Effect of hydrogels on moisture storage of irrigated automorphic soils in Uzbekistan

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Abstract. An experimental study on the development of water-conserving irrigation technology with the use of super swelling hydrogels synthesized out of local raw material has been conducted for three years under the condition of arid automorphic soils of western Uzbekistan. The development of new and affordable water-conserving technologies is critical for the sustainable development of irrigated agriculture in arid zones that severely affected by growing water scarcity. The experiments were aimed at determining the properties of hydrogels, establishing quantitative indicators of the water-holding ability of automorphic soils depending on the methods, norms, and time of application of highly swellable polymer hydrogels under conditions of cotton cultivation. The experiments were conducted under conditions of the irrigated by lifted water automorphic soils and cultivation of the Andijan-35 cotton variety. Results of the study show that use of highly swellable polymer hydrogels with a norm of 50 kg/ha under traditional agrotechnology conditions in conditions of automorphic soils based on improved traditional furrow irrigation technology allows reducing water consumption for irrigation by 15-17\% in the first year, by 12-14\% in the second year and by 9-11\% in the third year of experiments. Due to the longer duration of moisture conservation in the soil, the period between irrigations is extended by 10-12 days, the number of irrigations is reduced.

1. Introduction

Uzbekistan as many countries in the arid zone with developed irrigated agriculture pays great attention to improving water use efficiency, especially in irrigated agriculture. The development and implementation of new technologies for the rational use of water and land resources in agriculture are one of the contemporary problems of sustainable development. Of course, the use of existing advanced irrigation technologies such as sprinkling, drip irrigation, etc., can drastically reduce the consumption of irrigation water and improve its efficiency. However, they also require a sufficiently large capital investment, time, and retraining of farmers. Under the current conditions, the use of non-traditional methods of irrigation should be included into the list of promising areas in water conservation. One of these methods is the use of highly swellable polymer hydrogels, which increase the water-holding capacity and water-physical properties of the soil.

Currently, in many countries of the world, intensive scientific work is underway on the development and practical use of polymers in the agricultural sector. It has been established that the use of polymers in agrochemistry and the protection of plants from diseases and pests sharply reduces the application of mineral fertilizers and pesticides and guarantees the environmentally friendly management of agricultural production. Polymers are used in England (since 1890), in France,
Germany, Holland, the United Arab Emirates, Israel, Russia, Ukraine, Belarus, Central Asia and other countries [1,2,5,6,7,15,16,17,18,19,20,21].

The high demand for freshwater, increasing manufacturing costs of agrochemicals as well as a heightened awareness of their environmental adversities have rightfully shed light on these unsustainable practices. Developments in science and technology, however, have contributed to the improvement of soil conditions, nutrients, as well as water and plant management. Polymers are a class of versatile materials that have been used in many agricultural applications due to the ability to engineer application-specific polymers [10,11,12,13,16]. Depending on their uses, lifetime and economic viability, different classes of polymers have been used extensively in agriculture [11,12].

According to Abrosimov L.N., Timirova M.N., Mirzaev S.S., Yusupbekov O.N. [2,3,4] the history of research on the use of polymers is more than 100 years old. Swelling is a phenomenon that is accompanied by an increase in the volume and weight of the swelling substance, absorption of liquid, and a change in physical constants. The higher the charge of colloids, the more intense the process of gel swelling. Along with the synthesis of hydrogels with a good degree of swelling, the research on the development of water-saving irrigation technologies is critical.

Laboratory, field, and industrial studies on the effect of polymers on soil properties and plant yield in various soil and climatic zones have been and are being carried out both abroad and in Uzbekistan [4,14 etc.]. The results of these studies indicate that the use of polymers has always led to an increase in the water-resistance of the structure, porosity of aggregates, a decrease in water losses due to evaporation, crust formation, and erodibility, and an improvement in the germination of plant seeds.

