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ENHANCING THE SUSTAINABILITY OF AGROECOSYSTEMS UNDER CLIMATE STRESS THROUGH THE INTEGRATION OF LEGUME CROPS, BIOLOGICAL PREPARATIONS, AND LEGUME–CEREAL CROP ROTATIONS IN NORTHERN KAZAKHSTAN

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The article addresses the issues of increasing the sustainability and productivity of agroecosystems under conditions of climatic instability in Northern Kazakhstan, characterized by frequent droughts, uneven precipitation distribution, and increased temperature stress during the growing season. Particular attention is paid to the integration of leguminous crops, especially chickpea, as well as the use of biological preparations within legume–cereal crop rotation systems as a promising direction in the biologization of agriculture. The paper presents the results of field and laboratory studies aimed at a comprehensive assessment of the impact of agrotechnological practices on soil fertility, water regime, and crop productivity. The research examined agrochemical and agrophysical soil parameters, including humus content, macro- and micronutrient availability, soil acidity, bulk density, and water retention capacity, as well as plant biometric characteristics, leaf area development, and biomass accumulation dynamics. It was established that the use of biopreparations and seed inoculation with rhizobial bacteria enhances microbiological activity in the soil, improves nitrogen availability, and increases water use efficiency. A positive effect on soil structure and biological activity was also observed.

The application of these approaches ensures a stable increase in chickpea yield, improves product quality, and reduces dependence on mineral fertilizers. The economic evaluation demonstrated increased profitability due to cost optimization and higher productivity. The obtained results confirm the feasibility of implementing biologized technologies as an effective tool for adapting agriculture to changing climatic conditions and ensuring sustainable agricultural development in arid regions.

Keywords: *preparations; chernozem (black soil); legume crops; biodiversity; agroecosystem sustainability.*

КЛИМАТТЫҚ СТРЕСС ЖАҒДАЙЫНДА СОЛТҮСТІК ҚАЗАҚСТАНДА БҰРШАҚ ТҰҚЫМДАС ДАҚЫЛДАРДЫ, БИОПРЕПАРАТТАРДЫ ЖӘНЕ БҰРШАҚ-ТҰҚЫМДАС–АСТЫҚ АУЫСПАЛЫ ЕГІСТЕРІН ИНТЕГРАЦИЯЛАУ НЕГІЗІНДЕ АГРОЭКОЖҮЙЕЛЕРДІҢ ТҰРАҚТЫЛЫҒЫН АРТТЫРУ

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Мақалада Солтүстік Қазақстан жағдайындағы климаттық тұрақсыздық аясында агроэкожүйелердің тұрақтылығы мен өнімділігін арттыру мәселелері қарастырылады. Бұл өңірге жиі қайталанатын құрғақшылық, жауын-шашынның біркелкі түспеуі және вегетациялық кезеңде температуралық жүктеменің артуы тән. Зерттеуде бұршақ дақылдарын, атап айтқанда ноқатты енгізу, сондай-ақ бұршақ–дәнді дақылдар ауыспалы егіс жүйесінде биологиялық препараттарды қолдану агроөндірісті биологизациялаудың перспективалы бағыты ретінде қарастырылған. Еңбекте агротехнологиялық тәсілдердің топырақ құнарлылығына, су режиміне және дақыл өнімділігіне әсерін кешенді бағалауға бағытталған далалық және зертханалық зерттеулердің нәтижелері ұсынылған. Зерттеу барысында топырақтың агрохимиялық және агрофизикалық көрсеткіштері, соның ішінде гумус мөлшері, макро- және микроэлементтердің құрамы, қышқылдық деңгейі, тығыздығы және ылғал сақтау қабілеті, сондай-ақ өсімдіктердің биометриялық параметрлері, жапырақ бетінің қа-

лыптасу динамикасы мен биомасса жинақталуы зерттелді. Биопрепараттарды қолдану және тұқымды түйнек бактерияларымен инокуляциялау топырақтағы микробиологиялық процестерді белсендендіріп, азоттың қолжетімділігін арттырып, суды пайдалану тиімділігін жоғарылататыны анықталды. Сонымен қатар, топырақ құрылымы мен оның биологиялық белсенділігінің жақсаруы байқалды.

