surrounding atmosphere, the plants and their nutrition with fertilizers, air and water. Such monitoring and management of production processes and facilities can be carried out automatically with the help of information and communication technologies (ICT), which will allow more efficient use of natural resources and fertilizers, reduce environmental pollution, reduce the cost of growing plants, increase their viability and yield, as well as streamline their growth through the dosed application of various meliorants, water and air [1,2].

The plants develop normally in cultivated structural soils that contain the necessary amount of water, fertilizers and air. In particular, various sensors, counters and controllers can provide the collection and digitization of analog signals from the studied objects and transfer them to application servers and databases for processing and making management decisions to create favorable conditions for the vital activity of plants. To assess the characteristics of the soil and the environment of the plant and maintain a given state, various humidity sensors, PH meters, dosimeters and actuating valves implemented in the form of Internet of Things (IoT) are provided, which are turned on according to a given time schedule or at the time of occurrence of a precedent, and transmit information to the data processing center. Depending on the terrain, humidity sensors and PH meters are installed in the soil, with the corresponding

radio modems at a distance from each other. Two types of IoT are interesting: function according to the standards of the top (LTE) and function according to their individual communication networks [3,4].

Thus, it is important to assess the impact of various technological innovations, including specially designed cartridges of various shapes with polymer-mineral filler installed in the soil, on increasing the yield of cultivated plants and reducing the cost of resources of companies engaged in such activities.

Laboratory and field tests with PMM in the soil indicate the possibility of: increasing the viability and yield of cultivated plants, significantly reducing their fallout, fertilizer and water consumption, as well as the cost of electricity, human and other resources [5,6].

In order to increase the competitiveness of companies engaged in growing agricultural crops, it is necessary to reduce the consumption of resources for their production, take into account the shortage of fresh water in arid regions and increase their productivity through land reclamation. The reason for the decrease in soil moisture is not only an increase in ambient temperature and a decrease in precipitation, but also an anthropogenic impact on it [5]. As practice shows, with the increase in the capacity of agricultural machinery, intensity of agriculture, depth of land cultivation, use of enhanced loosening and traditional overturning of the reservoir, conditions for soil depletion and degradation are created. In this regard, minimal or zero tillage becomes important, using effective agrotechnical measures, such as scientifically based crop rotations, use of organic fertilizers and meliorants.

To improve physical and chemical properties of the soil, increase productivity and reduce the cost of production, it is proposed to streamline the water regime in the soil using information technologies and new innovative material PMM, that are polymer-mineral raw materials created on the basis of bentopowder and zeolite, with additives of a small amount of organic polymers and to determine the effect of its influence on the plant [6].

In the proposed technologies for growing plants we use PMM in the soil and various options for laying it, including using pre-created cartridges of various shapes. The amount of PMM in the cartridges and their dimensions are determined by the requirements for the moisture capacity of the soil in a container or in the open ground for the plants grown in the considered climatic conditions. In particular, to increase the moisture capacity of the soil by 20–30 %, it is necessary to add 3 gram of PMM per 1 kg of soil to the container (to mix it with the soil or to place it in a cartridge laid in the soil).

To monitor various production processes of the plant growing life cycle, the following objects can be distinguished:

- soil: its characteristics: temperature, humidity and saturation with fertilizers during the growing period of the plant, before planting seeds and after harvesting;
- ambient air: forecast and actual characteristics of the climatic conditions of the area under consideration: wind speed, pressure, temperature and humidity, precipitation and snow cover height;
- plant being grown: its characteristics: height, thickness and condition of roots and green mass;
- water, fertilizer and other resources added to the soil;

- life support systems: alerts, security, climate control, etc. necessary for effective and safe plant cultivation.

During the period of drought, the yield of many cultivated crops in rain-fed conditions is significantly lower than in irrigated soils of the same region. Therefore, growing without monitoring systems of their vital activity using ICT and in extreme cases without artificial irrigation, leads to uncompetitive products, up to its complete loss. Technological innovations based on ICT and new PMM will improve the water regime of plant nutrition, reduce the amount of fertilizers applied and increase yield, including by reducing the root system of plants. In difficult climatic conditions, agrotechnical measures are necessary to obtain a high yield at a low cost. Drought, hail and other natural disasters cause serious damage to agriculture, creating a danger of land desertification.