The hydrogels are very effective in the sandy soils [5,7 etc.]. Johnson mixed sand with different cross-linked polyacrylamides to produce a polymer [8]. The results indicated that all polymers tested increased the field capacity (FC) of coarse sand to 171 and 402%. Also, Johnson showed that the permanent wilting point (PWP) of the control sand was reached between 2–3 days, in comparison with between 6–7 days for the 1 g/kg of polymer treated sand and between 9–10 days for the 2 g/kg polymer treated sand [9].

Nevertheless, the efficiency of super swelling hydrogels synthesized out of local raw materials on arid automorphic soils such as in eastern Uzbekistan is not well studied. Studies on the development of water-conserving irrigation technology with the use of such hydrogels considering specific conditions are not enough.

2. Methods and materials

We have selected an automorphic soil of the arid part of the Namangan region, located in the newly irrigated zone of eastern Uzbekistan that provided with pump-lifted water, as the object for the experimental research on the development of a water-saving irrigation technology using highly swellable hydrogels. The soils of the experimental pilot area are homogeneous in its mechanical composition and contain a large portion of dust fractions. According to the western classification soils of the experimental pilot area called - silty loams (they are good, but not optimal in terms of the ratio of clay, sand, and dust fractions).

The experiments were conducted under field conditions to assess the effect of highly swellable polymer hydrogels synthesized out of local raw materials on the water-physical properties of automorphic soils. Phenological observations of cultivated crops – Andijan-35 variety of cotton were carried out, and the agrophysical properties of the soil were studied by the method of the Uzbek Cotton Research Institute [3, 4]. The most effective in terms of localization, i.e. use of local raw materials, are hydrogels based on hydrolyzed polyacrylonitrile (waste "Navoiazot" plant) and carboxymethyl cellulose. In the course of our studies, we used hydrogels developed by scientists of the Tashkent Research Institute of Chemical Technology based on acrylic acid and carboxymethyl cellulose (SM C) obtained from the waste of the Navoi chemical plant by the method of heterogeneous solid-phase esterification of sulfite wood pulp with monochloroacetic acid (MHUK) according to GOST 5.588-79 and OST 6-05-386-80, with a degree of substitution of 70 and polymerization of 450.
In the spring of 2015, a hydrogel with a swell ability degree of 200 – 300 g/g in the amount of 0.001% of the soil mass (calculated as 30, 50 and 70 kg/ha) in a granular state was applied into the soil (layer 0 - 35 sm). The layout of the experimental options in the plan was according to methodology.

On all variants, the Andijan-35 cotton variety was sown, zoned for this region. Cotton growing technology was generally in line with recommendations. When determining the timing of irrigation, schemes of pre-irrigation moisture in the soil of 70-60-60% of the maximum field moisture capacity were supported.

The experiments were aimed at determining the properties of hydrogels, establishing quantitative indicators of the water-holding ability of automorphic soils depending on the methods, norms and time of application of highly swellable polymer hydrogels in them under conditions of cotton cultivation.

Hydrogels at the experimental sites were introduced into the soil in such a way as to ensure maximum mixing of the planned rate of hydrogels in the soil with a thickness of 0-60 sm and their protection against direct penetration of ultraviolet rays, which could cause their decomposition.

3. Results and Discussion

Under field-experimental conditions, the properties of the super swelling hydrogel were assessed. Since it was planned to use hydrogels in the soil for several years, it became necessary to study the multiplicity of the hydrogels swelling property. It is known that with multiple changes in the state of aggregation of a hydrogel from maximum swelling to a minimum, its water-absorbing capacity decreases. As a result of this, one of the criteria for evaluating a hydrogel for its use in the field was the swelling ratio. We conducted experiments to study the behavior of samples of hydrogels subjected to repeated swelling and drying under real field conditions.

