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EVALUATION OF POSSIBILITIES FOR USING ELECTROCHEMICALLY ACTIVATED WATER FOR IRRIGATION

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Abstract. *In order to check the possibility of using electrochemically activated water (ECHAW) in irrigation, a study was conducted to determine the influence of anolyte on biological pollutants of wastewater and the reduction of water mineralization by electrochemical activation, as well as the influence of catholyte and anolyte on the germination of seeds of cereal crops, the development of seedlings of pepper and tomato, and the yield of tomato. The research was conducted in laboratory conditions on two varieties of pepper and four varieties of tomato. ECHAW was obtained using laboratory water activators of our own production. Wastewater samples were taken at the Bortnychy wastewater aeration station in Kyiv. Experiments were carried out using vegetation containers of various types and one-time bacteriological tests. It was found that by electrochemical activation of mineralized water it is possible to reduce the level of its total mineralization by more than 50 % and, with an anolyte, to destroy disease-causing bacteria in wastewater. The use of ECHAW accelerates the germination of seeds of cereal crops. On the 3rd day of germination, wheat grain germinated using EHCAW has a 9 % longer root length than the grain germinated under the same conditions using non-activated water. Wheat grain germinated using EHCAW also has 33 % longer sprouts. The growth rate when irrigated with activated water, depending on the variety of tomato plants, increases by 9.8…25.2 %, the increase in stem diameters was equal to 11.3…22.4 %. The yield of tomatoes when irrigated with activated water is 12.6…15.8 % higher than in the case of irrigation by ordinary water, the size of the fruits is 15.4…25.1 % larger. The results of the conducted research indicate the possibility and perspective of using EHCAW to increase the yield of crops under irrigation and improving the quality of drainage and wastewater by reducing their mineralization and providing their disinfection.*

Key words: *electrochemical activation of water (ECHAW), anolyte, catholyte, reduction of drainage water mineralization, wastewater disinfection, irrigation with activated water*

Relevance of research. The water shortage in Ukraine, which exists on the background of intense global warming, is intensificated as a result of the military aggression of the Russian Federation, in particular, the destruction of the Kakhovsky reservoir and other facilities intended for the storage, distribution, and supply of water to settlements, industrial and agricultural structures. In this situation, saving water when using it for various purposes, as well as the efficiency of this use, is of high importance. One of the promising means of increasing the efficiency of water use in irrigation, according to the results of the analysis of information sources, is the use of electrochemical activation of water to increase the yield of crops, to reduce the mineralization of drainage water, and to disinfect wastewater with the aim of using it for irrigation.

Analysis of recent research and publications. Studies devoted to the possibilities of using electrochemical activation and anolytes to reduce mineralization and to disinfect irrigation water have recently been conducted by K. Ghebremichael, E. Muchelemba, B. Petrusevski [1], Geletu Qing, Zahra Anari, Shelby L. Foster, Marty Matlock, Greg Thoma, Lauren F. Greenlee, Mojtaba Abolhassani, Raheleh Daneshpour [2, 3], John W. Bartok jr. [4] and other researchers. The Royal Brinkman company proposes the use of electrochemically activated water as an environmentally sound alternative to modern chemicals for disinfecting irrigation water in horticulture [5]. The prospects of electrochemical activation to reduce mineralization and anolytes for disinfection as an alternative to traditional disinfectants in agriculture were investigated by Ukrainian scientists H.S. Stolyarenko, R.O. Azizov, B.I. Tupytskyi, A.V. Lysitsa, Yu.M. Mandigra [6, 7] et al.

