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POLYMER GELS TO MANAGE WATER AVAILABILITY FOR WHEAT (*Triticum aestivum* L.) UNDER VARIOUS ENVIRONMENT CONDITIONS

T.N. DANILOVA[1], L.K. TABYNBAYEVA[2]

[1]*Agrophysical Research Institute*, 14, Grazhdanskii prosp., St. Petersburg, 195220 Russia, e-mail danilovatn@yandex.ru (✉ corresponding author);
[2]*LLP Kazakh Scientific Research Institute of Arable Farming and Horticulture*, 1, st. Erlepesov, Almaty Province, Karasay Region, Almalybak, 040909 Republic of Kazakhstan, e-mail tabynbaeva.lyalya@mail.ru
ORCID:
Danilova T.N. orcid.org/0000-0001-6926-6155 Tabynbayeva L.K. orcid.org/0000-0001-9721-6737
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Abstract

During the last years, due to climate changes and reducing water availability for crops, special attention is paid to moisture-swelling polymers. In this paper we compared the influence of Russian hydrogel Ritin-10 (LLC RITEK—ENPTs, Russia) and polymer Aquasorb (SNF s.a.s., France) on spring and winter wheats in Russia and Kazakhstan. The effect of Ritin-10 hydrogel on spring wheat Esther variety water supply was studied in a field experiment (Russia, 2011) with the hydrogel dosage of 400 kg/ha and its combination with nitrogen fertilizers (N_{60}, N_{90}, and N_{120}). Analysis of soil moisture during different periods of vegetation showed that Ritin-10 significantly ($p < 0.05$) increases soil moisture as compared to the control. The moisture content in use of nitrogen fertilizers combined with the hydrogel varied from 19.33 to 31.60%, and in use of nitrogen fertilizers without hydrogel from 13.14 to 17.40%. In the control, the soil moisture during the vegetation period was from 11.36 to 17.10%. Reserves of productive moisture under Aquasorb application on winter wheat Glassy variety 24 crops at tillering (Kazakhstan, 2015-2016) were 10.30-19.00% higher compared to the control. When using N_{45}, the reserves of productive moisture were 23.90-31.00%. The use of Ritin-10 hydrogel on wheat crops leads to a significant ($p < 0.001$) increase in grain yield. The grain yield of spring wheat under a combined effect of Ritin-10 hydrogel and nitrogen fertilizers varied from 33.23 to 35.7 c/ha. In our tests, the combination N_{120} + Ritin-10 provided the highest grain yield which exceeded control by 10 c/ha. Aquasorb without fertilizers and with N_{45} yields grain harvest of 27.0-35.7 c/ha for winter wheat variety Glassy 24. This study showed that Ritin-10, like superabsorbent polymer Aquasorb, can effectively manage water availability and water supply of crops.

Keywords: *Triticum aestivum* L.), spring wheat, winter wheat, water-absorbing polymers, soil moisture, root system, water availability, yield

The use of moisture-swelling polymers is considered one of the innovative non-traditional approaches in modern agricultural technologies. Strongly-swelling (moisture-swelling) polymeric hydrogels represent hydrophilic polymer material of acrylate nature. They repeatedly increase in volume at swelling, possess a high water-absorbing ability; at the same time, they are stable at repeated cycles of drying and swelling [1]. When applied to the soil root layer, gel particles are located in the inter-aggregate space and swell when moisture enters, providing an increase in humidity compared to the indicators in untreated soil. As a result, the water balance is optimized and moisture conditions favorable for the growth and development of plants are created. The main part of the water in the hydrogel has a potential of $4.2 > pF > 2.0$ (values characterizing biologically available moisture) and is used by plants effectively. When drying, the absorbent takes its original crystalline form and is ready for a new cycle with subsequent humidification. The cyclical nature of absorption and the delivery of moisture for several years are inherent in the hydrogels of polyacrylamide type, so their use is the most appropriate when carrying out agricultural activities [2, 3].

When using hydrogels, water and fertilizers (in the form of a soil solution) are stored in the zone of the root system of plants and feed them. Many researchers note [4-6] that hydrogels increase the amount of available moisture in the root zone, implying longer intervals between watering. Moisture capacity depends on the soil texture, type of hydrogel, size of particles (powder or granules), and pH of the soil solution.

