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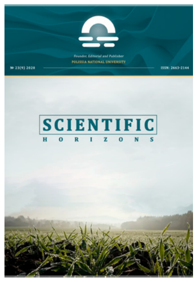



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## The Influence of Ecologised Fertiliser Systems on the Elements of Fertility and Productivity of Winter Wheat


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**Abstract**. One of the strategic areas for the development of modern agriculture is the use of ecologised fertiliser systems composed based on the straw of agricultural crops with the addition of microbiological, humus or chelated fertilisers. This will allow restoring natural resources and getting environmentally friendly products. The purpose of the research was to study the effect of ecologised fertiliser systems on the physical and chemical processes and nitrogen regime of grey forest soil, the development of bio-productivity of winter wheat, and the content of basic microelements in grain. The following methods were used in the research: field, laboratory-analytical, mathematical-statistical. Application of $N_{30}P_{45}K_{45}$ against the background of pea straw with the addition of a biostimulator and humus fertiliser mostly demonstrated modern approaches to technologies for managing the fertility of grey forest soils based on the principles of environmental safety and resource conservation. Such a fertiliser system provided alkalinisation of the soil solution, optimisation of the $Ca^{2+}$ and $Mg^{2+}$ content, improvement of the soil nitrogen regime. Under such conditions, optimal parameters of the production process elements (the number and mass of grains in the head) were formed. The most effective in the processes of accumulation of microelements was the organo-mineral system of the following composition: pea straw + $N_{30}R_{45}K_{45}$ + chelated fertiliser. No excess of the maximum permissible concentration for Cu, Zn, Mn, or Fe was detected. Thus, to harmonise the ecological and productive functions of grey forest soil in the winter wheat cultivation system, a combination of alternative agriculture, which consists in reducing the use of mineral fertilisers, and partial biologisation, is considered promising. This is a way to optimise soil fertility and bio-productivity



**Keywords**: soil acidity, exchange calcium and magnesium, nitrogen forms, elements of head productivity, microelements





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## INTRODUCTION

Ukraine is an agrarian state with considerable potential, the territory of which is occupied by more than 6 million hectares of winter wheat. To increase agricultural production, Ukrainian farmers have used intensive technologies based on high doses of agrochemicals for a long time. Without this, it was impossible to compete in production volumes in both internal and external markets. It is known that the intensification of agriculture has led to partial depletion of soils, disruption of potential, and effective fertility. Obtaining high yields under intensive farming conditions was accompanied by a deterioration in product quality and a stressful load on the agroecosystem [1-3]. First of all, under such conditions, the soil – the basis of the agroecosystem – undergoes a considerable load. The ecological state of the ecosystem's soil is characterised by physical and chemical processes, the nutrient regime of the soil, in particular, the nitrogen, humus state, and microbiological processes. All of them depend on the type and fertility of the soil, climatic conditions, as well as to a large extent on fertiliser systems that can contribute to the development of stable agroecosystems [4-6]. In this context, the functioning of any agroecosystem and increasing its productivity require rational fertiliser systems, which can become a basic link in the development of optimal agroecological functions of the soil (preventive, sanitary, etc.), their stable fertility and obtaining an optimal level of yield and good quality of plant products [7; 8].

In this regard, it is relevant to substantiate fertiliser systems, the use of which provides, on the one hand, a sufficient level of productivity of agrocenoses and disclosure of the biopotential of crops, and on the other – contributes to increasing their environmental stability, obtaining a biologically valuable crop, and preserving the environment, which is important at all levels [9].

For the effective use of the natural potential of soils in modern conditions, there is a development and improvement of technological measures for the use of ecologised fertiliser systems, arranged based on secondary crop production in combination with humus, microbiological [10; 11] or chelated fertilisers, growth-regulatory and biological chemicals [12-14].

In addition, it should be noted that due to the increase in the grain area and highly liquid industrial crops, there is a problem of rational use of non-commodity part of the crop. To date, there is a decrease in straw in the diet of cattle, which is advisable to use crunched to enrich soils with organic matter [15; 16], to improve their acid-base balance, nitrogen regime of the soil, and enrich it with microelements [17; 18].

Among the latest alternative organic fertilisers that can activate the native microflora and positively affect soil and biological processes, optimise the root nutrition of plants, humic chemicals (fertilisers) are known, in particular, Humin-Plus, Humisol, etc. They have a positive effect on the growth and development of plants. Humic acids increase the resistance of plants to stressful situations. The production of humic chemicals is based on the properties of humic acids (caustobolites) to form water-soluble salts with monovalent cations of sodium, potassium, and ammonium. They can be directly applied to the soil, used for foliar application, they are good decomposers of stubble and plant residues. Practical interest in the above fertilisers is conditioned upon the fact that they are created based on humus-containing substances or microorganisms isolated from natural biocenoses. They do not pollute the environment and are safe for animals and humans, improve plant nutrition, provide them with physiologically active substances, which positively affects the development of the crop and its quality [19-21]. The use of microbiological fertilisers ensures effective implementation of biological mechanisms of nutrition, growth stimulation, and plant protection. These are important arguments in favour of using such fertilisers as promising elements of nutrient correction [22].