Ұсынылған агротехнологияларды қолдану ноқат өнімділігінің тұрақты өсуін қамтамасыз етіп, өнім сапасын арттырады және минералдық тыңайтқыштарға тәуелділікті төмендетеді. Жүргізілген экономикалық бағалау шығындарды оңтайландыру және өнімділікті арттыру есебінен рентабельділіктің жоғарылағанын көрсетті. Алынған нәтижелер биологизацияланған технологияларды енгізудің ауыл шаруашылығын өзгермелі климат жағдайларына бейімдеудің тиімді құралы екенін және қуаң аймақтарда тұрақты дамуды қамтамасыз ететінін дәлелдейді.

Түйінді сөздер: *препараттар; қара топырақ; бұршақ дақылдары; биоалуантүрлілік; агрожүйелердің тұрақтылығы.*

ПОВЫШЕНИЕ УСТОЙЧИВОСТИ АГРОЭКОСИСТЕМ В УСЛОВИЯХ КЛИМАТИЧЕСКОГО СТРЕССА НА ОСНОВЕ ИНТЕГРАЦИИ БОБОВЫХ КУЛЬТУР, БИОПРЕПАРАТОВ И БОБОВО-ЗЛАКОВЫХ СЕВООБОРОТОВ В УСЛОВИЯХ СЕВЕРНОГО КАЗАХСТАНА

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В статье рассматриваются вопросы повышения устойчивости и продуктивности агроэкосистем в условиях климатической нестабильности Северного Казахстана, характеризующейся частыми засухами, неравномерным распределением осадков и повышенной температурной нагрузкой в вегетационный период. Особое внимание уделено интеграции бобовых культур, в частности нута, а также применению биологических препаратов в системе бобово-злаковых севооборотов как одному из перспективных направлений биологизации земледелия. Представлены результаты полевых и лабораторных исследований, направленных на комплексную оценку влияния агротехнологических приёмов на плодородие почвы, водный режим и урожайность культуры. В ходе исследований изучены агрохимические и агрофизические показатели почвы, включая содержание гумуса, макро- и микроэлементов питания, уровень кислотности, плотность сложения и водоудерживающую способность, а также биометрические параметры растений, динамику формирования листовой поверхности и накопления биомассы. Установлено, что использование биопрепаратов и инокуляция семян клубеньковыми бактериями способствуют активизации микробиологических процессов в почве, улучшению азотного питания растений и повышению коэффициента использования влаги. Отмечено положительное влияние данных приёмов на структуру почвы и её биологическую активность.

Применение предложенных агротехнологий обеспечивает устойчивый рост урожайности нута, улучшение качественных показателей продукции и снижение зависимости от минеральных удобрений. Проведённая экономическая оценка показала повышение рентабельности производства за счёт оптимизации затрат и повышения продуктивности. Полученные результаты подтверждают целесообразность внедрения биологизированных технологий как эффективного инструмента адаптации земледелия к изменяющимся климатическим условиям и обеспечения устойчивого развития сельского хозяйства в засушливых регионах.

Ключевые слова: *препараты, чернозем, бобовые культуры, биоразнообразие, устойчивость агросистем.*

Introduction

Under current conditions of global climate change, the agricultural sector faces a number of significant challenges that directly affect the sustainability and productivity of crop production. Rising average annual temperatures, changes in precipitation patterns, increasing frequency of extreme weather events (droughts, heavy rains, temperature anomalies), as well as soil degradation, necessitate a reconsideration of traditional approaches to farming. In this context, the development and implementation of adaptive agricultural technologies that not only increase crop yields but also conserve natural resources and restore the ecological balance of agroecosystems is of particular importance [1, p. 23].