The fertility of the soil depends on its structure, porosity, moisture capacity, absorption capacity, presence of colloidal particles in it and organomineral origin, which affect the volume of water and the amount of dissolved salts and gases retained in it for the root system of the plant [5]. If there are enough nutrients in the soil, but there is a shortage of water and air, the plant does not develop well and may die. Therefore, in the soil, in order to preserve water and air, it is necessary to create pores of 3-5 mm [7].

In the conditions of rain-fed agriculture, soil moisture is an important factor in obtaining stable yields. Therefore, information about soil moisture, patterns of its formation and changes over time is important. Establishing the dependence of the crop on soil moisture reserves is important for assessing the condition of crops and plantings and for determining the effectiveness of agrotechnical measures. For agricultural production, only productive moisture is important, it is a part of the soil moisture that ensures the formation of the crop of plants, i.e. exceeding the withering moisture [7].

In rain conditions, the main sources of moisture are precipitation and groundwater. The level of soil moisture is influenced by the type of vegetation, terrain, processing system, presence of winds, air temperature, etc. Water under the influence of gravity goes into the soil through large pores, and then through small pores and capillaries it is filtered into the depth, surrounding the particles of the earth. If the soil is rich in calcareous compounds, small particles, especially colloidal ones, stick together, forming strong porous grains that are not eroded by water for a long time, such soils acquire good filtration characteristics. The greater the porosity of the soil, the more water there is in it (the amount of water is determined by the displacement of the soil, which should be distinguished from the concept of the moisture-retaining ability of the soil (the amount of moisture remaining in the soil after full water saturation)).

The humidity of the air has a noticeable effect on plants. When there is a shortage of water vapor saturation, evaporation from the soil surface and plant transpiration increases sharply. Fluctuations in the yield of cultivated crops in different areas are largely associated with fluctuations in the precipitation of the growing season. The negative effect of wind is to increase unproductive evaporation from the soil surface, which causes soil drought. Evaporation rates, soil expelling properties, etc. are also important for plants. Thus, for the growth and development of plants, all the properties of the soil are important, which acquire

their best indicators in structural soils, where water and air are simultaneously contained in sufficient quantities.

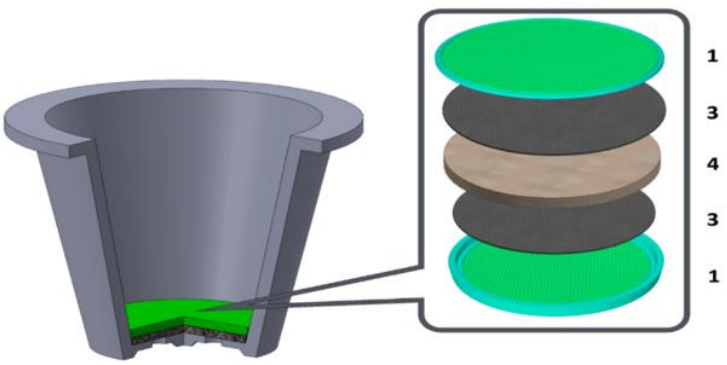
Conflict setting

Traditional methods of preserving soil structure are based on deep tillage, intensive loosening and turning over of the formation, use of crop rotation and fertilizers, treatment of acidic soils with limestone and saline lands with gypsum. Today, the conditions for preserving and improving the structure of the soil and increasing fertility are created with minimal and zero land cultivation, with the use of scientifically-based crop rotation, meliorants and fertilizers. In practice, various ameliorants of polymer and polymer-mineral origin are used to quickly improve the physical and chemical properties of the soil [6,7].

Therefore, in order to improve the physical and chemical properties of the soil for growing agricultural plants, it is necessary to conduct field and vegetation experiments to regulate the water regime in the soil using PMM. To determine the characteristics of the soil and the environment, as well as to control the processes of growing plants, various sensors, controllers and information systems are used that are adequate to the target IT architecture.

Depending on the method and the amount of used meliorant, the specific and volumetric mass of soil, porosity, moisture capacity, absorption capacity, humidity, displacement and inaccessible amount of water for plants in the soil, dynamics of humidity changes during the vegetative period, field germination of seeds, plant safety during the growing period, biological and total yield and economic efficiency are recorded.