In this regard, the use of humus or microbiological fertilisers together with secondary plant products and mineral fertilisers is an appropriate and relevant but understudied factor. In modern agricultural conditions, the use of chelated fertilisers and growth stimulants is also extremely important since their advantages are better bioavailability and low application doses [23; 24]. The effectiveness of these chemicals consists in mainly improving the quality and quantity of the yield [25]. In addition, they protect the plant from bacterial and fungal diseases by increasing plant resistance. The use of chelated fertilisers and growth-regulating chemicals in combination with mineral fertilisers against the background of straw of agricultural crops fully fits into the concept of optimising plant nutrition, increasing their yield and elements of plant productivity [26-28].

Thus, one of the strategic areas for the development of modern agriculture is the use of ecologised fertiliser systems for straw-based agricultural crops with the addition of microbiological, humus or chelated fertilisers, which will allow restoring natural resources and obtaining environmentally high-quality products.

*The purpose of research* is to establish and verify the possibility of simultaneously improving the signs of potential fertility of grey forest soil, head productivity and ecological quality of grain in ecologised fertiliser systems. For this purpose, the following *objectives* were set: 1) to study the $pH_{(KCl)}$ change pattern, content of $Ca^{2+}$ and $Mg^{2+}$ exchange cations in the soil solution, the content of nitrogen forms in the soil under the conditions of ecologised fertiliser systems; 2) to study the regularities of the development of head productivity (the number and mass of grains per head), the accumulation of Cu, Zn, Mn, Fe in wheat grain during ecologised fertiliser systems' performance; 3) to find such ecologised fertiliser systems that simultaneously predetermine the most pronounced positive effects on the studied indicators of both soil and plants among the studied ecologised fertiliser systems.

## MATERIALS AND METHODS

The study was conducted in the field conditions during 2018-2020 in the experimental field of the Institute of Agriculture of the Carpathian region to study the productivity of crop rotations in Stavchany, Lviv district, Lviv region. An experiment is micro-zonal, an area of the site is 1 $m^2$, the distance between the sites is 1 m, the repetition is 6 times. The experiment scheme is as follows: 1) control – without fertilisers; 2) pea straw; 3) pea straw + $N_{30}P_{45}K_{45}$; 4) pea straw + $N_{30}P_{45}K_{45}$ + BS (biological stimulator); 5) pea straw + $N_{30}P_{45}K_{45}$ + BS + HF (humus fertiliser); 6) pea straw + $N_{30}P_{45}K_{45}$ + BS + MF (microbiological fertiliser); 7) pea straw + $N_{30}P_{45}K_{45}$ + CF (chelated fertiliser). Field studies were conducted with winter wheat (*Triticum aestivum* L.) of Benefis cultivar.

Experimental fertiliser systems were assembled based on pea straw + $N_{30}P_{45}K_{45}$ with the addition of a biostimulator, humus, microbiological or chelated fertilisers. The characteristics of the chemicals are given below. Biostimulator terra-sorb; chemical composition: 25% – total amount of organic substances, 20% – amino acids, total amount of nitrogen – 5.5%, B – 1.5%, Fe – 1.0%, Mg – 0.8%, Zn and Mn – 0.1% of each, Mo – 0.001%.

Humus fertiliser – eco-impulse, is a concentrated aqueous solution of humic acid salts, composition: weight part of organic substances – 43.5%, weight part of ash – 56.5%. The chemical increases soil fertility, improves the ecological state – binds products of man-made pollution, prevents the accumulation of nitrates in plant products, activates maturation.

Microbiological fertiliser eco-soil; it contains microorganisms *Bacillus subtilis*, *Rhodococcus erytropolis* in the amount of 1000 million units. $g^{-1}$.

Chelated fertiliser-rose – salt 18-18-18+125+ME, its composition: 18% N, P, K; B of each – 128, Mn – 400, Cu – 94, Fe – 325, and Zn – 287 mg $kg^{-1}$. Microelements other than boron are in chelated form with edetic acid. The chemical ensures uniform development of the crop and the growth of vegetative mass, increases the resistance of plants to temperature stresses and diseases, and is effective on soils with acidic pH.

The chemicals were used as follows: the biostimulator (BS) terra-sorb was used to treat winter wheat crops in the phases of spring tillering and stem elongation – 0.5 l $ha^{-1}$; humus fertiliser (HF) – eco-impulse was applied to the corresponding areas from autumn when wrapping pea straw – a dose of 3.0 l $ha^{-1}$; microbiological fertiliser (MF) was applied at a dose of 3.0 l $ha^{-1}$ between the spring tillering phase and stem elongation; chelated fertiliser (CF) was applied in the stem elongation phase at a dose of 3.0 kg $ha^{-1}$.

The soil of the experimental sites is grey forest superficially gleic, light loamy. The physical, chemical and agrochemical parameters of the soil were determined before conducting the experiment: $pH_{(KCl)}$ – 4.85, hydrolytic acidity Hr – 25.81 mg-eq $kg^{-1}$ of soil, the sum of absorbed bases S – 55.23 mg-eq $kg^{-1}$ of soil, the content of easily hydrolysed nitrogen – 98.0 mg $kg^{-1}$ of soil, available phosphorus and exchange potassium (0.2 N HCl) – 108.4 and 87.2 mg $kg^{-1}$; the level of total humus according to Tyurin in the Nikitin modification is 2.1%.