One promising direction for sustainable agriculture is the use of scientifically based crop rotation systems that include legumes and cereals. These crops possess a range of biological and agroecological advantages, enabling effective regulation of soil fertility, optimization of water and nutrient use, and increased resilience of agrocenoses to environmental stress factors. Leguminous crops, such as chickpeas, lentils, peas, and others, play an important role in the biologization of agriculture due to their ability to fix atmospheric nitrogen symbiotically with the help of Rhizobium bacteria. This leads to the accumulation of bioavailable nitrogen in the soil, reducing the need for mineral fertilizers and decreasing anthropogenic environmental pressure. In turn, cereal crops (wheat, barley, oats) are highly adaptive and efficiently utilize natural resources, contributing to a stable structure of agro-phytocenoses [2,3, p. 32].

The combination of legumes and cereals within crop rotation creates a pronounced synergistic effect, manifested in improved agro-physical, agro-chemical, and biological properties of the soil. The extensive root systems of cereals enhance soil structure and water retention, while legumes contribute to organic matter accumulation and increased humus content. As a result, more resilient and productive agroecosystems are formed, capable of effective functioning under limited water availability and climatic instability. These processes are especially important for regions with a sharply continental climate, such as Northern Kazakhstan. This area is characterized by frequent drought periods, high temperature amplitudes, and limited soil moisture reserves. In these conditions, introducing drought-tolerant crops, such as chickpeas, in combination with adapted cereals is a key strategy for enhancing agricultural resilience. The relevance of this study is determined by the need to develop effective and environmentally sustainable farming systems capable of adapting to modern climate changes and ensuring stable agricultural production. Under conditions of water scarcity and declining soil fertility, the implementation of agronomic practices aimed at biologization and rational use of natural resources is particularly important. Crop rotations including legumes and cereals are considered among the most effective tools for enhancing the biodynamics of agroecosystems. Such systems promote soil microbiological activity, increase organic matter content, improve soil structure, and enhance water retention. This is especially critical under increasing climatic stress, where the resilience of agroecosystems becomes a key factor in ensuring food security [3,4, p. 72].

Another important aspect is the economic efficiency of these agronomic practices. Reduced costs for mineral fertilizers through biological nitrogen fixation, decreased need for plant protection agents, and increased crop yields contribute to higher profitability. At the same time, there is an environmental benefit through reduced chemical load on the soil and surrounding environment. The use of biological agents and growth stimulants further enhances the positive effects of crop rotations, activating physiological processes in plants and increasing their resilience to adverse environmental factors. Their integration into cultivation technology improves resource use efficiency and ensures more stable yields [4, p. 62].

Thus, the development and scientific justification of crop rotation systems involving legumes and cereals, as well as the improvement of their cultivation technologies, are highly relevant tasks for modern agricultural science. Implementing these approaches contributes to the formation of resilient agroecosystems, increased soil fertility, and long-term ecological and economic stability in agriculture.

Objective of the study: Implementation of sustainable agronomic technologies for legume cultivation to increase productivity and enhance the stability of agroecosystems.

Tasks:

1) To determine the meteorological and soil conditions of the experimental site;

2) To determine the content of nutrients (humus level, soil density, pH, etc.) affecting chickpea productivity and soil fertility improvement;

3) To evaluate the effect of biological agents;

4) To determine biometric parameters of crops (field germination, plant height) and chickpea yield depending on the use of biological agents;

5) To conduct an economic assessment of the effectiveness of new agronomic practices, including yield increase and improvement of environmental indicators.

Materials and Methods

Experimental studies were conducted at the stationary base of the Department of Agronomy following generally accepted methodological approaches for establishing and conducting field experiments according to B.D. Dospekhov [5, 6, p. 23], as well as in accordance with the methodology of state variety testing of agricultural crops. In Kostanay Region, Altynsarin District, Zhanasu village.