PMM can be put into the soil in various ways: to mix them at the rate of 2–3 grams of PMM per 1 kg of soil, which allows accumulating 30–75 grams of additional water in it, depending on the soil. In addition, PMM can be placed in specially created cartridges, for example, in the form of a bullet, which are easily pushed into the soil near the plant, not to damage its roots, or in the form of a flat cartridge, easily placed in the open ground or in a container with soil at a certain depth before planting it. Water, once in the cartridge, dissolves PMM particles, and thereby significantly increases the viscosity of the liquid, and therefore worsens its filtration characteristics, which leads to an increase in the moisture capacity of the soil and the accumulation of additional water in the soil around the cultivated plant.



In particular, the design of a flat cartridge with PMM filling is based on the geometry of a container – flower pot. Fig. 1 shows the debut idea of the cartridge: a flower pot and a disassembled cartridge are shown.

Fig. 1. Sketch of cartridge in flower pot:
1 – housing, 2 – lid, 3 – upper and lower lutrasyl gasket, 4 – PMM

The design of a typical cartridge consisting of housing 1, lid 2, upper and lower lutrasyl gasket 3 and PMM 4 has been developed. The structural material for the cartridge is polylactide (Fig. 2), which is made on the basis of an annually renewable resource of biological origin based on corn and sugar cane. Polylactide (PLA) is biodegradable, biocompatible polyester, the monomer of which is lactic acid. The biodegradable structural material allows implementing a line of green technologies.

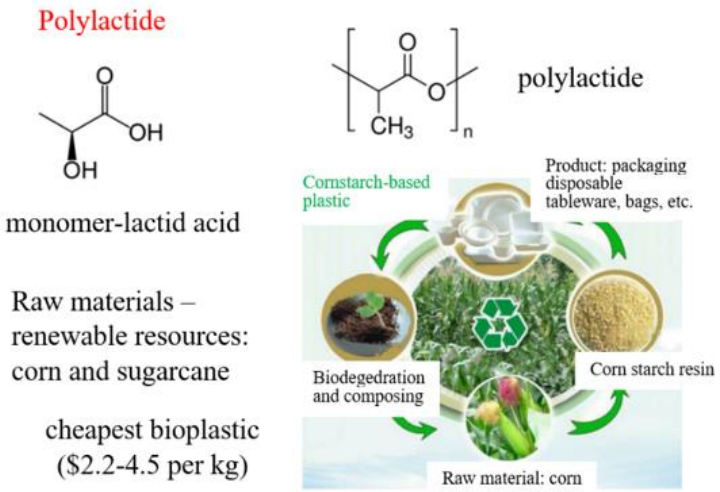


Fig. 2 Biodegradable construction material

Research Results

Additive technologies were used to conduct an experiment on the adaptation of a specially created cartridge. To verify the concept of the conducted research, it is advantageous to apply the principles of additive manufacturing. At the same time, such technologies can be considered not only for prototyping and organizing experimental work. Additive manufacturing technologies continue to develop from the point of view of their digitalization and automation and from the point of view of materials science innovations. The results of the conducted research provide the necessary data on the limits of applicability of layer-by-layer synthesis technologies, on economic indicators that depend on the geometric appearance of cartridges and on the seriality of their production. This stage of work involves preliminary research, which includes an analysis of the current state of technologies and their applicability to the problem being solved, as well as the search for the geometric appearance of cartridges that ensure the effectiveness of a water-retaining cartridge for growing a particular plant under the conditions under consideration.

Studies were conducted on the applicability of various methods of additive manufacturing to obtain a cumulative positive effect in the problem being solved.

The following methods of additive manufacturing are considered [3,4]:

- extrusion/wire;
- powder;
- polymerization;
- lamination;
- inkjet.

The conducted research can be divided into stages of analyzing materials and their properties from the point of view of the raw material base and environmental friendliness, as well as determining the combination of technological and economic indicators of prototyping and production. Powder and polymer methods were excluded, first of all, from the point of view

of materials and, accordingly, their properties, which determine the environmental friendliness, functionality of the cartridge and from the point of view of the cost of using technologies.

Lamination can be a very promising method of cartridge production, since one of the building materials of this technology is paper. The cost of equipment and consumables (binder, components) is quite high today.