Climatic conditions over the years of research (2018-2020) had their own characteristics. There were changes in the temperature regime and sharp changes in the amount of precipitation, especially in spring and summer. In 2019, the maximum amount of precipitation fell in May and in June 2020, against the background of an increase in air temperature by 0.9-1.6°C, compared to the long-term average. The growing conditions of winter wheat plants were quite satisfactory and the maturation of crops took place in optimal conditions.

Soil samples (depth 0-30 cm) from experimental variants and their preparation for laboratory and analytical work were carried out in accordance with DSTU ISO 11464-2001 [29]. $pH_{(KCl)}$ was determined in the obtained soil samples potentiometrically according to DSTU ISO 10390-2001 [30], as well as the content of exchange forms of calcium and magnesium by trilonometric method according to DSTU 7945:2015 [31], the nitrogen content of nitrate and ammonium compounds according to DSTU 4729:2007 [32], the content of easily hydrolysed nitrogen according to Kornfield and DSTU 7863:2015 [33]. The values of the listed indicators were determined in 3 repetitions and 2 analytical parallels (in general, $n$=6). Before determining the content of Cu, Zn, Mn, Fe, mineralisation of winter wheat flour (air-dry substance; waxy ripeness phase) was carried out by dry combustion with subsequent treatment with a solution of nitric acid (GOST 26657-85 [34]); the content of the listed microelements in grain flour was determined in accordance with [35] using an atomic absorption spectrophotometer C-115M (Russia) with atomisation in an air-acetylene flame and C-600, using graphite cuvettes and high temperatures (3 repetitions, 2 analytical parallels, $n$=6). Biometric indicators of crop structure elements – the number and mass of grains per head (3 repetitions, 4 plants per repetition, $n$=12; waxy ripeness phase) was determined according to Maisurian [36]. Analytical scales (±0.0001 g) (Radwag AS 220/R2, Poland) were used to measure the mass of grains per head. To obtain the final values of each feature, their values were averaged over two years of research (2019-2020).

Statistical analysis of results, in particular analysis of variance *ANOVA* (subject to the significance level $\alpha$=0.05), was performed using Excel 11.0.6560.0. To calculate the values of Student's $t$-test, corresponding degrees of freedom $k$, the formulas given in [37] were used for the corresponding values, $P$ – function *T.DIST.2T* of the specified Excel programme.

## RESULTS AND DISCUSSION

The results of the conducted studies showed a positive effect of by-products (pea straw) on the physical and chemical properties of grey forest surface-gleic soil under winter wheat. Thus, the introduction of only by-products (var. 2) slowed down the processes of soil acidification, the value of exchange acidity was higher by 0.27 pieces, compared to the control variant (var. 1) (Fig. 1). At the same time, there was an increase in the content of $Ca^{2+}$ and $Mg^{2+}$ exchange cations in the soil solution, compared to the control. This might be conditioned upon a decrease in relative losses of exchange $Ca^{2+}$ and $Mg^{2+}$ from the soil solution, as well as by increasing the dissociation of these cations from the soil absorption complex containing, in particular, pea straw residues in the soil solution. When adding + $N_{30}P_{45}K_{45}$ (var. 3), the value of $pH_{(KCl)}$, content of $Ca^{2+}$ and $MD^{2+}$ exchange cations in the soil solution increased by 0.16, 0.82-2.74 mg-eq $kg^{-1}$ in soil, respectively, relative to control. Therewith, under such conditions, there was a significant decrease in $pH_{(KCl)}$ by 0.11, a slight decrease in the exchange $Ca^{2+}$ (-0.07 mg-eq $kg^{-1}$ of soil), a significant decrease in the exchange $Mg^{2+}$ (-0.61 mg-eq $kg^{-1}$ of soil), compared to var. 2. Similar $pH_{(KCl)}$ and content of $Ca^{2+}$ and $Mg^{2+}$ exchange cations changes in the soil solution occurred under the conditions of using pea straw + $N_{30}P_{45}K_{45}$ + BS and pea straw + $N_{30}P_{45}K_{45}$ + CF (var. 4, 7, respectively). Joint application of $N_{30}P_{45}K_{45}$ + BS + MF or $N_{30}P_{45}K_{45}$ + BS + HF on the background of pea straw (var. 6, 5, respectively) to the greatest extent improved the physical and chemical properties of the soil relative to the control. Therewith, the values of $pH_{(KCl)}$, content of exchange $Ca^{2+}$ and $Mg^{2+}$ increased, respectively, by 0.26-0.39 units and by 2.32-6.41 mg-eq $kg^{-1}$ of soil, relative to control.