Agrotechnical methods of cotton crop cultivation applied during experiments in general corresponded to the norms and terms recommended for this zone. In the experimental and control fields in the second year of action of hydrogels, cotton was sown on April 28, 2016 after applying fertilizers to the soil according to the standards - amorphous with the norm of 100 kg/ha and ammonium sulfate 100 kg/ha accordingly. Cotton was sown in a mechanized way with a row spacing of 60x60 sm and seeding norm of 200 kg/ha. While scheduling the irrigations, the values of pre-irrigation soil moisture were kept at 70-60-60 percent of the maximum field moisture capacity. When determining the irrigation norm in the phase “the beginning of flowering and fruit formation”, the calculated layer was taken to be 60 sm, and in subsequent periods - 70 sm. The first irrigation (experiments were carried out under furrow irrigation) was carried out on May 8-11 with a norm of 1150 m3/ha. The first shoots were noted on May 12-14. In the spring (June) of 2016, cotton was fertilized with ammonium sulfate (150 kg/ha) and ammonium nitrate (350 kg/ha). After that, the second irrigation was carried out with a norm of 1300 m3/ha on 20-23 of June. The third irrigation was carried out on during 3-5 of August with the norm of 1250 m3/ha on control fields and 600 m3/ha on experimental fields. Totally three irrigation was carried out during the first year of experiments with the total norm of 3050 m3/ha in experimental fields and 3700 m3/ha in control fields. Under the existing conditions, 650 m3/ha less irrigation water was applied in the experimental fields compare to the control fields.

During the field experiment, observation and accounting cycles were organized according to the generally accepted methodology of the following indicators:

- considering the timing and composition of agro-technical methods of cotton cultivation;
- measuring the amount of irrigation water supplied to the control and experimental plots (according to variants);
- monitoring the dynamics of moisture in the calculated soil layer;
- phenological observations of the growth and development of cotton;
- determination of crop yields (biological and actual).

Studies conducted during three years under field conditions have made it possible to establish the possibility and justify the parameters for increasing the water holding capacity of the soil when a certain amount of hydrogel is applied.
The results of systematic observations of the dynamics of soil moisture indicate that under conditions of equal initial soil moisture both on the control and experimental variants with applied hydrogels, the soil moisture retention period in variants with hydrogels is relatively longer compared to the control that in control fields. So, in the experiment with cotton in the first year of experiments (2015), the first irrigation on all variants of the experiment was carried out on May 8-11 at a rate of 1150 m$^3$/ha. Before the second irrigation (June 19), the moisture content in the 0-60 cm layer of soil in the control variants was 9.42% (control-1) and 9.36% (control-2), and in the cases with hydrogel, accordingly was 10.56, 10.91% and 10.95 by weight of soil (see fig. 1). It should be noted that a more rational effect on increasing the water-holding capacity of the soil per unit volume of applied hydrogels was obtained at a norm of their application of 50 kg/ha.

It should be noted that in the second and third year of experiments, also a more rational effect on increasing the water-holding capacity of the soil per unit volume of applied hydrogels was obtained at a norm of their application of 50 kg/ha (see fig.1, fig.2, and fig.3).

![Figure 1. The dynamics of soil moisture in the experimental and control fields (for June 19, 2015 - i.e., 35 days after the first irrigation).](image)

The results of observations of the dynamics of soil moisture in the second and third years of experiments also show that for initially identical soil moisture in control and experimental fields with a hydrogel, the moisture retention period in variants with a hydrogel is relatively longer compared to the control, but a lesser extent than in the first year of experiments. It should be noted that in the second and third years of experiments, also a more rational effect on increasing the water-holding capacity of the soil per unit volume of applied hydrogels was obtained at a norm of their application of 50 kg/ha.

During experiments with cotton in the second year of study (2016), the first irrigation was carried out according to all variants of the experiment on May 21-24 with a norm of 1200 m3/ha. Before the second irrigation (June 25), the soil moisture in the 0-60 cm layer on the control variants was 9.40% (control-1) and 9.56% (control-2), and on the options with hydrogel, respectively, 10.23%, 10.96% and 11.11% of the mass of soil (see Figure 2).
During experiments with cotton in the third year of study (2017), the first irrigation was carried out according to all variants of the experiment on May 11-14 with a norm of 1250 m³/ha. Before the second irrigation (June 20), the soil moisture in the 0-60 sm layer on the control variants was 9.25% (control-1) and 9.18% (control-2), and on the options with hydrogel, respectively, 10.03%, 10.87% and 10.92% of the mass of soil (see Fig.3).