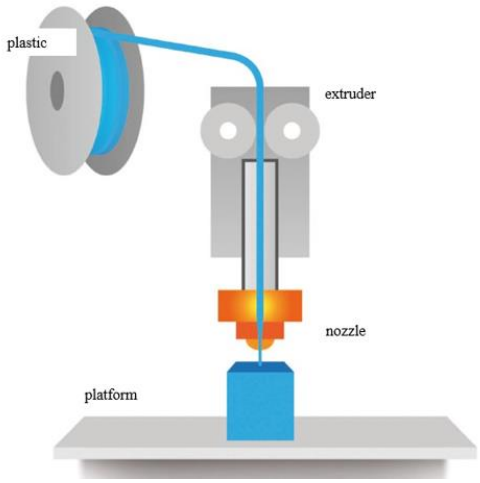


Fig. 3. Extrusion «printing»

According to the results of the analysis, an extrusion production method was chosen (Fig. 3), which implies layer-by-layer deposition modeling (Fusing Deposition Modeling (FDM)). The use of 3D printers allows adapting the technology to climate, plant characteristics, soil type, etc. In the Figure 4 there is a photo of the cartridge manufacturing process. The choice of this technology determined the boundaries of the search for geometric shapes of cartridges and the possibilities of serial production. The indisputable advantage of this method of additive manufacturing is the relatively low cost of equipment and materials.

The chosen technology makes it easier to create an electronic model of the cartridge, due to the fact that to speed up the synthesis process, the internal volume of the product is filled with different geometric patterns, which, depending on the percentage of filling of the cartridge volume, can provide the required parameters (Fig. 4).

(**a**) (**b**) (**c**)

Fig. 4 Fill ratio: a – 20 % (left); b – 50 % (middle); c – 75 % (right)

Fig. 5, Fig. 6 show a prototype of a cartridge that provides moisture accumulation for plants that require regular watering, reducing water consumption by 2 times, and when used in the open ground of the middle zone of Russia, it is practically excluded.

Thus, for regions with unstable humidity, water is the most important factor in the yield of cultivated crops in rain-fed conditions, which is due not only to regional climatic conditions,

but also to the use of agricultural technology. Traditional forms of land cultivation lead to an increase in the rate of splitting of humus, spraying of the arable layer, destruction of soil aggregates, loss of moisture, increase in the cost of growing plants, etc. To prevent soil degradation, minimal and zero processing is used.

In order to prevent soil degradation in rain-fed agriculture, regulate water and food regimes of cultivated crops and reduce the cost of production, it is proposed to introduce PMM into the soil in the form of mixing it with the soil and in the form of cartridges of various shapes, easily placed around the plant before planting and after planting, to improve the parameters of the water regime and to increase the yield.

Scientific and practical results are the following: in laboratory conditions, the expediency of using PMM in the soil to increase the yield and viability of plants due to the accumulation of precipitation, identifying various options for laying PMM, using PMM to create an ecological filtration layer under the root system of plants, including using specially created cartridges with PMM filling, reducing the cost of fertilizers in the soil and other resources.

By increasing the moisture capacity, it is possible to reduce the volume of irrigation water, as well as completely abandon it under favorable climatic conditions, reduce the amount of used fertilizers and thereby reduce environmental pollution and amount of toxic wastewater. The obtained positive results make it possible to grow various types of plants that could not be grown before, as well as to increase the yield and adaptability of plants to external conditions, improve the agrophysical properties of the soil and replicate the results to other regions with similar climatic conditions.

Laboratory and field experiments with PMM in the soil have shown their effectiveness. Mixing PMM with the soil, laying it on the bottom and along the side wall of the container, as well as in holes inside the soil, laying cartridges with PMM in containers and in the open ground, allow saving more water, thereby increasing the moisture capacity of the soil by 20–30 %.

At the end of the XX century, the Moscow State University (Research Institute of Mechanics) conducted tests with a similar polymer-mineral composite Kavelast, on the basis of which an eco-friendly water-accumulating soil-improving sugar composite was developed, its main properties and characteristics were studied and established, the influence of Kavelast and sugar on the growth and development of plants, in particular on beans, wheat and tomatoes, optimal doses of materials, norms and frequency of watering for each species were also studied.

