

Conference Paper

The Role of a Catholyte in the Foliar Nutrition of Winter Wheat Plants

Elena Alexandrova¹, Galina Khramko¹, Boris Alexandrov¹, Zhanati Hadisova², Aminat Abubakarova², and Murada Musaeva²

¹Kuban State Agrarian University named after I.T. Trubilin, 13, st. Kalinina, Krasnodar, 350044, Russia

²Grozny State Oil Technical University named after Academician MD Millionshtchikov, ul. Avtorkhanova, 14/53, Grozny, 364902, Russia

ORCID:

Zhanati Hadisova: <http://orcid.org/0000-0001-8797-4104>

Abstract

This study examined the content of nitrogen (N), phosphorus (P) and potassium (K) in Tanya winter wheat plants depending on the concentration of an aqueous solution of catholyte (EKHAV-K) combined with foliar fertilizing with FlorHumate. In all phases of the growing season, tillering–stooling–heading, an increase in the content of N in the leaf and stem mass by 0.04%, 0.19% and 0.07% was shown; the content of P increased by 0.04%, 0.03% and 0.05%; and that of K raised by 0.07%, 0.09% and 0.06%. A 20% aqueous solution of EKHAV-K (pH = 9.0 and ORP = –50 mV) promoted better assimilation of N, P and K from fertilizers. The ecological safety of the wheat grain was established. The accumulation of N, P₂O₅ and K₂O in the experimental variant of the grain was 3.09%, 8.90% and 9.09%, respectively, which was more than in the control variant.

Keywords: winter wheat, foliar nutrition, catholyte, role

Corresponding Author:

Zhanati Hadisova

janna_h@list.ru

Published: 5 April 2021

Publishing services provided by
Knowledge E

© Elena Alexandrova et al. This article is distributed under the terms of the [Creative Commons Attribution License](#), which permits unrestricted use and redistribution provided that the original author and source are credited.

Selection and Peer-review under the responsibility of the DonAgro Conference Committee.

1. Introduction

Currently, crop production in Russia needs extraordinary agrotechnical solutions to increase the productivity and consumer properties of the crop, as well as improve the ecological situation of the environment and agricultural land. At the same time, the main task of the agro-industrial complex is to increase the profitability of agricultural production of winter wheat [1–4].

One of the most rational ways to solve this problem is the development of innovative, environmentally friendly, energy-saving technologies for its production. In this regard, an innovative technology for increasing the efficiency of agricultural production of winter wheat using electrochemically activated water (EKHAV) is of considerable interest [5–11]. We have proposed an innovative technology of growing wheat under the influence of

OPEN ACCESS

EKhAV -K, a catholyte ($\text{pH} > 7$, $\text{ORP} < 0$), with foliar fertilizing of its plants [7]. Foliar dressing is deservedly considered a method of operational impact on the processes that determine the yield and its quality [12–20]. Foliar fertilizing of agricultural crops should be considered in relation not only to root feeding, but also to aerial feeding—photosynthesis [18–21]. There are very few targeted comprehensive studies on foliar fertilizing of winter wheat in the literature, and those involving EKhAV are virtually absent. The biological manifestation of EKhAV-K during foliar fertilizing of plants has not been described in the literature and requires experimental substantiation. EKhAV was obtained from low-mineralized tap water in a diaphragm electrolyzer with anolyte EKhAV-A ($\text{pH} < 7$, $\text{ORP} > 0$) at the anode and catholyte EKhAV-K ($\text{pH} > 7$, $\text{ORP} < 0$) at the cathode.

At present, the scientific interest of scientists-agronomists in EKhAV has increased markedly. However, experimental data on the use of EKhAV, in particular EKhAV-K, in foliar fertilizing of wheat plants were practically absent in the literature. For the further application of EKhAV in agriculture, namely in foliar fertilizing of winter wheat plants, an agrochemical substantiation of its biological activity, environmental safety and economic efficiency is necessary. Winter wheat is very demanding on nutritional conditions. From germination to complete tillering, wheat plants absorb 30–40% of nitrogen, phosphorus, potassium from the total amount consumed by them. The accumulation of dry matter during this period is only 8–10%. The consumption of mineral nutrition sharply increases in the phase of stooling and heading of plants, and then decreases [12–17]. This work was carried out by us for the first time. The analysis of literary and patent sources on the topic of work [1–24] showed its scientific novelty and practical value.

In this regard, the aim of the work was an experimental ecological-agrochemical assessment of the effect of catholyte (EKhAV-K) on the assimilation of nitrogen, phosphorus and potassium by plants of winter wheat varieties “Tanya” and the quality of grain when foliar fertilizing of its plants with FlorHumate.

2. Materials and Methods

The experiments were carried out on the experimental field of the educational farm “Kuban” in Krasnodar. The agricultural technology for growing winter wheat was used, which was recommended for the conditions of the central zone of the Krasnodar Krai. The consumption of the aqueous solution of fertilizers was 200 l/ha. Field experiments were carried out for two years. At the end of September, crop residues were tandem crushed using disc tools BDT-3 to a depth of 8–10 cm. Soil cultivation was superficial.

Ammonium nitrate (34% of N), ammophos (12% of N and 52% of P_2O_5) and potassium salt (44% of K_2O) were added to the soil equivalent to $N_{50}P_{50}K_{50}$. Before the resumption of spring vegetation, nitrogen fertilization was applied at a dose of N_{50} ; the general background of fertilizers was $N_{100}P_{50}K_{50}$.