The object of study was the regionally adapted chickpea variety (Cicer arietinum L.) – Volgograd 10. This early-maturing variety has a vegetation period of approximately 75 days, demonstrates resistance to major diseases, and is adapted to adverse climatic conditions. Field experiments were established with temporal replication over the period 2025–2027. The experimental design included three replicates. The total area of each plot was 120 m², with a working area of 100 m². Sowing was carried out in the second decade of May when the soil reached physical maturity, during the regionally optimal agronomic period. The preceding crop was spring wheat, sown after a clean fallow. The experimental site was selected based on soil maps, agrochemical maps, and historical field data. Additional information from the farm agronomy service regarding predecessors, applied agronomic practices, fertilization, and liming was also considered. Seed quality assessment was conducted in the laboratory in accordance with current state standards (GOST 12036–85 –

12042–80) [7, p. 23]. Parameters determined included germination energy (7th day), laboratory germination (14th day), and seed purity. Soil samples were collected from a 0–100 cm profile at 20 cm intervals to analyze soil moisture and nutrient content. To evaluate the impact of biological agents and fertilizers on soil fertility, additional samples were taken from depths of 0–20 and 20–40 cm at five points per plot. The following indicators were measured in the collected samples [8,9,10,11]:

- Soil moisture – by gravimetric method;
- Humus content – by Tyurin method (GOST 26213-91);
- Soil pH – by ionometric method;
- Nitrate nitrogen – using a nitrate analyzer;
- Available phosphorus and exchangeable potassium – by Machigin method;
- Absorbed calcium and magnesium – by titrimetric method.

During the growing season, plant samples (50 plants per plot along the diagonal) were collected to determine dry matter accumulation and chemical composition. All laboratory analyses were performed in duplicate. Humus content was determined before the experiment, mid-rotation, and at the end of the crop rotation. Total nitrogen was analyzed using the Kjeldahl method (macro- and micro-methods), and total phosphorus by the Lebedyantsev method with colorimetric determination. Fractional phosphate composition was studied using Chirikov and Chang-Jackson methods (modified by Ginzburg and Lebedeva). Phenological observations included field germination, plant density (measured diagonally on 0.25 m² sampling areas), and assessment of crop condition at different developmental stages. Aboveground biomass was measured by cutting plants at soil level every 10 days, starting from the full emergence phase. Weed infestation was assessed quantitatively by weight at tillering, flowering, and maturation stages using a 1 m² sampling frame at four diagonal points per plot. Plant height was measured at key developmental stages: emergence, third leaf, budding, flowering, end of flowering, and full maturity.

Agronomic Practices

Soil preparation included early spring harrowing to conserve moisture and destroy weed sprouts at the "white thread" stage (late March–early April). Prior to sowing, cultivation with harrowing and rolling was performed. Seeds were inoculated with strains of Rhizobium spp. five hours before sowing on a tarpaulin surface (4×6 m), avoiding direct sunlight. The inoculant used was "Rhizovit AKS," containing highly active Rhizobium strains on a peat base enriched with biologically active substances, applied at 400 g per hectare of seeds. During the growing season, the biological preparation "Baikal M" was applied using a backpack sprayer at a rate of 250 L/ha of working solution.

Data Processing

Reliability of the experimental data was ensured through mathematical statistics and correlation analysis to identify relationships between crop productivity and applied agronomic practices. Statistical analysis was performed using Microsoft Excel 2021 (ANOVA), as well as specialized statistical software packages "Snedecor" and "STATISTICA." For all laboratory tests, a significance level of $p < 0.05$ was applied.

Results and Discussion

Meteorological observations of air temperature and precipitation were conducted at the experimental site. In January, the average air temperature was −9.1 °C, with a minimum of −23.1 °C, a maximum of +1.3 °C, and precipitation of 27 mm. In February, the average temperature was −9.5 °C (min −24.3 °C, max +2.2 °C), precipitation 66 mm. In March, the average temperature was −1.6 °C (min −20.9 °C, max +14.5 °C), precipitation 86 mm (Figure 1).