The influence of Cavelast and sugar additives on the water storage capacity of non-cohesive soils, the duration of moisture retention, the norms and frequency of watering, germination and development of plants at different doses of Cavelast and sugar were determined, methods of seed grazing with the use of Cavelast and sugar were developed.

In addition, a number of authors used various meliorants to improve the physical and chemical properties of the soil, in particular, recycled dacite tuff was introduced into the soil, economic and environmental efficiency of organic fertilizers was studied against the background of mineral meliorants. Research in the field of the use of meliorants for plants shows the need to continue such work, as well as the selection of new meliorants that are environmentally safe and more effective for a significant increase in yield with limited moisture resources in rain conditions [8,9].

In particular, the use of PMM as such a meliorant has shown its effectiveness from the point of view of resource costs and from the point of view of increasing the yield and viability of plants, in particular, for this purpose, in order to establish correlation between these features and productivity, influence of fertilizers and PMM on the growth, development and preservation of winter wheat plants, as well as tomatoes, eggplant, pepper, peanuts and other plants, including seedlings of flowers and trees in containers was studied [5,6].

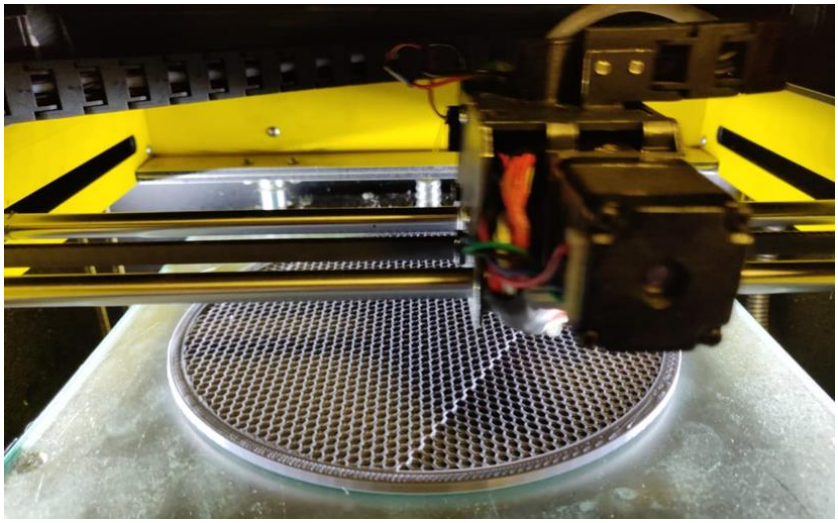
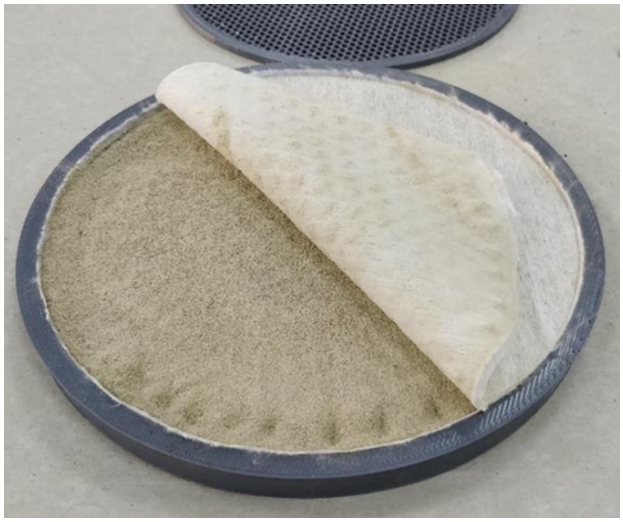


Fig. 5 Layer-by-layer surfacing (FDM)

It can be seen from the experiments that mineral fertilizers and PMM had a significant impact on the dynamics of growth and development of winter wheat.



In particular, fertilizers and PMM accelerate the phases of plant development. Biometric measurements and calculations show that PMM and fertilizers had a significant impact on field germination, winter hardiness and growth dynamics of winter wheat stems, which is explained by the ability of PMM to retain moisture in the root layer of the soil, while mineral fertilizers are used without losses and effectively in the presence of an appropriate amount of moisture.