Research objects. The object of the study was the *Tanya* winter wheat of the Krasnodar Research Institute of Agriculture named after P.P. Lukyanenko. The preceding crop was soy.

FlorHumate of natural origin (pH = 9.46) based on humic acids (18.0 g/l) was used as a fertilizer for foliar fertilizing of plants of this wheat variety. The fertilizer contained 2.0 g/l of N; 2.0 g/l of P_2O_5 ; 3.5 g/l of K_2O ; 0.5 g/l of MgO; 5.0 g/l of SO_3 ; 0.9 g/l of B; 0.3 g/l of Mo; 3.0 g/l Mn; 2.0 g/l of Zn; 1.2 g/l of Cu; 0.2 g/l of Co and 0.8 g/l of Fe. The concentration of the FlorHumate solution was 5 g/l. The FlorHumate solution was prepared using a mixture of catholyte (EKHAV-K) and tap water.

Characteristics of EKHAV-K. The biologically active aqueous solution of alkaline EKHAV-K fertilizer was prepared by electrolysis of tap water in Melesta-M and Izumrud-SI devices produced by ZAO NITs IKAR (Russia). In this case, the EKHAV-K solution ORP reached -600 mV and the pH of the solution was 10.2 (potentiometric measurements of pH and ORP were carried out using a universal Sartorius Professional pH Meter PP-25). Using the Inductively Coupled Plasma Mass Spectrometry (ICP-MS), it was determined that the content of heavy metals in EKHAV-K is significantly lower than the corresponding MPC values for drinking and household waters. The method of biotesting has shown the ecological safety of EKHAV-K on living organisms and populations at the cellular level. The environmentally safe concentrations of the EKHAV-K aqueous solution (less than 30%) for multicellular and unicellular organisms have been established. Negative ORP values indicate the presence of electron donors in the aqueous medium and the possibility of reduction processes. As a result of redox reactions accompanying the process of water electrolysis, EKHAV-K undergoes a decrease in the content of dissolved O_2 , giving way to H_2 ; CO_2 almost completely disappears; the hardness and dry residue decrease, mainly cations of alkali metals Na^+ and K^+ remain. As a result of the reduction process ($NO_3^{3-} \rightarrow NO_2^{2-} \rightarrow NH_4^+$) nitrate ions are converted into the ammonium form. Thus, the catholyte is ecologically safe and is in a metastable, energetically and chemically active state.

Research methods. The scheme of the experiment with FlorHumate on *Tanya* winter wheat involved 6 variants with solutions of EKHAV-K of different concentrations: 1) control (tap water, TW); 2) 100% EKHAV-K; 3) FlorHumate + TW; 4) FlorHumate + 5%-solution of EKHAV-K (solution of FlorHumate, prepared on a mixture of 5% EKHAV-K and 95% of the

original TW); 5) FlorHumate + 20%-solution of EKhAV-K; 6) FlorHumate + 50%-solution of EKhAV-K.

The plants were treated with a knapsack sprayer. The consumption of the aqueous solution of EKhAV-K with additional fertilizing was 200 l/ha, the concentration of FlorHumate was 5 g/l. Winter crops were harvested by direct combining with a small-sized Sampo combine at a grain moisture content of 13–15%.

The following phases of vegetation were considered: seedlings, tillering, stooling, heading, milk, waxy and full ripeness of the grain. In the course of the experiments, winter wheat crops were cultivated in the tillering phase in spring. The experiments were repeated four times, the placement of the plots was systematic. The total area of the plot was 30 m², the accounting area was 20 m². The seeding rate was 5 million viable seeds per 1 ha; wheat was sown by a Gaspardo seeder to a planting depth of 5 cm in the first ten days of October.

The selection of plant samples for physiological and agrochemical studies was carried out at various stages of their growth and development. To take into account the effect of foliar fertilizing, plant samples were taken 5 days after their treatment with aqueous solutions of FlorHumate. From the plot of each of the studied variants, 15 plants were selected. They were cut off the stem below the third leaf from the top, placed in water to prevent wilting and delivered to the laboratory. Accounting and phenological observations in the experiments were carried out in accordance with the methodology of the state variety testing of agricultural crops. The dry matter content in the plant material was determined by the gravimetric method. The discrepancy between parallel determinations did not exceed 0.5%. The accuracy of the analysis by drying method was $\pm 1\%$.

The grain quality indices (nature, vitreousness, content of wet gluten) were determined by the non-destructive method on an FT-01 infrared spectrophotometer [24]. The elemental chemical composition of the wheat grain was studied by inductively coupled plasma atomic emission spectrometry (ICP-AES) using an iCAP-6000 series atomic emission spectrometer (Thermo Scientific, USA).

The statistical processing of the research results was carried out according to the prescription of B.A. Dospekhov [22]. All tabular and graphical data represent the average of 3–12-fold repetition of a typical experiment with an indication of the error. The reliability of the difference between the variants was judged by the Student's t test at a significance level of $t = 0.05$ and LCD_{05} .

Accounting and phenological observations in the experiments were carried out in accordance with the methodology of state variety testing of agricultural crops [23]. At

the same time, the following phases of the growing season were considered: seedlings, tillering, stooling, heading, milk, waxy and full ripeness of grain. The accumulation of wet and absolutely dry mass was also studied in all phases of the growing season, for which samples of plants (two adjacent rows of 111 cm long) were taken from two non-adjacent repetitions of each variant in three places along the diagonal of the plot.