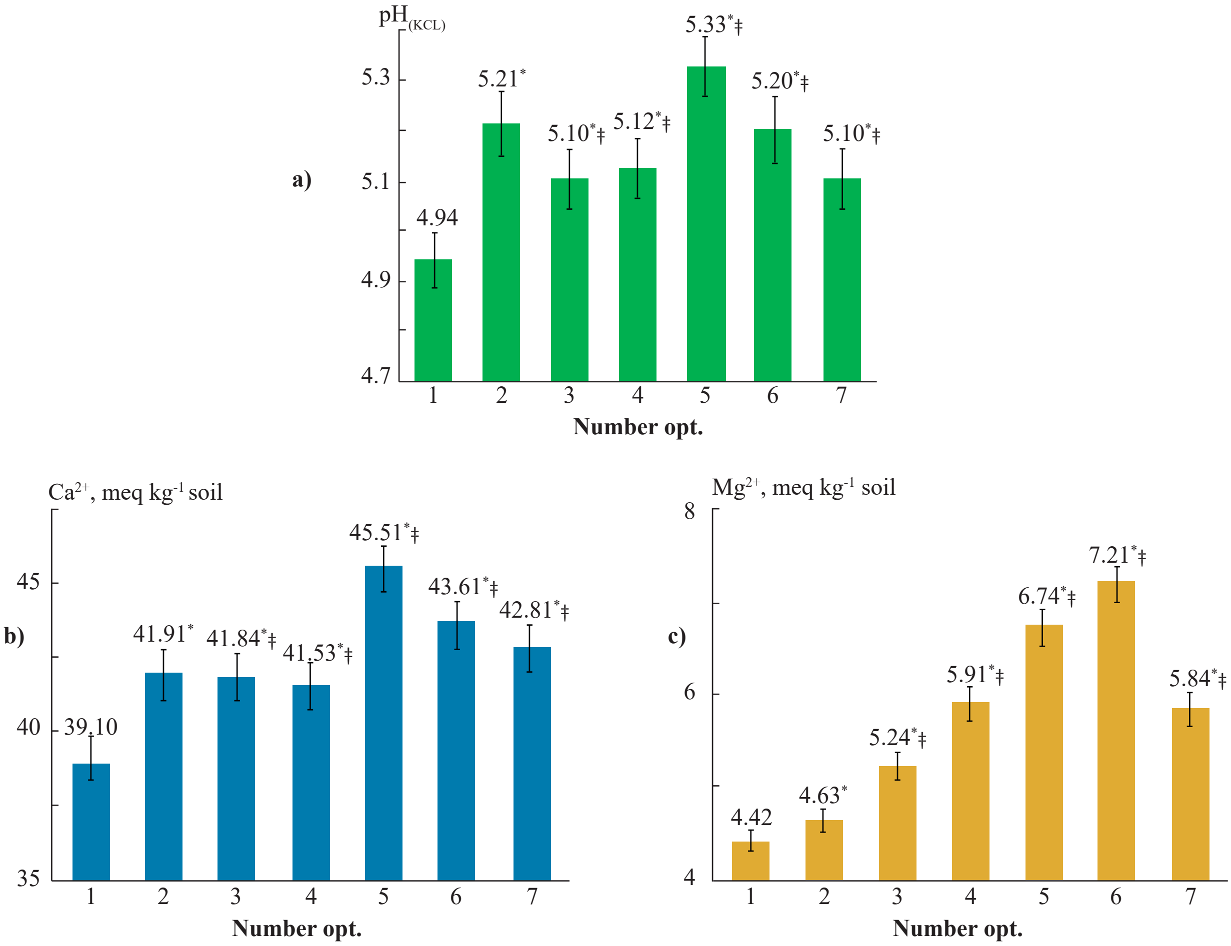


***Figure 1****. Effect of ecologised fertiliser systems on $pH_{(KCl)}$ (a), content of Ca exchange cations$^{2+}$ (b) and $Mg^{2+}$ (c) in soil solution (heading phase; 2019-2020)*

***Note****: significance level of differences between the ANOVA averages: a – P<0.01, b – P<0.001, c – P<0.001; *, ‡ – significance level of the difference compared to variants 1, 2, respectively, P<0.001-0.01*

The authors of this paper suggest that the processes of biological decomposition of pea straw in the soil played one of the leading roles in the processes of $Ca^{2+}$ and $Mg^{2+}$ cation enrichment and alkalinisation of the soil solution on experimental variants. Indeed, previous studies have shown that crop residues can have a considerable effect on the soil pH, especially with a low buffer capacity, as well as significantly increase the cationic exchange capacity of the soil absorbing complex [38]. Organic anions that are bound to the main $Ca^{2+}$, $Mg^{2+}$, $K^+$, and $Na^+$ cations in plant materials, are the main source of ash alkalinity. As a rule, legume straw has higher alkalinity, and, therefore, it should have a stronger effect on soil acidity compared to non-legume straw [39]. In particular, the content of $Ca^{2+}$ pea straw is about 6 times larger than winter wheat straw (1.82% vs. 0.28%). In general, the ash alkalinity of plant residues and the mineralisation of organic nitrogen are the main causes of an increase in soil pH, while subsequent nitrification of mineralised nitrogen can lead to a decrease in soil pH [40]. Notably, biochemical decarboxylation of carboxyl groups of organic anions released during straw destruction removes protons from the soil solution, causing alkalinisation of the latter [41].

It is possible that a decrease in $pH_{(KCl)}$ on var. 3, 4, 7, compared to var. 2, is at least partially conditioned upon the acidifying effect of nitrogen-containing mineral fertilisers [42], which, in particular, include sufficient amounts of $N{-}NH_4^+$ for nitrification. The fluctuations in the $Ca^{2+}$ content in a soil solution on var. 3, 4, 7, compared to var. 2, at least to a certain extent can be caused by increased absorption of this cation by plants (stimulation of plant growth processes under conditions of sufficient supply of organic matter, nitrogen, phosphorus – var. 3; combining this with the action of BS or CF – var. 4, 7). $Mg^{2+}$ content growth on var. 4, among other things, might be conditioned upon a decrease in the need of plants to absorb this cation from the soil under the conditions of using BS, which includes $Mg^{2+}$ cations. In the authors' opinion, the reasons for changes in the content of the $Mg^{2+}$ on var. 3, 7 are less unambiguous, and more detailed studies are required to clarify them. It is likely that the use of MF or HF as part of ecologised fertiliser systems (var. 6, 5, respectively) contributed to the strengthening of straw destruction processes and the release of $Ca^{2+}$ and $Mg^{2+}$ cations in the soil solution, which provided the highest content of them and the most optimal level of acidity in the soil among these fertiliser systems.

