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New record of *Anthocoptes platynotus* Nalepa (Acari: Eriophyoidea) and its abundance on *Cornus mas* L. in the northern part of a Forest-Steppe zone of Ukraine

Abstract. The superfamily Eriophyoidea is a large and diverse group of mites that includes a number of species that parasitise plants of economic importance, mainly perennial plants in agriculture and forestry. The purpose of this study is to examine the cornel plants plantations in

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the botanical gardens of Kyiv and Zhytomyr (Ukraine) for the presence and damage by mites of the superfamily Eriophyoidea. During the study, field and laboratory methods were used in accordance with generally accepted methods in acarology and plant protection. As a result of the study, on *Cornus mas* L. plants, a four-legged mite *Anthocoptes platynotus* Nalepa, 1898 was found. This is the farthest northern distribution zone of the species in Ukraine. New data on the harmfulness of this species were received. It was determined that under *A. platynotus* feeding, there was a slight deformation of the leaf lamina on both sides of the leaf veins, there was no leaf bleaching. The population level of *A. platynotus* on six varieties of a plant subg. Cornus was determined. It was established that it was different. Phytophage-mite damaged the varieties "Elegantnyi" and "Kubanskyi" the most. The least affected were the varieties "Mosvir-1" and "Novyi". The varieties "Bylda" and "Svitliachok" had a medium degree of damage. *A. platynotus* lives on the underside of a leaf and does not form galls or felt. The peak of phytophagous population in the research region occurs at the end of July. It was noted that a low number of *A. platynotus* does not substantially affect the growth and development of the leaves on the fodder plant. The practical value of the study lies in the fact that the information on *A. platynotus* presence, abundance, and spread will help in sampling the mites and making future management decisions

Keywords: four-legged mites; identification; varieties; spread; harmfulness; population

INTRODUCTION

Cornel (*Cornus mas* L.), a shrub or small tree, is one of the most valuable fruit, medicinal, technical, and ornamental plants. The fruits of cornel contain carbohydrates (glucose, fructose), pectin substances, polyphenols, ascorbic acid, various vitamins, mineral salts of potassium, phosphorus, calcium, phosphorus, iron, magnesium, biologically active substances. Sweet fruits of cornel are used for food – jams, jellies, marmalades, jams, extracts, fillings, syrups, kvass, compotes, soft drinks are made from them. Fresh fruits and juice of cornel are used in medicine as an astringent, tonic, antifever, appetizing, antirheumatic, antidiabetic remedy. For medicinal purposes, shoots, leaves, bark, roots, seeds are also used. Cornel is an excellent mellifer, blossoms one of the first fruit seed and stone crops. It is valued not only for its high yield and excellent nutritional and flavour qualities of fruits, but also for its high economic efficiency and environmental friendliness. However, cornel plantation is a habitat for some pest species. One of the groups of pests damaging cornel is mites of the superfamily Eriophyoidea (Acari: Eriophyoidea). They are very small organisms and are almost impossible to observe with the naked eye without the use of some kind of microscopic device.

Eriophioid mites are obligate phytophagous and for the most part exhibit a high level of host specificity and adaptability. They are capable of infesting almost all parts of plants, excluding roots. As noted by E. de Lillo *et al.* (2018), many species of Eriophioid mites are considered economically important because of certain damages such as chlorotic spots, galls, blotches, stunting, or curling of leaf edges that they can cause. Some species can transmit phytopathogenic viruses (Kubota *et al.*, 2022; Albrecht *et al.*, 2022).

To date, about 5000 species of Eriophioidea have been described, which, according to experts' estimates, is no more than 5-10% of their global diversity (Bondareva & Timoshchuk, 2020). One of the reasons for the poor examination of the group is the extremely small size of Eriophioidea (100-300 µm in length), which allows considering them as one of the examples of multicellular organisms that are on the verge of miniaturisation. According to K. Kołątaj (2017), the small size and low mobility of eriophioid mites allow them to passively spread over long distances through air currents, rain, and especially through trade in planting material and food.

Most quadrupedal mites are vagrant species on exposed plant parts, but latent forms are present among many Eriophiidae. According to V. Martynov *et al.* (2021), the response of plant cells to mite feeding varies considerably in severity. Free-living Eriophiidae in most cases do not cause damage visible to the naked eye, but in case of mass reproduction may lead to rusting, bronzing, or chlorotic appearance of damaged parts. A relatively limited proportion, approximately 10-15% of these mites, reside in natural storage sites on the host or within the galls they create (Jiang *et al.*, 2021).

In recent decades, there have been almost no focused studies of species and structural diversity of four-legged mites in Ukraine. However, every year acarological scientists around the world describe new species of mites of the superfamily Eriophyoidea that pose a threat to plants. For example, F. Bahirai *et al.* (2021) recorded 11 new species of four-legged mites in Lorestan province of Iran on different host plants. According to Y.P. Yanovskyi *et al.* (2021; 2022), currently, outbreaks of mass reproduction of four-legged mites on garden plants are recorded everywhere in Ukraine, which leads to the relevance of ecological and faunistic studies. Despite the importance of these mites as pests, knowledge about their distribution and trophic relationships in Ukraine is largely insufficient.

Overall, the examination of four-legged mite activity in various fruit and berry crops remains pertinent. Neglecting these potentially harmful biological factors could result in decreased drought and frost resistance, ultimately leading to a substantial decrease in crop yields. Knowledge of the biology, ecology, and behaviour of these phytophages is necessary to develop programmes for effective control of the number of four-legged mites. Detailed data on the development cycle of the main mite pests under natural conditions, including the influence of weather and climatic conditions and host plant type, are required.

Therefore, the objective of this study was to examine the botanical gardens of Kyiv and Zhytomyr to identify mites of the superfamily Eriophyoidea in cornel plantations. The tasks included the analysis of trophic relationships of phytophagous mites, and the primary assessment of population status and the degree of harmfulness. The use of sticky tapes as a method of effective phytosanitary monitoring of mites will allow for detecting mites at early stages.

MATERIALS AND METHODS

The monitoring was conducted in 2021-2022 from May to September on the territory of Botanical Garden named after academician O.V. Fomin in Kyiv, in the National Botanical Garden named after M.M. Hryshko (National Academy of Sciences of Ukraine), in the Laboratories of non-traditional fruit cultures of the production unit National University of Life and Environmental Sciences of Ukraine, in The Botanical Garden of Polissia National University in Zhytomyr.

Six varieties of *Cornus mas* L.: “Elehantnyi”, “Kubanskyi”, “Bylda”, “Svitliachok”, “Mosvir-1”, and “Novyi” were inspected in the Laboratories of non-traditional fruit cultures of the production unit of the National University of Life and Environmental Sciences of Ukraine. Thirty cornel leaves of each variety from the lower side were examined, and when the lamina was deformed, both the phytophagous density and the leaf damage were determined on a five-point scale (Table 1).

Table 1. The qualitative and quantitative scale of density of *Anthocoptes platynotus* population on the leaves of *Cornus mas*

Signs of damage	The area of the leaf surface with the signs of damage, %	Point
No damage	The leaf surface without noticeable signs of deformation near the main and the side veins	0
Damages are slightly noticeable (the surface across the main and the radial leaf veins is deformed)	3-4	1
Slight	5-10	2
Medium	11-20	3
Severe	21-50	4
Very severe	> 50	5

Source: developed based on the study by C.O. Trybel *et al.* (2001)

A transparent adhesive tape was used to identify and estimate the number of mites according to P.Y. Chumak *et al.* (2020) (Fig. 1). The adhesive side of the tape was placed on the cornel leaves and slightly pressed with the fingers.

Figure 1. The use of translucent adhesive tape for mite monitoring
Source: photo by the authors

The prints obtained on one piece of tape were placed on the appropriate sized glass slide with the sticky side to the glass, and a roll of tape was cut off from the preparation with the scissors. The mite samples were labelled with a marker. The sample number, date, and place of picking were noted in the notebook. The use of adhesive tape for the examination of eriophyoids allowed obtaining data on the presence of the object and simultaneously detecting almost all stages of both live and dead pests. While picking the pests, there are predatory insects and mites which after 'shaking off' disappear quickly and are out of sight. Therefore, this method opens up new possibilities for analysing the locations of mites on the lower and upper surface of leaves, near the base of leaves and evaluating the effectiveness of acaricides and their effect on predatory mites.

The mite specimens were placed on the slides in Hoyer's liquid. They were identified using a microscope Optika B-350 (Country of manufacture – Italy). Microphotographs of the live objects were taken with a microscope Leica M 165C (Country of manufacture – Germany), and the mite photographs were taken with a microscope Optika B-350 and a digital camera Sigeta MDC-200 2.0 MP (Country of manufacture – China). The material used in the study is stored in the collection of the Department of Entomology, Integrated Protection, and Plant Quarantine of the National University of Life and Environmental Sciences (Kyiv, Ukraine).

To determine the effect of eriophyoidous mites on the growth and development of leaves of *Cornus mas*, the leaf damage index (I_s) was used, which was determined by the formula (Trybel *et al.*, 2001):

$$I_s = \sum \frac{100ab}{5N}, \qquad (1),$$

where I_s – the index indicator of leaf damage, %; Σ (ab) 100 – the sum of indicators multiplication of tested leaves number (a) by the degree of phytophagous damage to the leaves (b); N – total number of the tested leaves; 5 – a higher degree of the damaged leaves on a five-point scale.

The area of a leaf surface was calculated according to P.V. Savchenko & N.S. Kozhushko (2013). Digital data were processed using indices accepted in statistics. The mathematical processing of the measurement results was conducted using the package of MS Excel. The experimental studies of plants (both cultivated and wild), including the collection of plant material, were conducted in accordance with institutional, national, or international guidelines. The authors adhered to the standards of the Convention on Biological Diversity (1992) and the Convention on Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS AND DISCUSSION

The *Anthocoptes platynotus* Nalepa (1898) (Acari: Eriophyoidea) was first registered when examining cornel (*C. mas*) in urbophytocenosis of northern Forest-Steppe of Ukraine in 2021 (Fig. 2).

For the first time, the mite species was found in the Botanical Garden named after academician O.V. Fomin in Kyiv (latitude: 50°44' N, longitude: 30°50' E), in the National Botanical Garden named after M.M. Hryshko (National Academy of Sciences of Ukraine (latitude: 50°41' N, longitude: 30°56' E), in the Laboratories of non-traditional fruit cultures of the production unit of the National University of Life and Environmental Sciences of Ukraine (latitude: 50°38’ N, longitude: 30°50’ E), in The Botanical Garden of Polissia National University in Zhytomyr (latitude: 50°25’ N, longitude: 28°69’ E).

Figure 2. *Anthocoptes platynotus* Nalepa
Source: photo by the authors

According to the original description of *A. platynotus* made by Nalepa in 1898, the body of the female is oblong and narrow. The shield is almost pentagonal and smooth and protrudes above the rostrum. Scapular setae (*sc*) are about half the length of the shield directed upwards; humps are large, widely spaced, and distant from the rear edge. Rostrum is small. Legs are rather short, Gl. 4 and 5 are almost the same length. The claw is 4-ryed. Sternal side is not bifurcated. The abdomen has 13 wide, smooth posterior half-rings, they are strongly flattened, their side parts bent at an angle. Setae *c2* are long and very delicate. Setae *d* are slightly shorter than setae *e*, very short and delicate. The cover flap is striped. Setae I are quite long. ♂ body length is 130 µm, width is 30 µm; ♀ body length is 150 µm and width is 40 µm. A species infests a fodder plant *C. mas*. Slightly twisted leaves are mostly discoloured (Nalepa, 1898).

There is very little information in the literature about the spread and harmfulness of *A. platynotus* on the plant species of Cornaceae in Europe. Earlier, the mite was identified on *Cornus sanguinea* and *Cornus mas* in Hungary and Italy (Hillring, 2003; Ripka, 2007; Ripka, 2008). In the authors’ opinion, the mite population in the northern part of a Forest-Steppe zone of Ukraine, characterised by more severe winter conditions compared with subtropical climates in Italy and the temperate climates in Hungary, points at the range of the ecological valence of a mite-phytophagous.

The feed attractiveness of six varieties of *C. mas* and the infestation density on the leaves were analysed (Table 2).

Table 2. Population density of *Anthocoptes platynotus* on *Cornus mas* plants (average during the period of 2021-2022)

Varieties	Point of damage	Adult, specimen/leaf		Larva and nymphs, specimen/leaf		Dead specimen/leaf, %
		Total	Per leaf	Total	Per leaf	
“Elehantnyi”	3-4	380.0	42.2	110.0	12.2	11.2
“Kubanskyi”	3-4	290.0	36.3	110.0	13.7	12.5
“Bylda”	2-3	350.0	31.8	20.0	1.8	9.1
“Svitliachok”	1-2	210.0	23.3	0.0	0.0	11.1
“Mosvir-1”	0-1	120.0	15.0	50.0	6.3	12.5
“Novyi”	0-1	10.0	1.3	0.0	0.0	12.3

Source: compiled by the authors

As follows from the results of a cornel plant inspection, there are some differences in the density of mite infestation on different varieties. The varieties "Elehantnyi" and "Kubanskyi" were the most damaged (4 points). The average number of adults per leaf equalled 36.3-42.2 specimens, larvae – 12.2-13.7 respectively. Medium mite infestation was registered in "Bylda" variety (point of damage – 2-3). There were registered 31.8 adult per leaf and 1.8 larvae per leaf on this variety. The degree of damage – 1-2 points and 23.3 adults per leaf were registered in the variety "Svitliachok". The plants grew side by side and did not have any separating barriers, the general insolation and the humidification conditions were similar, but the infestation of two varieties, "Mosvir-1" and "Novyi" with *A. platynotus,* was substantially less (the point of damage – 0-1), the mite number equalled 1.3-15.0 adult per leaf and 0.0-6.3 larva per leaf. The noticeable signs of plant damage were not detected.

Notably, there was a great amount (9.1-12.5% depending on the variety) of dead, dry, and transparent mites on the leaves of *C. mas*. It is known that no pesticides were applied on the plots of laboratories of non-traditional fruit cultures of production for 12 years. Perhaps, it is connected with the activity of a mite *Zetzellia mali* from Stigmaeidae, because its specimens were found on the leaves.

No larva was found on the varieties "Svitliachok" and "Novyi" when the samples were taken. It can indicate both the speed of a mite development and the resistance of the varieties to *A. platynotus*. Presumably, on some varieties, the mite goes through all stages of development faster than on others. There is age-related heterogeneity of a tested population of *A. platynotus* (larvae and nymphs, their ratio on different varieties), that can promote a population's survival and can be a sign of species viability.

The information about the eriophyoidous mites on plants is different in many taxonomic and faunistic papers. There are some singular studies that consider the real influence of these mites and the changes that occur in plants when they interact. As noted by L.A. Ivanova *et al*. (2022), the gall mite infestation resulted in chlorosis, destruction of photosynthetic apparatus in gall-infected leaf parts, leaf deformation, and a decrease in leaf area. Such a factor as a variety can affect the population of four-legged mites. There is fragmentary information in the available literature about the damage to the varieties of cultivated plants by eriophyoidous mites. V. Moskalets *et al.* (2022) observed that the damage inflicted by *Aceria huppopara* Nal. on early-ripening sea-buckthorn varieties was lower than the damage observed in medium- and late-ripening varieties.

L.M. Bondareva & P.Ya. Chumak (2021) point to the variability of infestation and damage by *Eriophyes pyri* Nal. to the plants of pear varieties. Heavily damaged are mostly the varieties of the winter-ripening period. As noted by J. Moreira *et al*. (2020), *Aculus schlechtendali* Nal. is found on all examined apple varieties in Brazil, with a greater number on the Fudzhy and Yeva varieties and a smaller phytophagous population on the Gala variety.

Mite reactions to different plant species can be different depending on the differences in the nutritional value of the leaves and surface morphology, the availability of toxic components and accumulation of secondary metabolites, the availability of necessary enzymes in mites and their digestive capability, etc. (Boom *et al*., 2003). The degree of mite infestation can depend on the degree of lamina pubescence. However, having conducted the comparison of lamina pubescence and intensity of infection by mites, the authors did not detect any coherence. It cannot be excluded that *A. platynotus* will infest other varieties of *Cornus mas* in the botanical gardens, considering the fact that a variety resistance to any specialised phytophagous is always relative, eventually, even a relatively resistant variety becomes a favourite one for a pest.

A. platynotus lives on the underside of a leaf and does not form galls or felt. This mite overwinters in a form of deitogeynous female inside the buds of cornel plants, and then all spring forms of mites move to the leaves and begin feeding and laying eggs. According to observations in the conditions of the northern Forest-Steppe zone of Ukraine, the activity of the mite begins in May and continues untill the middle of September. In general, the four-legged mites reproduce quickly. The peak of *A. platynotus* number in the research region is at the end of July.

The potential for eriophyoidous mites spreading by moving is limited, and the ways of spreading are wind or phoresis. The dispersion of phoresis occurs when these mites stick to other organisms to be transferred to a new host. Spreading by the wind is more risky for these organisms because due to the high host specificity of these mites, there is little chance of reaching the appropriate host. On the contrary, having a pollinator of the host plant, the chances for reaching the appropriate host increase as in the case of *Aceria litchii* Keifer (Acari: Eriophyidae), which is associated with bees that pollinate lychee trees (Jiang *et al.*, 2021) and *Aceria pallida* Keifer (Acari: Eriophyidae), which is associated with *psyllidae Bactericera gobica* Loginova (Hemiptera: Triozidae) (Liu *et al.*, 2019).

The biological colonisation of agricultural plants by four-legged mites can have negative consequences, including reduced yields. Hence, gathering and analysing data regarding the biological and ecological characteristics, including their dispersal abilities, serves as a valuable predictive model for pests, specifically, *A. platynotus*. As noted by L. Kuczyński *et al.* (2020), the examination of the settlement process is especially difficult when considering microscopic organisms, such as four-legged mites, which spread passively.

In order to detect a particular pest in a time, it is extremely important to identify the signs, characteristic of the damage caused by this pest. A. Nalepa (1898) indicates the reaction of a plant on mite nutrition in the form of slightly folded or twisted, mostly bleached leaves. In the available literature, there is no detailed description of the character and possible extent of damage which *A. platynotus* phytophagous can cause to a fodder plant. According to the authors' observations, the leaves of all tested varieties of cornel do not get twisted. There is a slight deformation of the lamina on both sides of leaf veins by the basis of side leaf veins. There is no leaf bleaching (Fig. 3).

The results of the study testify to the fact that there is some influence of *A. platynotus* on the growth and development of cornel leaves but it is characterised by rather low indicators (Table 3). According to the data received after a one-factor analysis, the average area of one leaf of *Cornus mas* "Macrocarpa" decreases from 56.1 dm^2 under a low degree of mite infestation (1 point) to 54.9 dm^2 in a variant with heavy leaf damage (4 points). Thus, no serious damage to the dogwood plant by *A. platynotus* was identified.

Figure 3. A lower side of a leaf of *Cornus mas* is infested with *A. platynotus*
Source: photo by the authors

Table 3. The influence of *Anthocoptes platynotus* on the growth and development of leaves of *Cornus mas* "Macrocarpa"

Degree of damage, point	Leaf parameters (dm^2)	Statistical comparison of the variants			
		Difference between the average	F-Fisher criteria	Relevance	Impact power
3-4	54.9 ± 1.935	1.20	0.178	0.8547	0.09998
0-1	56.1 ± 2.084				

Source: developed by the authors

The nature of the damage, caused by eriophyoidous mites and the assessment of yield losses still require detailed research if appropriate strategies on population control and risk reduction are to be planned. An important measure for plant protection from mites is to observe basic preventive measures. The new plants should be sufficiently isolated from those places where the plantations were colonised by phytophagous mites. Planting material must be checked for the absence of pest infestation. In addition, agrotechnical methods of plant care must be followed. Knowledge about the resistance of agricultural crop varieties to phytophagous mites will allow reducing pesticide burden and costs of conducting the protection measures.

The natural predators of four-legged mites, such as predatory mites or acariphages (*Amblyseius finlandicus* Oudemans, 1915; *Paraseiulus soleiger* Ribaga, 1904), *Phytoseiulus persimilis* (Athias-Henriot, 1957), thrips (*Scolothrips sexmaculatus* Pergande, 1891), (*Chrysoperla carnea* Stephens, 1836), and phytopathogenic fungi (*Beauveria bassiana* (Balsamo-Crivelli), Vuillemin, 1912; *Streptomyces avermectinius* Takahashi and others, 2002), induce epizootic outbreaks, contributing to the destruction of these four-legged mites (Moskalets *et al.*, 2022).

Biological control is not yet sufficiently used for the control of the mite, although entomopathogenic fungi are one of the most promising alternatives, which is demonstrated by the substantial mortality of eriophyoids in the field. Chemical control of eriophyoids leads to failures due to resistance to acaricides, which is surprising when compared to the global problem of fighting against spider mites (Van Leeuwen & Dermauw, 2016). The use of mites-resistant plant varieties leads to a reduction in economic costs in the cultivation of fruit and berry crops and is one of the factors in the development of cultivation technologies to increase yields. Results show differences in mite infestation among *C. mas* cultivars that can be used to develop new mite-resistant *C. mas* plantations.

Cornel has medicinal and decorative properties, and increasing global trade in this plant is likely to facilitate the further introduction of associated arthropods, particularly four-legged mites. The results support this claim. *A. platynotus* was first detected in the northern part of a Forest-Steppe zone of Ukraine. At low numbers, the mite rarely causes substantial damage to *C. mas*, but when its numbers increase, it can lead to serious damage. More intensive examination of cornel in the parks, gardens, and nurseries will undoubtedly lead to further records, providing a better understanding of the distribution of alien arthropod species in Ukraine.

CONCLUSIONS

Thus, the study informs about the first identification of *A. platynotus* Nalepa on the *C. mas* bushes in the botanical gardens of the Northern part of a Forest-Steppe zone of Ukraine. The mites were identified on six varieties of host plants with different infestation densities. At the time of inspection, the highest point (3-4) of cornel plant infestation with phytophagous was registered on "Elehantnyi" and "Kubanskyi" varieties. The number of adults per leaf was 36.3-42.2, and larvae – 12.2-13.7, respectively. The medium mite infestation was observed in the variety Bylda (2-3). On this variety, 31.8 adults per leaf and 1.8 larvae per leaf were recorded. The variety "Svitliachok" showed a damage level of 1-2 points and an adult number of 23.3 per leaf. The lowest point of damage by mites (0-1) was identified on "Mosvir-1" and "Novyi'' varieties. A further wide implementation of resistant varieties of dogwood will contribute to reducing the number of pests, in particular *A. platynotus*.

The low number of *A. platynotus* does not have a substantial influence on the growth and development of *C. mas* leaves. It was determined that the average area of one leaf of *Cornus mas* "Macrocarpa" decreased from 56.1 dm^2 with a low degree of mite infestation (1 point) to 54.9 dm^2 in the variant with severe leaf damage (4 points). The diagnostic signs of cornel leaves damaged by the mite are slight deformation of the leaf blade on both sides of the leaf veins at the base of the lateral leaf veins. Yellowing of the leaves is not observed. In the course of the study, the method of monitoring cornel plants when using adhesive tapes for selecting the specimen of this population has been improved. Knowledge of the number, location of the pest, and the damaged varieties is important for species monitoring and for future measures on pest control. Monitoring will help to understand the pattern of pest spread and contribute to the understanding of how the spread of this pest could have occurred on research areas.

Further research will be directed at researching the risk of the productivity reduction of the *C. mas* bushes infested by *A. platynotus,* determining the economic limits of its harmfulness and developing ecologically safe measures of establishing the phytophagous number.

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CONFLICT OF INTEREST

None.

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Нова знахідка *Anthocoptes platynotus* Nalepa (Acari: Eriophyoidea) та його чисельність у насадженнях *Cornus mas* L. в північній частині Лісостепової зони України

Анотація. Надродина Eriophyoidea є великою і різноманітною групою кліщів, які паразитують на багаторічних рослинах, що мають важливе економічне значення у сільському та лісовому господарстві. Їх поширення територією України може спричинити значні втрати врожаю, що визначає актуальність моніторингу насаджень на предмет наявності цього виду паразитів. Метою цього дослідження було обстеження насаджень кизилу в ботанічних садах м. Київ і м. Житомир (Україна) на предмет заселення та пошкодження кліщами надродини Eriophyoidea. Під час проведення досліджень використовували польові та лабораторні методи згідно із загальноприйнятими в акарології та захисті рослин методиками. В результаті досліджень вперше на рослинах *Cornus mas* L. виявлений чотириногий кліщ *Anthocoptes platynotus* Nalepa, 1898. Це найбільш північніша зона поширення виду в Україні. Отримано нові дані про шкідливість цього виду. Встановлено, що при живленні *A. platynotus* спостерігається незначна деформація листової пластини по обидва боки жилок, знебарвлення листків відсутнє. Визначили рівень заселеності *A. platynotus* на шести сортах рослин subg. Cornus. Встановлено, що вона була різною. Кліщ-фітофаг найбільше пошкоджував сорти: «Елегантний» і «Кубанський». Найменше заселяв сорти «Мосвір-1» і «Новий». Середній ступінь пошкодження мали сорти «Билда» і «Світлячок». *A. platynotus* мешкає з нижнього боку листка і не утворює гали чи повсть. Пік чисельності фітофага в регіоні досліджень припадає на кінець липня. Відмічено, що за низької чисельності *A. platynotus* не впливає суттєво на ріст і розвиток листків кормової рослини. Практична цінність роботи полягає в тому, що інформація присутності, чисельності та поширення *A. platynotus* допоможе у моніторингу кліща і прийнятті майбутніх управлінських рішень

Ключові слова: чотириногі кліщі; ідентифікація; сорти; поширення; шкідливість; популяція

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Agricultural landscape zoning of the Forest-Steppe zone of Ukraine to develop organic gardening

Abstract. The relevance of this study lies in the applied use of general scientific methods of landscape ecology in organic horticulture of the Forest-Steppe of Ukraine. The purpose of the study was to develop a system of targeted agricultural landscape assessment of the territory to determine the prospects for the development of organic horticulture on the example of the right-bank part of the Western Forest-Steppe. To fulfil this purpose, the methodology of targeted agricultural landscape zoning of agricultural land was used. For this, maps and diagrams of the distribution of the main structural components and factors of the agrosphere, namely, landscapes and morphological structures of the relief, soil and vegetation cover, water chemistry, rocks, functional use of land and traditional areas of agricultural production, were used. The cartographic method and expert assessments of land suitability for organic horticulture were based on the study of 8 natural and anthropogenic factors that form the corresponding taxonomic classification of agricultural landscapes of the Forest-Steppe from 30 taxa. The spatial differentiation of the factors

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is determined by the relevant quantitative and qualitative parameters of orchard lands. The expert assessment of agricultural landscapes for organic horticulture is based on the percentage level of alteration of the natural structure of the land. A full-scale model of the target map of agricultural landscapes was developed to assess the prospects for the development of organic horticulture on the example of the central part of the Right Bank of the Western Forest-Steppe. The study area of 5,400 square kilometres was located at the intersection of three administrative regions, namely Zhytomyr, Kyiv, and Vinnytsia. The study identified 21 agricultural landscapes, the territories of which are homogeneous in 8 parameters. Their comprehensive regional perspectives for organic horticulture are rated from 11 to 21. It was proposed to define 5 categories of agricultural landscapes according to their suitability for organic horticulture: the highest (21 points), high (19-20 points), medium (17-18 points), low (15-16 points) levels of suitability and unsuitable (11-12 points). Half of the study area is covered by agricultural landscapes of high suitability for organic horticulture, 15% each of medium and unsuitable, and 10% each of high and low suitability. The targeted classification of land for organic horticulture on an agricultural landscape basis is the scientific and methodological basis for the widespread development of a new, environmentally sound type of agricultural activity in Ukraine

Keywords: agrophytocenosis; organic fruits; land categories; target zoning; full-scale model of the target map of agricultural landscapes

INTRODUCTION

Organic agriculture is a holistic production management system that contributes to the development and strengthening of the viability of the agroecosystem, namely the maintenance of its biodiversity, biological cycles, and soil biological activity (Clark, 2020; Çakmakçı *et al.*, 2023). It is aimed at using natural resources (i.e., mineral and plant-based products) and avoiding synthetic fertilisers and pesticides.

Organic products have several advantages: they are grown without synthetic chemicals, do not contain genetically modified organisms, and are processed without preservatives and artificial colours, etc. (Paoli *et al.*, 2019). Therewith, the level of price premiums for it is much higher compared to conventional products (Pawlewicz, 2020). Global sales of organic food and drink continue to grow year on year. Furthermore, its growth in 2020 was also driven by the pandemic, which increased consumer interest in these products (Schlatter *et al.*, 2022).

Ukraine is a global supplier of agricultural products and plays a vital role in ensuring a sustainable food system and food security in the world, and organic production is still one of the priorities for the further development of its agricultural sector (Ostapenko *et al.*, 2020; Galashevskyi *et al.*, 2021). In 2021, the total volume of Ukrainian organic exports to more than 30 countries amounted to about 260.0 thousand tonnes of products, of which 82% were exported to the EU (Sahota, 2022).

Therewith, organic fruit and berry growing is becoming increasingly popular (Galashevskyi *et al.*, 2021). In 2020, the area of such plantations was about 3.9 thousand hectares (or 1.8% of all fruit and berry plantations). The leading place among other fruit crops in terms of this indicator (1,314.0 ha, or 33.3%) in Ukraine is occupied by apple trees, one of the oldest cultivated fruit plants in the temperate zone. The widespread distribution of this crop is explained by its high adaptability to different soil and climatic conditions, as well as the rich biochemical composition of the fruit, which, with the appropriate selection of varieties, can be consumed fresh almost all year round (Bublyk *et al.*, 2018). Other crops include walnuts – 1,212.8 ha (30.7%), raspberries – 585.0 ha (14.8%), blueberries – 227.3 ha (5.8%), hazelnuts – 86.9 ha (2.2%), currants – 80.8 ha (2.0%) (FiBL, 2022). The scientific and methodological basis for the further development of organic horticulture in Ukraine and new prospects in the European organic market is the targeted classification of land on an agricultural landscape basis to create environmentally sustainable agricultural landscapes.

Designing agricultural landscapes involves defining a set of desired ecosystem goals, assessing the current landscape structure considering these goals, and implementing targeted changes to achieve them (Aulia *et al*., 2020). Soil is a dynamic component of the landscape that is affected by human activity. It underlies gardening, providing space for plant growth as well as important nutrients and water (Teuber, 2021). Organic fruit cultivation usually depends on well-balanced soil with sufficient micronutrients. There is evidence that farming systems affect the level of the latter in the products grown. Researchers note that organic crops, compared to conventional crops, on average, have lower concentrations of pesticides and cadmium and higher antioxidant capacity and concentrations of a number of individual phytochemicals with antioxidant activity (e.g., phenols, minerals, other plant protection compounds) (Montgomery & Biklé, 2021).