3. Results

We have studied the effect of foliar fertilizing with FlorHumate in aqueous solutions of EKhAV-K of various concentrations on the assimilation of mineral nutrition elements (N, P, K) by the aboveground part of winter wheat plants during different periods of its growing season (Figures 1, 2 and 3).

Dynamics of nitrogen content in plants. It is known that nitrogen is of exceptional importance in the growth, development and formation of the yield of winter wheat, as it is a part of simple and complex proteins, amino acids, nucleins, chlorophyll, phosphatides, vitamins, enzymes and other organic compounds of cells. As follows from the work of A.Kh. Sheudzhen [17], with optimal nutrition of this element, the synthesis of protein substances increases, the vital activity of the organism lasts longer, growth accelerates and aging of leaves slows down, plants grow well and bush, the formation and development of reproductive organs improves. As a result, the yield and the protein content of the grain increase. Both the lack and the excess of nitrogen in the nutrient medium negatively affect the growth and development of plants, which ultimately leads to a shortage of crops and a decrease in their quality. Most of the nitrogen enters the grain from the leaves, and only 18-26% come from the roots [16–17]. The lack of nitrogen strongly affects the formation of pigment systems, chloroplast structures and its overall activity. The nitrogen concentration determines the amount and activity of the RuBisCO. With weakened photosynthesis in plants, an imbalance arises between nitrogen absorption and the products of photosynthesis. With a lack of nitrogen in the second half of the growing season, the accumulation of protein in the grain decreases, which worsens its baking qualities.

We carried out foliar fertilizing with FlorHumate (5 g/l) in TW and in 20%-solution of EKhAV-K in the tillering phase (Figure 1). Evidently from Figure 1, the mass content of nitrogen in dry mass (%) during the period of growth and development of wheat plants naturally decreased from the tillering phase (3.68; 3.70; 3.72) and stooling (2.88; 2.94; 3.07) to heading (1.53; 1.54; 1.6) by about 2 times. The use of FlorHumate in a 20%-solution of EKhAV-K for foliar fertilizing of wheat plants promoted an increase in

the nitrogen content in the leafy mass in the tillering, stooling and heading phases by 0.04, 0.19 and 0.07%, respectively, as well as by 0.07% in grain and by 0.03% in straw. The greatest influence of foliar fertilizing was manifested at the stooling stage, since during the stooling–heading period, the greatest accumulation of dry mass occurs and, therefore, the maximum average daily nitrogen consumption [15-17].

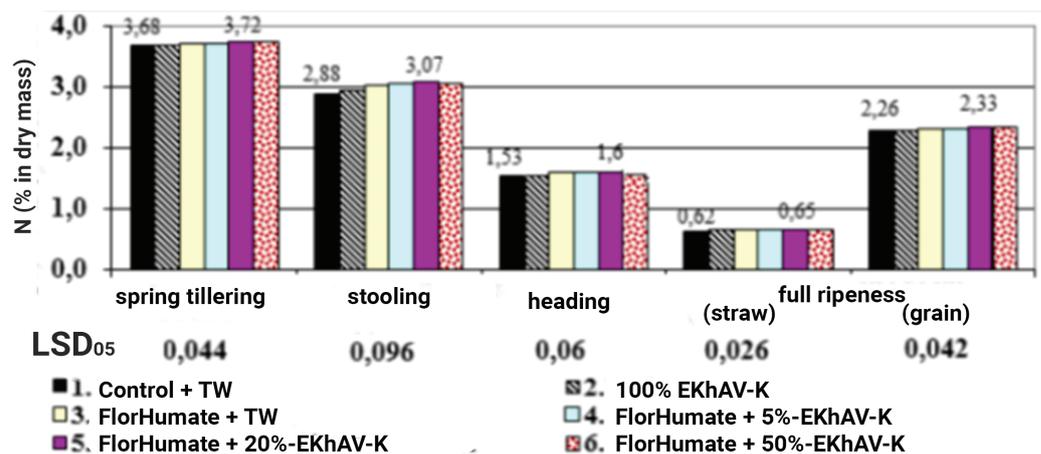


Figure 1: Dynamics of N content in Tanya wheat plants

The dynamics of the phosphorus content in wheat plants is shown in Figure 2. Phosphorus, like nitrogen, belongs to the main biogenic elements and participates in the most important vital processes of organisms: protein synthesis, respiration, cell division, carbohydrate, nitrogen and energy metabolism, photosynthesis reactions. It is utilized by the plant in the form of PO_4^{3-} . Under phosphorus deficiency, photochemical and dark reactions of photosynthesis are disrupted. Excess phosphorus can inhibit the rate of photosynthesis, which is supposedly associated with a change in membrane permeability. Optimal nutrition with phosphorus determines better nitrogen utilization, faster growth and development, improves grain content of the ear, increases winter hardiness, accelerates ripening, increases the yield and improves its quality [17]. It increases the water-holding capacity of plant tissues, the content of osmotic and colloid-bound water, and the hydration of protoplasmic components. Phosphate fertilizers play an important role in biochemical systems. This element is part of the phosphate groups of RNA and DNA molecules, which are responsible for the biosynthesis of proteins and the transmission of hereditary information. It is also part of the adenosine triphosphate (ATP) molecule, with which chemical energy is stored in biological cells. The bond of the terminal phosphate group in ATP is broken during hydrolysis with the release of energy: $\text{H}_2\text{O} + \text{ATP} \rightarrow \text{H}_3\text{PO}_4 + \text{ADP}$.