The above sources of scientific literature and considerations support the standpoint that the processes of nitrogen transformation in the soil are important for the development of the soil solution acidity. Therewith, the content of mobile nitrogen compounds in the soil, in particular nitrate, ammonium, easily hydrolysed, plays a major role in the development of soil nitrogen regime and the supply of nitrogen to plants. The listed nitrogen compounds are dynamic over time, highly mobile, soluble, and easily accessible; therefore, they can act as a diagnostic criterion for providing soil and plants with nitrogen. In the field, the role of nitrogen forms is not the same. It is known that nitrates are the main form of nitrogen nutrition for plants; the value of soil absorbed ammonium as a nitrogen source is less. This form of nitrogen is less accessible to plants; easily hydrolysed nitrogen is the closest reserve of mineral nitrogen.

Changes in the nitrogen regime under ecologised fertiliser systems were studied in the winter wheat field. Studies have shown that in fertiliser systems, the content of mineral forms of nitrogen ($N{-}NO_3^-$ + $N{-}NH_4^+$) in the heading phase of winter wheat was in the range of 18.75-25.80 mg $kg^{-1}$. The lowest level of the sum of mineral forms of nitrogen was in the control variant and in the variant of plowing pea straw (Table 1). When applying pea straw, the amounts of mineral forms of nitrogen and easily hydrolysed nitrogen slightly differed from the values in the control variant (-1.5–-0.88 mg $kg^{-1}$ of soil). In the options of applying pea straw + $N_{30}P_{45}K_{45}$, there was a significant increase in the amounts of these nitrogen forms – by 3.47-6.17 mg $kg^{-1}$ more, compared to the control option. Adding MF or HF on the background of pea straw + $N_{30}P_{45}K_{45}$ + BS provided the highest level of accumulation of ammonium and nitrate forms of nitrogen – by 4.22 and 6.47 mg $kg^{-1}$ more than the control variant. Under the conditions of pea straw + $N_{30}P_{45}K_{45}$ + CF the content of mineral forms of nitrogen was approximately the same as in the case of pea straw + $N_{30}P_{45}K_{45}$.

***Table 1***. *Influence of ecologised fertiliser systems on the total content of mineral forms of nitrogen and the content of easily hydrolysed nitrogen in the soil under winter wheat (heading phase; 2019-2020)*

| No. of var. | Sum of mineral forms of nitrogen | Easily hydrolysed nitrogen |
|---|---|---|
| | mg kg$^{-1}$ of soil | |
| 1 | 19.63±0.91 | 94.50±3.48 |
| 2 | 18.75±0.93[1] | 93.00±3.48[1] |
| 3 | 23.10±1.13[1,2] | 108.05±4.90[1,2] |
| 4 | 22.75±1.12[1,2] | 102.31±4.05[1,2] |
| 5 | 25.80±1.30[1,2] | 115.35±5.24[1,2] |
| 6 | 23.85±1.13[1,2] | 109.55±4.90[1,2] |
| 7 | 23.45±1.11[1,2] | 107.55±4.54[1,2] |
| Significance level of differences between the averages according to *ANOVA*: | | |
| | P<0.001 | P<0.01 |

***Note:*** *[1, 2] – significance level of the difference compared to options 1, 2, respectively, P<0.001-0.01*

Easily hydrolysed nitrogen is the closest reserve of mineral nitrogen. Under winter wheat, in the variant of plowing pea straw, its content did not considerably differ from the control variant (Table 1). The patterns of changes in this type of nitrogen according to fertiliser systems were similar to the pattern of changes in the content of mineral forms of nitrogen. The highest content of easily hydrolysed nitrogen was observed under the conditions of pea straw + $N_{30}P_{45}K_{45}$ + BS compositions with the addition of MF or HF. This obviously indicates the positive impact of the simultaneous use of mineral and organic fertilisers in ecologised fertiliser systems.

Thus, under the conditions of ecologised fertiliser systems on var. 4-7, an increase in the content of the tested forms of nitrogen in the soil could partly be caused by a decrease in the needs of winter wheat plants for nitrogen absorption (mainly $N-NO_3^-$) from the soil, due to the growing availability of the aboveground part of these plants with nitrogen forms that came with BS and CF chemicals. Introduction of HF or MF into the soil on the background of pea straw + $N_{30}P_{45}K_{45}$ (var. 5, 6) together with the effect on plants, BS considerably improved the nitrogen regime of the soil, increasing the content of mineral forms of nitrogen and easily hydrolysed varieties. As in the case of $pH_{(KCl)}$ values, content of the exchange $Ca^{2+}$ in the soil solution, the largest increases in the studied forms of nitrogen in the soil were achieved in var. 5.