According to experts, a fundamental component of programme research on organic horticulture areas should be the balance of soil nutrients (Pichura *et al*., 2022). This issue is one of the most important, as Ukraine's soils lack both the main plant nutrients and micronutrients. Regional biogeochemical studies over the past decade have shown differences in the balance of micronutrients in crops and outlined health risks for its consumers (Yehorova, 2018). For instance, in the Forest-Steppe of Ukraine, the authors describe agricultural landscapes with a lack of molybdenum, a complex molybdenum deficiency and an excess of zinc, as well as a predominant balance of Co, Mo, Zn, Mn, Cu, Sr (Yehorova, 2022). This substantially reduces the quality of plant materials and leads to the spread of a number of endemic diseases among the population of Ukraine, which is manifested by the increased incidence of micro-nutrient deficiencies among children (Liu-Helmersson *et al*., 2019).

Improving the soil-plant biogeochemical system by introducing certain micronutrients in certain agricultural landscapes will contribute to a substantial increase in the quality of the final product and, accordingly, a positive impact on the health of its consumers. An important aspect of the research is to increase the number of land zoning parameters by assessing the balance of key nutrients and microelements and considering radiation and industrial pollution.

Furthermore, unlike the scientific support for the cultivation of organic annual crops in fruit growing, these issues have been considered to a limited extent. Therefore, it is necessary to develop other methodological and practical approaches to agricultural landscape zoning for the further development of organic horticulture in Ukraine. The purpose of this study was to develop a system of targeted agricultural landscape assessment of the territory to determine the prospects for the development of organic horticulture on the example of the right-bank part of the Western Forest-Steppe.

MATERIALS AND METHODS

The developed system of targeted agricultural landscape assessment of territories is based on a comprehensive mapping method of agricultural landscapes for their suitability for organic gardening. For agricultural landscape assessment of the territories, maps and schemes of distribution of the main structural components and factors of agrosphere functioning, namely, landscapes and morphological structures of relief, soil and vegetation cover, water chemistry, rocks, functional use of land and traditional areas of agricultural production, were used. All these characteristics are highlighted in the materials of the Ministry of Ecology and Natural Resources of Ukraine, which are publicly available for the territory of Ukraine (National report..., 2014; 2017; 2018; 2019). It is the information support of mapping that determines the content of the technical stages of creating a graphical model of any territorial complexes chosen by the authors of this study – ecosystems, landscapes (geographical or geochemical), biogeocenoses, agricultural landscapes, etc.

The general methodology of targeted agricultural landscape assessment of territories is determined by the following technical stages:

1. Taxonomic classification of natural and anthropogenic factors and their targeted expert ranking (in points) according to the suitability of land for organic horticulture. The taxonomic classification includes qualitative and quantitative characteristics of 8 taxonomic categories and 30 taxa of natural and anthropogenic

factors of agricultural landscape functioning within the Forest-Steppe of Ukraine. The classification categories are series, type, family, class, subclass, genus, species, and subspecies of agricultural landscapes. The content of the categories is determined by the main structural and agro-ecological factors of agricultural landscape formation. The content of taxa within the category reflects the spatial differentiation of factors, considering those quantitative (quantitative and qualitative) parameters that are important for the development of organic horticulture or product quality. The quantitative parameters were determined as follows: level of disturbance of the natural structure of land (AD, %), mineralisation (M, dm^3/l) and major ions of surface water, prevalence of organic and transitional crop production (OP, %), acid-base soil buffering index (pH), nutrient trace elements with deficiency (ND) and excess (E) in the soil-crop system, surface slope angles (SS, degree), depths of groundwater in soil-forming rocks (H, m), nutrient elements of high concentrations in bedrock (MS).

2. Mapping the features and distribution of agricultural landscapes, comprehensive assessment (based on the sum of points) and categorisation of the suitability of the selected agricultural landscapes for organic gardening.

The mapping methodology developed by the authors was based on a targeted taxonomic classification of agricultural landscapes and involved three technological stages (Yehorova, 2018). The first stage is mapping (map chart) of agricultural landscape features based on the target taxonomic classification and existing analytical and information support of the experimental area. The second stage is the delineation of boundaries and indexation of agricultural landscapes as territories with homogeneous taxa of factors of their formation. The third stage is drafting a target map of agricultural landscapes by calculating the total score of the target assessment and categorising the territory accordingly.

Soil samples were collected from the genetic layers of 100 soil profiles and their physical and chemical properties were analysed. The study also analysed the terrain and climate data. After calculating the land suitability classes for the two crops, they were mapped using computer modelling and conventional approaches. The maps provided by the two approaches revealed noticeable differences. For instance, in the case of rainfed wheat, the results showed higher accuracy based on land suitability maps compared to maps produced by the conventional approach. Furthermore, the results showed that the areas with classes N2 (≈ 18%↑) and S3 (≈ 28%↑) were higher, and the area with class N1 (≈ 24%↓) was less predictable in the conventional approach compared to the computer modelling approach. The study was carried out in accordance with the standards of Convention on Biological Diversity (1992).

The main limitations of the study area were the amount of precipitation at the flowering stage, strong slopes, shallow soil depth, high pH, and high gravel content. Therefore, land improvement operations are proposed to increase production and create a sustainable agricultural system. The map of features and distribution of agricultural landscapes is a graphical model of generalised factors of agricultural landscape formation and their intended use.

RESULTS AND DISCUSSION

The targeted agricultural landscape assessment of the Forest-Steppe zone for fruit growing involved the selection of informative anthropogenic and natural factors of organic horticulture and their taxonomic classification; targeted expert assessment of taxa based on common practices; graphical modelling of areas of different levels of suitability for organic horticulture and selection of fruit crops for cultivation in relevant agro-soil and climatic conditions. This choice was limited by the information support on natural and anthropogenic factors of agricultural landscape formation in the area under study, its scale and the media of the created models (paper or electronic), as well as professional information on the existing level of organic gardening.

According to these parameters, the developed classification contains an expert assessment of taxa (in points) as natural and anthropogenic factors of organic horticulture functioning (Table 1).

Table 1. Targeted taxonomic classification of agricultural landscapes for regional assessment of organic horticulture conditions in the Forest-Steppe of Ukraine

Taxonomic categories and factors of agricultural landscape formation	Level of expert assessment (first digit, points), agricultural landscape taxa and their quantitative and qualitative parameters
Row: functional zoning of land according to the level of natural structure disturbance	2. Anthropogenic-natural (arable land, orchards and vineyards in combination with the settlement areas of villages and towns; AD = 25 ÷ 40). 1. Anthropogenic (industrial zones with protective strips of more than 15 km, transport motorways and railways with adjacent territories at a distance of 0.3 km; AD = 40 ÷ 60). 0. Natural (hayfields and grassland pastures, common water use of rivers and ponds, forests of wide use; AD ≤ 15).
Type: river basins according to hydrochemical composition of water	4. Basins of the Prut and Western Buh rivers on the Left Bank and Pripyat on the Right Bank (M = 0.2 ÷ 0.6, HCO_3 – Ca). 3. The Dnipro River basins on the Right Bank (M = 0.3 ÷ 0.9, HCO_3 – Ca, Mg). 2. The Siverskyi Donets River basin (M = 0.6 ÷ 0.7, HCO_3, SO_4 – Ca, Mg). 1. The Southern Buh and Dniester River basins on the Left Bank (M = 0.6 ÷ 3.9, HCO_3, SO_4, Cl – Ca, Mg, Na).
Family: natural and anthropogenic vegetation cover according to the spread of organic farming	5. Agrophytocenoses with a significant distribution of organic products (OP = 1.5 ÷ 7.2). 4. Agrophytocenoses with a low distribution of organic products (OP = 0.5 ÷ 1.0). 3. Agrophytocenoses with very low distribution of organic products (OP = 0.5 ÷ 0.2). 2. Agrocenoses and ornamental vegetation of rural and industrial areas of undetermined organic production potential (OP ≤ 0.2). 1. Meadow vegetation of river valleys, oak-hornbeam, and oak forests with no and uncertain organic production potential (OP ≤ 0.1).
Class: soil types according to acid-base index	5. Typical deep low-humus and shallow low-humus chernozem (pH= 6.4–7.9). 4. Podzolised chernozem (pH 5.2 – 6.4). 3. Alluvial meadow and soddy gleyed soils (pH = 6 – 6.9). 2. Grey forest soils (pH = 4.1 – 5.6). 1. Technogenic soils of rural and industrial areas (pH = 4.1 – 5.6).
Subclass: balance of nutrients in the soil-crop system	3. Balance (Co, Mo, Zn, Mn, Cu, Sr). 2. Shortage (ND – Mo) and balance (Co, Zn, Mn, Cu, Sr). 1. Shortage (ND – Mo), excess (E – Zn) and balance (Co, Mn, Cu, Sr).
Genus: terrain morphosculptures and surface angles	3. Levelled and slightly sloping watersheds of the forest plain (SS = 2 ÷ 10). 2. Disaggregated slopes of the forest plain (SS = 10 ÷ 15). 1. Levelled surfaces of floodplains and terraces of alluvial plains (SS = 0 ÷ 3).
Species: aquifers by groundwater depth	3. Sandy loam and sabulous deposits of water-glacial horizons (H = 5 ÷ 10). 2. Loess loams of aeolian-deluvial and eluvial horizons (H = 1 ÷ 15). 1. Sandy and sabulous loamy deposits of alluvial horizons (H = 1 ÷ 5).
Subspecies: Underlying rocks and their enrichment for nutrients	4. Volyn-Podilska mineralogenic province (Zn, P, Cu, Pb). 3. Prypiat-Donetsk mineralogenic province (Zn, P, Pb). 2. Carpathian mineralogical province (S). 1. Ukrainian shield (Zr, Au).

Source: compiled by the authors of this study

A full-scale model of the target map of agricultural landscapes for assessing the prospects for the development of organic horticulture was made to assess the conditions of organic horticulture on the Right Bank of the Western Forest-Steppe. Here is a medium-scale model of the northeastern part of this horticulture area. The 5.4 thousand km² of the model covers the connected part of three administrative regions of Ukraine – Kyiv, Zhytomyr, and Vinnytsia (Fig. 1).

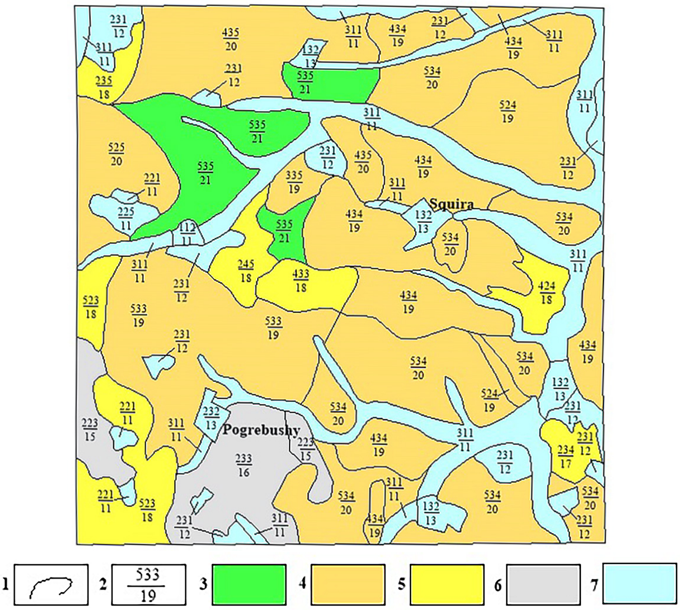

Figure 1. Target map of agricultural landscapes according to suitability for organic gardening on the Right Bank of the Western Forest-Steppe

Note: *1 – agricultural landscape boundary; 2 – agricultural landscape index in the numerator (according to Table 1: 4 – class score, 3 – genus, 5 – family) and the aggregate expert assessment score for the Forest-Steppe of Ukraine in the denominator. Categories of agricultural landscapes according to their suitability for organic horticulture: 2 – highest level (21 points), 3 – high level (19-20 points), 4 – medium level (17-18 points), 5 – low level (15-16 points), 6 – unsuitable according to regional assessments (11–12 points)*

Source: compiled by the authors of this study

Within the presented layout of the target map, 21 agricultural landscapes were identified, each of which has a homogeneous structure and prospects for the development of organic horticulture within the 8 taxonomic categories described by the authors of this study, which are spatially differentiated into 21 taxa (with a total of 30 in the Forest-Steppe of Ukraine). The type, subclass, and subspecies of agricultural landscapes are homogeneous across the experimental area. They define the common characteristics of a given territory. Namely, the territory belongs to the Dnipro river basin in the middle reaches with fresh hydrocarbonate calcium-magnesium waters (M = 0.3 - 0.9 dm^3/l); molybdenum ecological and geochemical province with a lack of Mo and a balance of Zn, Mn, Cu, Sr in the soil-plant system; distribution of underlying crystalline rocks of the Ukrainian Shield with no concentrations of the main nutrients.

The series, family, class, genus, and species of agricultural landscapes in this area were spatially differentiated and reflect the differences in the parameters of organic horticulture development. Namely: functional zoning of land (3 taxa), natural and anthropogenic vegetation cover (4 taxa), soil cover (5 taxa), terrain morphosculptures (3 taxa), aquifers (2 taxa).

According to the expert assessment of each agricultural landscape, the territory was divided into 4 categories of suitability for the development of organic horticulture and the development of transition measures. These categories of agricultural landscapes were characterised as follows. The highest level of suitability (21 points) was characterised by the agricultural landscape of levelled and slightly sloping watersheds with typical chernozems on loess loams with a groundwater table of up to 15 m within Zhytomyr Oblast, which has a relatively high percentage of arable land under organic farming and land in transition (3.5%). Agricultural landscape index 535. Clearly, these agricultural landscapes are zonally distributed in the Forest-Steppe, but they occupy about 10% of the area of the presented model. According to the acid-base index of the soil, these areas are considered the most suitable for growing apple, cherry, peach, and grape.

A high level of suitability (19-20 points) is characterised by agricultural landscapes of levelled and slightly sloping watersheds, as well as sloping slopes with typical black soil and podzolised loess loam within Zhytomyr and Kyiv Oblasts, which are characterised by relatively high percentages of arable land under organic farming and land in transition (0.6-3.5%). Agricultural landscape indices are 534, 524, 525, 434, 435; their territories cover about 50% of the map area. In terms of soil acidity, these areas are considered the most suitable for growing apple, cherry, peach, grape, pear, apricot, and red currant.

Medium and low suitability (15-18 points) is characterised by agricultural landscapes of levelled and slightly sloping watersheds, as well as sloping slopes with predominantly grey forest soils, as well as black soil podzolised on forest loam within the three oblasts with different percentages of arable land under organic farming and land in transition (0.2-3.5%). Agricultural landscape indices are 233, 234, 235, 223, 224, 225, 433, 424, 523; their territories cover about 25% of the map area. According to the acid-base index of the soil, these areas can be considered suitable for growing pears, apricots, red currants, gooseberries, bilberries, and blueberries.

According to the regional analysis, agricultural landscapes unsuitable for organic horticulture (11-12 points) are those of anthropogenic and natural series within the levelled and sloping watersheds of the forest plain, floodplains and river terraces of the alluvial plain with anthropogenic, grey forest, and alluvial meadow soils. They are common in all administrative regions of Ukraine. Agricultural landscape indices are 112, 132, 221, 231, 311, 335; their territories cover about 15% of the map area. Due to a complex of natural and anthropogenic factors, organic gardening is not feasible here.

Currently, there are five main methods of agricultural landscape assessment: geographic information systems (GIS), biodiversity analysis, soil assessment, analysis of socio-economic factors, modelling and simulation, and multi-criteria analysis. To obtain reliable results, several of these methods are often used simultaneously, or certain elements of each method are used, as was done by the authors. The authors of this study would like to emphasise that the agricultural landscape zoning of the Forest-Steppe zone of Ukraine for the development of organic horticulture was carried out for the first time.

An analogous work – "Agroecological substantiation of organic farming in the Kherson region" – was carried out by D. Breus (2018). He developed spatio-temporal models of soil fertility, which became the basis for agro-ecological substantiation of the prerequisites and prospects for organic farming in the Kherson region, improved and adapted the model of the structure of the geoinformation and analytical system of organic farming to support agricultural producers in the transition period to support their development. It was found that the lack of regular, uniform, and sufficient supply of mineral fertilisers, wind and water erosion, including irrigation, and soil deflation, as well as prolonged irrigation, led to a deterioration in the agro-ecological condition of soils. The humus content in the 0-20 cm layer of soil decreased by 16.0% on average, nitrifying nitrogen by 26.92%, mobile phosphorus by 34.84%, and exchangeable potassium by 25.52%. The author proposes a model of the structure of the geoinformation and analytical system of organic farming. The main difference between this study and the authors' study is that it was carried out under conditions of insufficient moisture and focused on field crops.

R. Taghizadeh-Mehrjardi *et al.* (2020) in Iran performed an analogous agricultural landscape assessment of land suitability for wheat and barley. However, for this development, the authors used computer modelling, which is planned for further research.

Some research papers have used certain elements of agricultural landscape assessment of territories. For instance, G.V. Titenko & V.V. Medvedev (2018) investigated the current state of the soil cover of Ukraine based on materials from the database of the Educational and Research Centre "O.N. Sokolovskyi Institute of Soil Science and Agrochemistry" – "Soil Properties of Ukraine". The materials of the last round of agrochemical certification of fields were also used, as well as generalised studies on the productive function of soils, degradation on arable land in Ukraine and the experience of 25 years of land reform in Ukraine. The study is particularly focused on the analysis of the impact of socio-economic factors on soil cover. Among other things, it was established that due to the incompleteness of land reform, almost complete irresponsibility of new land users who lease land plots, an inadequate land cadastre, ineffective legal protection of soil fertility, insufficient and practical imperfection of state control over soil fertility, the country is experiencing a chaotic type of land use with obvious negative (productive, environmental, social) consequences for future generations. Thus, soil cover and its favourable condition are an important prerequisite for the successful resolution of social issues in Ukraine.

Y.V. Rybalko & R.V. Babka (2018) considered the problem of integrated development of rural areas in terms of environmental sustainability of agricultural landscapes and anthropogenic pressure on them. The paper provides a detailed analysis of the land fund and calculates the coefficient of anthropogenic load, the level of ploughing and the coefficient of environmental stability of the territory of Chernihiv Oblast, which allow a comprehensive assessment of the rationality of the land fund structure. The ecological condition of the land was assessed, and the areas of land optimisation were identified according to the research results.

H. Davydiuk *et al*. (2022) conducted an ecological and chemical assessment of the state of agricultural landscapes in Ivano-Frankivsk Oblast, specifically in rural areas, based on monitoring studies. The condition of soils, natural waters, and crop products was investigated using the route monitoring method. It was found that some of the soil samples under study had very low acidity and a high content of nutrients, especially phosphorus and potassium. In some cases, the quality of natural water did not meet regulatory requirements. This is conditioned upon both natural factors, such as the hydrological regime, and anthropogenic factors, such as violation of sanitary rules for building up the territory, application of high doses of mineral and organic fertilisers, non-compliance with manure storage technologies, keeping of livestock and poultry, and disposal of livestock and household waste. Some samples of crop products did not meet sanitary and hygienic standards for lead, cadmium, nickel, copper, and iron. Studies show a considerable impact of the anthropogenic factor on changes in the quality of soil, natural waters, and crop products. It was found that the ecological and agrochemical assessment of the state of agricultural landscapes in the Western region, including the rural area, and the identification of the specific features of migration and accumulation of nutrients and ecotoxicants is a promising area of research for the development of measures to prevent pollution of soil, groundwater, open water bodies and crop products for the sustainable functioning of agroecosystems.

The FAO review (2020) emphasises the need to consider pollinator availability in agricultural landscape assessments and thus increase the sustainability and productivity of forestry and agriculture, which is crucial for the horticulture industry. The prevalence of forests and other natural habitats in the landscape plays a role in determining the species composition of pollinators. Agricultural landscapes adjacent to fragmented forests and natural areas benefit from the services of pollinators, and therefore crops pollinated by animals achieve greater fruit set. Hydrology and light availability can affect the composition and diversity of pollinator species and pollinator plant networks. Indigenous and local knowledge can contribute to the conservation of pollinators through conventional management practices. The review discusses the impacts of climate change and recommends measures to maintain pollinator diversity and abundance in forests.

Thus, agricultural landscape assessment is a valuable tool for investigating and analysing territories for agricultural development. The use of various methods and an integrated approach provides reliable results and allows making sound recommendations for optimising land use and preserving the environment.

CONCLUSIONS

The system of targeted agricultural landscape zoning of the territory on the example of the Forest-Steppe fruit-growing zone consists of a taxonomic classification of natural and anthropogenic factors and their quantitative and qualitative differentiation and assessment according to the needs of organic horticulture.

Within the presented layout of the target map, 21 agricultural landscapes were identified and classified based on 8 taxonomic categories. These categories are differentiated by spatial characteristics and prospects for the development of organic horticulture. Agricultural landscapes are homogeneous in the area under study and determine the common characteristics of this zone, such as the Dnipro River basin, ecological and geochemical province, distribution of underlying crystalline rocks, etc.

Each agricultural landscape on the model has been expertly assessed and divided into 4 categories of suitability for the development of organic horticulture. The highest level of suitability (21 points) is characterised by agricultural landscapes with levelled and slightly sloping watersheds with typical black soils on loess loams, which occupy about 10% of the model area. A high level of suitability (19-20 points) is characterised by agricultural landscapes of levelled and slightly sloping watersheds with typical black soils and podzolised loess loams in Zhytomyr and Kyiv Oblasts (about 50% of the area). The average level of suitability (15-18 points) is characterised by agricultural landscapes of levelled and slightly sloping watersheds with grey forest soils and podzolised black soils on forest loams (about 25% of the area). Agricultural landscapes that are unsuitable for organic horticulture (11-12 points) are in the levelled and sloping watersheds of the forest plain, floodplains, and river terraces of the alluvial plain with anthropogenic, grey forest and alluvial meadow soils (about 15% of the area).

Such suitability assessments are most appropriate during the transition period to organic horticulture, when the principles are only being established and the products are not yet considered purely organic; during this time, organic production methods are applied gradually, usually for three years, when certain organic technologies are carefully analysed and applied. The targeted classification of land for organic horticulture on an agricultural landscape basis is the scientific and methodological framework for its further development in Ukraine and new prospects in the European organic market. The methodology and results of the presented agricultural landscape zoning guide Ukrainian organic fruit and berry producers to develop areas with the highest suitability for the production of high-quality and competitive products on most of the land in Ukraine.

Further research in this area should be carried out for all fruit-growing zones of Ukraine based on the development of spatial and temporal soil fertility models, considering the ecological stability of agricultural landscapes and anthropogenic load on them, as well as crop-specific factors.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Агроландшафтне районування зони Лісостепу України для розвитку органічного садівництва

Анотація. Актуальність досліджень полягає у практичному використанні загальнонаукових методів ландшафтної екології в органічному садівництві Лісостепу України. Метою дослідження є розроблення системи цільового агроландшафтного оцінювання території для визначення перспектив розвитку органічного садівництва на прикладі правобережної частини Західного Лісостепу. Для досягнення цієї мети застосовувалась методологія цільового агроландшафтного районування земель сільськогосподарського призначення.

Для цього використано карти і схеми поширення основних структурних компонентів і факторів функціонування агросфери, а саме, ландшафтів і морфоструктур рельєфу, ґрунтово-рослинного покриву, хімізму вод, гірських порід, функціонального використання земель та традиційних напрямів сільськогосподарського виробництва. Картографічний метод та експертні оцінки придатності земель для органічного садівництва засновані на вивченні 8 природно-антропогенних чинників, що формують відповідну таксономічну класифікацію агроландшафтів Лісостепу з 30 таксонів. Просторову диференційованість чинників визначено за актуальними кількісно-якісними параметрами земель садів. Експертну оцінку агроландшафтів для органічного садівництва побудовано за відсотковим рівнем зрушеності природної структури земель. Розроблено натурний макет цільової карти агроландшафтів для оцінки перспектив розвитку органічного садівництва на прикладі центральної частини Правобережжя Західного Лісостепу. Досліджена площа 5 400 кв. км міститься на перетині трьох адміністративних областей, а саме Житомирської, Київської і Вінницької. Виділено 21 агроландшафт, території яких є однорідними за 8-ма параметрами. Їх комплексні регіональні перспективи для органічного садівництво оцінено у балах від 11 до 21. Запропоновано визначати 5 категорій земель агроландшафтів за їх придатністю до органічного садівництва: найвищого (21 бал), високого (19-20 балів), середнього (17-18 балів), низького (15-16 балів) рівнів придатності та непридатні (11-12 балів). Половину дослідженої території займають агроландшафти високого рівня придатності для органічного садівництва, по 15% – середнього рівня та непридатні, по 10% – найвищого і низького рівня. Цільова класифікація земель для органічного садівництва на агроландшафтній основі є науково-методичним підґрунтям для широкого розвитку в Україні нового, екологічно доцільного виду сільськогосподарської діяльності

Ключові слова: агрофітоценоз; органічні плоди; категорії земель цільове районування; натурний макет цільової карти агроландшафтів

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Humus state and nutrient regime of typical chernozem depending on fertilisation in short crop rotations

Abstract. The fertiliser system is the most effective factor in the intensification of crop cultivation technologies. The basis for scientifically sound fertiliser application systems, along with obtaining the planned level of yield of the appropriate quality, is the study of the organic matter content and soil nutrient regime during crop rotation. The purpose of this study was to determine the mineral nitrogen, mobile phosphorus, exchangeable potassium, and humus content in typical chernozem

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under different fertilisation systems in short-term crop rotations. To solve the problem of soil fertility, an important approach is to conduct field and laboratory research to determine changes in the humus state according to Tyurin, nitrogen, phosphorus, and potassium regimes of the soil according to Machigin, and dispersion methods to determine the reliability of experimental data. As a result of the research, it was found that the highest humus content in the soil was recorded under the organic-mineral fertilisation system at the end of the second rotation in the grain crop rotation by 0.13% compared to the fruit crop rotation. The use of a mineral fertiliser system in a row crop rotation reduced the humus content by 0.12%. An increase in the humus content of typical chernozem was recorded under fruit crop rotation and grain-row crop rotation. The organic-mineral fertilisation system tended to increase the mineral nitrogen content of the soil compared to the other systems. The mineral nitrogen content of the mineral fertilisation system decreased by 5.5 mg/kg of soil compared to the unfertilised variant. Under the organic-mineral and mineral fertilisation system, the content of mobile phosphate increased in all crop rotations. The content of mobile phosphorus in the tilled crop rotation was substantially reduced compared to the fruit crop rotation and grain-row crop rotation. The highest content of exchangeable potassium in the soil was recorded under the mineral fertilisation system. The materials of the publications are of practical importance in the analysis of the main elements of mineral nutrition of typical chernozem in short crop rotations

Keywords: mineral nitrogen; exchangeable potassium; sunflower; nutrients, agrocenosis

INTRODUCTION

As of 2023, under lease relations, soils are a source and means of profit. Agricultural landowners ignore the fact that without efforts to restore land fertility, significant resources will need to be spent today and, in the future, to achieve the original level of fertility. Analysing the changes in the quality of Ukraine's soils in recent years, there is a dangerous trend towards a decline in their fertility and deterioration of the environmental situation, which will lead to a crisis in agriculture. According to the National Research Centre "Institute of Agriculture of the National Academy of Agrarian Sciences of Ukraine", up to 20 million tonnes of humus are lost in Ukraine every year, which is 600-700 kg per 1 hectare of arable land. Other measures to restore soil fertility are needed to change the situation. It is necessary to optimise the organic matter regime and prevent the loss of humus and humus status of soils (Egorov *et al*., 2021).

The intensification of agricultural production technologies since 2010 has substantially exacerbated the problem of soil degradation (Grzebisz *et al*., 2022). According to I.M. Uzoh *et al*. (2019), optimisation of the fertilisation system and crop rotation structure are the simplest and most effective agronomic measures to achieve sustainable production and restore natural soil fertility. In Ukraine, there is currently a shortage of manure in agriculture and a significant decrease in the share of perennial legumes in crop rotations (Ivanina & Korotenko, 2023). According to M.A. Bolinder *et al*. (2020), R. Allende-Montalban *et al*. (2022), the countries of the European Union and the United States are developing the agricultural sector on the widespread use of biological nitrogen in crop rotation fertilisation, reducing carbon emissions in the soil. These measures significantly reduce the cost of nitrogen fertilisers, contribute to soil moisture conservation, improve soil structure, and enhance humus formation (Hossain *et al*., 2022). In the context of global warming, this practice helps to stabilise plant mineral nutrition and moisture supply, enhances their resistance to adverse weather conditions, and makes modern technologies more sustainable.

According to N.E. Borys & L.M. Krasyuk (2020), provided that chernozems have high agrophysical properties, it should be assumed that the content of total humus reaches its optimum. The importance of organic matter as a source of nitrogen for plants should be considered when determining the optimal humus content (Ting-ting *et al*., 2022). O.A. Tsyuk *et al*. (2022) noted that the humus content in the soil will be optimal when nitrogen nutrition of crops, along with agrophysical properties, does not limit the productivity of crops in crop rotations. For typical chernozems, the humus content is 4.0-6.5% (Hospodarenko *et al*., 2019).

The use of fertiliser systems for sunflower in short crop rotations is particularly relevant to preserve soil fertility. The issue of improving soil nutrition of plants by using different fertiliser systems, different agronomic practices and changing agrochemical parameters in short crop rotations is relevant. The purpose of this study was to determine changes in the humus state and specific features of the formation of nitrogen, phosphorus, and potassium regime of typical chernozem under different fertilisation systems in short crop rotations.

MATERIALS AND METHODS

The study was conducted in 2012-2021 in a stationary experiment of the Bila Tserkva National Agrarian University on typical black soil. The soil of the experimental plot is a typical deep low-humus black soil with the following physicochemical and agrochemical characteristics of the 0-30 cm layer: hydrolysed nitrogen – 110 mg/kg of soil; mobile phosphorus and exchangeable potassium – 120-110 mg/kg of soil, respectively; humus content according to Tyurin – 3.7-3.9%; salt pH – 6.0-6.4; Ng according to Kappen – 1.09-1.26 mg-eq/100 g of soil; the sum of absorbed bases according to Kappen-Hilkowitz – 23.8-27.2 mg-eq/100 g of soil; soil density within 1.16-1.25 g/cm^3, and the total porosity is 52-55%. The repetition of the experiment was threefold. The repetition was placed on the area (territory) in a continuous, systematic manner, with fertiliser variants placed in four tiers sequentially. The area of the elementary plots: 171 m^2, the accounting area – 112m^2.

The study was conducted in the agrocenosis of sunflower, which was grown after winter wheat in four five-field short crop rotations: fruit crop rotation (sunflower saturation of 10%) – alfalfa – winter wheat – sugar beet, sunflower – buckwheat – barley + alfalfa; grain-row crop rotation (sunflower saturation of 20%) – soybeans – winter wheat – sunflower – spring barley – maize; specialised grain-row crop rotation (30% sunflower content) – buckwheat – winter wheat – maize, sunflower – barley – sunflower; row crop rotation (40% sunflower content) – peas – winter wheat – sunflower – maize – sunflower.

Content of fertiliser system gradations. Zero level – no fertiliser. Organic – application of 8 tonnes and 3.0 tonnes of non-marketable part of the crop, mass of green manure per hectare of crop rotation area. The organic fertiliser rate was determined according to the need for a positive humus balance. Organo-mineral – priority use of organic fertilizers to restore soil fertility, application of 8 tonnes of manure per 1 ha of crop rotation area and 3.5 tonnes of siderable crop mass, by-products, application of 110 kg ($N_{27}P_{38}K_{45}$) of mineral fertilizers. Mineral – application of 8 tonnes of manure and 222 kg ($N_{68}P_{72}K_{82}$) of mineral fertilizers per 1 ha of crop rotation area. Semi-rotted manure, ammonium nitrate, simple granular superphosphate, and potassium salt were applied.