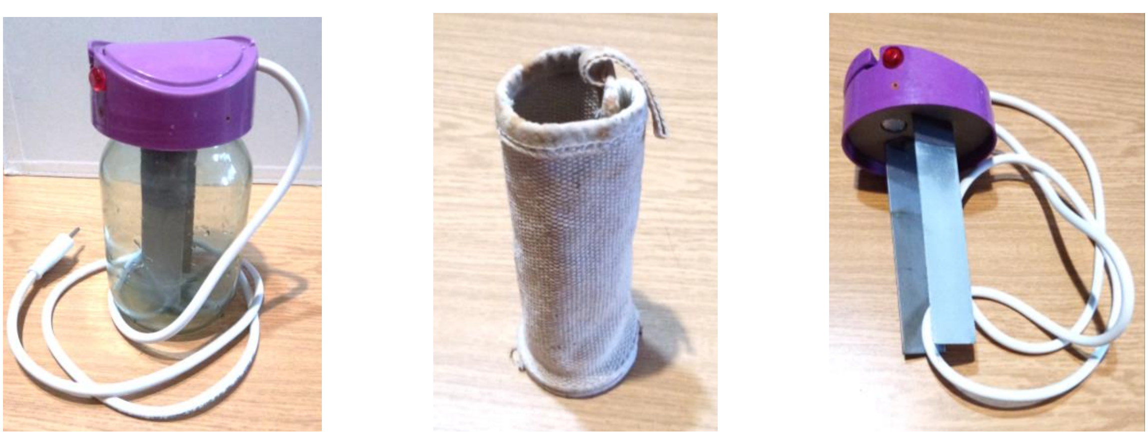
The works of Abdullaev M.T., Zakirov K.R., Khaitov B.A. and some other authors are devoted to the use of electrochemically activated water in the pre-sowing treatment of vegetable seeds [8]. Regulation of acidity in conditions of covered soil and improvement of vegetable crops with the help of electrochemically activated water was studied by D.S. Tsokura, S. Ya. Semenenko, M. N. Belitskaya, S. M. Lykholetova [9, 10] et al. O. I. Chushkin, S. Ya. Semenenko, M. N. Lytov, A. N. Chushkin, O.V. Amcheslavskyi [11–17] et al. investigated the issue of using ECHAW to increase the productivity of tomato and other vegetables under drip irrigation, which is considered the most promising method of irrigation for the use of electrochemically activated water.

The purpose of the research is to determine the possibilities of improving drainage and wastewater with components of electrochemically activated water for irrigation purposes, as well as to determine the effect of irrigation with such water on the germination of seeds of cereal crops, the development of seedlings and the yield of vegetable crops.

Research materials and methods. The devices for electrochemical activation of water, determination of its acidity and oxidation-reduction potential, air temperature, nutrient content and soil moisture, measuring instruments, scales, etc. were used. The following theoretical and practical methods of scientific research are applied: analytical method, modeling, laboratory-vegetation method.

Research results and their discussion. *Research on the possibilities of reducing the mineralization of drainage waters by means of their electrochemical activation and disinfection of wastewater with an anolyte.* In connection with the metastable properties of the components of the electrochemical activation of water and the need to have freshly prepared volumes of anolyte during the experiments, according to the well-known scheme of Krotov D.I. [10], a laboratory device was developed and manufactured. It allows us to obtain catholytes with pH values up to 10 and ORP up to −500 mV and anolytes with pH values up to 4 and ORP up to +600mV (Fig. 1a). The anolyte container is made of cotton ultrafiltration material Belting "BF" 2030 C-1 with the density equal to 1000 g/m^2 (Fig. 1b), the electrodes are made of VT1-00 titanium (Fig. 1c).

To determine the possibility of reducing the total mineralization of drainage waters by means of their electrochemical activation, laboratory studies using model solutions were conducted. Considering that Na and Cl ions significantly determine the level of general mineralization of drainage water and are the most difficult components in terms of removal during electrolysis, model solutions were prepared by adding table salt to tap water. Water solutions of table salt were prepared in volumes of 1 dm^3 with levels of total mineralization from 2100 ppm to 6900 ppm. These solutions were electrochemically activated in a 1 *l* container for 4 to 14 minutes. The activation time was limited by raising the temperature to 55…60 °C. The following devices were used during the



a b c

Fig. 1. Device for obtaining catholyte and anolyte in laboratory conditions: a – general view; b – cotton container for anolyte (ultrafiltration membrane); c – electrical unit

experiments: pH meter, TDS meter, ORP meter, thermometer, DT-830 multimeter.

Table 1 shows the changes in the general mineralization of water solutions under the influence of electrochemical activation.