Notably, other researchers have commented on the content of mineral forms of nitrogen in grey forest heavy loamy soil at the level of 14.3-21.8 mg $kg^{-1}$ (soil layer 0-20 cm) [43]. The content of easily hydrolysed nitrogen in the specified soil was 41.7-65.7 mg $kg^{-1}$ (soil layer 0-20 cm). Therewith, in the arable layer of cultivated grey, light grey, dark grey soils, the content of easily hydrolysed nitrogen was in the range of 35.4-93.7 mg $kg^{-1}$ [44]. Thus, the values of the content of mineral forms of nitrogen, easily hydrolysed nitrogen in the soil on var. 1 obtained in this paper are close to the results given in the above sources.

Reduction of the content of studied nitrogen forms in var. 2, compared to var. 1 can be explained by the ability of straw to reduce the content of easily hydrolysed nitrogen in the short term, support denitrifying microorganisms, and enhance denitrification, which is accompanied by nitrogen gas loss (e.g., $N_2O$), as well as activation of nitrogen immobilisation in the biomass of microorganisms [45; 46]. In addition, the ability of straw to increase the absorption of mineral forms of nitrogen by agricultural plants may be the reason for the decrease in the content of $N-NO_3^-$ + $N-NH_4^+$ in the soil on var. 2 [47].

Adding mineral fertilisers $N_{30}P_{45}K_{45}$ to straw in var. 3 eliminates N-restrictions on the development of microbial biomass and P-restrictions on metabolic processes in soil microorganisms [48]. For its part, this can be accompanied by a slight decrease in the rate of release of N-components of straw and/or an increase in the growth rate of microorganisms under conditions of sufficient carbon substrate, thus causing an increase in the microbiological activity of the soil; these processes create opportunities for increasing the enzymatic activity in the soil, which is involved in the hydrolysis of amino sugars, proteins, peptides, and, consequently, in the development of easily hydrolysed and mineral nitrogen funds [49].

Notably, the authors S. Yang et al., interpreting their results, assumed that large amounts of wheat straw in the soil can physically bind $NO_3^-$ [47]. This may be conditioned upon the presence of positive and negative charges on the straw surface, which can vary depending on protonation-deprotonation of pH-dependent functional carboxyl and hydroxyl groups. Soil organic matter and compost organic matter also have similar properties [50]. This suggests that the products of straw decomposition and the compounds that are formed from them can cause changes in the content of available forms of mineral nitrogen, other cations and anions in the soil. Looking at these issues in perspective can help to understand important aspects of shaping soil fertility and agricultural plant productivity under straw-based fertiliser systems.

It is reasonable to assume that under the conditions of ecologised fertiliser systems which include pea straw, humus, microbiological, chelated fertilisers, and a biostimulator, the efficiency of using winter wheat nutrients from the soil is considerably higher compared to the control. This might be conditioned upon an improvement in the elements of crop productivity, in particular, the state of the root system, the aboveground part of plants, and, as a result, an improvement in the grain content of the head, the mass of grain in it under such conditions. This is partly consistent with the results and hypotheses of the authors in the sources [51; 52]. Evidently, the lack of mineral nutrition in the control variant caused low values of biological productivity, which was accompanied by a decrease in the number and mass of grains in the head. The use of only pea straw as an organic fertiliser slightly increased the mass and number of grains in the head, relative to the control (+0.05 g and +1.41 pcs).

Analysis of data on the effect of pea straw + $N_{30}P_{45}K_{45}$ on the elements of grain productivity indicates the effectiveness of the use of this system, in comparison with the use of by-products or control (Fig. 2). This fertiliser system caused an increase in the grain content of the head by 8.41 pcs, the mass of grain from the head by 0.24 g, relative to the control. Treatment of winter wheat plants with BS on the background of pea straw + $N_{30}P_{45}K_{45}$ (var. 4) improved the parameters of the corresponding productivity elements, compared to the control or variant of plowing pea straw. Thus, in all variants of the experiment with the use of pea straw + $N_{30}P_{45}K_{45}$ and joint application of BS, CF, HF, or MF, an increase in the number and mass of grains in the head was noted, relative to the control variant. Therewith, the most effective fertiliser systems were compositions using HF or CF on var. 5 and 7. They contributed to an increase in the grain content of the head by 13.58-14.16 pcs, grain productivity of the head – by 0.38-0.40 g, compared to the control.