The studies of domestic scientists [7, 8] showed that hydrogels are one of the most powerful synthetic means of controlling the hydrophysical properties and water regime of soils. Doses of domestic polymer gels 0.10-0.25% by weight of the soil reduce its density by 1.2-1.5 times, which creates additional porosity and increases the total moisture content up to 30-40% against 23-25%. In foreign publications, it was reported [9-11] that the treatment of soil substrates with synthetic hydrophilic gels at doses of preparations from 0.1-0.3 to 0.5% of the soil weight contributed to better germination of seeds, stimulated the growth of crops and increased their yield by 30-40%. It was found that [12] Aquasorb (SNF s.a.s., France) absorbs 50% of water for 20 min and 100% of water for 120 min. Adsorption volumes vary from 30 to 500 liters per 1 kg of dry polymer. Such water absorption capacity can be effectively maintained for 4-5 years, and the water exchange between the soil and the polymer is reversible.

Hydrogels are used as additional additives in the cultivation of plants in regions where water resources are a limiting factor. The use of a superabsorbing polymer eliminates the effects of drought and contributes to the development of drought resistance in plants [13]. The use of hydrogels reduces the number of watering significantly, especially for soils with a rough structure [14, 15].

Ritin-10 is a cross-linked copolymer of polyacrylamide, synthesized by external exposure to ionizing radiation (technology of scientific and technical landfill of PAO LUKOIL—OOO RITEK-ENPTS, Russia) and is mainly used in the oil industry to improve the oil recovery of formations. The chemical composition of the hydrogel includes C 11%, N 4.7%, O_2 16.4%, Cl 1.01%, K 27.05% and Na 36.98%. It also finds application in crop production: 1 g of hydrogel holds about 300 ml of water, with the moisture availability for plants of 95% and productivity in the soil up to 5 years [16]. Agricultural tests of Ritin-10 were started in 2008 [17]. The results of field experiments on the cultivation of winter wheat under semi-fallow conditions showed the effectiveness of this hydrogel in the Stavropol Territory [18].

In the present paper, the domestic hydrogel Ritin-10 (OOO RITEK-ENPTS, Russia) obtained from the waste of oil industry was compared with the known water-absorbing polymer Aquasorb (SNF s.a.s., France) in field trials in Russia and Kazakhstan.

The work objective was to estimate the effectiveness of the hydrogel of Russian production (Ritin-10) in water supply of wheat plants depending on nitrogen nutrition and to compare this with superabsorbent Aquasorb when used on soils of different types.

Techniques. The effect of the hydrogel Ritin-10 **(**OOO RITEK—ENPTS, Russia**)** for the water supply of spring wheat (*Triticum aestivum* L.) Ester variety (the predecessor was the potato variety Skarb) was studied in the technological cycle seeding—commercial products in a field experiment (Agrophysical Institute, field station of the Menkovskii branch, the Leningrad Province, 2011) on sod-podzolic light loamy soils with different types of nitrogen nutrition. Agrochemical examination of the experimental site was performed according to the method of field experiment [19]. Soil samples were taken with a soil auger to a depth of arable layer; the acidity (pH of salt extract) was determined potentiometrically according to GOST 26483-85, the content of ammonium nitrogen

N-NH_4 according to GOST 26489-85, nitrate nitrogen according to GOST 26951-86, mobile forms of phosphorus and potassium by Kirsanov (GOST 26207-91), humidity according to GOST 28268-89. The hydrogel was introduced into the root layer (5-7 cm) in the pre-sowing period at a dose of 400 kg/ha. The size of the working plots is 80 m^2 (8×10 m), repetition is 2-fold. Combinations of hydrogel (400 kg/ha) with nitrogen fertilizers at doses of N_{60}, N_{90} or N_{120} were tested; the controls were the option without hydrogel and nitrogen fertilizers and the option with hydrogel (400 kg/ha) without nitrogen fertilizers. During the vegetation period, biometric and phenological observations were carried out according to the phases of plant development and soil samples were taken to determine the humidity.

The influence of Aquasorb absorbent (SNF s.a.s., France) on the water supply of winter wheat Steklovidnaya 24 variety was investigated in stationary field experiments (Kazakh Research Institute of Agriculture and Plant Growing, 2015-2016) on light-brown, light loamy soil. Two doses of the absorbent (20 and 40 kg/ha) and their combination with nitrogen fertilizer (N_{45}) were tested; the control was the option without the absorbent and nitrogen fertilizer.