The data given in Table 1 show that the electrochemical activation of mineralized water solutions allows after 4…14 min to reduce their total mineralization by 48,3…66,7 %. When conducting these experiments, the activation time and the activation electric current were also recorded. In view of this, it was determined that the energy intensity of the electrochemical activation of water by the laboratory activator was 30.5…39.7 kWh/m^3. The energy intensity of industrial facilities, as evidenced by literature, is almost an order of magnitude lower. The conducted studies confirm the possibility of reducing the mineralization of mineralized, in particular, drainage water by means of their electrochemical activation.

To assess the antimicrobial effect of anolyte, experiments were conducted on its ability to destroy widespread and dangerous microorganisms – E. Coli coliform bacteria, which are quite resistant to many standard disinfectants. The WaterWorks ™ Bacteria Check tests of the Industrial Test Systems Inc (USA) company were used for the experiments, which meet the requirements of the EPA – the US Agency for the Protection of the Environment and Human Health (Fig. 2a, 2b). The effect of anolyte on improving the biochemical composition of wastewater was studied by adding anolyte water to selected wastewater samples and further observing the result of the destruction of pathogenic microorganisms present in the water.

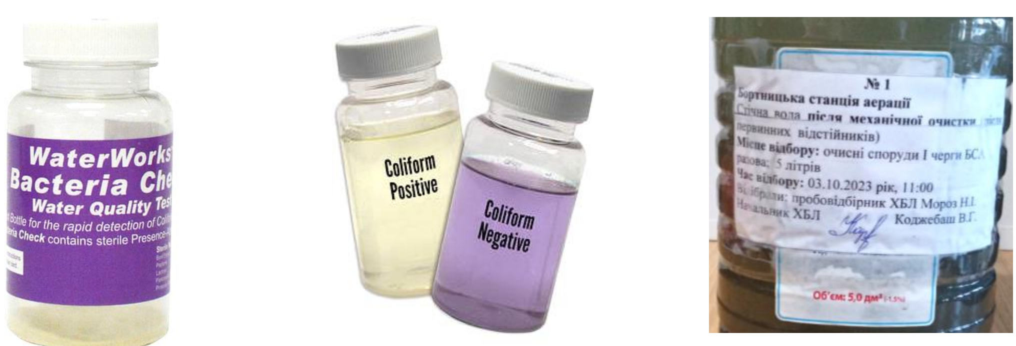
Wastewater samples were taken at the Bortnychy wastewater aeration station in Kyiv (Fig. 2c). The collection was carried out in accordance with the requirements of the "Instructions for the collection and preparation of water and soil samples for chemical and hydrobiological analysis by hydrometeorological stations and posts", approved by the order of the Emergency Department of Ukraine dated 19.01.2016 No. 30.

First, the presence of bacteria in each of the selected samples was tested (Fig. 3a, 3b). To do this, according to the instructions for using the tests, 100 ml of water from each sample was collected in 2 jars with bacteria and thoroughly mixed with the contents of the jars. After that, the mixture was left in the room for 48 hours. The results of this test demonstrated the presence of E. Coli bacteria in both water samples (Fig. 3c).

The volume of anolyte required for the destruction of biological pollutants in wastewater samples was calculated taking into account the existing information on this matter. The volume of 90 ml of waste water of each sample was collected in two jars and 10 ml of anolyte with values of ORP = +600 and pH 4 was added and thoroughly mixed with the contents of the jars. In

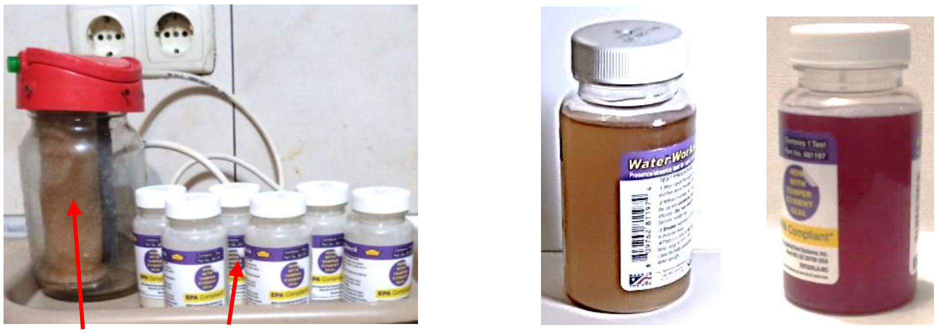
1. The change in the level of general mineralization of water solutions under the influence of electrochemical activation