In all variants, the remaining wheat straw was chopped after harvesting and incorporated into the soil with a disc harrow. After harvesting wheat, the soil was prepared for sowing white mustard on green manure. In late September and early October, post-harvest mustard crops were ploughed into the soil in all variants. Manure was applied at a rate of 40 t/ha.

Soil samples were collected in 0-25 cm layers at five points of each experimental plot. In a weighted average soil sample, the content of humus was determined according to Tyurin (DSTU 4289:2004..., 2004); nitrogen of mineral compounds (DSTU 4729:2007..., 2007); mobile phosphorus and potassium compounds – according to Machigin (DSTU 4114-2002..., 2002). The results of the study were statistically calculated using the method of analysis of variance and correlation. The study was conducted per the requirements of the International Convention on Biological Diversity (1992).

RESULTS

The results of the study showed that the humus content in chernozem, a typical sunflower agrocenosis in the 0-25 cm soil layer in short crop rotations, depended on the fertilisation system. Thus, in a grain-row specialised crop rotation with 30% sunflower saturation under the organic fertilisation system, the humus content increased by 0.10% in the tillage layer in a fruit crop rotation by 0.13% (Table 1). In the grain-row crop rotation, the humus content had a smaller increase compared to the fruit crop rotation.

Table 1. Changes in humus content in typical chernozem depending on crop rotation and fertilisation system, %, (2012-2021)

Crop rotation	Fertilizer system	Start of the first rotation	End of the second rotation	+/- to control
Fruit crop rotation	Without fertilisers (St)	3.83	3.58	-0.25
	Organic	3.87	3.99	+0.12
	Organic-mineral	3.89	4.06	+0.17
	Mineral	3.87	3.85	-0.02
Grain-row crop rotation	Without fertilisers (St)	3.91	3.77	-0.14
	Organic	4.02	4.18	+0.16
	Organic-mineral	3.96	4.19	+0.23
	Mineral	3.91	3.83	-0.08
Specialised grain-row crop rotation	Without fertilisers (St)	3.92	3.82	-0.10
	Organic	3.94	4.04	+0.10
	Organic-mineral	3.87	4.00	+0.13
	Mineral	3.81	3.72	-0.09
Row crop rotation	Without fertilisers (St)	3.80	3.70	-0.10
	Organic	3.86	3.96	+0.10
	Organic-mineral	3.85	3.93	+0.08
	Mineral	3.82	3.70	-0.12
LSD_{05}		0.14	0.22	

Source: compiled by the authors of this study

This is conditioned upon the fact that the synthesis of organic matter was somewhat slowed down by mineralisation, which was more intense under row crops as opposed to perennial grasses and cereals. In a grain-row crop rotation with 20% sunflower saturation, under the organic-mineral and organic fertilisation system, the humus content increased by 0.23% and 0.16% in the tilled soil layer at the beginning and end of the growing season, respectively, compared to the fruit crop rotation. The small increase in humus is explained by the fact that soybeans were sown in the crop rotation, followed by winter wheat, and as a result, the biological nitrogen that entered the soil as a result of nitrogen fixation was almost completely used by crops in the rotation and its replenishment in the soil was insignificant, which affected the humus content.

Under the organic-mineral fertilisation system in a row crop rotation, the amount of humus increased by 0.08% over two rotations. Thus, the organic-mineral fertilisation system stabilises and increases the humus content in crop rotations. The greatest increase in humus content was observed in fruit crop rotation and grain-row crop rotation. Under the mineral fertilisation system, the humus content decreased in all the crop rotations under study. In a rotational crop rotation with a mineral fertilisation system, the humus content decreased, and its losses reached 0.02%. In the grain-crop rotation, the humus losses under this fertilisation system were slightly higher than 0.08%. In the specialised grain-row crop rotation, the application of the fertilizer rate $N_{87}P_{75}K_{83}$ during the crop rotation period increased the mineralization of organic matter according to the norm of the organo-mineral fertilization system, 0.09% of humus was lost.

Application of a high rate of fertilisers $N_{68}P_{82}K_{84}$ for the row crop rotation decreased the content of humus and its losses reached 0.12%. The loss of humus in the lower layers of the soil in a row crop rotation is explained by the fact that cultivation and saturation with row crops create conditions for the mineralisation of organic matter throughout the root layer of the soil. This is also facilitated by hydrothermal conditions in autumn, winter, and spring, when microbiological processes continue to operate throughout the soil profile.

With the organic-mineral fertilisation system, the humus content in all crop rotations increased due to an increase in the amount of non-hydrolysed residue. The highest humus content was observed in fruit crop rotation and grain-row crop rotation, and less in specialised grain-row crop rotation. The soil nutritional regime was analysed according to the content of nutrients in the soil in the phase of full ripeness of sunflower. Nitrogen is essential, especially in plants, and in soil it is one of the main and key elements for the growth and development of crops. Dynamic mineral nitrogen that changes during the growing season due to the activity of biological processes and the use of nitrogen by plants during the growing season to form crop yields. The productivity of the crop and the quality of the product depends on the availability of mineral nitrogen.

It was noted that under the organic fertilisation system, the amount of mineral nitrogen did not significantly increase in the fruit crop rotation by 1.4 mg/kg of soil, and in the grain-row crop rotation by 1.6 mg/kg of soil compared to the organic-mineral system, but the specialised grain-row crop rotation and the row crop rotation tended to slightly reduce the content of mineral nitrogen in the soil compared to the organic-mineral system (Table 2).

Table 2. Mineral nitrogen content in typical chernozem depending on the fertilisation system in short crop rotations, mg/kg soil (2013-2016)

Fertilizer system	Crop rotation			
	fruit crop rotation	grain-row crop rotation	specialised grain-row crop rotation	row crop rotation
Without fertilisers	13.8	16.8	15.4	12.9
Organic	20.3	21.0	18.2	17.6
Organic-mineral	18.9	19.4	18.8	18.0
Mineral	19.0	18.3	18.1	16.8
LSD_{05}	1.7	2.0	1.6	1.1

Source: compiled by the authors of this study

In the mineral fertilisation system variant, the mineral nitrogen content decreased significantly in the grain-row crop rotation – by 2.7 mg/kg of soil compared to the organic system, due to the use of sunflower nitrogen, the development of nitrifying microorganisms and the course of sunflower mineralisation processes. The organo-mineral fertilisation system contributed to a substantial increase in the mineral nitrogen content of the specialised grain-row crop rotation and row crop rotation. The fertilisation system influenced the content of mobile phosphorus and exchangeable potassium. Under row crop rotation, the content of mobile phosphorus in the organic fertilisation system decreased by 7.4 mg/kg of soil compared to the organic-mineral system (Table 3).

Table 3. The content of mobile phosphorus in typical chernozem in sunflower agrocenosis depending on the fertilisation system in short crop rotations, mg/kg, soil

Fertilizer system	Crop rotation			
	fruit crop rotation	Grain-row crop rotation	specialised grain-row crop rotation	row crop rotation
Without fertilisers	16.9	13.0	13.9	16.4
Organic	21.7	21.2	21.0	18.8

Table 3, Continued

Fertilizer system	Crop rotation			
	fruit crop rotation	Grain-row crop rotation	specialised grain-row crop rotation	row crop rotation
Organic-mineral	28.9	29.6	27.6	26.2
Mineral	32.6	31.4	28.6	27.4
LSD_{05}	5.4	3.9	4.0	4.9

Source: compiled by the authors of this study

In fruit crop rotation and grain-row crop rotation, both with mineral and organo-mineral fertiliser backgrounds, the phosphorus content did not decrease due to less phosphorus use by plants. These variants tend to increase phosphate mobility across all crop rotations. In a row crop rotation, there is a substantial decrease in the content of mobile phosphorus in the cultivated soil layer compared to other crop rotations. This is conditioned upon the use of phosphorus by sunflower, which occupies 40% of the crop rotation area in row crop rotation, and, on the other hand, due to a decrease in the microbiological activity of black soil and its nitrification capacity, which results in less phosphate being transferred to the mobile state. The distribution of exchangeable potassium in the root layer of the soil is presented in Table 4.

Table 4. Availability of exchangeable potassium in the soil in sunflower agrocenosis depending on the fertilisation system in short crop rotations, mg/kg of soil (2013-2016)

Fertilizer system	Crop rotation			
	fruit crop rotation	grain-row crop rotation	specialised grain-row crop rotation	row crop rotation
Without fertilisers	109.0	111.4	107.0	108.0
Organic	117.0	114.0	111.0	108.0
Organic-mineral	129.0	131.0	125.0	120.0
Mineral	150.0	205.0	139.0	157.0
LSD_{05}	13.0	14.0	5.4	5.6

Source: developed by the author of this study

The organo-mineral fertilisation system considerably reduced the exchangeable potassium content compared to the mineral system, due to a decrease in soil potassium fixation and the release of non-exchangeable potassium into mobile exchangeable compounds. The organic fertilisation system did not achieve the optimum exchangeable potassium content for sunflower cultivation in typical black soil. Its level in the treated layer gradually decreased. When applying mineral fertilisers in the variants of the mineral and organo-mineral fertilisation system, a decrease in the proportion of easily soluble forms of potassium was found relative to mobile forms.

This is because the potassium in mineral fertilisers is in a highly soluble form and is quickly taken up by plants, resulting in increased crop yields and potassium removal. However, this dosage is insufficient to enhance the level of readily soluble potassium in the soil. The potassium contained in manure is part of organic matter, which is more difficult to transfer to the soil solution, and therefore plants in such conditions use other forms of potassium compounds in chernozem (Nikitina & Vasylenko, 2019). The authors' research revealed an insignificant, average relationship between the content of mineral nitrogen in the 0-25 cm layer and sunflower yield ($r = 0.41 \pm 0.24$), but a significant strong relationship was established between the content of mobile phosphorus in the 0-25 cm layer and sunflower yield ($r = 0.87 \pm 0.13$), exchangeable potassium and sunflower yield ($r = 0.72 \pm 0.18$).

DISCUSSION

In different years, scientists have conducted comparable studies on similar topics. Under the influence of the application of 7.5 t/ha of manure + $N_{50}P_{66}K_{66}$ in grain-row crop rotation in leached chernozems, the humus content increased by 0.13% (Pinkovskyi *et al.*, 2019). In works on chernozems in a soil-protective crop rotation, the humus content in the arable layer increased by 0.26% and 0.46% in the subsoil layer from the application of 7.5 t/ha of manure + $N_{70}P_{70}K_{35}$.

Some scientists believe that the annual loss of humus due to mineralisation in fruit crop rotation and green manure crop rotation is 1.32 t/ha (Tsyuk *et al.*, 2018). Thanks to plant residues, the loss of humus is compensated for, the rest must be compensated for by applying organic fertilisers (manure, green manure, straw). During humification, from 0.62 to 0.87 t/ha of humus can be produced from plant residues in a fruit crop rotation, depending on crop yields. Green manure crop rotation allows for an additional supply of 1.01 to 1.19 tonnes of humus per hectare. According to scientists, 40 tonnes of manure per hectare applied to potatoes and maize can produce 0.42 tonnes of humus. With 1 t of straw per hectare of the crop rotation area, the humus content increases by 0.15 t/ha.

Typical deep low-humus chernozems have a high absorption complex with a significant proportion of alkaline earth bases, which are characterised by an increase in humus substances, the amount of which depends on the organic-mineral fertiliser system, specific features of crop rotation, and soil cultivation. The humus content in a zone of sufficient moisture depends on both the fertilisation system and the presence of perennial grasses and legumes in the crop rotation.

In the crop rotation without legumes, humus losses were slightly higher, due to a lower stock of biological nitrogen in the soil, increased mineralisation of organic matter, and humus losses in the tilth and subsoil layers reached 0.35% and 0.32% (Plisko & Kutsova, 2023). The research by V.P. Boyko (2020), conducted at the Uladova-Lyulynetska Experimental Breeding Station, showed that the system of fertilisation of crops and their rotation in crop rotation affects the humus content. In a crop rotation without legumes, humus losses over 10 years in the tilth layer reached 0.27% and in the fallow layer 0.22%. The study by N.E. Borys & L.M. Krasyuk (2020), conducted at the Verkhnyatsk Experimental Breeding Station on podzolic heavy loam chernozems, observed stabilisation of organic matter, with an upward trend in its initial content. The authors explain this by suggesting that the amount of organic matter left by the crops in the rotation was sufficient to maintain a positive humus balance.

Research conducted by O. Kachmar *et al.* (2020) in the conditions of the Carpathian region shows that the combined application of mineral fertilizers $N_{120}R_{100}K_{100}$ for maize and $N_{90}R_{90}K_{90}$ for potatoes on a background of manure (40 t/ha) contributed to obtaining 568.36 mg/100 g and 537.61 mg/100 g, and 22.74 mg/100 g and 21.87 mg/100 g of soil of labile and water-soluble humus, respectively, in grain and fruit crop rotations. The use of an alternative fertilisation system ensured their values at the level of 482.15-470.84 mg/100 g of soil and 19.47-20.21 mg/100 g of soil.

In July, in the middle of the sunflower growing season, the content of mineral nitrogen in the surface and subsurface soil layers decreased significantly, due to the fact that sunflower plants use it and mineral nitrogen compounds migrate to the lower soil layers. Depending on the experimental variants, 70% of the total amount of mineral nitrogen was ammonium nitrogen, which is explained by the use of sunflower nitrates and an increase in the proportion of immobilised nitrogen, which is immobilised in the form of NH_4 (Boyko, 2020).

According to Egorov *et al.* (2021), if the phosphorus uptake from fertiliser phosphate application on all backgrounds is levelled out by day 130-150, the difference in phosphorus mobility persists until the end of the period. When a certain level of phosphorus saturation is reached, the soil acquires the ability to quickly restore the balance of soluble phosphates in the soil solution, i.e., it is characterised by greater capacity to meet the phosphate nutrition needs of plants. The supply of mobile phosphorus to sunflower agrocenosis is largely related to the seasonal dynamics of this nutrient (da Silva *et al.*, 2023), which depends on humidity and temperature (Tsentilo *et al.*, 2018).

In the research of S. Martyniuk *et al.* (2019), the consumption of phosphate fertilisers increased from 34 to 123 kg/ha on different soil types to increase the level of mobile phosphorus by 7 mg/kg of soil. To increase the content of mobile phosphate by 1 mg/kg of soil on chernozem soils, S.M. Kramarev *et al.* (2015) recommended applying phosphate fertilisers at rates of 40-60 kg, which exceeded the removal of this element and largely depended on the soil type and the level of phosphorus supply. The highest rates of nitrogen accumulation were observed in fruit crop rotation (+48.4 kg/ha) and grain-row crop rotation (+39.6-44.9 kg/ha) under the conventional fertilisation system. The lowest values of nitrogen balance (+28.9-33.1 kg/ha) were in grain crop rotations. A positive phosphorus balance was achieved by all fertilisation systems used in all crop rotations under study. The highest values of this indicator were obtained on conventional organic-mineral backgrounds of grain-row (+65.4-67.8 kg/ha) crop rotations. It was somewhat lower in the grain (+52.0 kg/ha), fruit (+45.0 kg/ha) and fodder (+44.3 kg/ha) crop rotations.

In other words, research on different soil types strongly suggests that the application of phosphate fertilisers to various crops can considerably affect phosphorus mobility and accumulation. The results of these studies suggest that the best rates of phosphate fertiliser application depend on the type of soil and crop requirements in the crop rotation system.

CONCLUSIONS

The humus content of the soil was determined by the application of mineral and organic fertilisers and did not significantly depend on crop rotation. The maximum humus content in the soil was reached by 0.13% higher at the end of the second rotation in the grain-row crop rotation compared to the fruit crop rotation when using the organic-mineral fertilizer system. With the organic-mineral fertilisation system, the humus content in all crop rotations increased due to an increase in the amount of non-hydrolysed residue. The highest humus content was observed in fruit and grain-row crop rotations, and the lowest – in specialised grain-row crop rotation. In the unfertilised variants, due to the growing mineralisation, the largest losses were in the specialised grain-row crop rotation.

The mineral nitrogen content of sunflower in short crop rotations was sufficient to obtain a sufficient level of yield. Under the mineral fertilisation system, the mineral nitrogen content decreased, due to the suppression of nitrification processes in the typical chernozem typical of the right-bank Forest-Steppe of Ukraine. The organic-mineral fertiliser system had an advantage in terms of its content in the soil compared to the mineral system. The organic fertilisation system had a slight tendency to increase the nitrogen content of mineral soils compared to the mineral one. The content of mineral nitrogen in the soil decreased significantly under the row crop rotation and specialised grain-row crop rotation.

The use of mineral and organo-mineral fertilisation systems in crop rotations contributes to a greater use of mobile phosphorus by crops in short crop rotations and the formation of high phosphate content in black soil. An increased content of mobile phosphorus was observed in fruit and grain-row crop rotation. Row crop rotation led to a decrease in the content of mobile phosphorus in typical chernozem. The migration of exchangeable potassium on typical chernozems depended on the system of fertilisation of crops in the crop rotation. The highest content of exchangeable potassium was observed in the fruit crop rotation under the mineral fertilisation system. A promising area for further research is the study of the fractional composition of humus and phosphate migration in the one-metre soil thickness under fruit and grain-row short crop rotation.

Extensive agrochemical analysis of the soil can provide detailed scientific information. Comparative analysis of research results in field stationary experiments is important. To establish the specific features of changes in indicators characterising soil fertility, the state and characteristics of microbiological processes, physical and chemical properties, and the intensity of soil load under diverse fertilisation systems, research institutions are recommended to conduct more in-depth studies that will cover these issues and establish the most suitable combination of regulated factors in the soil-plant-productivity system.

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CONFLICT OF INTEREST

None.

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Гумусний стан та поживний режим чорнозему типового залежно від удобрення в короткоротаційних сівозмінах

Анотація. Система удобрення – найдієвіший фактор інтенсифікації технологій вирощування сільськогосподарських культур. Основою науково обґрунтованих систем застосування добрив, разом з отриманням запланованого рівня врожаю відповідної якості, актуальним є вивчення показників вмісту органічної речовини та поживного режиму ґрунту за ротацію сівозміни. Метою даного дослідження є визначення мінерального азоту, рухомого фосфору, обмінного калію і вмісту гумусу, в чорнозему типового за різних систем удобрення у короткоротаційних сівозмінах. Для вирішення проблеми родючості ґрунту важливим підходом є проведення польових і лабораторних досліджень для визначення змін гумусного стану за Тюріним, азотного, фосфорного, калійного режиму ґрунту за Мачигіним та дисперсійні методи для визначення достовірності експериментальних даних. В результаті проведених досліджень, встановлено, що найвищий вміст гумусу у ґрунті зафіксовано за органо-мінеральної системи удобрення на кінець другої ротації у зернопросапній на 0,13 % у порівняно з плодозмінною сівозміною. Застосування мінеральної системи удобрення за просапної сівозміни вміст гумусу зменшився на 0,12 %. Зростання гумусованості чорнозему типового зафіксовано за плодозмінної і зернопросапної сівозміни. Органо-мінеральна система удобрення тенденційно підвищувала вміст у грунті мінерального азоту у порівняні з іншими системами. Вміст мінерального азоту за мінеральної системи удобрення зменшився на 5,5 мг/кг грунту порівняно з варіантом без удобрення. За органо-мінеральної і мінеральної системи удобрення вміст рухових фосфатів зростав за всіх сівозмін. Вміст рухомого фосфору у просапній сівозміні істотного знижувався у порівнянні з плодозмінною і зернопросапною сівозміною. Найбільший вміст обмінного калію у грунті зафіксовано за мінеральної системи удобрення. Матеріали публікацій мають практичне значення при аналізі основних елементів мінерального живлення чорнозему типового в коротко ротаційних сівозмінах

Ключові слова: мінеральний азот; обмінний калій; соняшник; елементи живлення; агроценоз

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The content of mineral nitrogen in a 0-30 cm soil layer as an indicator of ecosystem services: A case study of grasslands

Abstract. Nitrogen's role in agriculture lies in its mineral form, impacting plant availability and potential losses, with soil nitrogen content in grassy areas playing a vital role in ecosystem services like regulation and maintenance. The research aimed to evaluate these services using the mineral nitrogen indicator in the 0-30 cm soil layer, and to establish the link between their

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biophysical and financial values. This was done considering usage type, soil type, and corn as an alternative feed for ruminants. Services were assessed across 1,540 points in permanent green areas (meadows, pastures, alternating), grass cultivation areas (short-term), and corn fields. The study affirmed the significant contribution of grasslands to ecosystem services, evaluated through the "content of N_{min} in a 0-30 cm" soil layer, which exhibited variations based on usage, type, and regional distinctions. The highest biophysical and monetary values of ecosystem services were found in grasslands designated for meadow use, while the lowest accumulation of N_{min} in the 0-30 cm layer, thus impacting the scope of environmental services was observed in mineral soils subjected to short-term alternating crop cultivation (55.2 kg·ha^{-1}) and corn cultivation (70.9 kg·ha^{-1}). Across various usage methods and soil types, the region characterized by intensified livestock production, the Podlaskie Province displayed the highest biophysical and monetary values for grassland ecosystem services compared to the other provinces under study. In contrast, the remaining provinces exhibited comparatively lower values in this regard. The provided monetary value, based on current nitrogen fertilizer costs and grassland/corn extent, can universally gauge ecosystem service worth from fodder plants across farms, regions, and nations

Keywords: meadows; ecological benefits; nutrients, category "regulation and maintenance"; fodder crops

INTRODUCTION

The research on the function of green areas in the valuation of ecosystem services and nitrogen management in agriculture is to present the relationships between ecological and economic indicators. Such an integration leads to a sustainable and integrated management of natural resources. Green areas, which occupy about 20% of agricultural land in both Poland and Europe, are relatively poorly researched in terms of the assessment and evaluation of ecosystem services in the natural environment (Statistics Polish, n.d; Burczyk *et al.*, 2018). Therefore, M. Villoslada *et al.* (2018) noted that recognizing the role of these services and their quantification can prove very useful in supporting a range of decisions related to designing and preserving them, as well as sustainable management of grasslands.

Many research methods have been developed, which were often adapted to the research area (Richter *et al.*, 2021). However, there is little research that uses the physical and chemical properties of soils, including the management of mineral nutrients, as indicators.

The European Union has become a pioneer in the identification and standardization of ecosystem services, successively introducing legal regulations (including the European Green Deal (n.d.)), to help identify threats and develop research programs, as well as proposals for preventive actions against adverse changes occurring in ecosystems and the entire natural environment (Bongardt & Torres, 2022; Wieliczko & Floriańczyk, 2022). Y. Yuan *et al.* (2023) concluded that the demand for ecosystem services is a key aspect of sustainable development and environmental protection and is highly dependent on the condition and integrity of ecosystems capable of providing them. In the event of their degradation, they can be limited or even lost, which ultimately has negative consequences for humans. However, according to T. Ding *et al.* (2023) the demand for ecosystem services has broad applications and significant implications for decision-making in environmental protection, spatial planning, development of ecosystem markets, and assessment of the effectiveness of environmental policies.

Permanent green areas are the primary source of fodder for animals, both domestic and wild. They constitute an excellent geochemical barrier in the path of biogen flow, which is an important factor in preventing eutrophication of surface waters. Thus, they are of particular importance in the accumulation of nitrogen compounds in the soil (Giraud *et al.,* 2021). At the same time, meadow vegetation can absorb significant amounts of nutrients (e.g., nitrates), often preventing their migration to waters. V. Vooren *et al.* (2018) and M. Ignatyeva *et al.* (2022) claimed this positively influences their retention in the environment, thus providing specific ecosystem services.

Changes in the way green areas are used, both in Poland and many other countries, from a productive function to extensive or even unused, and a reduction in their area, lead to degradation or even destruction of their resources and loss of ecosystem services they provide, as confirmed by various scientific sources (Bengtsson *et al.,* 2019; Lipińska *et al.*, 2021).

Therefore, the aim of the research carried out was to evaluate the ecosystem services of green areas depending on their use compared to corn cultivation as a feed plant, for which the index was the mineral nitrogen resources in the topsoil layer (0-30 cm), under various economic and natural conditions. The research hypothesis assumes that green areas perform important ecosystem functions, and that the scope and value of these services are greater than other fodder crops. In grasslands, the scope of the services depends on both their location and soil category, and the type of their use.

MATERIALS AND METHODS

The research material used in this study comprised data collected as part of monitoring conducted by chemical and agricultural stations on farms located in the Lubelskie, Podlaskie, and Opolskie Provinces. A total of 1,540 research points were analysed, encompassing permanent grasslands, short-term alternating arable land, and arable land designated for grasses and corn. The study took place over 4 years and met all the standards specified in the Convention on Biological Diversity (1992). The geographical coordinates of each point were recorded using a GPS locator, ensuring consistent sampling in subsequent years. Soil samples, both mineral and organic, were collected from fields with a maximum area of 4 hectares.

Among the research points, 1,020 were selected from grasslands managed consistently throughout the study period (including mowing, pasture, hay, and mixed pasture), while 520 points were situated in areas cultivated with corn, exclusively on mineral soils (Table 1, Fig. 1, 2).

Table 1. Number of soil material samples

Soil category		Province		
		Lubelskie	Opolskie	Podlaskie
Mineral soils	very light and light	236	68	304
	medium and heavy	236	188	316
Organic soils		40	0	152
Total		512	256	772

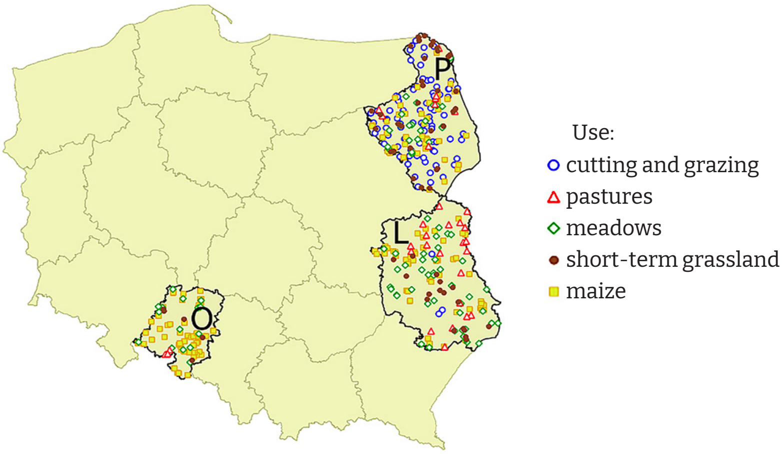

Figure 1. Location of objects according to their use

Note: L – Lubelskie, P – Podlaskie, O – Opolskie

Source: authors' own elaboration

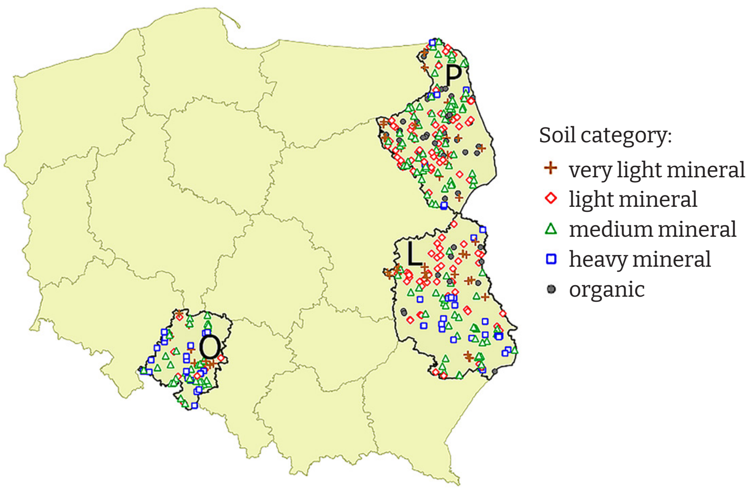

Figure 2. Location of objects according to soil type

Note: L – Lubelskie, P – Podlaskie, O – Opolskie

Source: authors' own elaboration

The naturally humid soil samples, in which the content of N_{min} was determined, were extracted with a 1% solution of potassium sulphate at a ratio of 1:10. The nitrate nitrogen and ammonium nitrogen content in the extracts were determined through spectrophotometry using the Skalar San Plus System autoanalyser(Netherlands, PKN: PN-R-04028:1997..., 1997). Additionally, the dry matter content of the samples was determined. The content of mineral nitrogen as the sum of nitrate and ammonium nitrogen was expressed in mg·kg^{-1} of dry mass of the soil sample.

To further analyse and interpret the data, it was converted the mineral nitrogen content into kilograms per hectare using specific conversion factors established for various agronomic categories of mineral soils, as determined by the Polish Committee for Standardization (PKN: PN-R-04028:1997..., 1997). It's important to note that these conversion factors were not applied to organic soils. As a result, for organic soils, it was utilized the results of $N\text{-}NO_3$ content determinations and $N\text{-}NH_4$ content (in mg·kg^{-1} dm) in the assessed soil layers. It was calculated the N_{min} content (in kg N · ha^{-1}) as the product of the sum of nitrate and ammonium nitrogen, the bulk density of the soil (assumed to be 0.5), and a conversion factor of 3 (representing a 30 cm layer of soil).

In the evaluation of the value, both biophysical and economic, of ecosystem services provided by grasslands, it was used the means derived from the spring and autumn data collection dates. It was considered the N_{min} content in the soil layer of 0-30 cm as the measure of the value of this service. This content is viewed as a resource of N_{min} available to plants, particularly those with shallow root systems. The higher the N_{min} content, the greater the ecosystem service provided. To quantify this value, it was multiplied the calculated N_{min} contents by the price of 1 kg of N in mineral fertilizers and expressed it in [EUR·kg^{-1}] (according to the average market price of the pure ingredient – Table 2).

Table 2. Monetary values used to assess the studied indicator ecosystem services

Indicator biophysical quantity	Economic unit	Lubelskie		Opolskie		Podlaskie		Mean (calculated)	
		Grassland	Corn cultivation	Grassland	Corn cultivation	Grassland	Corn cultivation	Grassland	Corn cultivation
N content in 0-30 cm layer [kg·ha^{-1}]	[EUR·kg^{-1}]	0.88	0.88	1	1	0.93	0.93	0.94	

Source: authors' own elaboration based on the data from the Statistics Polish (n.d.)

To confirm the research hypothesis, statistical analyses were performed to demonstrate the impact of selected factors (3 location, 5 method of use and 5 levels of type and category of soil) on the quantity or value of the assessed indicator of grassland ecosystem services compared to corn cultivation. Due to their highly asymmetric distribution, the physicochemical quantities studied were transformed for statistical analysis (the transforming function was $\log_{10}[x + 1]$). Thus, a normal distribution of the studied characteristics was obtained, which is required in the applied statistical methods and for the correct inference of the conducted analyses. Because of the logarithmic function used in the transformations, the differences between the groups should be understood as a comparison of the orders of magnitude of the determined measurements, and not the actual values.