Field and laboratory observations (analyses) and accountings were carried out by the method of field experiment [19].

Statistical processing was performed with Statistics 5.0 software (StatSoft, Inc., USA). The values of the mean (M) and standard deviations (±SD) were calculated. The significance of mean differences was assessed by two-factor analysis of variance (ANOVA), the differences were considered statistically significant at $p \leq 0.05$.

Results. Sod-weak- and sod-medium-podzolic soils are widespread in the Menkovskii branch. Among these soils, easy-medium-loamy soil and sandy loam on the moraine dominate. The granulometric composition of sod-podzolic light-loamy soil includes: physical clay 27.96%, large dust 22.4%, ooze 6.11% (K.G. Moiseev. The database of the soil cover of the Menkovskii branch of BSI Agrophysical Institute of RAA, the structure of the soil cover, geomorphological structure, physical, and geochemical properties of soils, 2013). The results of the agrochemical survey of the experimental site showed that the total nitrogen content is 0.37% with the high availability of phosphorus and potassium, i.e. P_2O_5 724.7 mg/kg, K_2O 280.9 mg/kg (according to Kirsanov). According to the pH_{KCl} 5.8, the soil refers to slightly acidic or close to neutral.

Fig. 1. The development of the root system in spring wheat (*Triticum aestivum* L.) Ester variety plants at tillering stage without the use of hydrogel (on the left) **and with the pre-sowing application of hydrogel Ritin-10 (Russia)** (on the right) (field trials, field station of the Menkovskii branch of the Agrophysical Institute, the Leningrad Province, 2011).

In the conditions of the Leningrad region, the introduction of hydrogel during the pre-sowing period had a positive effect on the development of the root system of spring wheat at tillering; a large part of the roots (Fig. 1, on the right) was in the area of hydrogel application. The effect of hydrogel was the greatest from tillering (in the North-Western zone of Russia, the end of May to the beginning of June is considered a dry period) to flowering and especially at the boot stage. These are the most critical stages of the development of spring wheat, when the crop is formed, and the lack of moisture in these periods affects the crop yield greatly [20].

The presence of hydrogel in the root layer affected the formation of biomass significantly. During the growing season, the increased plant growth with good standing density occurred. Phenological and biometric observations showed that plant biomass (compared to that in the control) significantly ($p < 0.001$) increased in vegetation stages, especially in variants where hydrogel was used together with nitrogen fertilizers at doses of N_{90} and N_{120} (Fig. 2).

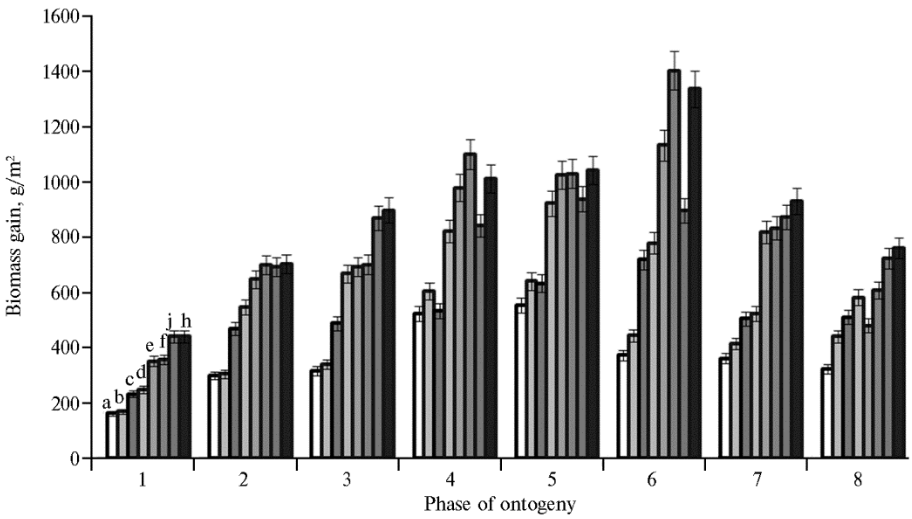

Fig. 2. Dynamics of biomass accumulation in spring wheat (*Triticum aestivum* L.) Ester variety plants under the influence of hydrogel Ritin-10 (Russia, 400 kg/ha) and nitrogen fertilizers: a — control 1, b — control 2 (control 1 + gel); c — N_{60}, d — N_{60} + gel; e — N_{90}; f — N_{90} + gel; g — N_{120}, h — N_{120} + gel; 1 — tillering; 2 — booting; 3 — earing; 4 — flowering; 5 — flowering-filling; 6 — milky ripeness; 7 — wax ripeness; 8 — full ripeness. The mean (*M*) and standard deviations (±SD) are given (field experiment, the field trials of the Menkovskii branch of the Agrophysical Institute, the Leningrad Province, 2011).