Primary total mineralization, g/dm^3	2.1	3.2	3.9	4.8	6.0	6.9
Activation time, min	14	12	10	8	6	4
Total mineralization after activation, g/dm^3	0.7	1.1	1.6	2.3	3.1	3.5
Reduction of total mineralization after activation, %	66.7	65.7	59.0	52.1	48.3	49.3



a b c

Fig. 2. WaterWorks ™ Bacteria Check tests on E. Coli bacteria and a sample of wastewater from the Bortnychy aeration station: a – the jar with the Bacteria Check test; b – the samples of tested subjects (on the left – yellow color – bacteria are present, on the right – purple color – bacteria are absent); c – the wastewater sample



a b c d

Fig. 3. Testing the presence of E. Coli bacteria in wastewater samples: a – the laboratory electrochemical water activator; b – WaterWorks ™ Bacteria Check tests; c – the test of wastewater samples without anolyte disinfection (positive – living bacteria are present); d – the test of wastewater samples after disinfection with anolyte (negative – no living bacteria present)

the same way, 95 ml of water from each sample was collected in two more jars, 5 ml of anolyte with values of ORP = +600 and pH 4 was added, thoroughly mixed, and left for 48 hours. The results of all tests proved the absence of living bacteria in the wastewater (Fig. 3d).

The conducted experiments demonstrate the possibility of using anolytes for wastewater disinfection during its preparation for irrigation.

Research on the influence of electrochemically activated water on the germination of cereal crops seeds. The influence of electrochemically activated water on the germination of cereal crop seeds was determined by conducting comparative experiments (when irrigated with activated and non-activated water) on the germination of wheat and corn seeds. Germination was carried out using germinating jars (Fig. 4a) and an automatic grain and seed germinator (Fig. 4b), which provides optimal temperature and humidity. Wheat of the "Diana" variety and corn of the "DB Khotyn" variety were used for the experiments. For germination, 100 g of corn and wheat grains were placed in germinating jars soaked in activated water (anolyte pH 4,6…5,1; ORP 480…550mV; catholyte pH 8,5…9,3; ORP: – 260… – 480 mV) and ordinary water. The seed were also placed in the automatic germinator.

Studies on the germination of wheat and corn seeds were carried out for 3 days. Fig. 5 shows the appearance of wheat and corn seeds at the end of the 3rd day of germination.

On the third day, 20 seeds with the largest roots and sprouts were selected from the germinated wheat and corn grains of each variant, their sizes were measured and the average values were determined. All variants were weighed. The results of the morphological indicators of the germination of wheat and corn seeds when soaked with ECHAW and ordinary water are given in table. 2.

From the analysis of the data given in Table 2 it can be seen that the wheat seeds germinated using ECHAW on the third day have a 9 % longer root length than in the case when non-activated water was used. They also have 33 % longer sprouts. For corn, it is 20 % and 3 %, respectively.

a b

Fig. 4. Germination of wheat and corn seeds: a – the germinating jars; b – the automatic germinator of grain and seeds

a b c

Fig. 5. Sprouts of wheat and corn seeds on the third day of germination: a and b – in the jars for germination; c – in the automatic seed germinator

2. Morphological indicators of germinated wheat and corn seeds when soaked in ECHAW and ordinary water

Seeds type	**Activated water**		**Non-activated water**	
	roots, mm	**sprouts, mm**	**roots, mm**	**sprouts, mm**
wheat	33	24	30	18
corn	18	36	15	35

3. Weighted indicators on the 1st and 3rd day of germination of wheat and corn seeds when soaked with ECHAW and ordinary water

Seeds type	**Seeds weight, g**					
	Activated water			**Non-activated water**		
	germination day		**%**	**germination day**		**%**
	1st mass, g	**3rd**		**1st**	**3rd**	
wheat	100	201	101	100	191	91
corn	100	154	54	100	152	52

Table 3 shows weighted indicators on the 3rd day of germination of wheat and corn seeds when soaked in ECHAW and ordinary water.