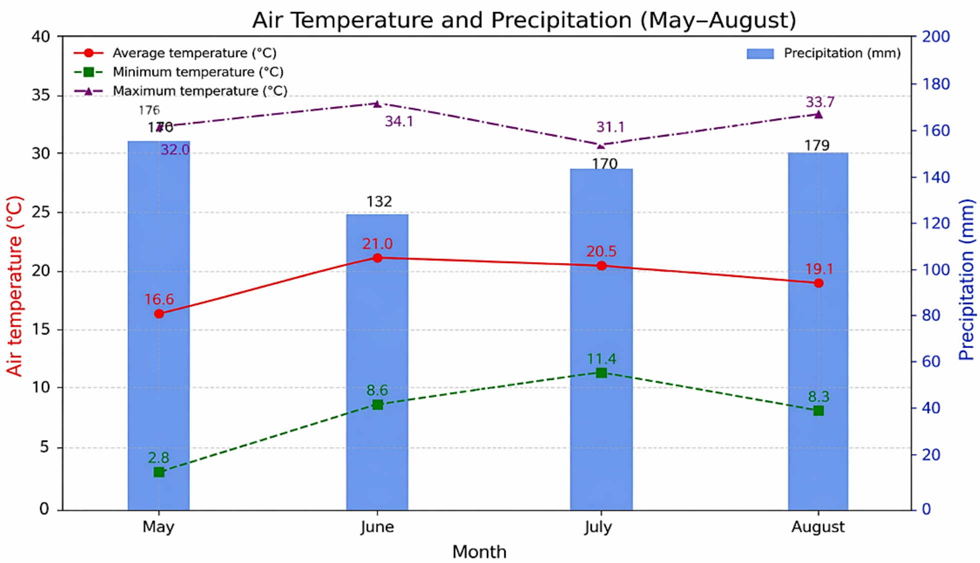

Figure 1 – Air Temperature and Precipitation Dynamics (May–August)

April showed an average of +11.6 °C (min 0.8 °C, max +25.5 °C), precipitation 144 mm. In May, the average temperature was +16.6 °C (min +2.8 °C, max +32.0 °C), precipitation 176 mm. June had an average of +21.0 °C (min 8.6 °C, max +34.1 °C), precipitation 132 mm. July recorded +20.5 °C (min +11.4 °C, max +31.1 °C), precipitation 170 mm. In August, the average was +19.1 °C (min +8.3 °C, max +33.7 °C), precipitation 179 mm. September: average +13.7 °C (min −6.2 °C, max +29.9 °C), precipitation 147 mm. October: average +5.9 °C (min −2.8 °C, max +16.6 °C), precipitation 97 mm.The hydrothermal coefficient (HTC) for the growing season (May–August) was calculated based on temperature and precipitation data, yielding K ≈ 0.21. This coefficient, representing the ratio of cumulative temperature differences (between mean and minimum temperatures) to the temperature range (maximum minus minimum), indicates a moderately humid and temperate climate, typical of regions with mild to moderately continental conditions. Summer months (May–August) show a wide temperature range (+2.8 °C to +34.1 °C), reflecting warm to hot weather. Minimum temperatures in August (8.3 °C) indicate a relatively mild late summer. Monthly precipitation (86–179 mm) confirms moderate moisture and rainfall presence, particularly in summer. The moderate HTC (~0.21) indicates favorable conditions for growing legumes, supporting normal development without excessive stress, promoting high yield and quality, and ensuring sustainable legume production in crop rotations.

Soil samples from 0–20 cm and 20–40 cm layers were analyzed for humus content, nitrate nitrogen, available phosphorus, exchangeable potassium, and pH. The soils are southern chernozems, characterized by low humus content (3.30 %), available phosphorus (24.6 mg/kg), nitrate nitrogen (2.32 mg/kg), and high exchangeable potassium (527 mg/kg). Soil pH was slightly alkaline (7.47). Based on temperature and moisture analysis, optimal sowing dates for legumes were determined (second decade of May), along with application rates for biological agents. Soil bulk density was 1.1–1.2 g/cm³, optimal for legume and cereal growth.