As is known [21-23], if water is available in the required quantities, a significant proportion of the energy released on the surface of actively developing plants is spent for transpiration. The intensity of transpiration is influenced by a large number of factors (temperature of the transpiration surface, soil moisture, relative humidity, coefficients of diffusion and air turbulent flow). The main part of the absorbed water, passing through the plant, transports minerals and evaporates through the stomata of the leaves into the atmosphere. With the lack of moisture, a decrease in transpiration due to the closure of stomata takes place, which leads to plant wilting. Hydrogel [23-25] is most effective in stressful conditions for plant growth and development (high temperature, lack of moisture in the soil). The results of soil moisture analysis in different periods of vegetation indicate that hydrogel ($p < 0.05$) increased this parameter compared to the control significantly. The moisture content in the options when nitrogen fertilizers were used in combination with hydrogel varied from 19.33 to 31.60%, in the presence of nitrogen fertilizers without hydrogel from 13.14 to 17.40%. In the control group without hydrogel, soil moisture during the growing season was from 11.36 to 17.10%. Consequently, the moisture retained by the hydrogel was sufficient for use in transpiration, which had a positive effect on the growth, development, and productivity of plants. It is especially important to have a minimum reserve of soil moisture in the early stages of development of wheat plants. The introduction of the hydrogel contributes to improving conditions for seed germination and plant nutrition during formation of the climatically secured crop [25, 26].

Aquasorb is a superabsorbent based on anionic polyacrylamide, a water-insoluble cross-linked copolymer of acrylamide and potassium acrylate. The absorbent is hardly affected by biodegradation, does not hydrolyze, and does not bioaccumulate. Specific gravity is 1.10 g/cm^3, pH = 8.10, 1 g holds about 400 ml of water; adsorption in deionized water is 400 g/g, in soil 150 g/g, moisture retention at pF 1 is 980 ml/l with 95% water return (near the drying point) and cation exchange capacity of 4.6 mEq/g. Productivity in soil is up to 5 years [26]. Aquasorb superabsorbent is widely used in crop production, forestry, and horticulture (for transportation and planting of seedlings), floriculture, vegetable growing (in greenhouses), melon production, animal husbandry (as a litter for animals), landscape design (Alpine slides, lawns).

In stationary experiments in the conditions of Kazakh Research Institute of Agriculture and Plant Growing, the density of light-brown light loamy soil was 1.16 and 1.33 g/cm^3. The mechanical composition of the soil refers to light loam, with the content of physical clay 39-42%, large dust 45-50%, ooze 12-17%. The content of carbonates in the upper layers is 2.7-3.6%, in the carbonate horizon 6.5%. The amount of absorbed bases does not exceed 12 mg-eq. per 100 g of soil. The calcium accounts for 80-90%, magnesium for 10-20%, the amount of absorbed sodium is negligible. The provision of soil with easily hydrolyzed nitrogen is medium, mobile phosphorus is low, exchangeable potassium is medium (according to Kirsanov, GOST 26207-91), light-brown soil in the upper horizon contains 0.12-0.14% gross nitrogen, 2.02% humus (GOST 26213-91), with no salinization with water-soluble salts (the amount of salts in the upper layer does not exceed 0.12%) [27]. The predecessor of winter wheat was complete fallow. The reclaiming with the blade cultivator KRN-2-150 (Humanimal, Russia) was carried out before sowing at a depth of 20-22 cm.