The following factors were taken into account in the analyses: the province (3 levels specifying the provinces from which the data were collected: Lubelskie, Podlaskie, and Opolskie), the soils (5 levels: very light mineral soil (up to 10% of particles with dimensions below 0.02 mm), light soil (11-20% of particles less than 0.02 mm), medium soil (21-35% of particles less than 0.02 mm), heavy soil (above 35% of particles less than 0.02 mm) and organic soil (above 10% of organic matter), as well as the method of use (5 levels: meadows, pastures, hay and pastures, short-term alternating land and corn).

To detect statistically significant differences among individual subgroups of data, it was utilized Tukey's post-hoc HSD test for unequal subclasses, as proposed by Spjotvoll and Stoline in 1973. A significance level of $\alpha = 0.05$ was adopted for determining statistically significant distinctions. The statistical analyses were performed using Dell Statistica software version 13.1. Data from a total 1540 measurement points were subjected to statistical analysis, including 772 from the Podlaskie Province, where the share of grassy ecosystems is the largest in Poland (32%). In the Lubelskie Province, where the share of grasslands is 16%, the research covered 512 measurement points, while in the Opolskie Province – only 256 points (corresponding to the lowest share of – 10%).

RESULTS

Biophysical value. When evaluating the differences in the content of N_{min} in the 0-30 cm soil layer, it was found that in Lubelskie Province, in light and very light mineral soils, these contents were similar, depending on the type of land use (Table 3). On the other hand, in medium and heavy mineral soils, the lowest content of N_{min} was found in alternating short-term soils and the highest in corn cultivation, with significant differences. Significantly higher N_{min} content was also recorded in soil than in alternate arable lands in objects used for pasture and mowing (in all cases $p < 0.001$). In the Opolskie Province, where only three types of land use were assessed on very light and light soils (Table 3), a significantly higher N_{min} content was found in soils under corn than in soils under meadows, and even under alternating arable land (cultivated similarly to corn on arable land). However, the method of use did not significantly differentiate the content of the tested component in mineral soils of medium and heavy categories.

Table 3. The biophysical value of the ecosystem services of grasslands and corn crops based on the content of N_{min} in the 0-30 cm soil layer [$kg \cdot ha^{-1}$]

Province Soil category	Type of use				
	cutting and pasturing	pastures	meadows	alternating use	Corn
Lubelskie					
mineral, very light and light		^{abz} 54.8	^{ax} 41.9	^{abx} 41.4	^{ax} 42.4
mineral, medium and heavy	$^{a\,xy}$ 35.0	$^{ab\,y}$ 54.8	$^{ab\,y}$ 53.8	^{ax} 25.0	$^{ab\,y}$ 67.2
Organic		^{ax} 25.2	^{cy} 83.3		
Opolskie					
mineral, very light and light			^{abx} 67.8	^{abx} 50.1	^{cy} 109.5
mineral, medium and heavy		^{bc} 57.8	^{bc} 73.1	^{c} 98.3	^{cb} 83.5
Organic	—	—	—	—	—
Podlaskie					
mineral, very light and light	^{by} 84.5	^{cy} 92.8	^{cxy} 82.8	^{bx} 56.5	^{bx} 58.7
mineral, medium and heavy	^{bxy} 73.1	^{dcy} 111.0	^{bcx} 72.5	$^{b\,x}$ 60.3	^{bx} 64.5
Organic	^{bx} 94.6	^{dcxy} 113.4	^{dy} 123.6		

Note: abcd – homogeneous groups within a column (for the specific province and soil category); xy – homogeneous groups within a verse (for the adopted use type), lack of letter markings: no significant differences
Source: authors' own elaboration

In the Podlaskie Province, in the 0-30 cm layer of very light and light soils, significantly higher content was found on hay-pasture, pasture and meadow grasslands than in soils under alternating arable land and corn crops. The highest N_{min} contents in the soil under pasture, and the lowest in the soils under alternating arable land and corn were also recorded in objects with medium and heavy soils. On the other hand, in organic soils, significantly higher content of this nutrient was found in objects used as meadows and pastures than, alternatively, in hay and pasture.

Using multiple comparison tests, the N_{min} content in the 0-30 cm soil layer was analysed for specific land uses across different soil types and provinces. Significant differences were found in various scenarios. Under hay and pasture use, differences were observed between medium and heavy soils in Lubelskie Province and the examined mineral and organic soils in the Podlaskie Province ($p = 0.014$). However, no significant differences were found among different soil types in the Podlaskie Province. For pasture use, no significant differences in N_{min} content were found between different soil types within provinces. In Lubelskie Province, N_{min} content in very light and light mineral soils ($p = 0.035$) and organic soils ($p < 0.001$) was lower compared to the Podlaskie Province. The lowest values were observed in pastures on organic soils in Lubelskie Province.

In the case of meadow use, significantly higher N_{min} contents were obtained in organic soils compared to mineral soils. In Lubelskie Province, N_{min} content was significantly lower in organic soils compared to the Podlaskie Province ($p < 0.001$) and very light and light mineral soils ($p < 0.001$), with no differences in medium and heavy mineral soils ($p = 0.774$). No significant differences were found between the same soil types in Opolskie and Lubelskie provinces.

When assessing N_{min} content on alternating lands (arable land), no significant differences were found between different soil types within the Lubelskie and Podlaskie provinces. In the Opolskie province, a significantly higher N_{min} content was found in medium and heavy mineral soils compared to very light and light ones. In Lubelskie Province, Nmin content in medium and heavy mineral soils was significantly lower than in the same soil types in the other two provinces ($p < 0.001$ in both cases), with the highest content observed in Opolskie Province. No significant differences were observed for objects located on very light and light mineral soils between provinces. For corn crops, no significant differences in N_{min} content were found between different soil types within provinces. However, nitrogen content in very light and light mineral soils in Lubelskie Province was significantly lower compared to Opolskie Province ($p < 0.001$).

Economic value. When assessing the estimated value of the services of the studied grassland ecosystems based on the nitrogen content index in the 0-30 cm soil layer in the Lubelskie Province, the highest nitrogen values were found in meadows on organic soil and were valued at approximately EUR 74 per ha (Table 4).

Table 4. Economic value of the ecosystem services of grasslands and corn crops based on the mineral nitrogen content index in the 0-30 cm soil layer [$EUR \cdot ha^{-1}$]

Province Soil category	Type of use				
	cutting and pasturing	pastures	meadows	alternating use	corn
Lubelskie					
mineral, very light and light		^{ab} 48.6	^{a} 37.3	^{ab} 36.8	^{a} 37.7
mineral, medium and heavy	$^{a\ xy}$ 31.1	$^{abc\ y}$ 48.7	$^{ab\ y}$ 47.9	$^{a\ x}$ 22.2	$^{ab\ y}$ 59.7
Organic		^{ax} 22.4	^{cy} 74.1		
Opolskie					
mineral, very light and light			^{bcxy} 67.8	^{bx} 50.1	^{cy} 109.5
mineral, medium and heavy		^{bc} 57.8	^{c} 73.1	^{c} 98.2	^{c} 83.5
Organic	—	—	—	—	—
Podlaskie					
mineral, very light and light	^{bcy} 76.8	^{cy} 86.6	^{cy} 77.3	^{bx} 52.7	^{abx} 54.8
mineral, medium and heavy	^{bx} 68.3	^{cdy} 103.6	^{bcx} 67.6	^{bx} 56.3	^{bx} 60.2
Organic	^{cx} 88.3	^{dxy} 105.8	^{dy} 115.4		

Note: abcd – homogeneous groups within a column (for the specific province and soil category); xy – homogeneous groups within a verse (for the adopted use type), lack of letter markings: no significant differences
Source: authors' own elaboration

The ecosystem services of pastures, also on organic soils, were valued the lowest (EUR $22.4 \cdot ha^{-1}$). Grassy ecosystems in the above-mentioned province, on very light and light mineral soils, generated the highest value of services when they were used for pasture. The level of services provided by ecosystems used for mowing (meadows) and as short-term alternating land, was at a level similar to that of corn cultivation. Grasslands used for pasture, located on medium and heavy soils, also generated the highest values of ecosystem services compared to other types of use, but these values were lower than for corn cultivation. From a statistical point of view, differences in the amount of nitrogen accumulated in the 0-30 cm soil layer were observed only between short-term alternating land and corn cultivation (both on arable land).

In the Opolskie Province, the highest values of this indicator (nitrogen in the 0-30 cm soil layer) were observed in objects with corn cultivation, on very light and light soils (EUR $109.5 \cdot ha^{-1}$), and the lowest – in objects used as short-term alternating land, also on very light and light soils (EUR 50.1 · ha^{-1}). Hay and pasture ecosystems, as well as pastures, were not analysed in this province. In medium and heavy soils, the highest amount, and thus highest value of N_{min}, was recorded on short-term alternating arable land. On the other hand, the lowest value of services was generated by pastures. On medium and heavy mineral soils, the values of the assessed indicator were higher than on objects with a comparable type of use, but on very light and light soils, however, statistical differences were not confirmed.

In the Podlaskie Province, the highest nitrogen content in the 0-30 cm soil layer was observed in areas designated for meadows on organic soils, amounting to EUR 115.4 per hectare. Conversely, the lowest content, at EUR 52.7 per hectare, was recorded on short-term alternating fields with very light and light soils. Notably, pastures and areas used for mowing and pasture yielded the highest ecosystem service values on these soils, exceeding the values generated by short-term alternating arable land and corn crops by approximately EUR 22.2 per hectare. Similar patterns were observed on heavier soils (medium and heavy mineral soils). Organic soils, on the other hand, primarily provided substantial ecosystem services through meadows, followed by pastures, with no grass crops on arable land and no corn crops on these soil types.

When evaluating the N_{min} value accumulated in the 0-30 cm soil layer across the studied provinces, the highest values were consistently found in the Podlaskie Province, irrespective of soil type and land use methods. When comparing this indicator between provinces with similar land use methods and soil types, significantly lower values were observed in meadows on medium and heavy soils in Lubelskie and Opolskie Provinces ($p = 0.010$) compared to Podlaskie Province. The same trend was noted for corn crops in this soil category, but with higher values in the Opolskie Province compared to Lubelskie ($p = 0.001$). Furthermore, mineral nitrogen accumulation in meadows on medium and heavy soils in Lubelskie Province received higher valuation than nitrogen in meadows on light soils in Podlaskie Province. Significant differences were also detected for short-term alternating agricultural lands in Lubelskie Province with very light and light soils, compared to those in Podlaskie Province with medium and heavy soils.

Considering the ecosystem services provided by grass communities based on mineral nitrogen content in the 0-30 cm soil layer, it's evident that the contents vary depending on land use and province, particularly on mineral soils. In the Lubelskie Province, in all the assessed sites, both the biophysical quantity (Fig. 3) and monetary value (Fig. 4) of this indicator were lower than in similar objects in the Opolskie and Podlaskie Provinces, despite only slightly higher doses of mineral nitrogen in fertilizers used in these areas (Fig. 5).

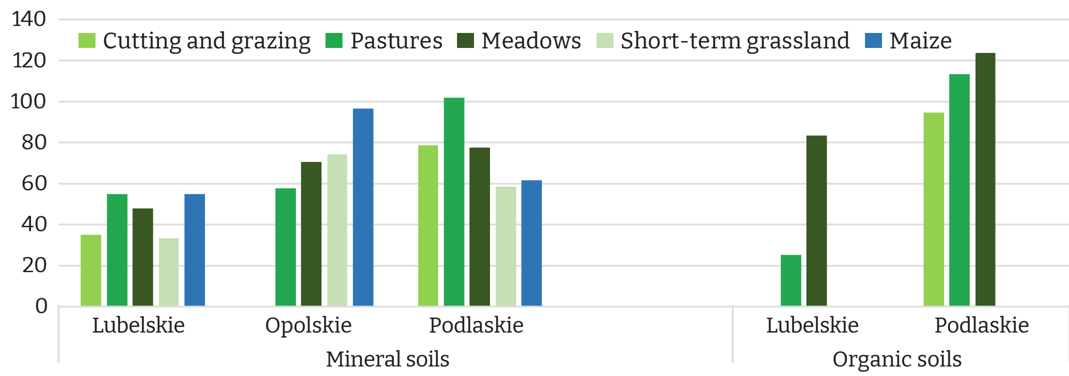

Figure 3. Biophysical quantity [kg · ha^{-1}] of ecosystem services based on the studied indicator (N_{min} in the 0-30 cm soil layer) depending on the method of use on mineral and organic soils in the surveyed province (as mean for the category)

Source: authors' own elaboration

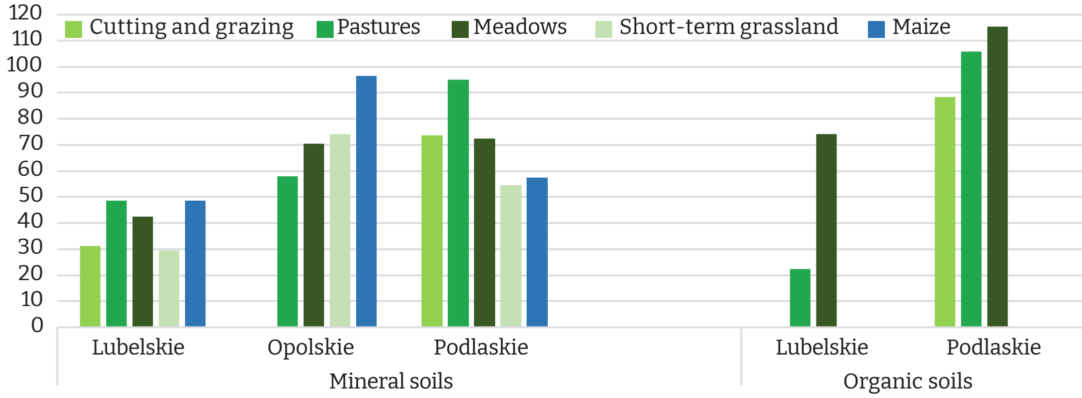

Figure 4. Economic value [EUR·ha^{-1}] of ecosystem services based on the studied indicator (N_{min} in the 0-30 cm soil layer) depending on the method of use on mineral and organic soils in the surveyed province (as mean for the category)

Source: authors' own elaboration

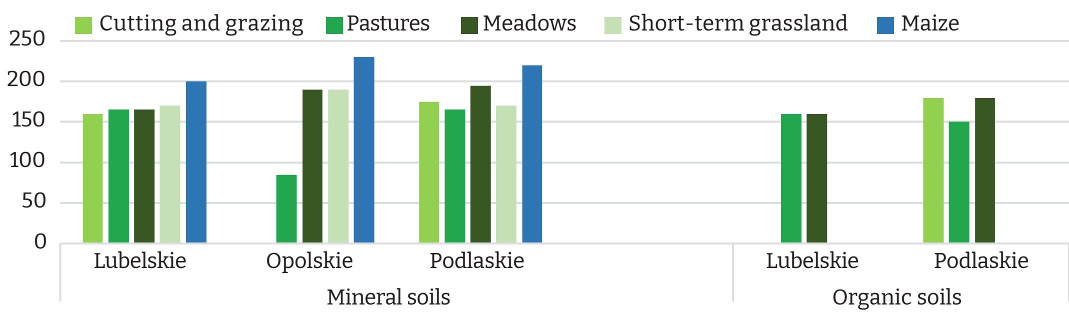

Figure 5. The amount of nitrogen dose [kg·ha^{-1}] applied depending on the method of use on mineral soils (average for the category), as well as on organic soils in the surveyed provinces

Source: authors' own elaboration

In the Lubelskie Province, the highest values of this indicator were recorded for objects with corn, and then for pastures. In the Opolskie Province, the highest content of mineral nitrogen in the layer up to 30 cm was found also in the soil under corn, and the lowest in the soil under pastures. In the latter case, it could also be related to lower fertilizer doses used in pastures, which are of marginal importance in intensively managed farms. This is contrary to the Podlaskie Province, where the highest values of the studied indicator were found in objects used for pasture. A similar, yet slightly lower content of mineral nitrogen was recorded in objects used for mowing and for mowing and pasture. In objects where cultivation was carried out on arable land, both short-term alternating land and corn cultivation, the lowest content of mineral nitrogen in the soil was found and the corresponding (lowest) monetary values. When examining the indicator on organic soils, it is evident that even in Lubelskie Province, these values were lower compared to those in Podlaskie Province. However, in both provinces, meadow areas consistently exhibited the highest values, while pastures consistently had the lowest values.

Analysing the computed values of ecosystem services in grasslands across provinces, irrespective of land use and soil type, the highest values were observed in the Opolskie Province, followed closely by the Podlaskie Province. In contrast, Lubelskie Province exhibited values approximately half as high, corresponding to the mineral nitrogen content in the soil root layer. Within Lubelskie Province, the lowest values for this service were observed across all studied land use forms, encompassing both grassland ecosystems and corn cultivation. In contrast, the Podlaskie Province showcased the highest service values for pasture areas, followed by meadows. For short-term alternating land use and corn cultivation, the Opolskie Province registered the highest service values. Interestingly, in this province, slightly greater values were recorded for areas under corn cultivation compared to short-term alternating arable land.

Comparative analyses were conducted using logarithmically transformed mean values to ensure consistency in the distribution of values and achieve a normal distribution. The biophysical values of ecosystem services were grouped together without differentiation based on soil types (Table 5). In the group of grassland ecosystems, the values for different types of use (mowing, hay and pasture, pastures, short-term alternating land) were averaged. Biophysical values were also used to calculate the economic value of individual services. In terms of the content of N_{min} in the 0-30 cm soil layer, grassy ecosystems retain 69.62 [kg·ha^{-1}] on average and are slightly higher to corn crops 68.10 [kg·ha^{-1}]. The highest biophysical values of this indicator in the assessed areas were observed in corn crops, 90.27 [kg·ha^{-1}] in the Opolskie Province, while the lowest – among grassy ecosystems in Lubelskie Province – 48.16 [kg·ha^{-1}]. The obtained biophysical value of ecosystem services is reflected in their monetary value (63.7 and 65.0 euro, respectively). However, taking into account the amount of nitrogen dose per hectare of the studied ecosystems (Fig. 5), even a slight advantage of grassy ecosystems in this respect can be indicated. Significantly higher values of the above-mentioned indicator were calculated for grassy ecosystems than for corn cultivation, applicable to objects located in the Podlaskie Voivodship (respectively 76.1 and 57.9 euro).

Table 5. Biophysical [kg·ha^{-1}] and monetary [eur·ha^{-1}] values of ecosystem services for grassland communities and corn crops per hectare based on nmin content in the 0-30 cm soil layer in the studied provinces

Study area – provinces							
Lubelskie		**Opolskie**		**Podlaskie**		**Medium**	
Type of use							
Grasslands	Corn crops	Grasslands	Corn crops	Grasslands	Corn crops	Grasslands	Corn crops
[kg·ha^{-1}]							
^{a} 48.16	^{a} 52.77	^{bc} 72.09	^{c} 90.27	^{c} 81.58	^{b} 62.06	69.62	68.10
[EUR·ha^{-1}]							
^{a} 42.8	^{a} 46.9	^{c} 72.1	^{d} 90.3	^{c} 76.1	^{b} 57.9	63.7	65.0

Note: abcd – homogeneous groups of means in a verse, according to province and form of use (if statistically significant differences at p = 0.05 were found); xy – homogeneous groups of means in a verse, regardless of province, for general means (if statistically significant differences at p = 0.05 were found)
Source: authors' own elaboration

The conditions for the growth and development of plants fundamentally depend on the presence of absorbable forms of mineral components in the soil, not only because of their structural or nutritive effect. According to H. Lipińska *et al.* (2020) absorbable minerals are responsible, among others, for maintaining ionic balance in the soil and thus impact the amount of crops and their quality. One of the most important nutrients for plants is nitrogen. Its content in the soil is variable and depends on many factors. Nitrogen is often depleted as a result of uptake by plants and soil microorganisms, but also due to leaching. Therefore, M Giraud *et al.* (2021) considered the constant supply of this element to the trophic chain is decisive in plant production.

In the search for solutions to optimize nitrogen management, it is necessary to take into account the significant diversity of soils (in natural conditions of agricultural production).

Previous research in this area was conducted primarily on arable land (Kopiński, 2018; Tkaczyk *et al.*, 2020). However, the amount of mineral nitrogen in the 0-30 cm layer of soil (mineral and organic) under grassland turf has not been studied as an important ecosystem service (especially compared to arable land soils). Also, while comprehensive mapping of ecosystem services of various crops on arable land is quite advanced, comprehensive analyses and methods of measuring indexes of these services in grassland ecosystems, which are an important element of many landscapes around the world (Richter *et al.*, 2021), are lacking.

M. Zisenis *et al.* (2020), H. Lipińska *et al.* (2020) believe that the results of research on ecosystem services can play a key role in implementing sustainable agricultural practices. By evaluating, for example, the contribution of ecosystems to agricultural productivity or soil fertility (which was the subject of research), they help promote nature-based agriculture, especially practices such as organic farming or precision agriculture. They also support the reduction of fertilizer consumption, including nitrogenous fertilizers. H. Lipińska *et al.* (2021), A. Bongardt & F. Torres (2022) described that this limits their dispersion in the environment and increases their efficiency, which raises the level of farm management, and reduces the harmful impact of agriculture on the environment. Therefore, they can be a very useful tool to support a variety of decisions related to the natural environment.

In the natural environment, grassland communities play an exceptional role. Their location and area are conditioned physiographically, which prevents arbitrary changes and promotes significant spatial stabilization. J. Bengtsson *et al.* (2019) summarized that these ecosystems have a significant share in the structure of land use and perform a variety of functions, from fodder, through environmental and landscape, to cultural). Used as meadows or pastures, less often variably (as mowing-pasture land) or as short-term alternate fodder (cultivation on arable lands), they occupy different land percentages, depending on animal stocking (according to data of Statistics Polish (n.d.)), corn for silage is growing increasingly in dominance as ruminant fodder). These ecosystems differ in terms of the management and species composition of plants, so they probably also differ in the size of ecosystem services. The attempt made in the work to value ecosystem services of differently used grassland communities against other fodder crops for ruminants fits into very few (still) studies in this area. Very few studies, both in Poland (Goliński & Foltynowicz, 2018; Lipińska *et al.*, 2020; Lipińska *et al.*, 2021) and in Europe address the identification, assessment, and valuation of grassland ecosystem services (Hönigová *et al.*, 2012; Bengtsson *et al.*, 2019).

Valuation of natural resources involves assigning monetary values to both their products and the benefits they offer through ecosystem services. This is commonly defined as "the value of ecosystem services". Valuation of individual and comprehensive economic services of grassland ecosystems is difficult due to the different methods and scope of research (Zisenis *et al.*, 2020). The first global valuation of ecosystem services for different types of land use was made by R. Costanza *et al.* (1997). This study showed an estimated value of grassland ecosystem services (based on 1994 prices) at USD 232 per hectare per year. In the studies carried out, the highest value of ecosystem services, at EUR 115.4 per hectare, was that of grassland communities in organic soils used for mowing. On the other hand, the lowest value was that of ecosystems on arable land (mineral soil), i.e., short-term alternate uses (EUR 22 per hectare).

The capacity of the studied services varied depending on land use, soil type, and area size, as indicated by previous research conducted by H. Lipińska *et al.* (2021). These studies focused on ecosystem services provided by grassland communities, using the mineral nitrogen losses index as a metric. On mineral soils, the services with the highest values (indicating the smallest losses of Nmin) were found in areas designated as pastures, while the lowest values were observed in areas used for corn cultivation.

In organic soils (excluding corn cultivation), the highest value of ecosystem services was identified in meadow areas, whereas the lowest values were noted in pastures. These findings suggest that organic soils generally exhibited lower values of ecosystem services compared to mineral soils. Additionally, when assessing grassland ecosystems, the Opolskie Province had the lowest value of ecosystem services, followed by the Podlaskie Province, and the highest values were recorded in the Lubelskie Province.

The highest biophysical values of the studied ecosystem services and areas were observed in corn crops: 90.27 [$kg \cdot ha^{-1}$] in the Opolskie Province, while the lowest – in grassland ecosystems in the Lubelskie Province: 48.16 [$kg \cdot ha^{-1}$]. The biophysical values obtained for ecosystem services are reflected in their monetary value (EUR 63.7 and 65.0, respectively). However, considering the size of the nitrogen dose per hectare of the studied ecosystems (Fig. 4), a slight advantage of grassland ecosystems can be observed in this respect. Significantly higher values of the index were calculated in objects with grassland ecosystems than with corn cultivation located in the Podlasie province (EUR 76.1 and 57.9, respectively). Upon analysing the calculated values of ecosystem services of grassland communities in individual provinces, regardless of the way of use and type of soil, the highest values were found in the Opole province and only slightly lower in the Podlaskie Province. Half-lower values of the mineral nitrogen content in the root layer of the soil were recorded in the Lubelskie Province. Assessing the monetary value of ecosystem services or natural resources promotes their conservation and rational use. (Arias-Arévalo *et al.*, 2018). The research results showed that the applied index of "content of mineral nitrogen in soil layer 0-30 cm" can be universal in the context of the farm, region, and country in assessing ecosystem services of fodder plants of great economic and natural significance. It is also an index available in many European countries, as it is frequently used in the assessment of actions resulting from the nitrate directive (Giraud *et al.*, 2021).

Studying the potential and capabilities of various ecosystems to provide services is necessary to preserve and protect these ecosystems, as well as biodiversity in general. They are related to soil-regulating treatments, as well as the quality of water and air (Valujeva *et al.*, 2022). The results of these studies can be successfully adapted and used not only for the analysis of the potential of ecosystem services, but also for research on the self-sufficiency of administrative units in the context of agricultural production and activities related to environmental protection (Yang *et al.*, 2022). The spatial aspect of this issue is also important, as it is a foundation for making many decisions regarding spatial planning (González-García *et al.*, 2022). Meanwhile, approximate valuations and mapping of ecosystem services can be a solid tool to assess the impact of erroneous decision-making and excessive exploitation of natural resources (Sannigrahi *et al.*, 2019).

In summary, the research demonstrates that the "content of mineral nitrogen in the soil layer 0-30 cm" can serve as a universal indicator for assessing ecosystem services across various types of ecosystems, reflecting both their economic and natural value. These findings not only underscore the importance of conserving ecosystems but also provide a tool to evaluate agricultural production and environmental protection measures. The research broad its scope by incorporating additional indicators of grassland ecosystem services, specifically focusing on phosphorus content and soil organic carbon sequestration. Additionally, the study seeks to encompass new geographical locations, including those in Ukraine.

CONCLUSIONS

The research confirmed the significant role of grasslands in ecosystem services, assessed by the content of N_{min} in a 0-30 cm layer of soil, which was differentiated by the use, type, and regionalization. The highest biophysical and monetary value of ecosystem services was observed in grasslands used for meadows. The lowest accumulation of N_{min} in the 0-30 cm layer, and thus the scope of environmental services, was observed in mineral soils with short-term alternating crop cultivation (55.2 $kg \cdot ha^{-1}$) and corn (70.9 $kg \cdot ha^{-1}$).

Irrespective of the method of use and type of soil, the highest biophysical and monetary values of grassland ecosystem services were found in the region with the most intensified livestock production (Podlaskie Province), while in the remaining provinces covered by the research it was lower. It is important to note that while grasslands consistently boast higher biophysical values than corn, the statistical significance of these differences was not confirmed in this study. This suggests that further investigation is warranted to comprehensively elucidate the intricate interplay between land use choices, soil attributes, and the resulting ecosystem services.

The introduced monetary value, calibrated against prevailing nitrogen fertilizer costs and the extent of grassland and corn cultivation, stands out as a versatile and adaptable indicator. It offers an instrument for assessing ecosystem service worth across different scales-ranging from individual farms to broader regions and entire countries. This monetary framework encapsulates the intricate blend of economic and environmental significance attributed to fodder plant-based ecosystem services.

In essence, this research provides crucial insights into the multifaceted connections between land use, nitrogen dynamics, and ecosystem service provisioning. By highlighting the varied impacts of different practices on grasslands and cropping systems, the study contributes to the broader understanding of sustainable land management and underscores the imperative of safeguarding grassland ecosystems for their profound ecological and economic contributions. Future research could focus on how other factors, such as climatic conditions, soil types, pasture management and land ownership, affect the biophysical and economic values of ecosystem services. This can help determine more accurate values and the factors that influence these values.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Вміст мінерального азоту в шарі ґрунту 0-30 см як індикатор екосистемних послуг: приклад пасовища

Анотація. Роль азоту в сільському господарстві полягає в його мінеральній формі, яка впливає на доступність рослин і потенційні втрати, причому вміст азоту в ґрунті в трав'янистих районах відіграє життєво важливу роль у екосистемних послугах, таких як регулювання та підтримка. Дослідження мало на меті оцінити ці послуги за допомогою показника мінерального азоту в шарі ґрунту 0-30 см, а також встановити зв'язок між їх біофізичними та фінансовими цінностями. Це було зроблено з урахуванням типу використання, типу ґрунту та кукурудзи як альтернативного корму для жуйних тварин. Послуги оцінювали за 1540 точками на постійних зелених насадженнях (луки, пасовища, що чергуються), на трав'яних ділянках (короткострокові) і на кукурудзяних полях. Дослідження підтвердило значний внесок луків у екосистемні послуги, оцінений за «вмістом N_{min} у шарі ґрунту 0-30 см», який демонстрував варіації залежно від використання, типу та регіональних відмінностей. Слід зазначити, що найвищі біофізичні та грошові значення екосистемних послуг були виявлені на луках, призначених для користування луками, тоді як найменше накопичення N_{min}

у шарі 0-30 см, що впливає на обсяг екологічних послуг, спостерігалося в мінеральних ґрунтах, які піддалися короткочасному впливу чергування сільськогосподарських культур (55,2 кг·га$^{-1}$) та вирощування кукурудзи (70,9 кг·га$^{-1}$). За різними методами використання та типами ґрунтів регіон, що характеризується інтенсифікацією тваринництва, Підляське воєводство продемонструвало найвищу біофізичну та грошову цінність екосистемних послуг луків порівняно з іншими досліджуваними провінціями. На відміну від цього, решта провінцій показали порівняно нижчі показники в цьому відношенні. Надана грошова вартість, заснована на поточних витратах на азотні добрива та площі пасовищ/кукурудзи, може універсально оцінити цінність екосистемних послуг від кормових рослин у фермах, регіонах і країнах

Ключові слова: луки; екологічна користь; поживні речовини; категорія «регулювання та утримання»; кормові культури

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Efficiency of the compensatory scheme of using Organic Acid Nano-Complex microfertilizers in spring wheat cultivation technologys

Abstract. In recent years, significant advances in nanotechnology have increased the ability to produce nanoparticles of physiologically important metals on a large scale, which are now used to improve fertilizer formulations to increase uptake by plant cells and minimize nutrient losses. Fertilizers with nanostructure can increase the efficiency of nutrient use through mechanisms such as targeted delivery, slow or controlled release. The aim of the research is to substantiate a

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compensatory scheme for the use of biodynamic nanofertilizers (nanocomplex micronutrient fertilizers with organic acids) by partially replacing the main macrofertilizers in the spring wheat fertilization system. The research was conducted on the basis of the educational and scientific laboratory Department of Plant Industry of the National University of Life and Environmental Sciences of Ukraine. In research, there were used the methods of field experiments of A.O. Rozhkov, notching method and scanning method for determination of leaf surface area. The studies showed that it is possible to replace within 30-40% of the recommended amount of mineral fertilizers with biodynamic nanofertilizers in the spring wheat fertilization system. In general, the use of nanofertilizers increased wheat growth and improved yield and yield components. Substitution of mineral fertilizers, Innoparmis Agroscience Biodynamic fertilizers, provides a more favourable 86-88% survival rate of spring wheat plants during the growing season. By replacing 34% of the recommended rate of mineral fertilizers, the content of photosynthetic pigments in wheat leaves increases by 5% and the leaf surface area increases by 7%. The created compensatory schemes for the use of biodynamic nanofertilizers by partial (34% in the wheat fertilization system) replacement of the main macronutrients can increase the yield of spring wheat by 9.9%. The proven possibility of replacing mineral fertilizers with biodynamic nanofertilizers in the fertilization system of agricultural crops will reduce environmental pollution and the economic dependency of using mineral fertilizers against the background of their rapid increase in price in recent years

Keywords: *Triticum aestivum* L.; biodynamic nanofertilizers; crop photosynthetic activity; yield; yield structure; quality of the products

INTRODUCTION

Fertilizers have a key role in increasing crop yields and the ecosystem surrounding agriculture. Excessive use of fertilizers irreversibly changes the soil ecology, reducing the area available for crop production. Sustainable agriculture involves the balanced use of agrochemicals, which over time can protect the environment and save certain species from extinction. The creation and implementation of new environmentally safe and technological preparations designed to increase the efficiency of plant nutrient use of mineral fertilizers and soil is relevant for Ukrainian agriculture. One of the ways to achieve this may be the development of innovative technologies for growing plants in crops. There are many solutions proposed on the market today that deliver mixed results from a crop efficiency and environmental impact perspective. Examples of these new products are: nanofertilizers, growth-stimulating complexes, biodynamic nanofertilizers etc.