After cultivation, legumes (chickpeas) positively influenced soil agrochemical and physical properties. Symbiotic nitrogen fixation increased nitrate nitrogen in the arable horizon by 15–20 % compared to the control, and humus content rose to 3.6–3.8 %. Improved soil structure and aggregate stability enhanced water-holding capacity by 8–10 %. Cereals (wheat), with developed root systems, promoted topsoil loosening and organic matter accumulation from root residues. Combined legume–cereal rotations stabilized pH to near-neutral values (7.1–7.2) and formed a more robust granular structure. Overall, legume–cereal cultivation improved soil nitrogen and carbon content, stabilized pH, enhanced structure, and increased water retention, thereby improving fertility. To enhance soil biological activity and nitrogen fixation, biological agents were applied. “Rhizovit AKS” inoculated seeds five hours before sowing with Rhizobium spp., on a 4×6 m tarpaulin to prevent direct sunlight. The inoculant contained highly effective rhizobial strains on a peat substrate enriched with carbohydrates, vitamins, and micronutrients, applied at 400 g per hectare of seeds. During the growing season, foliar sprays of “Respect” (active ingredients: imidacloprid, pencycuron) were applied at 250 L/ha to suppress pathogenic microflora, protect against bacterial infections, and stimulate nodule formation, phosphorus mobilization, and root development. Additionally, “Baikal M” (250 L/ha) containing lactic acid, photosynthetic, nitrogen-fixing, and other microorganisms, was applied to activate soil microbiological processes. These treatments increased microbial activity in the 0–20 cm soil layer by 20–25 % and raised organic carbon by 0.12–0.15 %, improving decomposition of plant residues and humus formation. Thus, biological agents enhanced soil organic carbon, beneficial microflora, plant nutrition, and overall soil biological activity [12, p. 3]. (Figure 2)

Figure 2 – Phenological stages of chickpea (Cicer arietinum)

Phenological observations showed positive effects of biological agents on chickpea growth, development, and yield formation. Field germination ranged from 85.4–91.0 %, indicating favorable growth dynamics during the vegetative period. Economic evaluation of new agronomic practices was conducted to assess yield increases, ecological benefits, and overall sustainability. Production costs were calculated, including seeds, fertilizers, fuel, plant protection, labor, and equipment depreciation. Gross yield was computed as crop productivity × selling price, net income as gross yield minus costs, and profitability (%) as a production efficiency indicator. Ecological effects were assessed by reduced nutrient loss, decreased fertilizer use, and improved soil structure. Adaptive agronomic measures (optimized sowing dates, green manure, minimal tillage, predictive yield models) reduced production costs by 10–15 %, increased legume yields by 8–12 % and cereals by 6–10 %, and raised net income by 15–20 % compared to conventional practices. Ecologically, integrating legumes reduced mineral fertilizer use by 10–20 %, enhanced soil structure and humus content, minimized degradation and nutrient leaching, and increased the biodynamics of crop rotations. Combined economic and ecological criteria showed that the integrated efficiency of innovative practices increased by 18–25 %, demonstrating high effectiveness [13, p. 4].

Correlation and regression analysis revealed strong positive relationships between yield and net income ($r = 0.86–0.92$). Mathematical processing confirmed significant dependencies of yield on weather conditions and agronomic factors. Regression and predictive models ($R^2 > 0.8$) can guide crop rotation planning, optimizing yield and enhancing agroecosystem biodynamics.

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Conclusion

The results of the study demonstrate that the introduction of legume–cereal crop rotations combined with biological agents significantly improves soil fertility, enhances agroecosystem stability, and increases chickpea yield under the arid and climatically unstable conditions of Northern Kazakhstan. The integration of chickpea into crop rotations activates soil microbiological processes, improves nitrogen availability, and strengthens soil structure and water retention capacity.

Overall, the proposed biologized agronomic practices provide both economic and ecological benefits, ensuring higher productivity, reduced dependence on mineral fertilizers, and long-term sustainable development of agricultural systems under climate change conditions.