Fig. 6 Prototype of cartridge in a flower pot

In the soil with fertilizer and PMM, the yield was almost twice as high as in the soil only with fertilizer in rain-fed conditions [9,10].

Conclusion

The tests carried out and the accumulated knowledge have shown the prospects of developing environmentally safe, highly effective methods for increasing the water retention capacity and improving the agro-reclamation properties of soils and technological processes for their implementation. The developed technologies provide an increase in reserves of productive moisture in soils to predetermined limits, creation of an optimal water regime for plants, reduction in the frequency and norms of irrigation, increase in anti-erosion resistance, reduction

or exclusion of waterlogging and salinization, increase in yield, reduction in capital investment and cost of agricultural products.

PMM and automation of plant growing processes will increase the yield and viability of plants and reduce the resources for their cultivation, including fresh water.

Ideas, technologies and methods of monitoring and controlling the process of growing plants, as well as calculations on the economic feasibility of introducing PMM into the soil, must be tested in full-scale tests in rain-fed conditions on large areas, in order to prove the validity of hypotheses and the correctness of the experimental results obtained, which can be recommended to agricultural producers for industrial use.

The solution of the tasks set will allow creating competitive technologies and products for their implementation on the world market.

In terms of creating various cartridges for introducing PMM into the soil, the following conclusions can be drawn:

- developed design of a typical cartridge allows ensuring the accumulation of moisture for plants that require regular watering, reducing water consumption by several times, and when used in the open ground of the middle zone of Russia, it is generally excluded;
- when growing plants in containers in closed rooms, the frequency of watering can be significantly reduced;
- use of biodegradable material in the design of the cartridge allows providing green technologies;
- 3D printers allow mobile adaptation of the technology to climate, plant characteristics, soil type, etc.

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ՊՈԼԻՄԵՐԱՀԱՆՔԱՅԻՆ ՆՅՈՒԹՈՎ ՀԱԿԱՖԻԼՏՐԱՑԻՈՆ ՔԱՐԹՐԻՋՆԵՐԻ ՄՇԱԿՈՒՄ

Ա.Ա. Վարտանյան[1], Մ.Յու. Կուպրիկով[2], Ա.Վ. Ռիպետսկի[2], Գ.Լ. Հայրիյան[3], Հ.Վ. Թոքմաջյան[3]
[1]Մ.Լոմոնոսովի անվան Մոսկվայի պետական համալսարան
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[3]Ակադեմիկոս Ի.Վ. Եղիազարովի անվան ջրային հիմնահարցերի և հիդրոտեխնիկայի ինստիտուտ

«Հող-ՊՄՄ» քարթրիջների փորձարկումները ցույց են տալիս գրունտում, մինչև կանխորոշված սահմաններ, ջրի պահպանման ծավալն ավելացնելու հնարավորություն:

Քարթրիջում ՊՄՄ-ի կոնցենտրացիայի աճի դեպքում, դրանք կարող են օգտագործվել որպես ջրամեկուսիչ նյութ, հողային ջրային համակարգերում և քաղաքաշինության բնագավառում:

Բանալի բառեր՝ պոլիմերահանքային նյութ, հողի խոնավունակություն, հիդրոակումուլյատոր, կենսադեգրադացիա, ցեոլիտ, մելիորանտ, հեղուկի մածուցիկություն, 3D տպիչ:

РАЗРАБОТКА ВОДОУДЕРЖИВАЮЩИХ КАРТРИДЖЕЙ С ПОЛИМЕРНО-МИНЕРАЛЬНЫМ МАТЕРИАЛОМ

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Проведенные испытания картриджей «грунт-ПММ» показывают перспективность разработок экологически безопасных высокоэффективных методов повышения водоудерживающей способности и улучшения агромелиоративных свойств почвогрунтов и технологических процессов их осуществления. Разработанные технологии обеспечивают повышение запасов продуктивной влаги в почвогрунтах до заранее заданных пределов.

При повышении концентрации ПММ, разработанные картриджы могут быть использованы как гидроизолиационное средство в гродостроительсте и грунтовых сооружениях водных систем.

Ключевые слова: полимерно-минеральный материал; влагоемкость почвы; гидроаккумулятор; биодеградация; цеолит; мелиорант; вязкость жидкости; 3D-принтеры.

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