S.K. Kumar *et al.* (2022) point out that rapid urbanization with shrinking agricultural land, dramatic climate change and the widespread use of agrochemicals in agricultural practices are causing environmental disturbances and threats to public health, affecting food security and agricultural sustainability. Besides this, agriculture soils are continuously losing their quality and physical properties as well as their chemical (imbalance of nutrients) and biological health due to indiscriminate use of agrochemicals. Therefore, the creation and implementation of new environmentally safe and technological preparations aimed at increasing the efficiency of plant nutrient use of mineral fertilizers and soil is relevant for the global agricultural sector, according to L. Batsmanova *et al.* (2020).

According to D.M. Mahapatra *et al.* (2022) the development of innovative technologies for growing plants in crops, such as nanofertilizers, growth-stimulating complexes, etc., are starting to play an important role in increasing the efficiencies and quality of crops. The same opinion is shared by C.F. Okey-Onyesolu *et al.* (2021), who believe that the development of new nanofertilizers offers a promising opportunity to improve plant mineral nutrition. R.K. Krishnasree *et al.* (2021) also find that through the use of nanostructured fertilizers, the long-term availability of all the supplemented nutrients to the plant throughout the growing season is crucial to promote germination, growth, flowering and fruiting. M.R. Rehana *et al.* (2022) also point out that the use of controlled release fertilizers (CRFs) is beginning to emerge as a promising area, offering excellent means to improve nutrient management and thus significantly reduce environmental threats while maintaining high yields of good quality crops. Controlled-release fertilizers allow for a better alignment of nutrient release with the plant life cycle. A. Gorczyca *et al.* (2021) and A. Padmakumar *et al.* (2023) concluded that the undoubted prospects for the development and widespread use of nanotechnology lie in the fact that nanoparticles of biogenic metals have extremely high activity and sizes corresponding to the size of living cells, contribute to an increase in yields, gross yields of crops and product quality; increase the efficiency of nutrient use and their intended use, and have a positive effect on reducing the toxicological burden on the environment due to a significant reduction in the gross volume of fertilizer and pesticide application. In addition, according to T. El-Saadony *et al.* (2021), nanoparticles in fertilizers are more reactive, able to penetrate the epidermis, providing gradual release and targeted distribution, and therefore reducing excess nutrients, increasing their use efficiency, are crucial in reducing abiotic stress and heavy metal toxicity. In general, the use of nanoparticles in nanofertilizers and nanopesticides, the use of nanoparticles in agriculture and their role in enhancing the function of biological factors is an important and interesting area of research.

The purpose of the study performed is to develop and substantiate a compensatory scheme for the use of organic acid complex fertilizers containing nano-particles by partially replacing the main macrofertilizers in crop cultivation technologies.

MATERIALS AND METHODS

Field studies were conducted in 2021-2022 in the educational and scientific laboratory "Demonstration collection field of crops" of the Department of Plant Industry of the National University of Life and Environmental Sciences of Ukraine (Kyiv) on the territory of the Botanical Garden of National University of Life and Environmental Sciences of Ukraine (NULES of Ukraine). Laboratory research was conducted in the laboratories of the Department of Plant Industry of the National University of Life and Environmental Sciences of Ukraine "Quality of seeds and planting material" and "Analytical research in plant production".

The soils of the Demonstration Collection Field of Crops of the Department of Plant Production are predominantly grey forest soils. On the elevated areas of the Kyiv plateau and in the upper parts of the slopes of the beams, grey forest and light grey forest soils prevail on loess deposits under the canopy of oak-hornbeam forests. The territory borders on Holosiivskyi Park.

The soil of the experimental plot is grey forest coarse-loamy – light loamy in terms of granulometric composition. The following horizons are distinguished in the profile of grey forest soils: No – forest floor (only in soils under forest); H – humus with a thickness of 12-30 cm, grey in colour; NE – humus-eluvial, with whitish SiO_2; I – illuvial with a nutty or nutty-prismatic structure (humus films are present on structural parts), grey-brown in colour; C – parent rock.

The physical and chemical parameters of the grey forest soil of the experimental plot are given in Table 1.

Table 1. Physical and chemical properties of the soils of the experimental site

Type of soil	Layer, cm	Humus content, %.	pH of the salt hood	Sum of absorbed bases, mg-eq/100 g of soil	Amount of absorbed cations, mg-eq/100 g of soil			Content of mobile forms of nutrients, mg/100 g of soil		
					Ca^{2+}	Mg^{2+}	H^+	N	$P\ O_{25}$	$K\ O_2$
Grey forest coarse-dusty-light loamy	0-10	3.0	5.8	10	9.1	1.9	3.1	8.3	12.0	10.1
	20-30	2.1	6.1	15	12.5	2.3	2.2	6.2	7.5	4.2

Source: the results were obtained from the Ukrainian Laboratory of Quality and Safety of Agricultural Products

The humus-eluvial horizon of these soils is 50-60 cm, with carbonates occurring at a depth of 110-150 cm. They are medium loamy in terms of particle size distribution. The humus content in the topsoil is 2.1-3.0%, the amount of absorbed bases is 10-15 mg-eq/100 g of soil, the degree of saturation with bases is 82-88%, and the reaction of the soil solution is slightly acidic (pH = 5.8 - 6.1). Groundwater is located at a depth of 2-4 metres. The soil density in the equilibrium state is 1.1-1.2 g/cm, the moisture content of stable wilting is 10.2%. The total moisture capacity of the soil is 39-40%, the field moisture capacity of this soil is 27.2%, the capillary break moisture is 19.4%, the maximum hygroscopicity is 7.3%, and the moisture inaccessible to plants is 10%.

The soil is characterized by a high content of gross and mobile forms of nutrients. As a result of the regradation process, the carbonate line has risen in these soils, the illuvial horizon has become looser, the humus content has increased, and the saturation with bases has increased compared to dark grey and podzolic chernozems. From the above data, it can be said that the soil is quite favourable for growing many crops, as it has favourable water and physical and chemical soil properties. With a sound soil cultivation system and rational fertilization, the decline in its economic properties can be prevented.

The contrast of temperature regime and uneven precipitation during the season, individual months and even decades observed during the months of vegetation of the studied crops in the years of research created extreme conditions for the formation of plant productivity in some periods, the degree of negative impact of which on the level of crop yield was determined by time (developmental phase, stage of organogenesis) and duration of their action.

The weather conditions in 2021 also differed significantly from the long-term average in terms of monthly average air temperature, the sum of active temperatures and precipitation. The average daily temperature in April and May 2021 was lower than the long-term average, which led to a shift in the sowing of crops to later dates. The total precipitation in May was 77 mm, which is 29 mm above the long-term average, and due to the lower temperature, the moisture regime in this month corresponded to the excessive one, as the calculated HCC was 1.7. The air temperature in June increased significantly and reached 21.3°C, which is 2.8°C above the long-term average, and lower precipitation (24 mm) resulted in a moisture regime that corresponded to dry conditions, and the negative impact was partially avoided due to waterlogging in the previous month.

The total precipitation for July was 61 mm, which is only 22 mm less than normal, but the average monthly temperature was 24.6°C, which is 5°C higher than the long-term average. In such extreme conditions, even with sufficient precipitation, the HTC (hydrothermal coefficient) dropped to 0.8, indicating dry conditions. In August, the temperature regime stabilized, and the excess of the long-term average was only 0.9°C. At the same time, the amount of precipitation was 55 mm, which, combined with the heat input, corresponded to the HTC of 0.8, i.e. slightly dry conditions close to normal. The average monthly temperature in September was 0.8°C below the long-term average, and the amount of precipitation was 23 mm, which was generally favourable for soybean maturation.

The research in 2019-2022 was aimed at proving the possibility of partial replacement of basic macrofertilizers with *organic acid nano-complex* (OAC) micronutrient fertilizers and developing compensatory schemes for their application. In the research, the organic acid complex micronutrient fertilizers manufactured by UAB Innoparmis Agrocience (Republic of Lithuania) supplied by *Natural Fertilizers* Limited (Ireland), ("*Innoparmis Agroscience*" ™) were used.

The research was conducted on spring wheat crops of the Elegia Myronivska variety and soybean variety Khorol. The reaction of plants to the application of macro-microfertilisers was determined by assessing the dynamics of formation and functioning of the photosynthetic (pigment content in leaves) and symbiotic (number and weight of nodules) systems, yield, and quality of the products obtained.

Spring soft wheat – Elegia Myronivska variety, seeding rate of spring wheat seeds – 5 million germinating seeds per hectare, row spacing – 15 cm. Fertilization background: $N_{20}P_{60}K_{60}$ – in pre-sowing cultivation + N_{20} – the beginning of the tube (BBCH 30-32) + N_{20} – the beginning or full earing (BBCH 51-59). Scheme of field experiments of the second block of research: 1) Control $N_{60}P_{60}K_{60}$, 2) $N_{50}P_{50}K_{50}$+OAC, 3) $N_{50}P_{40}K_{30}$+OAC, 4) $N_{40}P_{40}K_{30}$+OAC, 5) $N_{40}P_{30}K_{30}$+OAC, 6) $N_{30}P_{30}K_{30}$+OAC.

It was registered for cultivation in the Forest-Steppe and Polissya regions back in 2004. It belongs to high-yielding wheat of a strong type. It is suitable for early sowing and produces yields of up to 6.5 tonnes per hectare. Plant height is 90-100 cm. Variety type: low-growing, semi-intensive. Grain quality: weight of 1000 grains is 46.7 g, grain weight is 740 g/l, crude gluten content is 28%, protein is 15.7%, flour strength is 320 o.a.

The research was conducted in accordance with the methods of field experiments of A.O. Rozhkov *et al.* (2016). The location of the plots was systematic. Field research was conducted using the small plot method. The area of the accounting plot is 5 m^2, with six replications.

Leaf surface area was determined by the Nichiporovich notching method and scanning method. The content of chlorophyll *a* and *b in* the leaves was determined by biochemical analysis using a spectrophotometer, with subsequent calculation of pigment concentration according to the equation of Wetstein and Holm (Gritsayenko *et al.*, 2003). Stages and microstages of crop growth and development were determined according to the BBSH (Biologische Bundesanstalt für Land- und Forstwirtschaft, Bundessortenamt und der CHemischen Industrie) scale.

Yields of the main and by-products were determined in plots by the method of continuous accounting using a Minibatt (France) hand combine harvester. The resulting weight of spring wheat grain was converted to the yield per 1 hectare, taking into account weediness and moisture content by 14% (DSTU 3768:2010..., 2010). Before threshing, a "trial sheaf" of each variant was taken from 1 metre running length to determine the structure of the crop. The study was conducted per the requirements of the International Convention on Biological Diversity (1992).

The quality of grain was determined in the laboratory "Analytical Research in Plant Production" using the method of infrared spectrometry on the device "Infratec 1241 FOSS" (Denmark). Statistical analysis of the data was performed using the Serial Attached SCSI (SAS) 9.4 software package.

RESULTS AND DISCUSSION

The grain yield of the wheat variety Elegia Myronivska in the 2021/2022 growing season was somewhat low, due to extremely dry conditions throughout the growing season. At the same time, partial (up to 35%) compensation of the mineral fertilizer application rate with Organic Acid Complex micronutrient fertilizers allowed the crop to generate higher yields. According to A.K. Márquez-Rrieto *et al.* (2022), the absorption efficiency of macronutrients is 19% higher when applying nanofertilizers compared to conventional fertilizers, it is logical that crop yields are higher. In research, the average yield varied from 4.63 t/ha in the control variant ($N_{60}P_{60}K_{60}$) to 5.09 t/ha (9.9% higher than the control) in the variant of substitution $N_{50}P_{50}K_{50}$+OAC (compensation scheme 16:16:16%) (Table 2, Fig. 1).

Table 2. Spring wheat yield depending on the compensatory fertilizer substitution scheme, t/ha

Fertilizers	% compensation	2021	2022	Average	Increase	
					t/ha	%
Control $N_{60}P_{60}K_{60}$	—	4.14 **a**	5.11 **b**	4.63 **b**	—	—
$N_{50}P_{50}K_{50}$+OAC	16:16:16	4.44 **b**	5.74 **a**	5.09 **a**	+0.46	+ 9.9
$N_{50}P_{40}K_{30}$+OAC	16:34:50	4.40 **b**	5.65 **a**	5.02 **a**	+0.39	+ 8.4
$N_{40}P_{40}K_{30}$+OAC	34:34:34	4.32	5.50	4.91	+0.28	+ 6.0
$N_{40}P_{30}K_{30}$+OAC	34:50:50	4.14 **a**	5.26	4.70	+0.07	+ 1.5
$N_{30}P_{30}K_{30}$+OAC	50:50:50	4.07 **a**	5.15 **b**	4.61 **b**	-0.02	-0.5

Note: the same letters in a column indicate no significant difference between the variants, no letters – the variant has a significant difference in NIR05 (the least significant difference) with the rest (Analysis of variance (ANOVA) was performed to test the effect of substitution of mineral fertilizers with nanofertilizers. The analysis was performed using the Tukey's HSD test. Statistically significant differences do not have letters (two-factor analysis of variance, Tukey's test, $p < 0.01$)

Source: developed by the authors

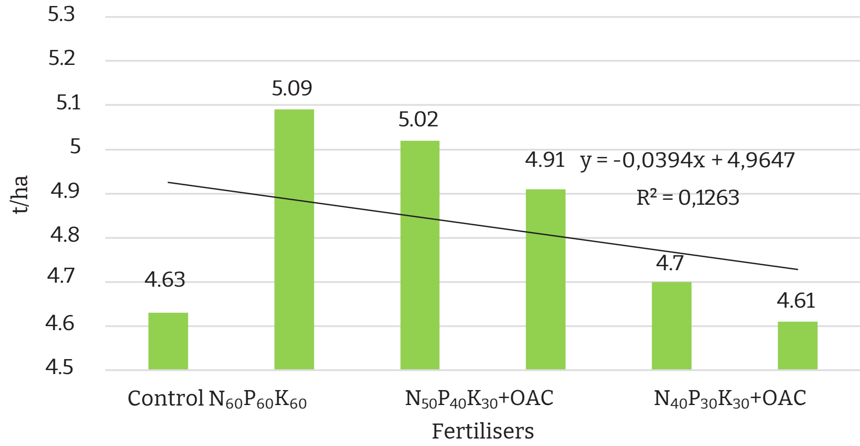

Figure 1. Average yield of spring wheat, t/ha (2021-2022)

Source: developed by the authors

With a further increase in the percentage of compensation of mineral fertilizers with Organic Acid Complex micronutrient fertilizers, the yield gradually decreased and, under the condition of 50% replacement, was the lowest – 4.61%, below the control by 0.5%. Replacement of 34% of fertilizers with Organic Acid Complex fertilizers increased wheat yield by only 6.0%. The yields of the fertilizer substitution variants $N_{50}P_{50}K_{50}$+OAC and $N_{50}P_{40}K_{30}$+OAC – 4.91 and 4.85 t/ha – did not differ significantly from each other according to the analysis of variance.

The reasons for the increase in yields under the influence of organic acid complex fertilizers are related to the optimization of plant nutrition through microelements and the overall improvement of physiological processes in the plant. Another possible reason for the increase in yields is the minimization of external negative factors, in particular, air drought on some days in May and June 2021. Fertilizing spring wheat crops with Organic Acid Complex micronutrient fertilizers in the tillering – earing phase allows us to maintain plants in good condition during the dangerous period of summer droughts, which leads to a significant increase in yield.

The compensatory scheme of replacing 50% of the norm of applied mineral fertilizers ($N_{30}P_{30}K_{30}$+OAC) did not work to increase spring wheat yield due to a decrease in other elements of the spring wheat yield structure, in particular, crop density and leaf area. In contrast to results, B. Hasan & T. Saad (2020), who conducted similar studies on the partial replacement (0.25, 0.5 and 0.75%) of mineral NPK fertilizers with nanofertilizers, showed a significant increase in grain yield for all years of research in the variant with 50% replacement of NPK fertilizers. K. Al-Saidan *et al.* (2019), who also studied the interaction between mineral and nano-organic fertilizers and their impact on durum wheat, found that various combinations of organic and biological fertilizers with nanoparticles provide higher yields than 50 and even 100% of the recommended rate of mineral fertilizer application.

The advantage of replacing NPK with nanofertilizers is firstly in their complex composition and secondly in their foliar application, which contributes to the rapid absorption of the minerals and their incorporation into the plant's metabolic processes without loss and environmental pollution. A review article by A. Alhasan *et al.* (2022) indicates that foliar application of nanofertilizers directly leads to a reduction in the time delay between application and plant uptake during the rapid growth phase, and can improve the efficiency and rate of immediate utilization of the nutrient. required by the plant for maximum growth and yield. The application of nanobiological fertilizer increased the spike length, number of spikes, number of seeds, number of seeds per spike, seed weight and number of days to physiological maturity. In general, the use of nanobiological fertilizers has a positive effect on the growth and development of crops, in particular, nano-iron had a significant effect on yield, plasma membrane stability and chlorophyll content (Delfani *et al.*, 2014), nanozinc had a positive effect on seed yield, lipid peroxidation and various antioxidant biomarkers in soybean (Yusefi-Tanha *et al.*, 2020).

Field germination of seeds in all compensatory schemes of Organic Acid Complex micronutrient fertilizers application was quite high – 84-86%, while field germination in the control variant ($N_{60}P_{60}K_{60}$) was 85% (Table 3). Substitution of 50% of mineral NPK fertilizers reduced the field germination of spring wheat. During the growing season, the difference between the variants in terms of intensity of metamer development and reduction increased. In the control variant, only 81% of plants survived to the full ripeness stage. Under different combinations of substitution of 16 and 34% NPK, plant survival was the highest – 88 and 86%, respectively. Substitution of half of the recommended rate of PK with nanofertilizers provided less favourable survival of spring wheat plants during the growing season – 82%.

Table 3. Structure of spring wheat agrocenosis depending on the compensatory fertilizer replacement scheme, average for 2021-2022

Fertilizers	% compensation	Stairs, *VVSN 10*		Full ripeness, *VVSN*		
		field similarity seed	CR*	survival plants	PDA	CPS
		%	pcs/m²	%		pcs/m²
Control $N_{60}P_{60}K_{60}$	—	85	425	81	1.30	447
$N_{50}P_{50}K_{50}$+OAC	16:16:16	86	430	88	1.38	522
$N_{50}P_{40}K_{30}$+OAC	16:34:50	86	430	88	1.34	507
$N_{40}P_{40}K_{30}$+OAC	34:34:34	86	426	86	1.32	483
$N_{40}P_{30}K_{30}$+OAC	34:50:50	84	420	84	1.32	465
$N_{30}P_{30}K_{30}$+OAC	50:50:50	84	420	82	1.31	451

Note: NP – number of plants; CPC – coefficient of productive tillering; CPS – number of productive stems
Source: developed by the authors

An important structural component of yield is the number of productive stems per unit area at full maturity. The range of changes in the number of productive stems in field experiments reached 507-522 pieces/m² with no more than 34% of the recommended rate of mineral fertilizer application. The lowest number of productive stems was formed in the control variant, in which plants were grown without additional nutrients, which led to the lowest coefficient of productive tillering – 1.30 and the formation of 447 productive stems/m². Substitution of half ($N_{30}P_{30}K_{30}$+OAC) of the recommended rate of mineral fertilizers did not contribute to the formation of a high productive stem (451 productive stems/m²), the coefficient of productive tillering was also low – 1.31.

The photosynthetic activity of crop plants is the basis of their productivity and largely depends on the pigment content of the plants. Of particular importance are green pigments, chlorophylls *a* and *b, which are* sensitive indicators of the physiological state of plants. The amount and functional activity of these pigments is an indicator of the potential ability of plants to form a biological yield. These pigments are directly involved in the formation of the structure of the photosynthetic apparatus, play an important role in photosynthetic and photochemical reactions associated with the absorption and transformation of energy used in the synthesis of substances necessary for plant growth and development (Long *et al.*, 2006; Bramley, 2013).

The most important photosynthetic pigments are chlorophylls, and therefore a positive correlation between their content in leaves and photosynthesis leads to an increase in plant productivity. The maximum level of photosynthetic pigments in the leaves of durum spring wheat plants, on average, was reached during the earing phase. The decrease in the amount of photosynthetic pigments in spring wheat plants, starting from the flowering phase, is a natural process, since the chloroplast stroma loses water, they break down into granules, resulting in the destruction of chloroplasts.

It has been shown that the higher the percentage of mineral fertilizer substitution by Organic Acid Complex micronutrient fertilizers in the fertilization system, the higher the pigment content in wheat leaves, with a direct and close correlation of r = 0.96. The positive effect of partial fertilizer substitution on the content of chlorophyll *a* and *b* compared to this indicator in the control was found in all experimental variants. The difference in the amount of chlorophyll *a* in the leaves of plants between the least effective variant of substitution $N_{50}P_{50}K_{50}$+OAC and the control averaged 0.31 mg/g in the earing phase (Fig. 2).

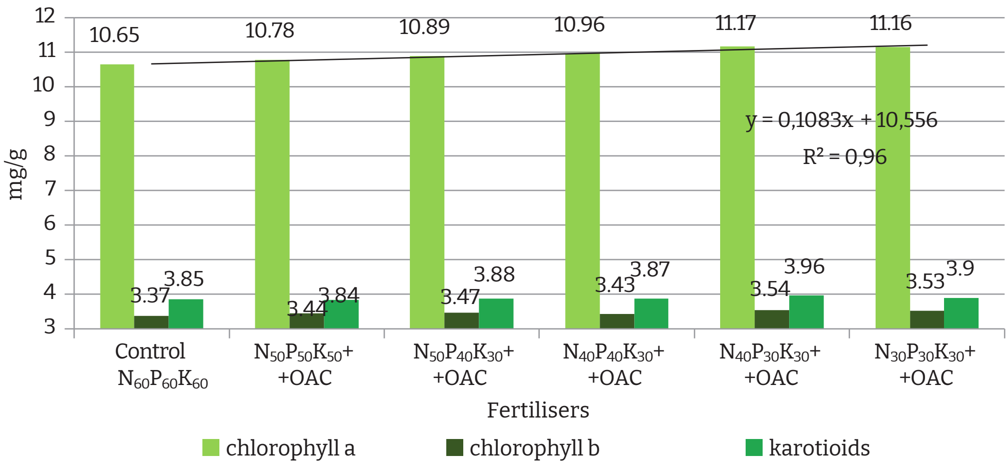

Figure 2. Content of photosynthetic pigments in spring wheat leaves in the earing phase, mg/g
Source: developed by the authors

In the least effective variant of the same substitution, the content of chlorophyll *b* compared to the control in the indicated stages of development was 0.04, 0.08 and 0.07 mg/g higher than in NIR_{05} – 0.03, 0.07 and 0.03 mg/g, respectively. It should be noted that the use of low rates of mineral fertilizer replacement – from 16 to 34% ($N_{50}P_{50}K_{50}$+OAC, $N_{50}P_{40}K_{30}$+OAC, $N_{40}P_{40}K_{30}$+OAC) did not provide a significant increase in the amount of carotenoids in plant leaves. Indicators of carotenoids content in the leaves of plants of these variants and control belonged to one homogeneous group. The greatest influence on the amount of chlorophyll *a* and *b and the* amount of carotenoids in the leaves of spring wheat plants was recorded in the variants with the replacement of 50% of the norm of phosphorous and potassium fertilizers and 34% ($N_{40}P_{30}K_{30}$+OAC) of nitrogen fertilizers. Its further increase to 50% ($N_{30}P_{30}K_{30}$+OAC) did not provide a significant increase in the content of photosynthetic pigments in the leaf mass of plants. In the experiment, it was found a direct close relationship between wheat yield and leaf area index (r = 0.948). The studies also showed a tendency to reduce the leaf surface area with an increase in the proportion of Organic Acid Complex microfertilizers in the spring wheat fertilization system (Fig. 3).

Two-year studies of the compensatory scheme of using Organic Acid Complex microfertilizers in spring wheat cultivation technology convincingly proved the possibility of replacing from 16 to 34% of the recommended NPK rate with Organic Acid Complex microfertilizers (Table 4). An increase of 12% in the number of grains per ear and 17% in the weight of grains per ear was observed, and the weight of 1000 seeds increased by 7% under the compensatory scheme $N_{50}P_{50}K_{50}$+OAC. In the variant with NPK substitution by 34% ($N_{40}P_{40}K_{30}$+OAC), the number of grains per ear increased by 6%, the weight of grain per ear – by 5%, the weight of 1000 seeds – by 7% compared to the control.

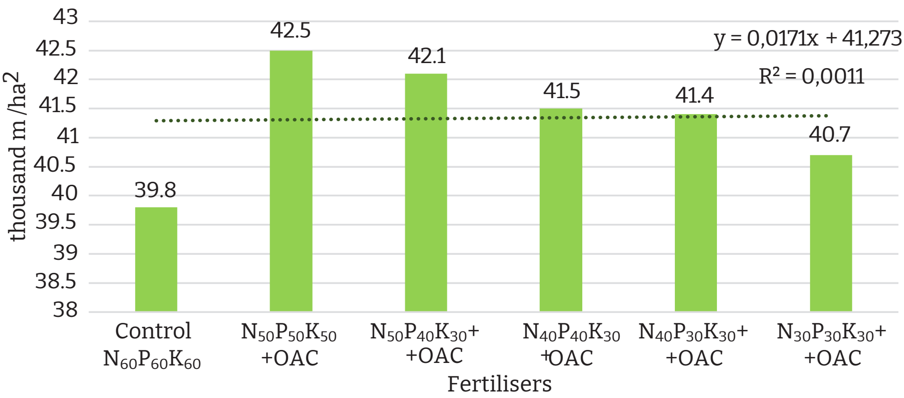

Figure 3. Leaf area of spring wheat in the earing phase, thousand m /ha^2

Source: developed by the authors

Table 4. Individual productivity of wheat plants depending on the compensatory fertilizer replacement scheme (average for 2021-2022)

	Fertilizers	Plant height, cm	Spike length, cm	Number of grains per ear, pcs	Grain weight per ear, g	Weight of 1000 seeds, g
1	Control $N_{60}P_{60}K_{60}$	85.7	11.4	44.6	1.20	41.6
2	$N_{50}P_{50}K_{50}$+OAC	85.2	11.8	50.1	1.40	45.7
3	$N_{50}P_{40}K_{30}$+OAC	83.3	11.8	51.2	1.38	44.4
4	$N_{40}P_{40}K_{30}$+OAC	86.5	11.4	47.4	1.26	43.6
5	$N_{40}P_{30}K_{30}$+OAC	84.8	11.4	44.0	1.28	43.3
6	$N_{30}P_{30}K_{30}$+OAC	86.7	11.5	43.6	1.22	42.9
	NIR $_{0.05}$	1.5	0.3	1.7	0.07	1.4

Source: developed by the authors

The effectiveness of the compensatory fertilizer replacement schemes developed by us for the formation of wheat grain quality has been demonstrated. The quality of wheat grain is determined by the whole range of technological factors, but the most important is the supply of nutrients to plants. Substitution of basic fertilizers for spring wheat with Organic Acid Complex microfertilizers contributed to an increase in protein synthesis in the grain – from 13,2 in the control variant to 13.8% in the variants $N_{40}P_{30}K_{30}$+OAC and $N_{30}P_{30}K_{30}$+OAC (Table 5). The protein content, in contrast to the yield indicator, increased with an increase in the proportion of replacement of mineral fertilizers with Organic Acid Complex microfertilizers. When substituting according to the schemes $N_{50}P_{50}K_{50}$+OAC – $N_{50}P_{40}K_{30}$+OAC, the trend towards an increase in protein content in grain was maintained, but the indicators were somewhat lower.

Table 5. Wheat grain quality depending on the compensatory fertilizer replacement scheme (average for 2021-2022)

	Fertilizers	Content of 1, %.					
		Protein	gluten	ash	fat	fibre	starch
1	Control $N_{60}P_{60}K_{60}$	14.8	24.4	1.7	2.5	3.0	66.4
2	$N_{50}P_{50}K_{50}$+OAC	14.4	23.4	1.6	2.3	3.0	65.8
3	$N_{50}P_{40}K_{30}$+OAC	14.4	23.2	1.7	2.5	3.0	65.8
4	$N_{40}P_{40}K_{30}$+OAC	14.6	23.6	1.7	2.5	3.0	65.0

Table 5, Continued

Fertilizers		Content of 1, %.					
		Protein	gluten	ash	fat	fibre	starch
5	$N_{40}P_{30}K_{30}$+OAC	14.8	24.8	1.7	2.5	3.1	64.7
6	N30P30K30+OAC	14.8	24.6	1.7	2.6	3.0	64.6
NIR 0.05		1.5	0.3	1.7	0.07	0.1	1.4

Notes: the content of quality indicators is recalculated for standard wheat grain moisture content of 14%
Source: developed by the authors

The gluten content of grain is closely related to balanced nutrition, especially nitrogen. The lowest gluten content of 20.4% was in the grain formed in the control variant for the application of the recommended rate of mineral fertilizers, where nitrogen fertilizers were applied in the form of N_{20} kg/ha d.m. at the beginning of the tube and at full earing. The replacement of mineral nitrogen fertilizers with Organic Acid Complex fertilizers, which are characterized by higher solubility, more active penetration through the cuticle, which ensures targeted delivery and controlled release of elements, and rapid incorporation into plant metabolic processes, contributed to an increase in gluten in grain by 3-5% compared to the control. The fat content in the grain was 2.3 to 2.6% and varied slightly depending on the proportion of the Organic Acid Complex fertilizer substitution. Wheat grain is characterized by a low ash content of 1.7%, and the dynamics of change was practically absent in the variants of compensatory fertilization schemes. The starch content in the grain varied from 64.6 to 66.4% in an inverse correlation with the protein content.