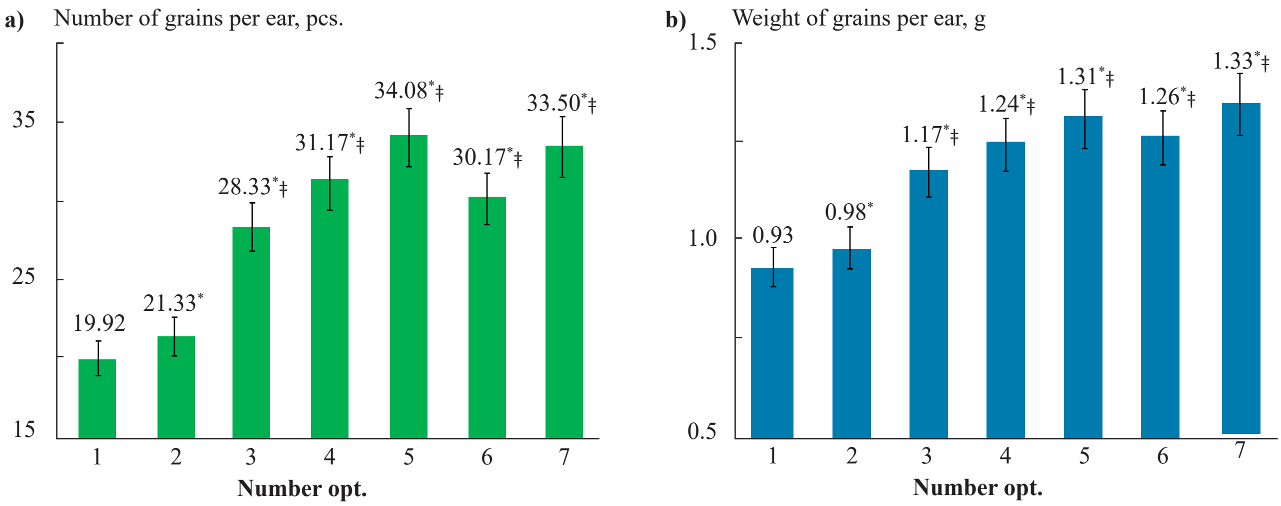


***Figure 2**. Influence of ecologised fertiliser systems on the number (a) and mass (b) of grains in a head of winter wheat (waxy ripeness phase; 2019-2020)*

***Note**: significance level of differences between averages according to ANOVA: a, b – P<0.001; *, ‡ – significance level of the difference compared to options 1, 2, respectively, P<0.001-0.01*

Evidently, ecologised fertiliser systems increase the efficiency of plants' use of nutrient elements of fertilisers and soil, forming the best parameters of the winter wheat yield, which is also indicated by the results of other authors' research [53; 54].

The winter wheat crop formed with ecologised fertiliser systems was analysed for the content of microelements (ME) in the grain. ME promote the accumulation of vitamins, pigments, affect the metabolism of carbohydrates and proteins, activate the synthesis of necessary enzymes, and increase plant immunity. With their shortage, a state of physiological depression occurs.

Data on the content of ME (Cu, Zn, Mn, Fe) in winter wheat grain are shown in Table 2. Evidently, against the background of the use of ecologised fertiliser systems, the ME content is higher compared to the control. Under such conditions, these substances have a greater degree of mobility in the soil, and therefore, plants can absorb and distribute ME more efficiently to improve productivity and quality of final products. According to these results, the content of the studied ME decreases in the following order: Fe>Mn>Zn>Cu.

The Fe content in wheat grain against the background of plowing pea straw was 1.0 mg $kg^{-1}$ more than in the control variant (Table 2). On the background of pea straw + $N_{30}P_{45}K_{45}$ or with the addition of BS, and especially CF (var. 3, 4, 7), the Fe content increased by 3.8-4.1 mg $kg^{-1}$ compared to the control. Using BS + HF or BS + MF against the specified background (var. 5, 6, respectively) caused a less significant increase in the Fe content in the grain compared to the control (+3.4 mg $kg^{-1}$).

Under the conditions of $pH_{(KCl)}$ in the range of 5.2-5.3, the need of plants for Mn is met almost completely due to the soil itself. Since on experimental var. 2-7, $pH_{(KCl)}$=5.10-5.33 (Fig. 1), i.e. close to the above interval, it is likely that the Mn content in wheat grain under the conditions of ecologised fertiliser systems is optimal. On var. 2, 5, 6, there was a considerable decrease in the Mn content in the grain compared to the control (var. 1). Therewith, ecologised fertiliser systems on var. 3, 4, 7 caused an increase in this indicator by 0.3-0.9 mg $kg^{-1}$, compared to var. 1. Regularities of changes in the content of Zn, Cu in var. 2-4, 7 were similar to the pattern of changes in the Fe content in wheat grains compared to the control. Therewith, in contrast to the latter among the indicated ME, the content of Zn, Cu in grain in var. 5, 6 was larger compared to var. 3, 4.

***Table 2**. Content of trace elements in winter wheat grain under ecologised fertiliser systems (waxy ripeness phase; 2019-2020)*

| No. of var. | Fe | Mn | Zn | Cu |
|---|---|---|---|---|
| | mg $kg^{-1}$ | | | |
| 1 | 14.4 ± 0.4 | 13.0 ± 0.3 | 10.08 ± 0.24 | 3.10 ± 0.07 |
| 2 | 15.4 ± 0.4[1] | 11.8 ± 0.2[1] | 10.37 ± 0.25[1] | 3.15 ± 0.07[1] |
| 3 | 18.2 ± 0.6[1,2] | 13.3 ± 0.3[1,2] | 11.72 ± 0.34[1,2] | 3.30 ± 0.07[1,2] |
| 4 | 18.4 ± 0.7[1,2] | 13.5 ± 0.3[1,2] | 11.60 ± 0.31[1,2] | 3.30 ± 0.07[1,2] |
| 5 | 17.8 ± 0.6[1,2] | 12.8 ± 0.3[1,2] | 11.93 ± 0.34[1,2] | 3.40 ± 0.07[1,2] |
| 6 | 17.8 ± 0.6[1,2] | 12.7 ± 0.3[1,2] | 11.80 ± 0.32[1,2] | 3.35 ± 0.07[1,2] |
| 7 | 18.5 ± 0.7[1,2] | 13.9 ± 0.3[1,2] | 12.04 ± 0.34[1,2] | 3.50 ± 0.08[1,2] |
| Significance level of differences between the averages according to *ANOVA*: | | | | |
| | P<0.001 | P<0.001 | P<0.001 | P<0.01 |

***Note:** Indexes [1,2] – significance level of the difference compared to options 1, 2, respectively, P<0.001-0.01*

Notably, the applied ecologised fertiliser systems caused a low level of variation in the content of the studied microelements in winter wheat grain (Cv= 4.71-9.29%).