In this reaction, ATP and ADP serve as carriers of the phosphate group. In addition, the phosphate ion regulates the direction of intracellular oxidation processes by blocking reactive hydrogen atoms, the oxidation of which can lead to unwanted by-products. Due to these features, the lack of phosphorus in the environment can be a factor limiting life processes.

The content of phosphorus in the aboveground leaf-stem mass of plants, as well as nitrogen, varied according to the phases of development of winter wheat (Figure 2).

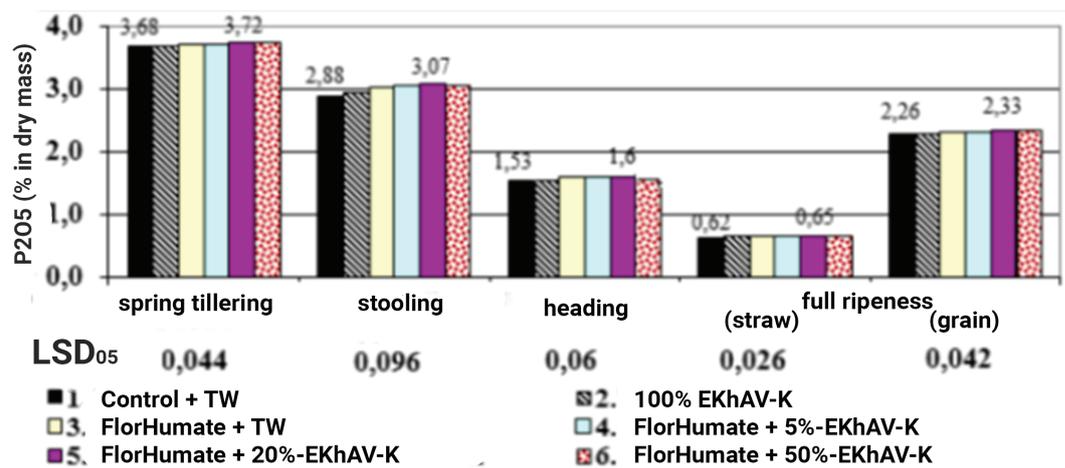


Figure 2: Dynamics of the P content in wheat plants of the Tanya variety

The intensive growth of vegetative organs and the formation of an ear is a critical period, and in the process of grain maturation, the phosphorus content in the plant decreases in comparison with the phase of waxy ripeness of grain as a result of its outflow into the root system [17–18]. The results of our experiments are in good agreement qualitatively and quantitatively with the above-mentioned regularities noted in the work of A.Kh. Sheudzhen [17]. It was shown that during the entire growing season of wheat plants, foliar fertilizing by a 20%-solution of EKHAV-K (pH = 9.0 and ORP = – 50 mV) unambiguously promotes an increase in the mass content of phosphorus in the dry matter of the leafy mass of plants. The foliar fertilizing had the predominant influence on the accumulation of phosphorus in the aboveground vegetative mass of plants during the heading period. Plants of the control variant (TW) were characterized by a lower phosphorus content in the vegetative mass during all phases of the winter wheat growing season. In plants with the use of FlorHumate in a 20%-solution of EKHAV-K (variant 5), in comparison with the control variant, the phosphorus content increased in

the phases of spring tillering, stooling, heading and full ripeness of grain, respectively, by 0.04, 0.03, 0.05 and 0.03%.

Dynamics of potassium content in plants. Potassium plays an exceptional role in maintaining cell and tissue homeostasis (osmotic pressure, charge balance, cation-anion balance, transmembrane potential, pH) [15, 17]. Potassium is assimilated by the plant from the salts of KCl, KNO₃, KH₂PO₄, K₂SO₄. In plant nutrition, the main role is played by exchangeable potassium. Unlike nitrogen and phosphorus, it is not a part of organic compounds in a plant, but is in a plant cell in the form of ions of soluble salts in the cell sap. Potassium ion is the main counterion that neutralizes inorganic anions of cellular polyelectrolytes. It creates an electrical potential difference between the cell and the outside environment. It is possible that this is precisely where the specific function of potassium is manifested, making it a necessary and indispensable element of plant nutrition in maintaining the electrical properties of boundary protoplast formations. A change in the magnitude of the gradient of the electric potential and the flow of substances through the cell membrane can cause many metabolic disorders in potassium deficiency. Potassium enters winter wheat plants from the first days of growth and continues until flowering. However, most of all it is consumed in the phases of stemming and heading. It enhances the formation of lateral roots, the total absorbing surface of the root system, can increase the water content of the cytoplasm, accelerate the outflow of assimilants from the leaves, increase the degree of stomata openness, thereby indirectly affecting photosynthesis. There is also a direct effect of potassium, since it activates phosphorylation processes [18–21]. Like nitrogen and phosphorus, the potassium content in winter wheat plants is not constant and is subject to very significant fluctuations (Figure 3). Improving the provision of winter wheat with potassium affects its content in vegetative organs and grain.

When treated with FlorHumate in combination with 20%-solution of EKhAV-K, the plants accumulated potassium in the phases as follows: up to 4.39% of dry weight in the spring tillering phase (0.07% higher than in the control variant with TW), 3.77% in the stooling phase (0.09% higher than in the control variant), 1.96% in the heading phase (0.06% higher than in the control), 1.48% in the ripening phase (0.04% higher than in the control variant). Its content in grain amounted to 0.6%.