According to the analysis of the data from Table 3 it can be seen that the use of activated water during the germination of corn and wheat seeds at the temperature of 18…21 °C and water changes three times per day ensures an increase in the mass of germinated wheat by 10 %, and corn by 2 %.

Research on the influence of electrochemically activated water on the development of seedlings and the yield of vegetables. The influence of irrigation with ECHAW on the development of vegetables seeds was studied by conducting laboratory vegetation experiments during irrigation with activated and non-activated (control) water in vegetation containers made of polyethylene bottles (Fig. 6a, 6b). Establishing the influence of irrigation with ECHAW on the development and yield of vegetables in covered soil conditions was carried out using "Grow Bag" vegetation containers made of moisture-resistant "breathable" eco-fabric (Fig. 6c). Agrotechnical characteristics of the soil was as follows: pH level – 6.0…6.5; total nitrogen – 80…120 mg/l; phosphorus – 100…150 g/l; potassium – 140…180 g/l; trace elements – B, Cu, Fe, Mn, Mg, Mo, Zn.

Experiments on growing seedlings of vegetables were conducted on two varieties of peppers ("Gourme" and "Lecho") and two varieties of tomatoes ("Orange" and "Cardinal"). Seeds were sown directly into the soil in vegetation containers. Soil moisture during sowing was 70…89 % of field capacity (which is the optimal moisture level for tomato and pepper), air temperature – 18…20 °C, air humidity – 50…60 %. Parameters of electrochemically activated water were as follows: ORP of anolyte = + 500….+550 mV, pH – ~5; OVP of the catholyte – 260…–480 mV at pH 8.5…9.3.

Evaluation the effect of ECHAW on the development of tomatoes from sowing to harvesting was carried out for two varieties of dwarf tomatoes: indoor "Bonsai" and balcony "Cherry gold".

a b c

Fig. 6. Vegetation containers for conducting research in laboratory conditions:
a, b – made of 2 and 5 *l* polyethylene bottles for germination and seedling growth;
c – 20-liter containers “Grow Bag”

Peppers were sown on March 4, 2023. 80 seeds of the “Lecho” variety and 80 seeds of the “Gourme” variety were selected for sowing. The seeds of each variety were sown into a depth of 7 mm in four 2-liter PET bottles with soil. The soil was irrigated with the mixture of catholyte with the following parameters: pH – 8.5…9.3; ORP: −260…−480 mV and anolyte with pH 4.6…5.1; ORP 500…550 mV. The watering, in accordance with existing information on this matter, were carried out with a ratio of anolyte to catholyte equal to 1:4 in one irrigation with separation of non-activated water in a ratio of 1:1 with non-activated water. The total mineralization of non-activated water (from the city water network) during the experiments was from 120 to 180 ppm. After each watering with activated water, 3 irrigations with ordinary water were carried out. Soil moisture was monitored using a conductometric soil moisture sensor and maintained at the level of 75…90 % of field capacity. Germination of pepper plants appeared from March 18 to March 23, 2023.

Table 4 contained the data on seeds germination and average plant height of pepper seedlings as of April 27, 2023. As it can be seen from Table 4, watering pepper seeds with electrochemically activated water increased the percentage of germination of the “Gourme” variety by 3,3 %.

On the 37th day of development, watering with activated water ensured an increase in the height of “Lecho” and “Gurme” pepper plants by 13.2…18.1 % compared to plants irrigated with non-activated water, and on the 46th day of development – by 14…19.2 %. Tomatoes of the “Orange” and “Cardinal” varieties were sown on March 30, 2023, and sprouted from April 5, 2023 to April 09, 2023. Table 5 contained the data on seeds germination and average plant height of tomato seedlings as of April 27, 2023.