Studies carried out in Kazakhstan have shown that the use of Aquasorb in winter wheat crops effectively increases moisture reserves, especially when grown without irrigation [28]. It was found that during the tillering of winter wheat, productive moisture reserves in the soil layer depth of 1 m when applying Aquasorb at doses of 20 and 40 kg/ha were higher by 13-19 mm (or 10.3-19.0%) compared to the control group (without Aquasorb). When using nitrogen fertilizers N_{45} with hydrogel, the reserves of productive moisture were 30-39 mm (or 23.9-31.0% higher than in the control). The reserves of productive moisture in the cultivation of winter wheat were the largest when applying Aquasorb (40 kg/ha) with a nitrogen fertilizer N_{45} and the smallest with nitrogen fertilizer N_{45} only, with moisture reserves only 6 mm (4.8%) higher than in the control.

When using Aquasorb without fertilizers and in combination with fertilizer, the yield of winter wheat ranged from 27.00 to 35.70 c/ha (Fig. 3, A). Aquasorb significantly ($p < 0.05$) increased grain yield, especially in combination with nitrogen fertilizers. The highest yield without the use of nitrogen fertilizers was obtained at 40 kg/ha of Aquasorb (32.20 c/ha, that is, by 5.20 c/ha higher than in the control), and the combination of Aquasorb 40 kg/ha + N_{45} gave an increase of 8.70 c/ha compared to the control. Treatment with hydrogel Ritin-10 led to a significant ($p < 0.001$) increase in the yield of spring wheat (see Fig. 3, B). This figure in the options with hydrogel in combination with nitrogen fertilizers ranged from 33.23 to 35.70 c/ha. The highest yield was obtained with N_{120} + Ritin-10 (grain yield was 10 kg/ha more than in the control without fertilizers and without gel). The increase in yield was 20.6% for N_{60} + Ritin-10, 33.0% for N_{90} + Ritin-10, and 38.9% for N_{120} + Ritin-10 as compared to the control.

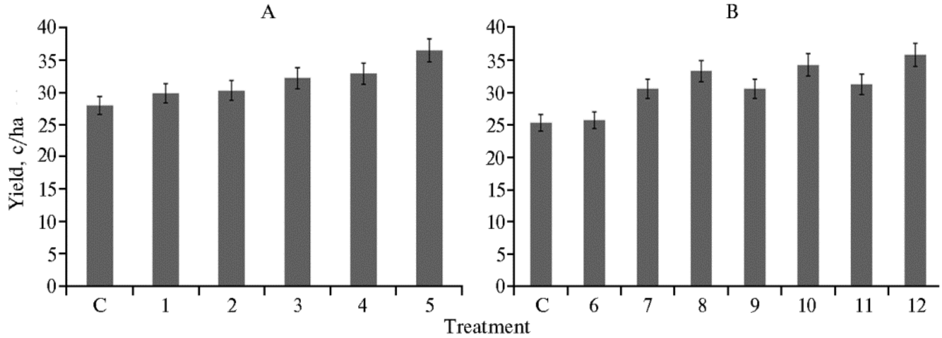

Fig. 3. The yield of wheat (*Triticum aestivum* L.) under application of hydrogels and nitrogen fertilizers: A — winter wheat (the Steklovidnaya 24 variety, Aquasorb, Kazakhstan), B — spring wheat (the Ester variety Ritin-10, Russia); C — control (without additives), 1 — N_{45}, 2 — Aquasorb 20 kg/ha, 3 — N_{45} + Aquasorb 20 kg/ha, 4 — Aquasorb 40 kg/ha, 5 v N_{45} + Aquasorb 40 kg/ha; 6 — Ritin-10 400 kg/ha, 7 — N_{60}, 8 — N_{60} + Ritin-10 400 kg/ha, 9 — N_{90}, 10 — N_{90} + Ritin-10 400 kg/ha, 11 — N_{120}, 12 — N_{120} + Ritin-10 400 kg/ha. The mean (*M*) and standard deviations (±SD) are given. Field experiments, field stations of Kazakh Research Institute of Agriculture and Plant Growing (2015-2016) and the Menkovskii branch of the Agrophysical Institute (Leningrad Province, 2011).

Thus, assessment of the effect of hydrogel Ritin-10 on the water availability for wheat crops have shown that pre-sowing introduction of Ritin-10 improves the development of the root system during plant tillering stage. It was revealed that the hydrogel accumulates a sufficient amount of soil moisture for normal growth and development of wheat plants during dry periods of the growing season, thereby increasing crop yield. In terms of the effect on the water availability of plants, hydrogel Ritin-10 shows high efficiency in comparison to the superabsorbent Aquasorb.

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