The results obtained are consistent with the results of B. Hasan & T. Saad (2020), M. Mardalipour *et al.* (2014), who in their studies also showed the advantage of treating wheat crops with nanofertilizers over mineral fertilizers in terms of leaf area, number of ears, number of grains, weight of 1000 grains and grain yield. A. Joshi *et al.* (2022) generally noted a doubling of the number of grains in a wheat ear when seeds were treated with nanofertilizers before sowing. Results indicated that significant response was spraying of SMP Organic Acid Complex fertilizer followed by the spraying combined of tri (N+P+K), di (N+P), (N+K) and (P+K) Organic Acid Complex fertilizer compared to control and traditional (NPK+TE) fertilizer treatments respectively in all growth and yield parameters of wheat with an increment of the spray foliar (SMP) of 87.77 cm, 12.22 cm, 58.22 spad, 3.17%, 0.66% and 2.88% for plant height, length of spike, total chlorophyll, concentration of N, P and K respectively compared to control treatment (Al-Juthery *et al.*, 2018). However, in research A. Dapkekar *et al.* (2018), nanofertilizer application increased grain zinc content without affecting grain yield, protein content, spikelets per spike, thousand kernel weight, etc.

Literature data (Naderi & Abedi, 2012; Subbaiah *et al.*, 2016) confirms that foliar application of nanochelate microfertilizers helps to stimulate metabolic activity and increases leaf area, as it has a larger contact area, which increases physical and chemical activity.The leaf surface area of spring wheat under the replacement of 16% of the norm of NRC fertilizers ($N_{50}P_{50}K_{50}$+OAC) in the earing phase reached its maximum in the experiment – 42.5 thousand m²/ha, exceeding the control $N_{60}P_{60}K_{60}$ by 7% or 2.7 thousand m²/ha. However, the compensatory 50% rate of nanofertilizer application did not contribute to the formation of a sufficiently high leaf surface area – 40.7 thousand m²/ha, which was higher than the control $N_{60}P_{60}K_{60}$ only by 2% or 0.9 thousand m²/ha. The positive effect of nanofertilizers on the leaf area index of crops of different crops was also noted in B. Hasan & T. Saad (2020), N. Basavegowda & K.H. Baek (2021).

The impact of nanofertilizers on product quality improvement was noted in A. Sabir *et al.* (2014). Similar results were also obtained by researchers T. Zhang *et al.* (2018), P. Sheoran *et al.* (2021), who observed the effect of foliar application of zinc nanofertilizers on wheat plant growth and found an increase of more than 20% in grain protein content and a significant increase in photosynthetic pigments compared to the usual foliar application of mineral zinc fertilizer. Also, a two-year experiment by F. Behboudi *et al*. (2018) showed an increase in grain protein content with all nanofertilizers compared to the control under both full irrigation and drought conditions. The increase was highest under water deficit conditions with nano-Zn and then nano-Si treatment, due to a decrease in yield under drought conditions, which leads to an increase in nitrogen content in grain.

CONCLUSIONS

The three season study has convincingly demonstrated the possibility of replacing no more than 30-40% of the recommended amount of traditional mineral fertilizers in the fertilization system for cereals (wheat) with Organic Acid Complex microfertilizers produced by UAB Innoparmis AgroScience. This will help reduce environmental pollution and reduce the economic costs of using mineral fertilizers against the backdrop of their extreme rise in price under martial law.

Organic Acid Complex microfertilizers are needed to reduce the use of inorganic fertilizers and their antagonistic effect on the environment. Organic Acid Complex fertilizers have a higher reactivity, can penetrate the epidermis, providing a gradual release and targeted distribution, thus reducing excess nutrients, increasing the efficiency of nutrient use. Also concluded that Organic Acid Complex microfertilizers are crucial for mitigating abiotic stress caused by drought.

Compensatory schemes for the use of biodynamic Organic Acid Complex fertilizers were created by partial (16 to 34%) replacement of the main macronutrients in the wheat fertilizer system – $N_{50}P_{50}K_{50}$+OAC – $N_{50}P_{40}K_{30}$+OAC, which can increase the yield of spring wheat by 9.9% due to more favourable (86-88%) survival of spring wheat plants during the growing season; increase of photosynthetic pigments content in wheat leaves by 5% and leaf surface area by 7%. Also, when replacing from 16 to 34% of the recommended NPK rate with biodynamic Organic Acid Complex fertilizers, an increase of 12% in the number of grains per ear and 17% in the weight of grains per ear was observed, and the weight of 1000 seeds increased by 7%.

Questions that may be the basis for future research are to determine the impact of these biodynamic Organic Acid Complex fertilizers on living organisms in the soil, as well as on humans and livestock, accumulation in cultivated products, especially at higher doses. It is also necessary to study the role of biodynamic Organic Acid Complex fertilizers in the conditions of climate change based on different scenarios and the expected adaptive behaviour of cultivated crops under such stresses.

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CONFLICT OF INTEREST

None.

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Ефективність компенсаційної схеми застосування нанокомплексних мікродобрив на основі органічних кислот у технології вирощування ярої пшениці

Анотація. В останні роки значні досягнення в галузі нанотехнологій збільшили можливості широкомасштабного виробництва наночастинок фізіологічно важливих металів, які зараз використовуються для поліпшення складу добрив, з метою збільшення поглинання рослинними клітинами та мінімізації втрат поживних речовин. Добрива з наноструктурою можуть підвищити ефективність використання поживних речовин за допомогою таких механізмів як цільова доставка, повільне або контрольоване вивільнення. Мета досліджень: обґрунтувати компенсаторну схему використання біодинамічних нанодобрив (нанокомплексні мікродобрива з органічними кислотами) шляхом часткового заміщення основних макродобрив в системі удобрення пшениці ярої. Дослідження проводились на базі навчально-наукової лабораторії кафедри рослинництва Національного університету біоресурсів і природокористування України. Було використано методи польових дослідів А.О. Рожкова, метод надрізу та метод сканування для визначення площі листкової поверхні. Проведені дослідження засвідчили можливість заміни в межах 30-40 % рекомендованої кількості мінеральних добрив біодинамічними нанодобривами в системі удобрення пшениці ярої. Загалом застосування нанодобрив збільшило ріст пшениці і покращило врожайність і компоненти врожайності. Заміщення мінеральних добрив нанодобривами забезпечує більш сприятливе – 86-88 % виживання рослин пшениці ярої упродовж вегетації. За рахунок заміщення 34 % рекомендованої норми внесення мінеральних добрив на 5 % підвищується уміст фотосинтетичних пігментів в листках пшениці, на 7 % зростає площа листкової поверхні. Створені компенсаторні схеми використання біодинамічних нанодобрив шляхом часткового (на 34 % в системі удобрення пшениці) заміщення основних макроелементів здатні підвищувати врожайність пшениці ярої на 9,9 %. Доведена можливість заміни в системі удобрення сільськогосподарських культур мінеральних добрив біодинамічними нанодобривами дозволить зменшити забруднення навколишнього середовища та знизить економічні витрати від використання мінеральних добрив на фоні надзвичайного їх здорожчання в умовах військового стану

Ключові слова: *Triticum aestivum* L.; біодинамічні нанодобрива; фотосинтетична діяльність посівів; урожайність; структура врожаю; якість отриманої продукції

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Efficiency of biological preparations against scab and powdery mildew of apple trees

Abstract. Scab (caused by *Venturia inaequalis* Cooke (Wint.)) and powdery mildew *(Podospaera leucotricha* (Ellis & Everh. Salmon)) are harmful diseases of the apple tree, the protection against which is based on repeated spraying with chemical fungicides. To reduce the pesticide burden on agrocenoses, the use of biological protection products is relevant. The purpose of this study was to investigate the effectiveness of biological preparations based on fungi and bacteria (mycoparasites and antagonists) against scab and powdery mildew of apple trees. For this, a set of methods was used, including phytopathological diagnostics and disease monitoring, phenological observations, yield recording, and statistical analysis. The biological preparations Ampelomycin BT (6 l/ha) based on the fungus of the genus Ampelomyces Ces ex Shlecht., Gliocladin BT (10 l/ha), which contains mycelium and spores of the fungus of the genus *Gliocladium*, and Fluorescin BT (8 l/ha), which is based on bacteria of the genus *Pseudomonas*, were investigated. Their use led to a decrease in the spread and development of apple scab, and the technical efficiency of the preparations ranged from 68% to 79%. The biological preparations also reduced the damage to plants by the powdery mildew pathogen with a technical efficiency of 59-76%. Treatment of apple plants with Gliocladin BT, Ampelomycin BT, and Fluorescin BT reduced the number of scab-affected fruits by 22.7-35.6%. The technical effectiveness of the preparations was 62-78%. The use of the biological preparations under study ensured the preservation of the yield within 3.7-4.4 t/ha. The results obtained indicate the prospects of using biological preparations against scab and powdery mildew of apple trees for the ecologisation of plant protection

Keywords: apple tree diseases; fungi; microorganisms-antagonists; technical efficiency; yield

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INTRODUCTION

The apple tree (*Malus domestica* Borkh) is the most common fruit crop in temperate regions. Its fruits are used for fresh consumption and in the food industry, as well as to produce medicines. At the same time, one of the obstacles to increasing the yields of various crops is biotic stress, specifically, plant pathogens. The apple tree is particularly susceptible to diseases such as scab and powdery mildew. These diseases are among the most harmful to apple trees and can cause considerable yield losses, which makes it important to investigate the ability of biological preparations to limit plant damage.

According to FAOSTAT (n.d.), apple fruit production ranks second in the world with a share of 9.6%. According to The State of Food Security and Nutrition in the World (FAO *et al.*, 2020), the World Health Organization (WHO) and the Food and Agriculture Organization of the United Nations (FAO) recommend a minimum consumption of 400 g of fruit and vegetables per day. In Ukraine, only half of the population's demand for apples is met.

One of the obstacles to increasing crop yields is plant damage caused by pathogens. Modern research shows that plant diseases cause major losses to the global economy. According to FAO estimates (Climate change..., 2023), they amount to more than $220 billion annually. Many scientists have devoted their research to the study of apple diseases. M.S. Mullett *et al.* (2023) point out that the fungus *Phytophthora × cambivora*, which is an invasive pathogen in Europe and North America, but also poses a serious threat to agricultural fruit tree ecosystems. Research by M. Papp-Rupar *et al.* (2023) indicates that European canker caused by *Neonectria ditissima* (Tul. and C. Tul.) is widespread on apple trees worldwide. However, the apple tree is particularly susceptible to diseases such as scab and powdery mildew. According to M. Chatzidimopoulos *et al.* (2022), scab (caused by the fungus *Venturia inaequalis* Cooke (Wint.)) and powdery mildew (caused by the fungus *Podospaera leucotricha* (Ellis & Everh. Salmon)) are among the most harmful diseases of apple trees and can cause yield losses of more than 70%.

According to H. George (2023), the powdery mildew pathogen, infecting young shoots and leaves, inhibits plant growth, which ultimately leads to weakening of trees and reduced productivity and fruit quality. D.A. Strickland *et al.* (2022) point out that fungicides have to be applied multiple times during the growing season to control scab and powdery mildew. Studies conducted in the Precarpathian province of the Carpathian mountainous zone of Ukraine have established that in conditions of significant pest infestation of apple stands, it is advisable to use a chemical protection system that includes 12 treatments (Hunchak *et al.*, 2022). At the same time, various alternative methods of controlling apple diseases are being developed to reduce the pesticide burden on agrocenoses. L.A. Shuttleworth (2021) emphasises that in this aspect, it is important to use biological agents that should be cost-effective, ensure environmental sustainability and food safety.

The rhizobacterium *Bacillus subtilis* is being investigated and used as a potential biocontrol agent (Leconte *et al.*, 2022). Some strains of *B. subtilis* are registered for commercial use against plant pathogens. H. Desmyttere *et al.* (2019) indicate that natural substances (fungicin, surfactin, mycosubtilin) produced by *B. subtilis* showed *in vitro* antifungal effects against strains of the apple tree scab pathogen *V. inaequalis*. In the scientific literature, there are also reports of the use of fungi *Gliocladium spp*. and *Ampelomyces spp*. and bacteria of the genus *Pseudomonas* against plant diseases (Rahman *et al.*, 2021). In Ukraine, studies have been conducted on the use of certain biofungicides on apple trees (Hradchenko, 2022). However, biological preparations based on microbial agents – fungi *Gliocladium* spp. and *Ampelomyces* spp. and bacteria of the genus Pseudomonas – against diseases are understudied, which may be an obstacle to their development and introduction into production.

Given the above, the purpose of this study was to determine the ability of biological preparations to limit the damage to apple plants by *V. inaequalis* and *P. leucotricha* fungi, which cause scab and powdery mildew, respectively.

MATERIALS AND METHODS

The study was conducted during 2021-2022 in the apple tree stands of the Renet Simirenko variety of the Institute of Horticulture of the National Academy of Agrarian Sciences of Ukraine

(IH NAAS). This variety is susceptible to the most common diseases and is a model object for studying the effectiveness of protection measures. The tree layout is 5.0×1.0 m, the number of plants per hectare is 2,000 pcs. Soil of the experimental plot: dark grey podzolised light loamy, pH – 6.2, humus content – 2.8%.

The effectiveness of the following biological preparations was studied against scab and powdery mildew of apple trees: Ampelomycin BT (6 l/ha), based on the fungus of the genus *Ampelomyces* Ces ex Shlecht., containing mycelium and spores (pycnospora) with a titer of at least 4.0×10^9 CFU/cm^3 and biologically active substances; Gliocladin BT (10 l/ha), containing mycelium and spores of the fungus from the genus *Gliocladium* with a titer of at least 1.5×10^9 CFU/cm^3 and biologically active substances; Fluorescin BT (8 l/ha), contains bacteria of the genus *Pseudomonas* with a titer of at least 5.0×10^9 CFU/cm^3, as well as biologically active substances (phenazine-carboxylic acids, siderophores, cytokinins).

The apple trees were sprayed with biological preparations in the morning in the absence of dew on the surface of plants using a STIHL SR 450 sprayer (Germany). The working fluid consumption was 600 l/ha. Each variant is repeated three times. The placement of accounting trees of different repetitions of the same variant is randomised. Meteorological information during the apple tree growing season was obtained from the it Lynx weather station (Ukraine). Apple plants were sprayed with biological preparations against diseases in the following stages of crop development according to the BBCH scale of stages of development and growth of plants: the first spraying – 67 (Flowers fading: majority of petals fallen), the second – 72 (Development of fruit; fruit size up to 20 mm), the third – 74 (Fruit diameter up to 40 mm; fruit erect), the fourth – 75 (Fruit about half final size), the fifth – 78 (Fruit about 80% final size). Records of disease spread, development, and technical effectiveness of biological preparations were carried out according to generally accepted methods (Trybel & Sigareva, 2001).

The spread of scab and powdery mildew on apple trees was determined according to the following formula:

$$P = \frac{n\times100}{N}, \tag{1}$$

where *P* is the disease prevalence (disease incidence), %; *N* is the total number of plants in samples, pcs; *n* is the number of diseased plants in samples, pcs.

A six-point scale was used to determine the intensity of scab lesions (Trybel & Sigareva, 2001): 0 points – healthy leaves; 0.1 points – up to 1% of the leaf surface is covered by individual small spots; 1 point – 1-10% of the leaf surface is covered by individual small or medium-sized spots; 2 points – 11-25% of the leaf surface is covered by individual large spots (up to 5 mm) or small spots; 3 points – spots are mostly larger than 5 mm, often merging and covering 26-50% of the leaf surface; 4 points – spots are mostly larger than 10 mm, over 50% of the leaf surface is covered, leaves turn yellow, deformed, dry out. Powdery mildew of apple trees was recorded on the following scale (in points): 0 – no signs of damage; 0.1 – separate small spots of fungal mycelium with damage to the leaf surface of 0.1-1.0%; 1 – separate small, sometimes merging spots (1.1-10% of the leaf surface affected); 2 – small, blurry spots, merging; 11-25% of the leaf surface affected; 3 – large, blurry spots, merging with 26-50% of the leaf surface affected; 4 – large spots, with intense sporulation of the fungus, the leaf is deformed, dries up (over 50% of the leaf surface is affected).

Disease progression (lesion intensity, disease index) was determined according to the formula (Trybel & Sigareva, 2001):

$$Rx = \frac{\Sigma(a\times b)\times100}{N\times K}, \tag{2}$$

where *Rx* is the disease development, %; Σ (a x *b)* x 100 is the sum of the product of the number of diseased plants and the corresponding damage score; *N* is the total number of plants (healthy and diseased), pcs; *K* is the highest score of the accounting scale.

The technical efficacy of the preparations (*Te*, %) was determined according to the formula (Trybel & Sigareva, 2001):

$$Te = \frac{100\times(Dc-De)}{Dc}, \tag{3}$$

where *Dc* is the indicator of disease development in the control; *De* is the indicator of disease development in the experimental variant.

Experimental studies of plants (both cultivated and wild), including the collection of plant material, were following institutional, national, or international guidelines. The authors adhered to the standards of the Convention on Biological Diversity (1992) and the Convention on the Trade in Endangered Species of Wild Fauna and Flora (1973).

RESULTS AND DISCUSSION

An analysis of the meteorological conditions of the 2021 growing season (April–August) showed that the average daily air temperature and precipitation were substantially different from the long-term average (Table 1). Thus, only in April and May was the air temperature slightly lower than long-term indicators (by 0.5-1.2°C), while in June and August the excess of the average daily temperature reached 4°C. In April–July 2021, there was a shortage of precipitation. Although there were 6 to 15 rainy days with precipitation per month, the shortfall compared to the long-term average was 20.4-66.6 mm. In just one month, during April-August, there was between 16.5 and 57.6 mm of precipitation. The largest number of them was recorded in August. An analysis of weather conditions (April-August 2022) showed that the average daily air temperature and precipitation data differed substantially from the long-term average (Table 1). Specifically, in April and May, the air temperature was slightly lower than long-term indicators (by 0.5-1.0°C), and in June and August, the excess of the average daily temperature ranged within 0.2-3.5°C. During the growing season of apple plants in April–August, from 19 to 26.3 mm of precipitation was recorded monthly. There is a substantial deficit of precipitation (26.7-59.6%) compared to the average long-term figures. In general, the meteorological conditions of 2021-2022 ensured the accumulation and spread of the inoculum of apple scab and powdery mildew pathogens and the manifestation of diseases.

Table 1. Characteristics of meteorological conditions during the apple tree vegetation (Institute of Horticulture of NAAS, 2021-2022)

Main indicators	Months and years									
	April		May		June		July		August	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
air temperature, ˚C										
average long-term	9.2		15.3		18.6		20.8		19.5	
of the current year	8.0	8.2	14.7	14.8	21.8	22.1	25.0	21	21.2	22.6
deviations from long-term	-1.2	-1.0	-0.6	-0.5	+3.2	+3.5	+4.2	+0.2	+1.7	+3.1
precipitation, mm										
average long-term	45.7		55.0		83.1		69.5		54.8	
of the current year	24.0	19	34.6	26.3	16.5	23.5	33.5	24	57.6	21.2
deviations from long-term	-21.7	-26.7	-20.4	-28.7	-66.6	-59.6	-36.0	-45.5	+2.8	-33.6

Source: weather station of the Institute of Horticulture of the National Academy of Sciences of Ukraine

During the period under study, apple scab was observed on leaves and fruits (Fig. 1a). On the affected leaf blades, the symptoms of the disease were characterised by the appearance of chlorotic spots, which eventually became covered with a velvety greenish-olive coating. On diseased fruits, crustal spots of assorted sizes were formed, covered with a velvety olive coating. Powdery mildew developed on young shoots and leaves (Fig. 1b). A white bloom was formed mainly on the underside of the leaves, which curled over time. Subsequently, the symptoms of the disease on the leaves and young shoots changed: the plaque acquired a dirty grey hue with black dots – cleistothecia. Intensively affected shoots had shortened internodes.

a b

Figure 1. Symptoms of apple scab (a) and powdery mildew (b)

The use of biological preparations Ampelomycin, Glyocladin, and Fluorescin on apple trees led to a 15.0-21.9% reduction in the spread of apple scab, and the development of the disease was reduced by 9.5-11.1% compared to the control (Table 2). Therewith, the technical efficiency of the preparations ranged from 68% to 79%. The tested biological preparations also controlled powdery mildew, reducing the prevalence of the disease by 5.6-7.0% and its development by 2.2-2.5%. The technical efficiency was within 59-76%. The most effective against the disease was the application of Ampelomycin at a rate of 6.0 l/ha.

Table 2. Efficiency of biological preparations against scab and powdery mildew of apple trees (Institute of Horticulture of NAAS, Renet Simirenko variety, average for 2021-2022)

Variant	Consumption rate, l/ha	Scab			Powdery mildew		
		DP	DD	TE	DP	DD	TE
Control (without processing)	–	37.7	14.0	–	11.6	3.3	–
Ampelomycin BT	6.0	15.8	2.9	79	4.6	0.8	76
Gliocladin BT	10.0	22.3	4.5	68	6.0	1.4	59
Fluorescin BT	8.0	20.1	3.9	72	6.6	1.3	61
LSD$_{05}$			2.9			1.5	

Note: DP – disease prevalence, %; DD – disease development, %; TE – technical efficiency, %
Source: research results of the authors of this study

The study of the effect of biological preparations on scab damage to apple fruit helped establish their negative impact on the pathogen. The number of diseased fruits decreased by 22.7-35.6%, and the intensity of their damage was lower by 5.1-6.4% (Table 3). The technical efficacy of the preparations was as follows: Ampelomycin – 68%, Gliocladin – 62%, and Fluorescin – 78%.

The analysis of yields in variants involving biological preparations against apple diseases showed their positive impact on this indicator. The preserved fruit yield was within 3.7-4.4 t/ha compared to the variant where no preparations were used (Fig. 2). The highest yield of apple trees was observed in the case of spraying the plants with the biological preparation Ampelomycin at a rate of 6 l/ha.

Table 3. The effect of biological preparations on scab damage to apple fruit (Institute of Horticulture NAAS, Renet Simirenko variety, average for 2021-2022)

Variant	Consumption rate, l/ha	Fruits		
		DP	DD	TE
Control (without processing)	–	53.1	8.2	
Ampelomycin BT	6.0	30.2	2.6	68
Gliocladin BT	10.0	30.4	3.1	62
Fluorescin BT	8.0	17.5	1.8	78
LSD_{05}			1.9	

Note: DP – disease prevalence, %; DD – disease development, %; TE – technical efficiency, %
Source: research by the authors of this study

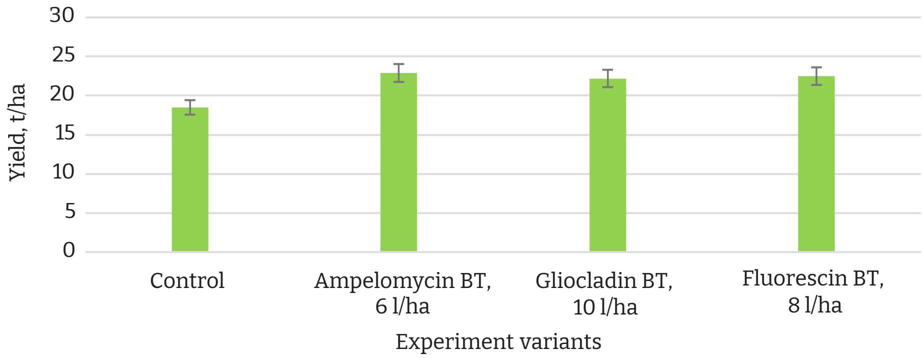

Figure 2. The impact of biological preparations on apple yields
Note: average for 2021-2022, Renet Simirenko variety
Source: developed by the authors

The presented findings indicate the ability of biological preparations Ampelomycin BT (based on the fungus of the genus *Ampelomyces* Ces ex Shlecht.), Gliocladin BT (containing mycelium and spores of the fungus of the genus *Gliocladium*) and Fluorescin BT (bacteria of the genus *Pseudomonas*) to reduce the spread and development of scab and powdery mildew of apple trees, which ultimately ensures the preservation of the crop yield. Notably, the scientific world has already conducted research on the control of powdery mildew fungi using representatives of the genus *Ampelomyces*. They were among the first mycoparasites to be used for this purpose, due to their ability to effectively inhibit the growth of pathogen mycelium and reduce the amount of infectious material (Prahl *et al.*, 2023).

The results of the study are consistent with the findings of Y. Kimura *et al.* (2023) on the effectiveness of Ampelomyces hyperparasites against powdery mildew on different crops. Thus, in the conditions of protected soil *Ampelomyces sp.* strain Xs-q suppressed colonies of *Podosphaera xanthii*, the causative agent of melon powdery mildew. The strain *Ampelomyces quisqualis* CPA-9 (2.5×10^5 conidia/ml) was effective against powdery mildew of zucchini and reduced the development of the disease by 61.5%. A concentration of 7.3×10^7 conidia/ml reduced the incidence by 83% (Carbó *et al.*, 2020). T.D. Kushare *et al.* (2020) found that among the biological agents investigated for the control of grape powdery mildew, *Ampelomyces quisqualis* provided 52.67% disease control.

In the study by M. Hassine *et al.* (2022), a preparation based on *Gliocladium catenulatum* strain J1446 controlled grey rot of lettuce *in vitro* by 91%. The filtrates of cell-free cultures of *G. catenulatum* Gc1 and *G. virens* Gv1 limited the growth of mycelium of the anthracnose pathogen – *Colletotrichum coccodes* and reduced the development of rot on tomato fruits. The use of *Pseudomonas fluorescens* bacteria on celery plants provided 61.2% control of powdery mildew (Ahmed *et al*., 2021). Some studies have also confirmed the ability of the bacterium genus *Pseudomonas* to reduce the spread and development of scab and powdery mildew of apple trees. Thus, K. Paliwal *et al*. (2023) investigated the compatibility of a biocontrol agent (*Pseudomonas*) with a carbendazim-based fungicide against the root rot pathogen of soybean (*Rhizoctonia solani*). Scientists have found that *P. fluorescence* inhibited the growth of *R. solani* mycelium (43%) and could withstand 0.05-0.15% carbendazim concentration. This method reduced the development of the disease by 72% compared to the control.

L.A. Shuttleworth (2021), analysing alternative strategies for controlling apple diseases, notes the possibility of using bacterial strains as potential bioagents against scab, specifically the isolate *Pseudomonas syringae*, which suppressed the disease. There is also information in the literature about the ability of *Pseudomonas fluorescens* strains to inhibit the fungus *Alternaria brassicae in vitro* and *in vivo* (Gupta *et al*., 2020). S.I. Hradchenko (2022) investigated biological preparations Kazumin 2L, RK, Phytocide-r, PhytoHelp, and MycoHelp in Ukraine, which were effective against apple scab at the level of 71-86% in years without epiphytic development of the disease. There are different opinions on the specifics of using biological preparations against *V. inaequalis*. Specifically, they can be integrated with forecasting models for the appropriate time of application (Berrie, 2019).

The studies of Z. Polat & H. Bayraktar (2021) and M. Chatzidimopoulos *et al.* (2022) indicated that the control of apple diseases is largely based on the frequent use of chemicals. Studies conducted in Greece have suggested that fivefold spraying of plants with fungicides ensured the intensity of scab development on apple fruits below 1.88% (Chatzidimopoulos *et al*., 2020). D.A. Strickland *et al*. (2022) reported that in the US, powdery mildew management programmes that included flutriafol or myclobutanil in the previous season tended to reduce the incidence of apple disease in the following spring, probably due to reduced inoculum overwintering. At the same time, scientists point out that pathogens are resistant to fungicides, which is a widespread problem (Polat & Bayraktar, 2021; Chatzidimopoulos *et al*., 2022).

Thus, further, more detailed work is needed to understand the effectiveness of biological preparations on apple trees under different environmental conditions, which will help to develop more effective disease management strategies and reduce the pesticide burden on the agrocenosis.

CONCLUSIONS

The phytopathogenic fungi *V. inaequalis* and *P. leucotricha* infect apple trees and cause dangerous diseases such as scab and powdery mildew, which lead to a shortage of fruit yield, deterioration of its quality and a considerable decrease in plant productivity. The specific feature of pathogens is the production of many generations of sporulation and the development of various diseases throughout the entire period of plant vegetation. In this study, biofungicides from antagonist and hyperparasite microbial cultures were evaluated to limit the damage to apple plants by dangerous mycoses such as scab and powdery mildew. During the experiment, they were applied five times by spraying apple plants of the Renet Simirenko variety of the Institute of Horticulture of the National Academy of Agrarian Sciences of Ukraine (IH NAAS) in the following phases: BBCH 67, 72, 74, 75, and 78. Thus, microbiological preparations based on the pycnidial fungus of the genus *Ampelomyces* Ces ex Shlecht. (Ampelomycin BT), a micromycete from the genus *Gliocladium* (Gliocladin BT,) and bacteria of the genus *Pseudomonas* (Fluorescin BT) controlled scab and powdery mildew of apple trees. Ampelomycin BT (at a rate of 6 l/ha) provided technical efficiency against scab 79% and powdery mildew – 76%, Glyocladin BT (10 l/ha) – 68% and 59%, respectively, Fluorescin BT (8 l/ha) – 72% and 61%. These biological preparations also reduced the development of scab on apple fruit, while the technical efficiency was within 62-78%. The use of biological plant protection products ensured the preservation of apple fruit yields from 3.7 to 4.4 t/ha. The highest rate was in the variant with the biological product Ampelomycin BT. The results obtained can be used to develop a system for protecting apple trees from diseases.