The presented small—at first glance—absolute values of the percentage differences, taking into account the amount of dry matter in plants, can quite significantly affect the accumulation of nutrients. It is quite evident from the relative percentage increase in the content of N, P and K in grain by 3.09, 8.90 and 9.09% (vs. control variant: 2.26,

0.78 and 0.55% in dry matter) and in straw by 4.83, 5.26 and 2.77% (vs. control variant: 0.62, 0.19 and 1.44% in dry matter), respectively.

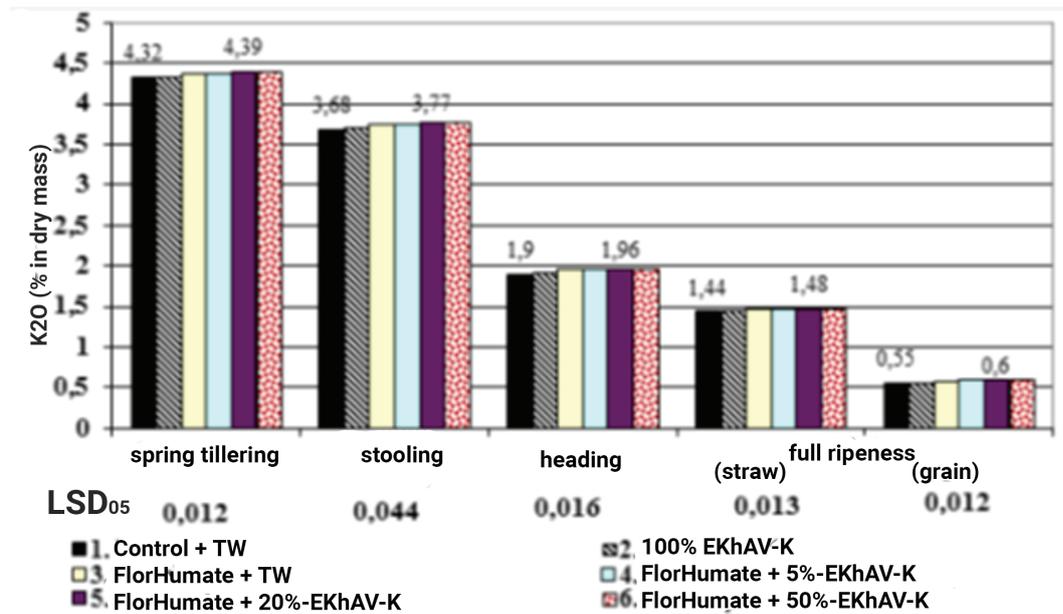


Figure 3: Dynamics of the K content in wheat plants of the Tanya variety

The analysis of the results obtained demonstrated the following peculiarities. The dynamics of nitrogen content during the growth and development of wheat plants is associated with a change in organ-forming processes during grain formation and is consistent with literature data [11–14, 17–21]. The phosphorus outflow during this period of development was 40.5%, including 21.8% during the tillering–stooling period and 18.7% during the stooling–heading period. The largest outflow of 70.8% in this period of plant development was demonstrated by potassium, and to a greater extent (56%) it occurred during the period from stooling to heading. Against the background of the introduction of K_{50} , winter wheat plants in the spring tillering, stooling and heading phases respectively contained 4.32, 3.68 and 1.9% of potassium in dry mass. It is the young, actively growing parts of the plant that are richest in potassium. The improvement in the provision of wheat with potassium affected its content in vegetative organs and grain. At the same time, potassium—unlike nitrogen and phosphorus—accumulated more in straw than in grain.

During the period of grain formation, the growth of the vegetative mass completes, the consumption of all nutrients gradually decreases and their intake suspends. Further formation of organic matter and other vital processes are carried out through the reuse of nutrients previously accumulated in the plant [12–15]. These scientific facts explain the average statistical figures given in the educational and scientific literature on the

dynamics of consumption by plants of various agricultural crops, including winter wheat, during the growing season and the removal of nutrients with the harvest. The revealed patterns for different crops are a valuable generalization of the centuries-old experience of agrochemists.

The above results make it possible to consider the 20%-concentration of EKhAV-K as the most preferable in terms of influence efficiency and economy. The use of a 20%-solution of EKhAV-K (pH = 9.0 and ORP = -50 mV) in foliar fertilizing with FlorHumate contributed to the greatest increase in the content of nitrogen, phosphorus and potassium in winter wheat plants, especially in the initial periods of growth and a more complete assimilation of these nutrients from fertilizers.

3.1. Assessment of crop removal and balance of elements of mineral nutrition in the system "soil-fertilizer-plant"

The study of the balance of nutrients in the "soil-fertilizer-plant" system is of particular importance in the context of the application of a new foliar fertilizing with EKhAV-K and its rational use. Based on the analysis of the obtained yield of the main and by-products, the crop removal of N, P and K by Tanya winter wheat was calculated. According to the data in Table 1, the yield removes 106.2 kg/ha of nitrogen, 36.6 kg/ha of phosphorus and 26 kg/ha of potassium.

The use of foliar fertilizing increased the crop removal of mineral nutrients (nitrogen, phosphorus and potassium) with the harvest. When treated with FlorHumate, the removal of N, P and K increased by 6.7, 4.0 and 2.5 kg/ha as compared to the control variant. When this humic fertilizer was applied in a 20%-solution of EKhAV-K, the removal of N, P and K increased by 6.1, 2.9 and 1.3 kg/ha, respectively, as compared to the treatment with the solution of FlorHumate in tap water.