During the experiments on the development of tomato seedlings, the increase in the diameters

4. Germination of seeds and average height of pepper plants as of 27.04.2023.

Variety	Germination of seeds		Increase in growing, %	The average height of plants, cm		Increase in growing, %
	Activated water	Ordinary water		Activated water	Ordinary water	
Lecho	28	28	0	5.3	4.6	13.2
Gourme	30	29	3.3	5.5	4.5	18.1

5. Germination of seeds and average height of tomato plants as of 27.04.2023.

Variety	Germination of the seeds		Increase in growing, %	The average height of plants, cm		Increase in growing, %
	Activated water	Ordinary water		Activated water	Ordinary water	
Orange	30	30	0	6.5	4.8	20.1
Cardinal	39	34	18.8	7.3	5.5	24.6

of plant stems at the height of 10 mm above the soil was also analyzed. The average stem diameter of tomato plants of the "Orange" variety at the height of 10 mm above the soil on the 45th–50th day of development under irrigation with activated water was 22.4 % larger than the average diameter of plants irrigated with ordinary water. For the "Cardinal" variety this percentage was equal to 11,3 %.

Evaluation of the influence of electrochemically activated water on the development of vegetables from sowing to harvesting was carried out on two varieties of dwarf tomatoes: indoor "Bonsai" and balcony "Cherry gold". These tomatoes were sown in two-liter seedling containers on May 14, 2023. 12 seeds of each variety were sown, half of which were irrigated with activated water and another half – with ordinary water according to the above-described scheme. The seeds of these tomatoes germinated on May 19…20, 2023. After growing the seedlings, 8 plants of each variety were planted in the "Grow Bag" containers (Fig. 6b) for the continuation of laboratory vegetation experiments, 4 of which were irrigated with activated water and 4 with non-activated water (16 plants in total).

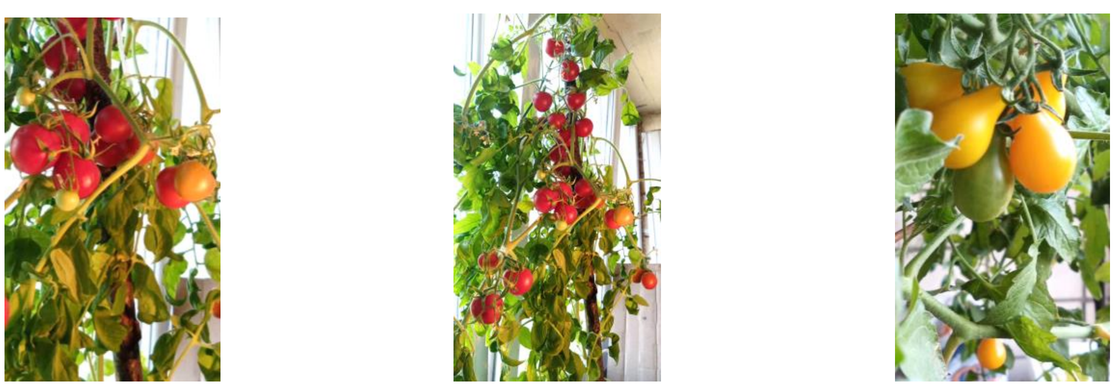
"Bonsai" tomatoes entered the flowering phase on July 03, 2023, "Cherry Gold" – on July 12, 2023. "Bonsai" tomatoes began to bear fruit on August 14, 2023, and "Cherry Gold" – on August 23, 2023 (Fig. 7).

Table 6 contains data on the collection period and the yield obtained from 8 tomatoes bushes of the "Bonsai" variety and from 8 bushes of the "Cherry Gold" variety.

Analysis of the data in Table 6 shows that the use of electrochemically activated water for irrigating balcony tomatoes of the "Bonsai" variety led to an increase in their yield by 15,8 %. When irrigating "Cherry Gold" tomatoes an increase was equal to 12,6 %. Weighing and comparing the geometric dimensions of "Bonsai" and "Cherry Gold" tomatoes showed that watering with activated water leads to an increase in the size of the fruits of the "Bonsai" variety by 15.4…25.1 % and an increase in weight by 15.3 … 38.5 %. For the "Cherry Gold" variety, this increase was, respectively, 16.2…17.4 % and 17.9…28.2 %.

Taking into account that this paper is prepared on the basis of the results of exploratory scientific research, statistical substantiation, with high reliability of the given data, can be obtained only after the implementation of full-fledged projects in this scientific field.