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БИОГИДРОГЕЛЬДІҢ ЖАЗДЫҚ АРПА (*HORDEUM VULGARE L.*) ТҰҚЫМДАРЫНЫҢ ӨНГІШТІГІНЕ ӘСЕРІН БАҒАЛАУ

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Жұмыста $CaCl_2$ және лимон қышқылы арқылы торланған КМЦ, альгинат және ПВС негізіндегі биогидрогельдің арпа (Hordeum vulgare L.) тұқымдарының өнуіне және өскіндердің ерте өсуіне әсері зерттелді. Тұқымдар құрамында гидрогельдің әртүрлі концентрациялары бар құм толтырылған контейнерлерде өнді: 0, 0,1, 0,25, 0,5 және 0,7 %. Өну энергиясы мен толық өну көрсеткіштері (GP_3, GP_7), өнуінің интегралдық индексі (GI), орташа өну уақыты (AGT), өскіндердің өміршеңдік индекстері (SVI I, SVI II), сондай-ақ сабақтар мен тамырлардың ұзындығы бағаланды. Төмен және орташа концентрациядағы гидрогельдер (0,1–0,5 %) тұқымдардың өнуін және өскіндердің өсуін ынталандырып, GI және SVI интегралдық көрсеткіштерінің жоғарылауына ықпал ететіні анықталды. 0,25 % концентрациясы ең жоғары өну пайызын және GI мәндерін қамтамасыз етіп, бұл ретте тамыр жүйесі мен жерүсті бөлігінің дамуы біркелкі және тежелу белгілерінсіз жүрді. Гидрогельдің ең жоғары концентрациясы (0,7 %) барлық өміршеңдік көрсеткіштерінің төмендеуіне, орташа өну уақытының ұзаруына, тамырлар мен сабақтардың ұзындығының қысқаруына әкелді, бұл субстратта полимерлік матрицаның артық мөлшері кезінде ауа мен ылғалдың қолжетімділігінің шектелетінін көрсетеді. Жалпы алғанда, алынған нәтижелер КМЦ, альгинат және ПВС негізіндегі гидрогельдің 0,1–0,5 % оңтайлы концентрациялар диапазонында арпаның ерте өсуін тиімді ынталандыратынын, ал бұл шектен асып кетуі тұқымдардың өнуі мен өсімдіктердің бастапқы дамуына тежеуші әсер етуі мүмкін екенін дәлелдейді.

***Түйінді сөздер:** жаздық арпа, биогидрогель, карбоксиметилцеллюлоза (КМЦ), альгинат, поливинил спирті (ПВС), өнгіштік индексі (GI), өскіндердің тіршілікке қабілеттілік индексі (SVI).*

ОЦЕНКА ВЛИЯНИЯ БИОГИДРОГЕЛЯ НА ПРОРАСТАНИЕ СЕМЯН ЯРОВОГО ЯЧМЕНЯ (*HORDEUM VULGARE L.*)

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В работе изучено влияние биогидрогеля на основе КМЦ, альгината и ПВС с сшивкой $CaCl_2$ и лимонной кислоты на прорастание и ранний рост проростков ячменя (Hordeum vulgare L.). Семена проращивались в контейнерах с песком с содержанием различных концентраций гидрогеля: 0, 0,1, 0,25, 0,5 и 0,7 %. Оценивались энергия и полнота прорастания (GP_3, GP_7), интегральный индекс прорастания (GI), среднее время прорастания (AGT), индексы жизнеспособности проростков (SVI I, SVI II), а также длина побегов и корней. Установлено, что низкие и средние концентрации гидрогеля (0,1–0,5 %) стимулируют прорастание и рост проростков, повышая интегральные показатели GI и SVI. Концентрация 0,25 % обеспечивала максимальный процент прорастания и наиболее высокие значения GI, при этом развитие корневой системы и надземной части происходило равномерно и без признаков угнетения. Наибольшая концентрация гидрогеля (0,7 %) приводила к снижению всех