Foliar fertilizing with FlorHumate in combination with a 20%-solution of EKhAV-K—contributing to a more complete assimilation of N, P and K by plants—can perform ecological functions in the agrocenosis, since it limits the flow of residual amounts of mineral fertilizers into the environment.

In the "soil – fertilizer – plant" system, a nitrogen deficit of 6.2–19.1 kg/ha was observed; however, an excess of phosphorus was 6.6–13.3 kg/ha and that of potassium was 20.4–24.1 kg/ha. The compensation for the removal of these nutrients from the soil was as follows: 94.2% and 84% of nitrogen in the control variant and in variant 5 (FlorHumate + 20% solution of EKhAV-K), respectively; 136.4% and 115.1% of phosphorus in variants 1 and 5, respectively; 193.4% and 168.7% of potassium, respectively.

The calculation of the crop removal of nutrients for Tanya winter wheat showed that the grain yield removes 106.22 kg/ha of nitrogen, 36.66 kg/ha of phosphorus and 25.85 kg/ha of potassium. With foliar fertilizing of plants with FlorHumate in a 20%-solution of EKhAV-K, the crop removal of N, P₂O₅ and K₂O increased by 6.1, 2.9 and 1.3 kg/ha, respectively. The net income from the use of FlorHumate in a 20%-solution of EKhAV-K for foliar fertilizing of Tanya winter wheat plants increased by 2003 rubles per 1 ha compared to the control variant.

TABLE 1: Crop removal and balance of nutrients in the soil, depending on the applied foliar fertilizing on the crops of Tanya winter wheat varieties, kg/ha.

Variant	Crop removal [kg/ha]			Balance of nutrients [kg/ha]			Removal compensation [%]		
	N	P	K	N	P	K	N	P	K
Control (TW)	106.2	36.7	25.9	-6.2	13.3	24.1	94.2	136.4	193.4
EKhAV-K 100 %	110.4	38.0	26.6	-10.4	12.0	23.4	90.6	131.5	188.0
FlorHumate + TW	112.9	40.7	28.4	-12.9	9.3	21.6	88.5	123.2	176.0
FlorHumate + 5%-EKhAV-K	113.4	41.0	28.9	-13.4	9.0	21.1	88.2	121.9	173.0
FlorHumate + 20%-EKhAV-K	119.0	43.5	29.7	-19.0	6.5	20.3	84.0	115.1	168.7
FlorHumate + 50%-EKhAV-K	115.1	42.0	28.3	-15.1	8.0	21.7	86.8	119.0	176.6
Average				-12.9	9.7	22.1	88.7	124.5	179.3

TABLE 2: Grain quality indicators for Tanya winter wheat

Variant	Nature [g/l]	Vitreousness [%]	Content of wet gluten [%]	FDM-1 [a.u.]	Protein content [%]	Protein accumulation [kg/ha]
Tanya varieties						
Control (TW)	792	50.5	21.4	68.6	13.6	638.0
EKhAV-K 100 %	796	51.0	21.9	68.4	13.8	667.4
FlorHumate + TW	800	51.5	22.5	70.5	13.9	680.6
FlorHumate + 5%-EKhAV-K	797	51.8	22.3	71.6	13.9	683.3
FlorHumate + 20%-EKhAV-K	805	52.6	22.7	68.3	14.2	724.9
FlorHumate + 50%-EKhAV-K	802	52.0	22.0	70.4	14.0	694.0
LSD ₀₅	4.0	0.41	0.56	--	0.24	--

It should be noted that the increase in the biological yield of Tanya winter wheat variety under the influence of a 20%-solution of EKhAV-K in combination with FlorHumate

reached 7.4%, while more than half of the increase was provided only by EKhAV-K. The highest yield of winter wheat grain of the Tanya variety was obtained after application of foliar fertilizing with FlorHumate in a 20%-solution of EKhAV-K. It averaged 5.11 t/ha over three years of research, while an increase in the yield of 8.7% was provided, while the control level was 4.7 t/ha. The use of FlorHumate + TW gave a yield increase of 4.1%. As can be seen from these indicators, a 20%-solution of EKhAV-K as a FlorHumate solvent provided an increase in yield by more than 2 times.

3.2. Indicators of grain quality of Tanya winter wheat

The grain quality indicators consist of many characteristics that are determined by varietal characteristics, conditions of cultivation, harvesting, storage and processing of wheat grain. They are subdivided into groups characterizing the general condition of the grain mass, flour-grinding and baking properties.

We investigated the quality parameters that partially determine the milling (vitreousness, nature) and baking (protein content, quantity and quality of gluten) properties of grain, which are most important for selling it at prices that ensure the profitability of grain production (Table 2).

Russian standard GOST R 52554-2006 "Wheat. Technical conditions" regulates the following indicators of soft wheat grain quality: mass fraction of protein in % in dry matter (not less than 14.5 for class 1, 13.5 for class 2; 12.0 for class 3; 10.0 for class 3); vitreousness in % (not less than 60 for classes 1 and 2, 40 for class 3; for 4 the value is not limited); nature in g/l (not less than 750 for classes 1 and 2; 730 for class 3; 710 for class 4); mass fraction of wet gluten in % (not less than 32.0 for class 1; 28.0 for class 2; 23 for class 3; 18 for class 4).