Figure 3. The dynamics of soil moisture in the experimental and control fields June 20, 2017 (36 days after irrigation)

Figure 4 illustrates the average soil moisture storage over the growing season and its dynamics over the layers. The graph also shows the effect of hydrogels on the water holding capacity of the soil. So, thanks to the effect of hydrogels, the average soil moisture content over its layers in the experimental field turned out to be higher compared to the value in the control fields.
The use of hydrogels, thanks to its effects allowed to collect an additional moisture reserve in the root layer of the soil that is necessary for a cotton plant. It made it possible to reduce the norm of the third vegetation irrigation without prejudice to the growth and development of cotton plants. It should be noted that the effect of water conservation was lower compared with cases observed under hydromorphic soils and previously used imported varieties of the hydrogel, but it allowed to conserve enough soil moisture to provide higher yields with less amount of applied irrigation water.

In 2015, on the control options for the growing season of cotton, 3 irrigation was carried out with an irrigation rate of 3700 m3/ha. The inter-irrigation period was 40–41 days. In the case of a hydrogel application, 3 irrigation was carried out with an irrigation rate of 3050 m3/ha (with a reduced norm of third irrigation). The duration of the inter-irrigation period (between 1 and 3 vegetative irrigation) was 74 days.

Systematic observation of the dynamics of soil moisture made it possible to establish that after full saturation with water of the estimated soil thickness (primarily before irrigation), the permissible (optimal) moisture level before irrigation is 70% of the maximum field moisture, the capacity for the soils of the gray earth belt of the republic established by S. N. Ryzhov [3], in the case of using hydrogels, comes much later. So, in the control fields in the first year of experiments, this soil moisture level was observed on the 34th day after irrigation, and in the experimental field with hydrogel, respectively, on the 46th day after irrigation. Thus, this shows that the use of hydrogels with a norm of 50 kg/ha allowed to extend the period between first and second irrigation by 10–12 days.

The above indicates that, irrigation technology with the application of hydrogels into the soil, in justified norms at a given depth, allows to purposefully control the water, nutrient, and salt regime of the soil, migration processes in the root zone. Thanks to this, real conditions for water conservation and higher yields are created when cultivating crops on an irrigated field.

4. Conclusions

1. The use of highly swellable polymer hydrogels under conditions of automorphic soils based on improved traditional furrow irrigation technology has made it possible to reduce water consumption for irrigation by 15-17% in the first year, by 12-14% in the second year and by 9-11% in the third year of experiments when cultivating cotton. Due to the longer duration of moisture conservation in the soil, the period between irrigations is extended by 10-12 days, the number of irrigations is reduced;
2. The use of polymer hydrogels allows cotton to tolerate periods of stress more steadily (a sharp increase in temperature, decrease in soil moisture);
3. Results of field experimental studies show that hydrogels (the type of hydrogels used in the experiments) contribute to longer preservation of moisture in automorphic soils.