According to M. Kuleshov [55], the content of microelements in grain used for production purposes should not exceed 5 mg $kg^{-1}$ Cu, 50 mg $kg^{-1}$ – Fe, and 2.3 mg $kg^{-1}$ Zn. As a result of the studies, the maximum permissible concentrations (MPC) were not exceeded in terms of the content of the studied microelements in wheat grain.

The low potential level of providing grey forest soils with microelements and the ability of the applied ecologised fertiliser systems to increase their content in winter wheat grains create opportunities for important research in the future. In particular, it will be advisable to study the regularities of productivity development of these plants depending on the provision of microelements to soil and plants in the conditions of ecologised fertiliser systems.

## CONCLUSIONS

The studied ecologised fertiliser systems caused a simultaneous improvement in physical and chemical parameters and signs of the nitrogen regime of grey forest soil (heading phase), an increase in average head productivity (number and weight of grains per head; waxy ripeness), and the content of Zn, Cu in winter wheat grain. The most pronounced improvement in soil indicators took place under conditions of simultaneous influence of greening elements on plant growth, their availability of macro- and microelements (biostimulator), and the probable rate of destruction of plant residues (humus fertiliser, microbiological fertiliser) against the background of pea straw + $N_{30}P_{45}K_{45}$. The greatest increases in head productivity and Cu, Zn content in wheat grain occurred under the conditions of biostimulator and humus fertiliser (effect on the plant and soil) or chelated fertiliser (effect on the plant) against the background of pea straw + $N_{30}P_{45}K_{45}$. The fertiliser system, which included a biostimulator + humus fertiliser on the background of pea straw + $N_{30}P_{45}K_{45}$, had indisputable advantages in the simultaneous improvement of the studied soil indicators and signs of head productivity. The pattern of forming a positive effect of this fertiliser system on the studied indicators (soil and plant) was characterised by the following features:

1. Maximum $pH_{(KCl)}$ gains, content of the exchange $Ca^{2+}$, comparing to the control – 7.9-16.4%; submaximal increase in the content of exchange $Mg^{2+}$, compared to the control – 52.5% (the corresponding maximum was +63.1% under the conditions of biostimulator + microbiological fertiliser on the background of pea straw + $N_{30}P_{45}K_{45}$);
2. Maximum increase of $N-NO_3^-$ + $N-NH_4^+$, easily hydrolysed nitrogen, compared to the control – 22.1-31.4%;
3. Maximum increases in the number and mass of grains per head, compared to the control – 71.1% and 40.9%, respectively; comparable increase in grain mass per head – under the conditions of chelated fertiliser against the background of pea straw + $N_{30}P_{45}K_{45}$ (+43.0%);
4. Submaximal increase of Zn, Cu in winter wheat grain, compared to the control – 9.7-18.4% (the corresponding maxima were +12.9–+19.4% under chelated fertiliser conditions on the background of pea straw + $N_{30}P_{45}K_{45}$.

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## Вплив екологізованих систем удобрення на елементи родючості та продуктивності пшениці озимої

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**Анотація**. Одним із стратегічних напрямів розвитку сучасного землеробства є використання екологізованих систем удобрення, скомпонованих на базі соломи сільськогосподарських культур з додаванням мікробіологічного, гумусного або хелатного добрив. Це дасть змогу відновити природні ресурси й отримати екологічно якісну продукцію. Метою досліджень було вивчення дії екологізованих систем удобрення на фізико-хімічні процеси та азотний режим сірого лісового ґрунту, формування біопродуктивності пшениці озимої та вміст основних мікроелементів у зерні. У дослідженнях використано такі методи: польові, лабораторно-аналітичні, математико-статистичні. Застосування $N_{30}P_{45}K_{45}$ на фоні соломи гороху з додаванням біостимулятора та гумусного добрива найбільшою мірою демонструвало сучасні підходи до технологій управління родючістю сірих лісових ґрунтів на принципах екологічної безпеки й збереження ресурсів. Така система удобрення забезпечувала підлужнення ґрунтового розчину, оптимізацію вмісту $Ca^{2+}$ та $Mg^{2+}$, покращення азотного режиму ґрунту. За таких умов формувались оптимальні параметри елементів продукційного процесу (кількість і маса зерен у колосі). Найефективнішою у процесах накопичення мікроелементів була органо-мінеральна система такого складу: солома гороху + $N_{30}P_{45}K_{45}$ + хелатне добриво. Перевищення гранично допустимої концентрації за елементами Cu, Zn, Mn, Fe не було виявлено. Отже, з метою гармонізації екологовідтворних і продуктивних функцій сірого лісового ґрунту у системі вирощування пшениці озимої перспективним є поєднання альтернативного землеробства, що полягає в зменшенні використання мінеральних добрив, та часткової біологізації. Це шлях оптимізації родючості та біопродуктивності ґрунтів

**Ключові слова**: кислотність ґрунту, обмінний кальцій і магній, форми азоту, елементи продуктивності колосу, мікроелементи