We compared these values with the best indicators of the quality of grain grown with the use of foliar fertilizing with FlorHumate in a 20%-solution of EKhAV-K, which ensured its maximum yield. At the same time, the quality of grain was assessed in the variants where the highest yield was obtained, in comparison with the control. The comparative analysis of the data led to the following conclusions. For grain of the Tanya variety in the 5th variant, there was a slight increase in a number of quality indicators (%): 6 for gluten, 4.2 for vitreousness; 4.4 for protein; 13.6 for protein accumulation. Tanya wheat grain (14.2%) had insignificant differences from the indicators of the 1st class. The vitreousness index in the range of 52.6÷56% significantly exceeded the values for third grade grain. The nature of the grain corresponds to the indicators of the 1st class. In accordance with GOST R 52554-2006, the wheat class was determined by the lowest value of one

of the quality indicators. In our case, such a limiting indicator of grain quality was the mass fraction of wet gluten. In terms of gluten, Tanya wheat grain, containing 22.7%, is very close to class 3. The quality of gluten corresponds to the group II. Thus, according to average annual data, the grown Tanya winter wheat grain is quite consistent with the food grade of the 4th class.

An assessment of the ecological safety of winter wheat grain grown with the use of foliar fertilizing by FlorHumate in combination with EKhAV-K was carried out by comparative analysis of the mass concentration of chemical elements—including heavy metals—in wheat grain of the Tanya variety grown without the use of foliar fertilizing (control variant, sample 1), using FlorHumate + 20%-solution of EKhAV-K (sample 2). The results are shown in Table 3. The studies were carried out by inductively coupled plasma atomic emission spectrometry (ICP-AES) using an iCAP-6000 series atomic emission spectrometer (Thermo Scientific, USA). The detailed research methodology is described above.

For wheat, the grain (seeds) contains the following toxic elements the content of which is regulated by SanPiN 2.3.2.1078-01 ("Food raw materials and food products. Hygienic requirements for the safety and nutritional value of food products"): lead (MPC is no more than 0.5 mg/kg), arsenic (MPC is no more than 0.2 mg/kg), cadmium (MPC is no more than 0.1 mg/kg) and mercury (MPC is no more than 0.03 mg/kg). As follows from the results of the AES analysis (Table 3), the quality of wheat grain in the studied variants meets the requirements of SanPiN 2.3.2.1078-01 for grain (seeds). Foliar fertilizing with FlorHumate based on natural spropel with the use of EKhAV-K did not affect the elemental chemical composition of the grown wheat grain

4. Resolution

Winter wheat is the main agricultural crop in the south of Russia and is a very important object of agrochemical research. There are very few targeted comprehensive studies on foliar fertilizing of winter wheat in the literature, and there are practically none of them about the use of EKhAV. Foliar fertilizing of Tanya wheat plants with catholyte (EKhAV-K) should be considered in connection not only with root nutrition, but also with air nutrition—photosynthesis. The main characteristics that determine the properties of EKhAV are the values of ORP and pH. We have patented the method of foliar fertilizing of winter wheat plants with EKhAV-K [7], which confirms the scientific novelty of the work. This work for the first time experimentally studied and biochemically substantiated

TABLE 3: Comparison of the elemental chemical composition of wheat grain grown with foliar fertilizing by FlorHumate

Element	Content of chemical elements in wheat grain [mg/kg]	
	1. Control	2. FlorHumate + 20%-EKhAV-K
Ba	3.2±0.9	3.8±1.1
Cd	<0.05	<0.05
Co	<0.1	<0.1
Cr	0.083±0.017	0.073±0.015
Cu	4.6±0.9	4.5±0.9
Fe	35±10	31±9
Li	<0.1	<0.1
Mo	<0.1	<0.1
Na	28±11	36±15
Ni	0.51±0.18	0.41±0.14
Pb	0.11±0.03	0.14±0.04
Rb	4.2±1.7	6.3±2.5
Si	28±8	25±7
Sr	1.9±0.6	2.0±0.6
Ti	0.27±0.13	0.19±0.09
V	<0.1	<0.1
Zn	28±6	27±5
As	0.12±0.06	<0.1
Mn	28±8	27±8
Mg	820±246	821±246
K	3600±1400	4200±1700
Ca	261±78	253±76
Hg	<0.01	<0.01

the effect of a 20%-solution of EKhAV-K catholyte (pH = 9.0 and ORP = -50 mV) on the assimilation of nitrogen, phosphorus and potassium by the plants of Tanya winter wheat. The calculation of the crop removal of nutrients by Tanya winter wheat showed that with foliar fertilizing of plants with FlorHumate in a 20%-solution of EKhAV-K, the crop removal of N, P₂O₅, K₂O increased by 6.1, 2.9 and 1.3 kg/ha, respectively. The net income from the use of FlorHumate in a 20%-solution of EKhAV-K for foliar fertilizing of Tanya winter wheat plants increased by 2003 rubles per 1 ha, as compared to the control variant. At present, it is possible to create a new direction for the use of EKhAV for intensifying agricultural production.

5. Conclusions

1. The dynamics of the content of N, P and K in Tanya winter wheat plants was studied depending on the concentration of an aqueous solution of EKhAV-K with foliar fertilizer with FlorHumate. The use of a 20%-solution of EKhAV-K (pH = 9.0 and ORP = -50 mV) promoted better assimilation of N, P and K from the fertilizers.

2. In all the phases of the growing season—tillering—stooling—heading—the following increase in the content of elements in the leafy mass was established: by 0.04, 0.19 and 0.07% of nitrogen; by 0.04, 0.03 and 0.05% of phosphorus; by 0.07, 0.09 and 0.06% of potassium. The accumulation of N, P₂O₅ and K₂O in grain was 3.09, 8.90 and 9.09 rel.% correspondingly more than in the control variant (2.26, 0.78 and 0.55% in dry matter).