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References
[1] Abrosimova L N 1987 The use of polymers to accelerate soil reclamation Tez III All-Conf “Water-soluble polymers and their use” p 207
[2] The use of soil-improving agents to create a favorable soil water regime in arid zones 1987 In the book Methods to the problem of increasing the sustainability of agriculture. Gosagromprom of the USSR Agricultural Academy pp 115-127
[3] Ryzhov S N 1948 Cotton irrigation in the Ferghana Valley Academy of Sciences of Uzbekistan (Tashkent)
[4] Timirova M N Mirzaev S Sh Yusupbekov O N Salokhiddinov A T 2001 Water conservation is the way to rationally use water and prevent water pollution J Agrarian Science No 1 (Tashkent) pp 26-27
[5] Ekebafe L O Ogbeifun D E and Okieimen F E 2011 Effect of native cassava starch-poly (sodium acrylate-co-acrylamide) hydrogel on the growth performance of maize (Zea may) seedlings Am J Polymer Sci 1 pp 6-11
[6] Geesing D and Schmidhalter U 2004 Influence of sodium polyacrylate on the water-holding capacity of three different soils a effects on growth of wheat Soil Use Manage 20 pp 207-209
[7] Ingram D L and Yeager T H 1987 Effects of irrigation frequency and a water-absorbing polymer amended on Ligustrum growth and moisture retention by a container medium Journal of Environmental Horticulture 5 pp 19–21
[8] Johnson M S 1984 Effect of soluble salts on water absorption by gel-forming soil conditioners Journal of the Science of Food and Agriculture 35 pp 1063–1066
[9] Johnson M S 1984 The effects of gel-forming polyacrylamides on moisture storage in sandy soils Journal of the Science of Food and Agriculture 35 pp 1196–1200
[10] Jhurry D 1998 Agricultural polymers In Proceedings of the Second Annual Meeting of Agricultural Scientists p 109
[11] Puoci F Iemma F Spizzirri U G Cirillo G Curcio M & Picci N 2008 Polymer in agriculture a review American Journal of Agricultural and Biological Sciences 3(1) pp 299-314
[12] Woodhouse J & Johnson M S 1991 Effect of superabsorbent polymers on survival and growth of crop seedlings Agricultural Water Management 20(1) pp 63-70
[13] Aniket Kalhapure Rajeew Kumar Singh V P and Pandey D S 2016 Hydrogels: a boon for increasing agricultural productivity in water-stressed environment Current Science Vol 111 No 11 10 december pp 1773-1779
[14] Salokhiddinov A T 2004 Highly swellable polymer hydrogel is an unconventional method of water conservation in irrigated agriculture Journal of Fergana Polytechnic Institute No 1 pp 73-77
[15] Montesano Francesco F Parente Angelo Santamaria Pietro Sannino Alessandro Serio Francesco 2015 Biodegradable Superabsorbent Hydrogel Increases Water Retention Properties of Growing Media and Plant Growth Agriculture and Agricultural Science Procedia 4 pp 451-458 DOI:10.1016/j.aaspro.2015.03.052
[16] Agaba H Orikiriza L Obua J 2011 Hydrogel amendment to sandy soil reduces irrigation frequency and improves the biomass of Agrostis stolonifera Agricultural Sciences 02(04) 544-550 DOI:10.4236/as.2011.24071

[17] Kolodynska D Skiba A Gorecka B & Hubicki Z 2016 Hydrogels from Fundaments to Application In Emerging Concepts in Analysis and Applications of Hydrogels In Tech https://doi.org/10.5772/63466

[18] El-Hady O A Shaaban S M & Wanas S A 2012 Effect of hydrogels and organic composts on soil hydrophysical properties and on production of tomato International Society for Horticultural Science In Acta Horticulture Vol 933 pp 115–122 https://doi.org/10.17660/ActaHortic.2012.933.12

[19] Vosoughi S Mahmoudreza Hojjati S & Kasraian A 2018 Preparation and Study on Properties Superabsorbent Hydrogel Composite of Acryl-amide-Acrylic Acid and Zeolite in Agricultural Uses Iran J Polym. Sci Technol Persian 30(5) pp 391–404 https://doi.org/10.22063/JIPST.2017.1528

[20] Adi S H 2012 Nanotechnology for Agriculture: Application of Hydrogel for Irrigation Efficiency Journal Sumberdaya Lahan 6(1) pp 1–8

[21] Parvanak K & Chamheidar H 2014 The effect of Tarawat hydrogel and irrigation interval on available water and rooting indices in Nerium oleander Advances in Environmental Biology 8 11 spec issue 5 pp 271–277

[22] Đurović N Pivić R & Počuča V 2012 Effects of the application of a hydrogel in different soils Agriculture & Forestry 53(07) pp 1–4

[23] Dabhi R Bhatt N & Pandit B 2014 Effect on the Absorption Rate of Agricultural Super Absorbent Polymers under the Mixer of Soil and Different Quality of Irrigation Water International Journal of Emerging Technology and Advanced Engineering IJETAE 3(1) pp 1402–1406