Promising areas for future research include the study of the specific features of using biological preparations on apple varieties characterised by different degrees of susceptibility to scab and powdery mildew. The use of biological preparations based on biocontrol agents can be an alternative to environmental protection against diseases and increase fruit production.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Ефективність біологічних препаратів проти парші та борошнистої роси яблуні

Анотація. Парша (збудник *Venturia inaequalis* Cooke (Wint.)) та борошниста роса (*Podospaera leucotricha* (Ellis & Everh. Salmon)) є шкідливими хворобами яблуні захист від яких ґрунтується на багаторазовому обприскуванні хімічними фунгіцидами. Для зменшення пестицидного навантаження на агроценози актуальним є застосування біологічних засобів захисту. Мета роботи полягала у дослідженні ефективності біопрепаратів на основі грибів і бактерій (мікопаразитів та антагоністів) проти парші та борошнистої роси яблуні. Для цього використовували комплекс методів, які включали фітопатологічну діагностику та моніторинг хвороб, фенологічні спостереження, облік урожайності, статистичний аналіз. Вивчено біопрепарати Ампеломіцин БТ (6 л/га) на основі гриба роду Ampelomyces Ces ex Shlecht., Гліокладін БТ (10 л/га), який містить міцелій та спори гриба з роду *Gliocladium* та Флуоресцин БТ (8 л/га), основою якого є бактерії роду *Pseudomonas*. Їх застосування призводило до зменшення поширення та розвитку парші яблуні, а технічна ефективність препаратів становила від 68 до 79 %. Біопрепарати також знижували ураження рослин збудником борошнистої роси за технічної ефективності 59-76 %. Обробка рослин яблуні препаратами Гліокладін БТ, Ампеломіцин БТ та Флуоресцин БТ зменшувала кількість плодів уражених паршею на 22,7-35,6 %. Технічна ефективність препаратів при цьому становила 62-78 %. Застосування досліджуваних біопрепаратів забезпечувало збереження урожаю в межах 3,7-4,4 т/га. Отримані результати свідчать про перспективність використання біологічних препаратів проти парші та борошнистої роси яблуні для екологізації захисту рослин

Ключові слова: хвороби яблуні; гриби; мікроорганізми-антагоністи; технічна ефективність; урожайність

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Influence of biologisation of the nutrition system on the transformation of biological nitrogen and formation of soybean productivity

Abstract. Rising prices for mineral fertilisers stimulate the search for alternative ways to optimise the existing and develop new technological methods of growing crops, including soybeans. One of these approaches is the intensive use of biological ways to enhance the ability of legumes to symbiosis and natural fixation of biological nitrogen from the soil air, which will help reduce the cost of plant cultivation technology. That is why the purpose of this study was to determine the effect of biological preparations on atmospheric nitrogen fixation by soybean plants using symbiotic nodule bacteria. In these studies, the method of calculation based on active symbiotic potential and symbiotic specific activity was used to determine the amount of biologically fixed nitrogen. The study analysed the effect of some inoculants and biofertilisers intended for foliar application on the development and formation of symbiotic processes in soybean plants, namely, the specific features of the formation of both general and active symbiotic potential in the vegetation stages. The influence of symbiotic productivity on soybean grain yield was also determined. Treatment of seeds with the selected preparations for the entire period of symbiosis duration provided an increase in the total symbiotic potential and active symbiotic potential. It was found that the treatment of seeds with the inoculant Bioinoculant BTU (2 l/ha) before sowing

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was more productive. Therewith, the maximum soybean grain yield of 3.31 t/ha was recorded in areas where the preparation Bioinoculant BTU (2 l/t) was treated before sowing and two fertilising applications were made in the 3rd ternate leaf stage and in the budding stage with Helprost soybean fertiliser (2.5 l/ha). The findings of this study indicate a substantial impact of symbiotic productivity and its value on soybean grain yield. Correlation and regression analyses showed that the accumulation of biological nitrogen has a considerable impact on grain yield. Thus, the use of biological preparations is an alternative to mineral fertilisers in soybean cultivation technology and they can be implemented in the production conditions of agricultural enterprises

Keywords: inoculant treatment; foliar feeding; preparations of natural origin; symbiotic potential; yield

INTRODUCTION

Nitrogen fixation is the main function of the symbiotic system formed in legumes. The strength of this indicator is determined by the efficiency (activity) of nodule bacteria. Nitrogen fixation begins when rhizobia become bacteroids that intensively synthesise nitrogenases, the content of which can reach 30% of the total protein. Together with the plants, they also protect the nitrogenases from oxygen, meet energy requirements, and assimilate nitrogen fixation products. Considering the significant climate change and, accordingly, the development and needs of modern agriculture, it is promising to find ways to increase the productivity of nitrogen-fixing symbiotic systems and their adaptive capabilities. Specifically, it is the impact of environmental factors, including stress factors, on the relationship between plants and microorganisms, elucidation of mechanisms for increasing plant resistance and improving symbiotic activity to increase plant yields. The use of biologically active substances of natural origin has been an effective means of regulating plant growth and development, optimising their relationships with microorganisms, namely nodule bacteria, which ensure the process of biological nitrogen fixation from the air by legumes.

According to the findings of S. Didur *et al.* (2019), scientists found a positive effect on nitrogen fixation processes due to optimisation of soil acidity. It was found that the maximum dynamics in the formation of the number of nodule bacteria and their mass during the vegetation of perennial legumes was caused by pre-sowing seed treatment with the biological preparation Rhizobophyt and its combination with the plant growth regulator of natural origin Emistim C. This determines the importance of investigating the effect of biological preparations on the nitrogen fixation in legumes.

Detailed studies of the biological fixation of atmospheric nitrogen by legumes under different growing conditions, its impact on the nitrogen balance in the soil and the increase of the coefficient of biological nitrogen utilisation in agriculture are among the main tasks of intensifying agricultural production. H.V. Pantsyreva *et al.* (2020) indicated that the maximum grain yield of white lupine of the Veresnevyi variety was obtained in the experimental variants with pre-sowing seed treatment with the inoculum Rhizogumin and the growth stimulator Emistim C in combination with two foliar dressings with Emistim C. Therewith, the grain yield was 3.61 t/ha. H.M. Zabolotnyi *et al.* (2020) point out that the growth characteristics, passage of distinct stages of development of legumes and nitrogen fixation activity are determined by the genetic characteristics of the species or variety. L. Symochko (2020) and O. Tkachuk & N. Telekalo (2020) investigated the features of soil microflora, the number of soil microorganisms, their functional activity and impact on biological nitrogen fixation processes. Multiparametric indicators are recommended for assessing the environmental impact of soils: microbiological and biochemical.

S.Ya. Kots *et al.* (2021) and S. Tanchyk *et al.* (2021) indicate that the study of the complex use of biological preparations made based on active strains of microorganisms – nitrogen fixers to create highly effective symbiotic systems, prevention and protection of legumes from pathogens of various aetiologies is of particular relevance. Furthermore, despite all the challenges and risks facing agriculture in Ukraine, demand for organic crop production is still important. Therefore, the development of environmentally safe ways to increase the productivity of legumes based on the use of organic-mineral fertilisers and biological preparations is relevant and is an aspect that requires further research.

Leading Ukrainian scientists V. Mazur *et al.* (2021) investigate the specific features of the development and implementation of an environmentally friendly technology to produce vegetable protein based on the symbiotic interaction of highly efficient microorganisms with modern varieties of legumes. The specific features of the influence of fungicides on the formation of the symbiotic apparatus during the pre-treatment of soybean seeds were also established. The number of root nodules under Fever treatment at the stage of two true leaves was at the level of plants without treatment. During the flowering phase of soybean, the number of root nodules gradually levelled off to the control level and increased by 33% during the bean formation phase. At the same time, the weight of root nodules was 36% less than that of control plants in the phase of two true leaves. Subsequently, during the vegetation period, the root nodule weight was observed to equalise to the values of the control plants, exceeding them by 33% in the phase of bean formation.

That is why the purpose of this study was to determine the impact of biological preparations on the process of atmospheric nitrogen fixation by soybean plants using symbiotic nodule bacteria. And determination of the relationship between the indicators of fixed symbiotic nitrogen and the level of soybean grain yield in different variants of the experiment.

MATERIALS AND METHODS

Field research was conducted in 2017-2021 in the conditions of the experimental field subordinated to Vinnytsia National Agrarian University and located in the village of Ahronomichne (Vinnytsia region). The research was conducted in compliance with the provisions of the Convention on Safety and Health in Agriculture No. 184. Soil cultivation in the experiment was generally accepted for the Forest-Steppe zone of Ukraine and ensured the formation of optimal conditions for plant growth and development by maximising weed control, moisture conservation, and levelling the soil surface. The soil of the experimental field is grey forest medium loam. On the day of sowing, the seeds were inoculated with biological preparations based on active strains of nodule bacteria (*Bradyrhizobium japonicum*), and foliar fertilisation was performed in the corresponding experimental variants according to the experimental scheme (Kots, 2021).

The field experiment was designed as follows: Factor A – Seed treatment: 1) control, 2) seed treatment with BTU bio-inoculant (2 l/t), 3) seed treatment with Rhizoline (2 l/t) + Rhizosave (2 l/t), 4) seed treatment with Anderhiz (1.5 l/t). Factor B – Foliar feeding: 1) control, 2) Biocomplex BTU (1.0 l/ha), 3) Humifriend (1.0 l/ha), 4) Helprost soya (2.5 l/ha).

The size of the experimental plot is 40 m^2, and the accounting plot is 25 m^2. The replication was fourfold, and the plots are systematically placed. Climatic conditions, such as temperature and precipitation, were generally favourable for soybean growth and development in the years under study, although there were deviations from the long-term average. For the research, the Madison soybean variety was sown. The biological preparations for inoculation and foliar dressing under study are products of BTU Center. When the soil was warmed up to a depth of 10 cm to +12°C, seeds were sown at a seeding rate of 650 thous./ha and a row spacing of 45 cm. Foliar application of biological preparations in the areas defined by the scheme in the experiment was performed in the phase of the 3rd ternate leaf and budding. The research was conducted according to generally accepted methodological guidelines. The number and wet weight of nodules on the roots and, accordingly, the symbiotic productivity of soybean plants were estimated based on calculations of total (TSP) and active (ASP) symbiotic potential and specific symbiosis activity (SSA) according to the method of H.S. Posypanov (1991).

$$TSP = \frac{M_1+M_2}{2} * T, \tag{1}$$

where TSP is the total symbiotic potential, thous. kg day/ha; T is the period between two adjacent periods of analysis, days; M_1, M_2 is the average mass of nodules for the period T, kg/ha.

$$ASP = \frac{M_1+M_2}{2} * T, \quad (2)$$

where ASP is the active symbiotic potential, thous. kg day/ha; T is the period between two adjacent periods of analysis, days; M_1, M_2 is the average mass of nodules for the period T, kg/ha.

$$SSA = \frac{N_1+N_2}{ASP_1-ASP_2}, \quad (3)$$

where SSA is the specific symbiosis activity, gN/kg; N_1, N_2 is the maximum use of nitrogen by plants in the corresponding variants of the experiment for separate periods or for the vegetation as a whole, kg/ha; ASP_1, ASP_2 is the active symbiotic potential in the compared variants, thous. kg day/ha.

Before harvesting, a sample sheaf from each variant was selected to determine the individual productivity of the plants. Harvesting was performed according to the method of separate threshing in the phase of full ripeness, adjusted for standard moisture. The mathematical processing of the results was performed according to the method of dispersion and correlation-regression analysis using computer software packages (Excel, Statistica, Agrostat) according to the methodology of V.O. Ushkarenko *et al.* (2013). Experimental studies of plants (both cultivated and wild), including the collection of plant material, were following the institutional, national, or international guidelines. The method of calculating fixed nitrogen according to active symbiotic potential and specific symbiosis activity was used in the research. The authors adhered to the standards of the Convention on Biological Diversity (1992) and the Convention on the Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS AND DISCUSSION

The specific feature of the formation of the total symbiotic potential of soybean and the impact of pre-sowing seed treatment and foliar fertilisation on this indicator are presented in Table 1.

Table 1. Dynamics of the formation of the total symbiotic potential of soybean depending on pre-sowing seed treatment and foliar fertilisation, on average for 2017-2021, thous. kg d/ha

Seed treatment	Foliar dressing	Phases of growth and development					Over the entire period of symbiosis
		3rd ternate leaf	beginning of flowering	end of flowering	full filling of seeds	physiological maturity	
Control	1	1.069	2.320	4.013	3.244	0.828	11.474
	2	1.126	2.636	4.966	4.299	1.085	14.113
	3	1.100	2.526	4.222	3.610	0.906	12.364
	4	1.108	3.222	5.544	5.140	1.150	16.164
Bio-inoculant BTU	1	1.676	4.057	6.362	5.248	1.248	18.592
	2	2.019	5.289	7.833	6.316	1.524	22.980
	3	1.986	4.813	6.844	5.743	1.253	20.641
	4	2.116	6.074	8.115	6.886	1.620	24.811
Rhizoline + Rhizosave	1	1.210	3.086	4.986	3.798	0.860	13.940
	2	1.320	4.288	5.908	5.055	1.216	17.787
	3	1.233	3.778	5.500	4.805	1.100	16.417
	4	1.347	4.876	6.926	5.910	1.467	20.526
Anderhiz	1	1.334	3.171	5.175	4.130	0.944	14.753
	2	1.464	4.476	6.582	5.520	1.311	19.353
	3	1.493	3.885	5.740	5.029	1.156	17.303
	4	1.519	5.200	7.209	5.986	1.482	21.395
V, %		23.6	27.7	20.1	20.3	20.3	21.6
Sx %		6.0	6.9	5.0	5.2	5.1	5.4

Note: without fertilisation (control); 2. Biocomplex BTU (1 l/ha); 3. Humifriend (1 l/ha); 4. Helprost soya (2.5 l/ha)
Source: developed by the authors of this paper based on own research

Based on the results obtained, it was found that the percentage of ASP in the TSP before the period of end of flowering – full seed filling, in terms of experimental variants, ranged within 83-97%, and later this ratio decreased to 41-57%, which is explained by the deterioration of nitrogen fixation conditions. During the research, data were obtained indicating the formation of the maximum indicators of the total – 4.013-8.111 thous. kg-days/ha and active symbiotic potential – 3.702-7.258 thou. kg-days/ha in the phase of the end of flowering. It was found that the formation of the level of symbiotic potential of soybean plants was significantly influenced by pre-sowing seed treatment with inoculants, which provided more active colonisation of soybean plant roots by symbiotic bacteria, activation of the process of symbiosis formation, which in turn contributed to the growth of biological nitrogen fixation by microorganisms. The data obtained in the experiment on the formation of active symbiotic potential of soybean in the dynamics under the influence of pre-sowing seed treatment and foliar feeding are presented in Table 2.

Table 2. Dynamics of formation of active symbiotic potential of soybean depending on pre-sowing seed treatment and foliar dressing, on average for 2017-2021, thous. kg d/ha

Seed treatment	Foliar dressing	Phases of growth and development					Over the entire period of symbiosis
		3rd ternate leaf	beginning of flowering	end of flowering	full seed filling	physiological maturity	
Control	1	0.876	1.998	3.702	3.134	0.405	10.116
	2	0.933	2.375	4.572	3.786	0.440	12.106
	3	0.894	2.094	4.015	3.522	0.418	10.943
	4	0.896	2.597	4.820	4.090	0.530	12.933
Bio-inoculant BTU	1	1.305	3.542	5.253	4.699	0.601	15.401
	2	1.789	5.072	6.733	5.166	0.790	19.550
	3	1.655	4.421	6.335	4.917	0.698	18.026
	4	1.818	5.590	7.258	5.260	0.804	20.730
Rhizoline + Rhizosave	1	1.120	2.717	4.149	3.644	0.460	12.091
	2	1.248	4.071	5.636	4.230	0.499	15.684
	3	1.175	3.594	5.271	4.046	0.473	14.558
	4	1.264	4.461	6.709	4.587	0.607	17.628
Anderhiz	1	1.223	3.041	4.276	3.833	0.537	12.910
	2	1.317	4.321	5.828	4.400	0.645	16.511
	3	1.271	3.756	5.532	4.251	0.554	15.364
	4	1.337	4.661	6.820	4.850	0.736	18.404
V, %		23.5	29.9	20.6	14.3	22.5	20.8
Sx %		5.9	7.5	5.1	3.6	5.6	5.0

Note: 1. without fertilisation (control); 2. Biocomplex BTU (1 l/ha); 3. Humifriend (1 l/ha); 4. Helprost soya (2.5 l/ha)
Source: developed by the authors of this paper based on own research

Thus, analysing the generalised data for the years of research, considering the duration of the entire symbiotic period, seed treatment with Rhizolineh (2 l/t) + Rhizosave (2 l/t) and Anderhiz (1.5 l/t) contributed to an increase in the indicators of TSP and ASP, respectively, by 2.466-3.280 thous. kg d/ha and 1.975-2.794 thous. kg d/ha compared to the data on the control variant without inoculation. The pre-sowing treatment of seeds with the inoculant Bioinoculant BTU (2 l/ha) proved to be more productive, with an increase in the level of total symbiotic potential compared to the control of 7.118 thous. kg-days/ha, and active 5.285 thous. kg-days/ha.

The research results suggest that one of the ways to mobilise internal reserves of nitrogen fixers to achieve maximum intensification of the biological nitrogen fixation, apart from seed inoculation, is foliar dressing, which improves the physiological activity of nodule bacteria, improves physiological and biochemical processes that take place during the fusion of inert nitrogen molecules and their conversion into compounds available to plants, resulting in an increase in the value of active symbiotic potential.

Foliar application of Biocomplex BTU biological preparation (1.0 l/ha) provided an increase in TSP and ASP, depending on pre-sowing seed inoculation, by 2.639-4.599 thous. kg-days/ha and 1.990-4.149 thous. kg-days/ha, respectively. Somewhat lower efficiency was observed when using a complex fertiliser based on potassium humate Humifriend (1.0 l/ha) for foliar dressing, with an increase in the TSP and ASP compared to the control of 0.890-2.550 thous. kg-days/ha and 0.827-2.625 thous. kg-days/ha, depending on the variants for pre-sowing seed treatment. The use of Helprost Soya fertiliser (2.5 l/ha) for foliar fertilisation increased these indicators by 4.691-6.642 thous. kg-days/ha and 2.817-5.537 thous. kg-days/ha, respectively.

Based on the results of the study, it was found that on average in 2017-2021, the amount of biologically fixed nitrogen was the lowest in the control, i.e., without seed inoculation and foliar feeding, and amounted to 49.7 kg/ha. Pre-sowing treatment of seeds with Bioinoculant BTU (2 l/t) increased the accumulation of biologically fixed nitrogen by 26 kg/ha, treatment with Rhizoline (2 l/t) + Rhizosave (2 l/t) – by 10.1 kg/ha, and the use of Anderhiz inoculant (1.5 l/t) increased this indicator by 13.8 kg/ha, respectively, compared to the untreated variants.

Foliar feeding of plants had a positive effect on photosynthesis performance, which led to a better supply of carbohydrates to plants and nodules used for biological nitrogen fixation, increased the value of symbiotic potential, and as a result, had an intensive impact on nitrogen fixation performance. According to the research results, it was found that foliar fertilisation in the phase of the 3rd ternate leaf and again in the budding phase with the biological preparation Biocomplex BTU (1.0 l/ha) increased nitrogen fixation by 9.8-20.4 kg/ha (59.5-96.5 kg/ha), depending on seed inoculation. The level of nitrogen fixation was 53.9-88.7 kg/ha, which is 4.1-12.9 kg/ha more than in the control variants where foliar fertilisation was performed using a complex fertiliser based on potassium humate Humifriend (1.0 l/ha) (Fig. 1).

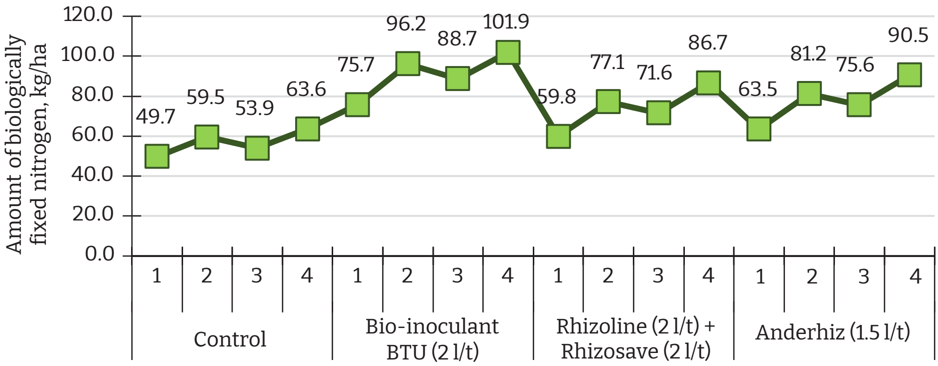

Figure 1. Amount of biologically fixed nitrogen depending on seed treatment and foliar fertilisation, on average for 2017-2021, kg/ha

Note: 1. without fertilisation (control); 2. Biocomplex BTU (1 l/ha); 3. Humifriend (1 l/ha); 4. Helprost soya (2.5 l/ha)

Source: compiled by the authors of this study

The most intensive fixation of biological nitrogen by soybean plants was observed in those areas of the experiment, where the organo-mineral fertiliser Helprost soybean (2.5 l/ha) was used for foliar feeding. In these variants, depending on the pre-sowing seed treatment, the amount of biologically fixed nitrogen was 63.6-101.9 kg/ha, which is 13.8-26.2 kg/ha more than in the control. These studies on the grey forest soils of the Right-Bank Forest-Steppe showed that soybean grain yields strongly depend on the climatic conditions of the year under study and the factors under study, namely pre-sowing inoculation of the seed and foliar dressing. It was found that the average grain yields for 2017-2021 ranged from 2.47 to 3.31 t/ha (Fig. 2).

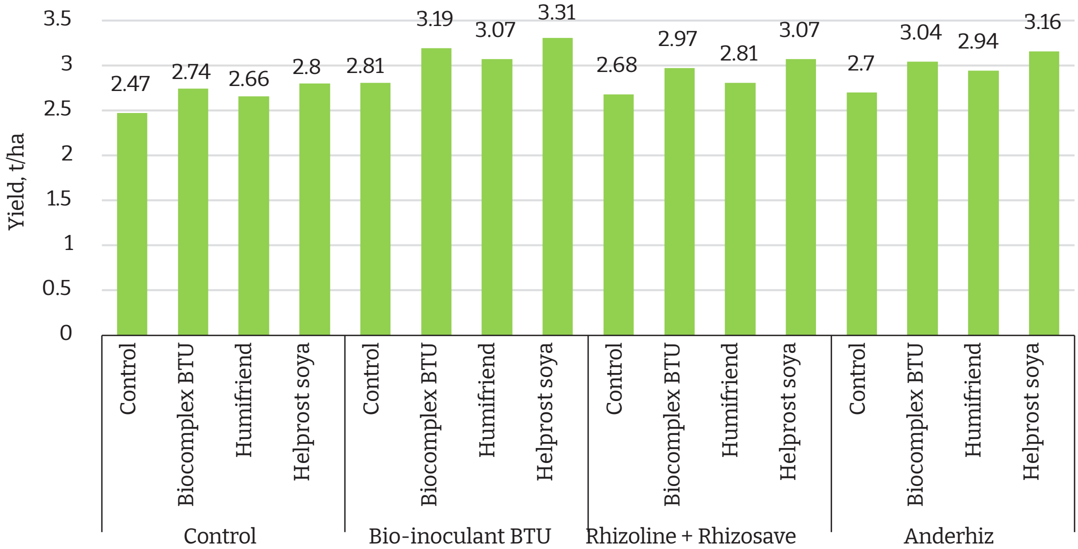

Figure 2. Soybean grain yield depending on pre-sowing seed treatment and foliar feeding, average for 2017-2021, t/ha

Source: compiled by the authors of this study

In the variant where soybean seeds were treated with the inoculant Bioinoculant BTU (2 l/t) before sowing and two foliar fertilisations were performed in the phase of 3 leaves and budding with the organo-mineral fertiliser Helprost soybean (2.5 l/ha), the maximum soybean grain yield was 3.31 t/ha, which is 0.84 t/ha (34.0%) more than in the control without pre-sowing seed treatment and foliar dressing. The symbiotic productivity of crops had a significant impact on soybean grain yield. Thus, statistical analysis of the data revealed a significant impact of the amount of biological nitrogen accumulation on grain yield. A regression equation can be used to describe this relationship between grain yield and the amount of biological nitrogen accumulated in the soil:

$$\gamma = 1{,}2618 + 0{,}022 \times \chi, \tag{4}$$

where *Y* is the grain yield, t/ha; X is the amount of biological nitrogen accumulated in the soil, kg/ha.

The correlation coefficient was r = 0.938, and the adjusted coefficient of determination, respectively, was $r^2 = 0.879$. O. Tkachuk & N. Telekalo (2020) showed that under conditions of growing field crops with insufficient fertilisation and the absence of legumes, there is a gradual decrease in the content of organic matter and nitrogen in the soil. This process is caused not only by mechanical tillage and intensification of oxidation processes, but also by the removal of nitrogen with the crops. Thus, the consumption of humus (mineralisation) during grain cultivation reaches 0.5-0.7 and even 1.0 t ha^{-1}, including 25-50 kg ha^{-1} of nitrogen. Under row crops, and especially in conditions of clean vapours, there is a further increase in the mineralisation of organic matter and a growing nitrogen deficit in the soil (1.5-2.0 t ha^{-1}, including 75-100 kg ha^{-1} of nitrogen), which subsequently leads to a general deterioration in the physical, physicochemical properties, and nutritional regime of the soil.

According to the findings of S. Tanchyk *et al.* (2021), nitrogen replenishment through symbiotic and associative nitrogen fixation is effective in the system of short crop rotations on chernozem. Against the background of fertiliser use and high crop yields, the consumption of biological nitrogen due to nitrogen fixation in pea crop rotations is 261-294 kg ha^{-1}, soybeans – 312 kg ha^{-1}, and perennial grasses (alfalfa) – 468 kg ha^{-1}. The introduction of a legume component into the crop rotation allows compensating for 40-89% of the nitrogen consumption from fertilisers and soil for subsequent crops through nitrogen fixation. According to the research results, the amount of biologically fixed nitrogen by soybean plants was 63.6-101.9 kg/ha, with the best results obtained in variants using foliar dressing with organic-mineral fertiliser. This suggests that the priority measure for the efficient use of biological nitrogen by legumes in agriculture should be a scientifically sound structure of sown areas with an optimal share of these crops and the use of biological factors to intensify cultivation technology.

The findings of V.F. Petrichenko *et al.* (2017) and H.M. Zabolotnyi *et al.* (2020) show that the most powerful fixers of biological nitrogen in crop production are perennial legumes such as clover, sainfoin, alfalfa, with a nitrogen fixation factor of 0.7-0.8. During the growing season, these crops accumulate between 30 and 38 kg of biological nitrogen per tonne of dry matter. In general, perennial legumes involve 100 to 300 kg ha^{-1} of nitrogen in the biological cycle, of which 75-200 kg is a net product for the plant; the rest is consumed by the plant from the soil. The assimilative capacity of legumes is somewhat lower than that of perennial legumes. The nitrogen fixation rate ranges from 0.4 to 0.5, with the rest of the nitrogen being used from the soil. For every tonne of dry matter of the main and by-products, lupine and fodder beans absorb 20-27 kg of nitrogen from the air; peas, soybeans, and others absorb 10-15 kg of nitrogen. A considerable part of biological nitrogen (sometimes up to 90%) during the growing season is concentrated in the above-ground mass, usually removed from the field, while the rest stays in the soil in roots and post-harvest residues, causing nitrogen to be added to the soil after mineralisation. The present study on the influence of the nutrition system on the transformation of biological nitrogen and the formation of soybean crop productivity indicates that intensive fixation of biological nitrogen by soybean plants occurs when foliar dressing with organic-mineral fertiliser is performed. In other words, to improve nitrogen fixation rates, specifically to increase the amount of biologically fixed nitrogen in legumes and soybeans, it is necessary to introduce measures of pre-sowing seed treatment and foliar dressing during the growing season with biological preparations and organo-mineral fertilisers into the crop cultivation technology.

I.M. Didur *et al.* (2019) confirms the dependence of the amount of nitrogen fixed symbiotically on the mass of root nodules with leghaemoglobin and the duration of their functioning, i.e., the period from the appearance of leghaemoglobin in the nodules to its transition to choleglobin. The indicator of active symbiotic potential ASP combines these two criteria of nitrogen fixation. The ASP for the growing season is determined by the sum of the ASP indicators for individual periods. Similarly, the total symbiotic potential of the TSP is calculated, which factors in the mass of all nodules. This indicator has a more theoretical value and is determined in cases where there is a need to determine the effect of individual environmental factors on symbiosis activity. According to the findings of O. Litvinova *et al.* (2021), the factors under study have a more intense effect on the weight of the nodules with leghaemoglobin than on their total weight. Accordingly, the formation of the indicator of active symbiotic potential is more intensively influenced. However, the data of the authors' research strongly suggest that pre-sowing treatment of seeds with the inoculant Bioinoculant BTU (2 l/ha) led to an increase in the level of total symbiotic potential compared to the control at the level of 7.118 thous. kg-days/ha, and active symbiotic potential at the level of 5.285 thous. kg-days/ha.

P. Boyko *et al.* (2019) argue that one of the ways to solve the problem of nitrogen deficiency in the soil is the use of biological features of legumes, including soybeans, which, using symbiotic nodule bacteria, can fix significant amounts of atmospheric nitrogen. To date, scientists have developed ways to not only effectively use the nitrogen-fixing capacity of this crop, but also to simultaneously mobilise hard-to-reach forms of phosphorus in the soil. O. Demyanyuk *et al.* (2019) and O.M. Kolisnyk *et al.* (2020) point out that the use of modern bacterial preparations, which, apart from symbiotic nodule bacteria, also contain phosphorus-mobilising microorganisms, can mobilise hard-to-reach forms of phosphorus.

Scientists such as L.I. Onufran & V.I. Netis (2017) argue that photosynthetic processes, which synthesise carbohydrates that serve as a source of energy for complex nitrogenase reactions of N_2 reduction, have a considerable impact on the course and activity of symbiotic nitrogen fixation. In other words, plants, through interaction with nodule bacteria, provide them with photosynthetic products, and under these conditions, they receive biologically fixed nitrogen. According to the findings of V. Mazur *et al.* (2021) and I. Gorodiska *et al.* (2018) found that nodule bacteria are biological stimulants, and therefore, apart from the ability to "fix" molecular nitrogen from the air and leave it in the soil bound in compounds easily accessible to plants, they can synthesise amino acids, vitamins, and some biologically active substances. The findings strongly suggest that one of the ways to mobilise internal reserves of nitrogen fixers to achieve maximum intensification of the biological nitrogen fixation, apart from seed inoculation, is foliar dressing, which improves the physiological activity of nodule bacteria, improves physiological and biochemical processes that take place during the fusion of inert nitrogen molecules and their conversion into compounds available to plants, resulting in an increase in the value of active symbiotic potential.

V. Mazur *et al.* (2021) note that the activity and viability of nodules on the root system in legumes, including soybeans, depends on hydrothermal factors, species and variety, mineral nutrition and soil moisture in spring and the first half of summer, soil temperature of 22-26°C, which contribute to the cyclical processes of photosynthesis and biological nitrogen fixation. This feature is also confirmed by the authors' research results. It was noted that the maximum formation of the active symbiotic potential of soybean, depending on pre-sowing seed treatment and foliar fertilisation, occurred in the flowering phase of plants with a subsequent decrease in this indicator during the vegetation of soybean crops. Under conditions of low soil temperature, there is a considerable slowdown in the work of nodule bacteria.

Scientific studies by P.S. Vyshnivskyi & O.V. Furman (2020), V.F. Petrichenko *et al.* (2017) and H.M. Zabolotnyi *et al.* (2020) reflect the dependence of the symbiotic apparatus of legumes and its intensity of development not only on the effective interaction of host plant genotypes and symbiotic microorganisms under certain growing conditions, but also on the fact that it can be influenced by certain technological methods of cultivation. Namely, the use of bacterial preparations and foliar feeding. When studying the influence of these technological methods, the authors found that pre-sowing seed treatment with the preparation Bioinoculant BTU (2 l/t) increased the accumulation of biologically fixed nitrogen by 26 kg/ha, treatment with Rhizoline (2 l/t) + Rhizosave (2 l/t) – by 10.1 kg/ha, and the use of Anderhiz inoculant (1.5 l/t) increased this indicator, respectively, by 13.8 kg/ha compared to the variants without treatment.