3. The use of a 20%-solution of catholyte as a solvent for FlorHumate for foliar fertilizing of Tanya wheat plants in the spring tillering phase provided a more than double increase in the yield (by 8.7% against the control variant 4.7 t/ha) and an increase in net income by 2003 RUB per 1 ha compared to the control variant.

4. Food grain of the 4th class wheat, grown using the proposed foliar fertilizing, has an ecologically safe elemental chemical composition according to the MPC of heavy metals (0.14 mg/kg of lead; <0.05 mg/kg of cadmium; <0.1 mg/kg of arsenic and <0.01 mg/kg of mercury).

References

- [1] Malyuga, N. G. (1992). *Strong Winter Wheat in the Kuban*. Krasnodar: Book Publishing House.
- [2] Tyupakov, E. F. and Brovkina, T. Y. (2008). *Winter Wheat in the North Caucasus*. Elista: Dzhangar.
- [3] Mineev, V. G. and Dodukhova, E. N. (2005). Efficiency of Fertilizers in the Cultivation of Winter Wheat on Carbonate Chernozem, Depending on Meteorological Conditions. *Agrochemistry*, vol. 3, pp. 30–35.
- [4] Lebedeva, L. A. and Edemskaya, N. L. (2005). *Scientific Principles of the Fertilization System with the Basics of Ecological Agrochemistry*. Moscow: Publishing House of Moscow University.
- [5] Pasko, O. A. and Domboev, D. D. (2011). *Activated Water and the Possibilities of its Use in Plant Growing and Animal Husbandry*. Tomsk: Tomsk Polytechnic University.
- [6] Cloete, E. (2009). Electrochemically Activated Water as a Non Polluting Biofilm Control Technology. *Journal of Applied Microbiology*, vol. 107, pp. 379–384.

- [7] Aleksandrova, E. A. and Gergaulova, R. M. (2009). Method of Foliar Fertilizing of Winter Wheat. *Patent for invention RU No. 2349072 C1*.
- [8] Filhol, J-S. and Neurock, M. (2006). Elucidation of the Electrochemical Activation of Water over Pd by First Principles. *ngewandte Chemie International Edition*, vol. 45, pp. 416 – 420.
- [9] Bakhir, V. M. (2005). *Electrochemical Activation: A Universal Tool of Green Chemistry*. Moscow: Bookinist.
- [10] Petrushanko, I. Y. and Lobyshev, V. I. (2001). Non-Equilibrium State of Electrochemically Activated Water and its Biological Activity. *Biophysics*, vol. 46, issue 3, pp. 389-401.
- [11] Dudka, V. (2011). Foliar Dressing: Main Mistakes and Mistakes. *Grain (Kiev)*, vol. 7, pp. 19-20.
- [12] Beslaneev, S. M. and Bagov, M. B. (2006). Fractional Application of Nitrogen Fertilizers. *Agrochemical Bulletin*, vol. 4, pp. 24-25.
- [13] Kuznetsov, V. V. and Dmitrieva, G. A. (2006). *Plant Physiology*. Moscow: Vysshaya Shkola.
- [14] Aleksandrova, E. A. and Gergaulova, R. M. (2009). Method of Processing Winter Wheat. *Patent for invention RU No. 2349071 C1*.
- [15] Mark, S. (1999). Nitrate Regulation of Metabolism and Growth. *Current Opinion in Plant Biology*, vol. 2, pp. 178 – 186.
- [16] Li, X., Li, Y. and Li, L. (2003). Study Methods Fertilizer to Produce High Yields of Winter Wheat Varieties Shaan 354. *Xibeinonglin kejidaxixue xuebao. Ziran kexue bari* vol. 31, issue 1, pp. 67-69.
- [17] Sheudzhen, A. K. and Bondareva, T. N. (2012). *Nutrition and Fertilization of Grain, Cereals and Leguminous Crops*. Krasnodar: KubGAU.
- [18] Wallsgrave, R. M. and Keys, A. J. (1983). Photosynthesis, Photorespiration and Nitrogen Metabolism. *Plant Cell Environment*, vol. 6, pp. 301-309.
- [19] Lafond, G. P. and Gan, Y. T. (2001). Ensure Full Need for Nitrogen and Phosphorus by a Single Fertilizer at Planting Winter Wheat Cultivated in Zero Tillage. *Canadian Journal of Plant Science*, vol. 8, issue 3, pp. 373 – 383.
- [20] Cloete, T. E. and Thantsha, M. S. (2008). The Antimicrobial Mechanism of Electrochemically Activated Water Against *Pseudomonas Aeruginosa* and *Escherichia Coli* as Determined by SDS-PAGE Analysis. *Journal of Applied Microbiology*, vol. 11, pp 9-31.
- [21] Nichiporovich, A. A. (1982). *Physiology of Photosynthesis*. Moscow: Nauka.

- [22] Dospikhov, B. A. (1979). *Field Experiment Technique: (With the Basics of Statistical Processing of Research Results)*. Moscow: Kolos.
- [23] Fedin, M. A. (1985). *Methodology of State Variety Testing of Agricultural Crops*. Moscow: Rosselkhozizdat.
- [24] Smirnov A.P. (1977). *Guidelines for Assessing the Quality of Grain*. Moscow: Rosselkhozizdat.