Conclusions. The performed studies confirmed the possibility of reducing the mineralization of drainage waters by means of their electrotechnical activation and of disinfection of



a b c

Fig. 7. Appearance of tomato fruits and plants in the fruiting phase: a and b – "Bonsai"; c – "Cherry Gold"

6. Dates and yield of "Bonsai" and "Cherry Gold" tomatoes

"Bonsai"									
Water	dates	15.08	19.08	23.08	28.08	5.09	11.09	Total	Increase, %
Activated	yield, g	532	890	1760	733	583	207	4705	15,8
Non-activated		308	739	1643	652	430	188	3960	

"Cherry Gold"								
Water	dates	23.08	28.08	3.09	10.09	17.09	Total	Increase, %
Activated	yield, g	315	634	512	436	186	2083	12,6
Non-activated		377	529	472	306	136	1820	

wastewater with anolyte during their preparation for irrigation. Final recommendations on the use of electrochemically activated water and its components for these purposes can be formulated after full-fledged research on this topic. It was established that the use of electrochemically activated water improves the germination of cereals and has a positive effect on the growth of sprouts and roots of the germinating seeds. Wheat seeds germinated using electrochemically activated water on the 3rd day of germination has a 9 % longer root length than grain germinated under the same conditions using non-activated water. The sprout length in this case was 33 % longer. Irrigation of pepper and tomato with electrochemically activated water confirmed its influence on accelerating the development of these crops. The germination of tomatoes when watering with activated water increased by 18.8 %, the growth of the height of pepper plants – up to 19.2 %, tomatoes – up to 25.2 %. The yield of tomatoes irrigated with activated water increased by 15.8 %, the size of the fruits – by 25.1 % (with an increase in weight by 38.5 %). Detailed recommendations for the use of electrochemically activated water in the cultivation of vegetable crops can be developed after conducting full-fledged research. Taking into account the peculiarities of the components of electrochemically activated water – a short relaxation time of the catholyte and a rather long relaxation time of the anolyte, as well as the scope of their application in irrigation abroad – the use of electrochemically activated water in drip irrigation systems can be considered the most promising.

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ОЦІНЮВАННЯ МОЖЛИВОСТЕЙ ЗАСТОСУВАННЯ ЕЛЕКТРОХІМІЧНО АКТИВОВАНОЇ ВОДИ ДЛЯ ЦІЛЕЙ ЗРОШЕННЯ

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Анотація. *З метою перевірки можливостей застосування електрохімічно активованої води (ЕХАВ) для цілей зрошення проведено дослідження з визначення впливу аноліту на біологічні забруднювачі стічних вод і зменшення електрохімічною активацією рівня мінералізації вод, а також впливу католіту і аноліту на проростання насіння зернових культур, розвиток розсади перців і томатів та врожайність томатів. Дослідження проводили в лабораторних умовах на двох сортах перцю і чотирьох сортах томату. Отримання ЕХАВ здійснювалось із використанням лабораторних активаторів води власного виготовлення. Проби стічної води відбирали на Бортницькій станції аерації стічних вод міста Києва. Досліди проводили з використанням вегетаційних контейнерів різних видів та одноразових бактеріологічних тестів. Встановлено, що електрохімічною активацією мінералізованих вод можна досягати зниження рівня їх загальної мінералізації більш, ніж на 50 %, а анолітом знищувати хвороботворюючі бактерії в стічних водах. Застосування ЕХАВ прискорює проростання насіння зернових культур. Зерно пшениці, пророщене за використання ЕХАВ, на 3-й день пророщування має довжину коренів на 9 % довшу, ніж зерно, що пророщене в таких самих умовах за використання неактивованої води, а довжину паростків – на 33 %. Швидкість росту при зрошенні активованою водою, залежно від сорту рослин томатів, підвищується на 9,8–25,2 %, збільшення діаметрів стебел – на 11,3–22,4 %. Врожайність томатів при зрошенні активованою водою на 12,6–15,8 % вища, ніж при зрошенні звичайною водою, крупність плодів більша на 15,4–25,1 %. Результати проведених досліджень свідчать про можливість і перспективність застосування ЕХАВ для підвищення врожайності с.-г. культур в зрошенні та поліпшення якості дренажних і стічних вод шляхом зниження їх мінералізації та знезараження.*

Ключові слова: *електрохімічна активація води (ЕХАВ), аноліт, католіт, зниження мінералізації дренажних вод, обеззараження стічних вод, зрошення активованою водою*