Researchers are interested in identifying and investigating the morphogenesis of nodules with the rhizobial system of legumes. O. Tkachuk & N. Telekalo (2020) proved that the expansion of the area under legumes in intensive crop rotation will have a positive impact on the agro-ecological state of the soil. The researchers draw attention to the possibility of accumulating a large amount of mineral nitrogen in the soil with by-products after soybean cultivation – 38.4 kg/ha. Among the legumes investigated by scientists, soybeans have the highest symbiotic nitrogen fixation capacity of 120 kg/ha. The most intensive fixation of biological nitrogen by soybean plants in the study of the authors was noted in those variants where foliar dressing with the organo-mineral fertiliser Helprost soybean (2.5 l/ha) was carried out. In these variants, depending on the pre-sowing seed treatment, the amount of biologically fixed nitrogen was 63.6-101.9 kg/ha, which is 13.8-26.2 kg/ha more than in the control.

Thus, the symbiotic productivity of crops has a significant impact on soybean grain yield. The dependence of the soybean symbiotic apparatus and the intensity of its development is determined not only by the effective interaction of the host plant genotype and symbiotic microorganisms under certain growing conditions, but also by the influence of certain technological methods of cultivation. Specifically, the use of bacterial preparations and foliar dressing.

CONCLUSIONS

Cultivating leguminous crops enables the replenishment of nitrogen through symbiotic and associative nitrogen fixation. One of the alternative ways to optimise existing developments and new technological methods of growing crops is to intensify the use of biological methods to enhance the ability of legumes to symbiosis and natural fixation of biological nitrogen from the soil air. The shortage of mineral fertilisers and the rapid and constant increase in their cost are driving research in this area.

As a result of the experiment on grey forest soils of the Right-Bank Forest-Steppe, the maximum value of the total 24.811 thousand kg-days/ha and the active symbiotic potential of 20.730 thous. kg-day/ha of soybean plants, for the entire period of symbiosis, was formed under the conditions of a combination of pre-sowing seed treatment with Bioinoculant BTU (2 l/t) and foliar feeding with organo-mineral fertiliser Helprost soybean (2.5 l/ha). The highest amount of biological nitrogen in the atmosphere of 101.9 kg/ha of soybean plants was observed in those variants of the experiment where foliar feeding with organo-mineral fertilizer Helprost soybean (2.5 l/ha) was performed against the background of seed inoculation with Biocomplex BTU (1.0 l/ha). Therewith, the value of symbiotic productivity had a significant impact on soybean grain yield. Thus, the correlation and regression analysis revealed a close relationship between the amount of biological nitrogen accumulation and grain yield. The data obtained indicate that the use of biological preparations is a viable alternative to mineral fertilisers in soybean cultivation. The effect of the biological preparations and organic-mineral fertiliser under study on symbiotic nitrogen fixation by soybean plants is a confirmation of this. That is why one of the priority measures for the efficient use of biological nitrogen from legumes in agriculture should be a scientifically sound structure of sown areas with an optimal share of these crops. A promising area for future research is a detailed study of the specific features of symbiotic nitrogen fixation in legumes under the biologisation of their nutrition system.

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CONFLICT OF INTEREST

None.

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Вплив біологізації системи живлення на трансформацію біологічного азоту та формування продуктивності посівів сої

Анотація. Зростання цін на мінеральні добрива стимулює пошук альтернативних шляхів оптимізації існуючих та розробки нових технологічних прийомів вирощування сільськогосподарських культур, зокрема сої. Одним із таких підходів є інтенсивне застосування біологічних шляхів посилення здатності бобових культур до симбіозу і природної фіксації біологічного азоту із ґрунтового повітря, що сприятиме здешевленню технології вирощування рослин. Саме тому метою досліджень було визначення впливу біологічних препаратів на процес фіксації атмосферного азоту за допомогою симбіотичних бульбочкових бактерій рослинами сої. У цих дослідженнях для визначення кількості біологічно фіксованого азоту використовувався метод обчислення за активним симбіотичним потенціалом та симбіотичною питомою активністю. В ході дослідження було проаналізовано дію ряду препаратів для інокуляції та біодобрив, призначених для листкового підживлення, на розвиток та формування симбіотичних процесів в рослинах сої, а саме – особливості формування по фазах вегетації як загального, так і активного симбіотичного потенціалу. Також визначено вплив величини симбіотичної продуктивності на урожайність зерна сої. Оброблення насіння обраними препаратами за весь період тривалості симбіозу забезпечила зростання загального симбіотичного потенціалу та активного симбіотичного потенціалу. Встановлено, що оброблення насіння інокулянтом Біоінокулянт БТУ (2 л/га) перед посівом виявилось більш продуктивним. При цьому показник максимальної урожайності зерна сої 3,31 т/га зафіксований на ділянках, де до посіву проводили обробку препаратом Біоінокулянт БТУ (2 л/т) а, також, здійснювали два лситкових підживлення добривами у фазу 3-го трійчастого листка та у фазу бутонізації добривом Хелпрост соя (2,5 л/га). Результати дослідження свідчать про суттєвий вплив симбіотичної продуктивності та її величини на урожайність зерна сої. Кореляційний та регресійний аналізи показали, що накопичення біологічного азоту має значний вплив на врожайність зерна. Таким чином, використання біологічних препаратів є альтернативою мінеральним добривам в технології вирощування сої і вони можуть впроваджуватися у виробничих умовах сільськогосподарських підприємств

Ключові слова: обробка інокулянтом; листкові підживлення; препарати природнього походження; симбіотичний потенціал; урожайність

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Sensory and bioactive quality indicators of fresh and dried blue honeysuckle fruits (*Lonícera caeruléa* L.)

Abstract. The relevance of the study is based on the special value of blue honeysuckle berries, since they contain a significant amount of biologically active substances that are endowed with antioxidant properties, but they have a short period of consumption. To extend it and provide the population with nutritional products, the goal was set to identify varieties whose fruits are the most suitable for processing by drying. Laboratory methods were used for the biochemical study

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of fruits and statistical methods (using the STATISTICA programme and Anova variance analysis, sensory indicators of the quality and content of phytosubstances, namely: vitamin C, polyphenols, flavonoids, anthocyanins and chalcones in fresh and dried fruits of the varieties `Boreal Blizzard`, `Boreal Beauty`, `Boreal Bist` and `Karina` were considered). As a result of the conducted research, varieties were identified that, in the process of heat treatment, preserved sensory and consumer quality indicators as much as possible in relation to the fresh analogue. The range of variation of polyphenolic substances was established, which was within the minimum of 7,370 (`Karina') and the maximum of 7,336 mg/100 g of dry weight (`Boreal Blizzard'), the percentage of their preservation in dried berries was the highest in the variety `Boreal Beauty`. The average content of flavonoids in fresh fruits of the studied varieties was 1,064 ± 240 mg/100 g, anthocyanins – 1,520 ± 289 mg/100 g of dry weight. Drying of berries contributed to an increase in the amount of these substances by 55-110% for flavonoids and by 48% for anthocyanins. It is proved that during the drying process, the fruits of blue honeysuckle lose vitamin C, losses depending on the variety are 65-72%. The findings will be useful in selecting parent forms for creating raw varieties and when choosing a variety for drying and making natural fruit powder concentrates with a high content of biologically active substances

Keywords: organoleptic analysis of fruits; drying; polyphenols; flavonoids; anthocyanins; chalcones

INTRODUCTION

Honeysuckle berries attract attention not only because of their attractive appearance and taste, but also because of their rich biocomponent composition. The fruits of berry crops are a useful food product due to the high content of biologically active substances, which are natural antioxidants (Sun *et al.*, 2019). One of which is ascorbic acid, also known as vitamin C. The fruit is rich in ascorbic acid and is the main source of human consumption (Zheng *et al.*, 2022). Vitamin C plays an important role as an antioxidant, counteracting harmful processes such as inflammation. Blue honeysuckle is considered one of the richest sources of ascorbic acid among all berries. Its content may vary depending on the climate and growing conditions, genotype, stage of ripeness, and time of harvesting. Another important phytoelement of blue honeysuckle fruits is polyphenolic substances. As stated by B. Sgorbini *et al.* (2019), it is these substances that can protect the human body from the effects of exogenous and endogenous free radicals. They are important components of the fruits of many fruit plants. These substances have antioxidant properties, help fight stress and prevent the development of a number of diseases.

Berries contain a significant amount of water in their composition, so during a short storage time, quality loss and deterioration of appearance are possible, which leads to a decrease in the economic efficiency of their production. E. Dermesonlouoglou *et al.* (2018) noted that its harvest seasons are short, and therefore, fruits are not available all year round, which limits their commercialisation and consumption. Therefore, drying processes occupy an important place in the food industry. Usually, heat treatment is used to reduce the harmful microbiological and chemical load, which worsens the quality of products. According to Y.V. Yevchuk *et al.* (2019), drying fruit is one of the easiest ways to extend the shelf life of fruit, especially berries.

Hot air drying is most commonly used for the production of dehydrated fruit and berry crops. The advantage of dried products over fresh ones is the possibility of their long-term storage. In addition, drying results in a significant reduction in volume, which facilitates transportation and storage (Shende *et al.* 2019). S. Alasalvar *et al.* (2020) claim that dried fruits contain a wide range of biologically active compounds, such as phenolic acids, flavonoids, anthocyanins, vitamin C, as well as proanthocyanidin and chalcones. It is these substances that, with their strong antioxidant activity, among other mechanisms, have a positive effect on human health. A serving (40 g or about a quarter cup) of dried fruit is a good balanced dietary product, particularly in terms of fibre, water-soluble vitamins and minerals.

Dried fruits can easily be stored for a long period of time due to their reduced water content, which can also help in the production of new functional foods. A. Pažereckaitė *et al.* (2020) suggest that they can be used in food formulations, and this approach is of great importance for consumers and the processing industry. Recently, the European Commission recognised blue honeysuckle (*Lonicera caerulea* L.) as a new food product on the European market. Berries of this crop due to their significant content of high-value secondary metabolites such as ascorbic acid, anthocyanins, phenolic acids, and fatty acids are endowed with a wide range of antioxidant properties (Martinez *et al.*, 2020). Blue honeysuckle is a new crop for the European and Ukrainian markets, so it requires a comprehensive study, including its suitability for various types of processing, one of which is drying by convection. According to R. Becker & A. Szakiel (2019), growing plants of the species *Lonicera caerela* L. is popular because of the early ripening of the fruit, the exceptional resistance of the plant to frost, pests and diseases, and because of its potential health and healing properties.

Researchers M. Senica *et al.* (2020) found that drying blue honeysuckle berries helped reduce the polyphenol content by more than 70% compared to fresh ones. As a result of the analysis of literature sources, it was found that there is a gap and a lack of data on the effect of heat treatment on the preservation of sensory and phytochemical indicators of the quality of blue honeysuckle fruits, namely the varieties `Boreal Blizzard`, `Boreal Beauty`, `Boreal Bist` and `Karina`, so the conducted research is relevant and necessary, both for scientists and producers of dried fruits. Since according to the data, drying of food products usually leads to deterioration of the product not only from a sensory standpoint, but also from a physico-chemical and nutritional standpoint, the purpose of the study was to investigate changes that occur in the fruits of blue honeysuckle during the drying process and to identify varieties whose fruits are an excellent raw material for this type of processing according to a complex of preserved quality indicators.

MATERIALS AND METHODS

The study was conducted during 2020-2021. The objects of research were the fruits of blue honeysuckle – varieties of Canadian selection 'Boreal Blizzard', 'Boreal Beauty', 'Boreal Bist', as well as Polish – 'Karina'. Fruits for laboratory tests were selected at experimental sites of the laboratory of selection and technology of growing berry crops of the Institute of Horticulture of the National Academy of Agrarian Sciences (NAAS) of Ukraine. Year of creation of plantings – 2016, planting scheme 1×3 m, the soil of the site is grey forest medium loamy. The system of soil retention in a row is mulching with sawdust, in the row spacing – sodification. The experiment was laid with irrigation, the care of plantings is recommended for the forest-steppe zone of Ukraine. The zone's climate is temperate continental. According to long-term data, the average air temperature was +9.7°C and the amount of precipitation for the year was 466.3 mm. The minimum average long-term temperature – negative 28.4°C (February), the maximum – 37.7°C (August).

Analytical studies were conducted in the laboratory of post-harvest quality of fruit and berry products of the Institute of Horticulture of the National Academy of Agrarian Sciences (NAAS) of Ukraine. The weight of one sample was one kilogramme (National Standard ISO 874-2002, 2003). On the day of fruit collection, the content of total polyphenols, anthocyanins, flavonoids, and chalcones was determined. Blue honeysuckle berries in a state of consumer ripeness with a characteristic shape and colour for each of the studied varieties were subject to laboratory tests according to the "Methodology for assessing the quality of fruit and berry products" (Kondratenko *et al.*, 2008). For analytical studies of fruits, in particular, determination of the content of biologically active substances, samples were prepared using a laboratory homogeniser – Waring 800s (USA). The sample was weighed on an analytical scale – TVE-3-0,05-a (Ukraine) with an accuracy of up to the second sign.

Drying of blue honeysuckle berries was carried out in a drying cabinet "Sadochok 2M" (Ukraine) at a temperature of 65°C for 14 hours. The fruit was cut in half for drying and placed in a single layer on trays to be sent into the drying oven. The drying process was considered complete when the final moisture content of the fruit was 18%. At this humidity, the product is suitable for long-term storage under certain conditions.

Before and after drying, organoleptic analysis of fruits was performed for the following sensory indicators: appearance, colour, taste, and the content of total polyphenols, flavonoids, anthocyanins, and chalcones were determined from biochemical indicators. For both fresh and dried fruits, the data obtained were expressed in mg/100 g of dry weight, and the results of the tasting assessment were expressed in points.

Sensory analysis of dried samples was performed on a 9-point Hedonic Scale with the following levels of preference: 9 – Like Extremely, 8 – Like Very Much, 7 – Like Moderately, 6 – Like Slightly, 5 – Neither Like nor Dislike, 4 – Dislike Slightly, 3 – Dislike Moderately, 2 – Dislike Very Much, 1 – Dislike Extremely (Civille & Carr, 2015). For organoleptic analysis, a group of tasters of different ages was selected from fifteen researchers, six of whom were men, the rest were women. The tasting was conducted without specifying the name of the variety, each taster was presented with samples of fresh and dried fruits in the amount of 50 g on a separate tray. Each sample had a separate number. The results of organoleptic assessment of sensory traits, namely appearance, colour, taste, and the overall score, expressed in points, were mathematically processed and presented as an average.

Vitamin C content (ascorbic acid) was determined according to the method based on its extraction from berry samples with a mixture of 2% aqueous oxalic solution and 1% aqueous hydrochloric acid solution (80:20). 5 g of crushed fruit was ground using broken glass and transferred to a measuring flask with a capacity of 100 ml. The contents of the flask were brought to the mark with a mixture of 2% oxalic and 1% acetic acids (80:20) and left for extraction for 10 minutes. The resulting extract was filtered through a cotton wool filter into a 100 ml flat-bottomed flask. In a glass with a capacity of 50 ml, 10 ml of the extract was added and titrated from the microburette with a solution of 2.6 – dichlorophenol-indophenol with sodium salt (Tilmans paint) until a slightly pink colour appeared, which did not disappear for 1 min. The amount of paint that has been oxidised is used to determine the vitamin C content, and a mixture of oxalic and acetic acids is used as a control (Kondratenko *et al.*, 2008).

The content of total polyphenols was determined according to the method of P.V. Kondratenko *et al.* (2008), which is based on the extraction of phenolic substances from berry samples with ethyl alcohol. To do this, 5 g of crushed berry samples were added to a porcelain mortar, a small amount of ethyl alcohol was added and filtered under vacuum on a Buchner funnel through a blue ribbon paper filter into a Bunsen flask. The residue on the filter was washed with a small amount of ethyl alcohol until the sample was completely discoloured. The number of washes depended on the intensity of staining of the sample and was 3-5 times. The volume of alcohol used is recorded in ml. 7.9 ml of distilled water, 0.1 ml of extract, 1 ml of Folin-Denis reagent were added to the test tube, mixed and after 3 minutes 1 ml of saturated sodium carbonate solution was added and mixed again. For an hour, the optical density of the contents of test tubes was recorded on an ULAB 102UV (China) spectrophotometer at a wavelength of 640 Nm. For control, a mixture prepared from 8 ml of distilled water, 1 ml of Folin-Denis reagent and after 3 minutes, 1 ml of saturated sodium carbonate solution was added.

Total polyphenol content in the sample was calculated by equation (1):

$$X = (A \times V \times 100) \div (V_1 \times M), \tag{1}$$

where X – total polyphenol content in the sample, mg/100 g; A – amount of chlorogenic acid in the volume taken for spectrophotometric determination, found according to the calibration graph, mcg; V – total volume of the final extract of the sample, ml; V_1 – volume of aliquot of the final extract of the sample taken for analysis, ml; M – sample weight, g (Kondratenko *et al.*, 2008). The content of anthocyanins and chalcones was determined by spectrophotometric method (ULAB 102UV spectrophotometer). The absorption of extracts was determined at wavelengths of 530 and 364 Nm, respectively, using an alcohol extract from plant homogenate acidified with 3.5% hydrochloric acid (Kryventsov, 1982). Flavonoid content was determined by absorption spectrophotometry by measuring the absorption of a flavonoid complex with a 3% aluminium chloride solution. An ULAB 102UV spectrophotometer with a wavelength of 410 Nm was used for the measurement (Vronska, 2018).

Statistical data processing was performed using the STATISTICA 13/1 software suite (StatSoft, Inc., USA). The results are presented as averages with their standard errors as the mean ± standard error (x ± SE). Differences between repetitions and relative to the average inter-varietal value were determined using ANOVA statistical model. The results of the research are presented at the level of reliability in $P < 0.05$. Univariate variance analysis of the materiality of the influence of the genotype of the variety on the content of biologically active substances in blue honeysuckle fruits and correlation analysis were performed in Excel, Data Analysis tab.

The research was conducted within the framework of scientific studies, the results of which comply with the norms of the Convention on Biological Diversity (1992) and the Convention on the Trade in Endangered Species of Wild Fauna and Flora (1973).

RESULTS AND DISCUSSION

The appearance and colour of fresh fruits and products made from them play an important role in the consumer's choice. Secondary sensory experiences, such as taste and aroma, play a crucial role in the demand for products. Usually, when drying, organoleptic and consumer indicators of fruit quality change significantly and not for the better when compared with fresh analogues (Guiné, 2018). During the drying process, all fruits, without exception, undergo drastic changes, namely, as a result of biochemical transformations, the taste, aroma and colour change, the latter becomes less bright and acquires a brownish hue. Darkening of fruits can be caused by both enzymatic and non-enzymatic reactions.

As a result of drying, the berries of blue honeysuckle became wrinkled, lost their original shape and colour. The most drastic changes in appearance were made to the fruits of the 'Karina' variety, the tasting score of this sensory indicator was 5, while fresh berries had it at the level of 8. The appearance of fresh and dried fruits of the remaining varieties studied was rated one point higher, 9 and 6 points, respectively.

Fresh fruits of the studied varieties of blue honeysuckle were black in colour with a pronounced waxy coating. According to the results of the tasting, fresh fruits of the 'Boreal Bist' and 'Boreal Beauty' varieties had a one-dimensional colour, a tasting score of 9 points. 'Karina' and 'Boreal Blizzard' berries were rated at the level of 8 points for the specified sensory indicator. During the drying process, the wax coating of the berries degraded, they became black in colour with a pronounced gloss of varying intensity. As stated by A. Calín-Sánchez *et al.* (2020), changes in fruit colour during processing occur as a result of enzymatic darkening of the pulp. Namely, the oxidation of polyphenolic compounds by polyphenol oxidase takes place, which is accompanied by the formation of brown pigments (melanins), the so-called *o*-quinones.

The highest score, namely at the level of 8, was evaluated for this indicator in dried berries of the 'Boreal Bist' variety. A crucial role in the suitability of fruits for processing by drying is played by their ability to keep the taste as close as possible to the fresh analog. From the study group, these were berries of the 'Boreal Blizzard' variety. Tasters gave the fruits of this variety the maximum score of 8 points for taste (Fig. 1).

One of the most important components of berries is the amount of ascorbic acid. On average, it was 30.3 mg/100 g of dry matter (Krzykowski, *et al.*, 2020). An unusually large amount of vitamin C was found in the varieties \`Pereslenka\` (100.5 mg/100 g of dry matter) and \`Pavlivska\` (70.6 mg/g of dry matter). The ascorbic acid content of honeysuckle berries grown in Switzerland was 10.78-40.21 mg/g of dry matter (Auzanneau *et al.* 2018), whereas those grown in Slovenia had 17.75-25.77 mg/100 g (Senica *et al.* 2019). Blue honeysuckle varieties 'Duet' and 'Karina' grown in Poland accumulated 44.4 and 62.6 mg/100 g of vitamin C in raw weight, (Gökçe *et al.*, 2022). Berries grown in Ukraine contained vitamin C from 22.7 to 27.6 mg/100 g of raw weigh, which in terms of dry weight was 173 ('Karina') to 209 mg/100 g of dry matter ('Boreal Blizzard'). The coefficient of variation of the ascorbic acid content in the studied varieties was at a minimum level, and amounted to 13.9 – 2020, 9.6 – in 2021. These indicators of vitamin C fixation indicate a small varietal difference in its content, in particular, in the study group of varieties.

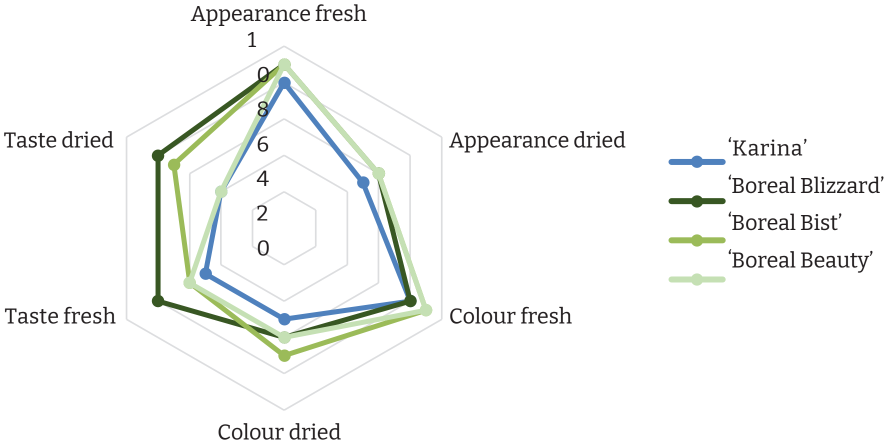

Figure 1. Sensory quality indicators of fresh and dried blue honeysuckle fruits
Source: compiled by the authors

As noted by G. Akar *et al.* (2018), drying helps to reduce vitamin C, in particular, in rosehip fruits by 2.7 times, and in wild strawberry fruits when using the convector method at a temperature of 60°C by 77.6, at a temperature of 40°C – 66.8 and 25°C – 59.6% (Krzykowski *et al.*, 2020). With other types of processing, in particular, spreads and juices, the content of vitamin C in the finished product, on the contrary, increases compared to the content in fresh fruits (Senica *et al.*, 2019). Of the blue honeysuckle varieties studied, vitamin C losses during the drying process were at least 65% for the 'Boreal Beauty' variety and 72% for the 'Boreal Blizzard' variety, 69% for the 'Karina' variety and 71% for the 'Boreal Bist' variety (Table 1).

Table 1. Ascorbic acid content in fresh and dried blue honeysuckle fruits (average for 2020-2021), mg/100 g of dry weight

Varieties	2020		2021		Average for 2020-2021		% losses
	Fresh	Dried	Fresh	Dried	Fresh	Dried	
'Karina'	183±0.05	57±0.12	162±0.08	52±0.16	173±0.06	54±0.10	69
'Boreal Blizzard'	251±0.03	70±0.08	166±0.08	47±0.17	209±0.18	59±0.19	72
'Boreal Bist'	208±0.03	56±0.12	179±0.04	55±0.21	194±0.07	55±0.11	71
'Boreal Beauty'	197±0.04	70±0.07	200±0.06	71±0.06	199±0.03	70±0.04	65
Average	210±0.02	63±0.04	177±0.04	56±0.10	193±0.09	60±0.07	69
Variation coefficient, %	13.9	12.5	9.6	18.4	7.8	12.3	4.4
min	183	56	162	47	173	54	65
max	251	70	200	71	209	70	72

Source: compiled by the authors

According to researchers from Poland, blue honeysuckle has the highest content of total polyphenols among small fruits (Ponder *et al.*, 2022). Researchers from Croatia proved that the total content of polyphenols in fresh samples of blue honeysuckle was 6,209 mg/100 g of dry matter (Žlabur *et al.*, 2019). These findings is consistent with the data obtained by researchers in the conditions of the forest-steppe of Ukraine, where blue honeysuckle berries accumulated 6,499 mg/100 g of dry weight, with a minimum value of 5,370 ('Karina' variety) and a maximum – 7,336 mg/100 g dry weight ('Boreal Blizzard' (Fig. 2), and this was significantly more than in berries grown in Poland, where the content of the above substances was 2,118.9 in organic berries and 27,263.97 mg/100 g of dry matter in berries grown using intensive technologies (Ponder *et al.*, 2022).

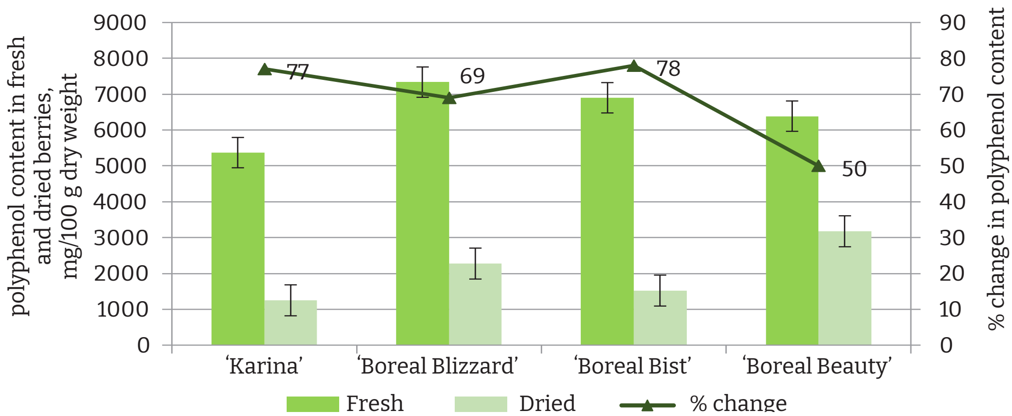

Figure 1. Content of polyphenolic substances in fresh and dried blue honeysuckle fruits (average for 2020 and 2021)

Source: compiled by the authors

The content of polyphenolic substances in fresh blue honeysuckle fruits ranged from 5,370 mg/100 g of dry matter ('Karina' variety) to 7,336 mg/100 g of dry matter ('Boreal Blizzard'). According to L. Shevchuk *et al.* (2022), the variation in the content of polyphenolic substances in blue honeysuckle is quite high, with a coefficient of variation of 22%, as also evidenced by studies by M. Senica *et al.* (2020). At the level of 6,900 and 6,387 mg/100 g of dry matter, they were accumulated by the fruits of 'Boreal Bist' and 'Boreal Beauty', respectively. Previously, the high content of polyphenolic substances in the fruits of blue honeysuckle was reported by Polish researchers. E. Hallmann *et al.* (2020) noted that the genetic characteristics of varieties of this crop have a significant impact on the chemical composition of fruits. A. Grobelna *et al.* (2020) found that berries, due to the presence of active antioxidants and anti-inflammatory compounds, help reduce the harmful effects of free radicals. They are rich sources of vitamin C, contain polyphenols, and are widely used in dietary supplements and medications. Since they have a high nutritional value, growing these berries is of great importance. Their resistance to low temperatures and early maturation make them a valuable raw material.

The most significant losses of polyphenolic compounds during the drying process were observed in the varieties 'Karina' and 'Boreal Bist' – 77 and 78%, respectively, while the best content of polyphenols was preserved in berries of 'Boreal Beauty' variety (50%). For example, pear fruits lost 30% of these substances during the drying process for 10 hours, according to A. Wilkowska *et al.* (2016). As noted by X. Li *et al.* (2019), the loss of polyphenolic substances significantly depends on their quantitative and qualitative composition. They investigated the relationship between the accumulation of polyphenols and the process of darkening apple slices during hot air drying (65°C, air velocity 2 m/s). The composition of polyphenols was determined for different varieties of apples, and among them chlorogenic acid and epicatechin were the most common, accounting for 44.47-75.45 g/100 g and 30.31-35.16 g/100 g of the total amount of polyphenols in the apple pulp, respectively. According to K.M. Moon *et al.* (2020), the decrease in total polyphenols in dried berries can be explained by the fact that the biological processes of berries are destroyed by the degradation of specific compounds due to the natural activity of the enzyme polyphenol oxidase, which induces the enzymatic browning process as soon as the berry tissue is damaged.

It is worth noting that the varietal variation of the polyphenolic component in the studied varieties was strong, as indicated by the corresponding coefficient – 43%. The conducted studies show that the flavonoid content in fresh blue honeysuckle fruits was 1,064 ± 240 mg/100 g of dry weight, significantly less than the average value of them contained berries of the varieties 'Karina' (812 ± 23 mg/100 g) and 'Boreal Bist' (961 ± 29 mg/100 g) (Table 2).

Table 2. Content of flavonoids, anthocyanins, and chalcones in fresh and dried blue honeysuckle berries (average for 2020-2021), mg/100 g of dry weight

Varieties	Flavonoids		Anthocyanins		Chalcones	
	Fresh	Dried	Fresh	Dried	Fresh	Dried
'Karina'	812 ± 23	1,708 ± 180	1,108 ± 60	1,724 ± 133	337 ± 16	977 ± 19
'Boreal Blizzard'	1,108 ± 39	1,977 ± 22	1,699 ± 100	2,325 ± 144	292 ± 18	1,268 ± 21
'Boreal Bist'	961 ± 29	2,418 ± 146	1,531 ± 91	2,440 ± 80	313 ± 22	1,140 ± 75
'Boreal Beauty'	1,376 ± 39	2,130 ± 57	1,741 ± 25	2,420 ± 90	367 ± 16	1,182 ± 123
Average	1,064 ± 240	2,058 ± 296	1,520 ± 289	2,227 ± 339	327 ± 32	1,142 ± 122
Variation coefficient, %	23	14	19	15	10	11
min	812	1,708	1,108	1,724	292	977
max	1,376	2,418	1,741	2,440	367	1,268

Source: compiled by the authors

Unlike fruits, the total flavanoid content of blue honeysuckle leaves varies from 37.21 to 20.61 mg/100 g, according to J. Xie *et al.* (2019). This difference may be related to the morphology of various plant organs and varietal characteristics, location and growing conditions, etc. Drying at 65°C for 14 hours contributed to an increase in the flavonoid content from 55 to 110%. On average, the content of the above substances in dried blue honeysuckle berries was 2,058 ± 296 mg/100 g dry weight, and the fruits of the 'Boreal Bist' variety contained more than the average value (2,418 ± 146 mg/100 g).

Blue honeysuckle fruits under growing conditions in the forest-steppe of Ukraine accumulate 1,520 ± 289 mg/100 g of dry anthocyanin weight, their maximum amount of 1,741 ± 25 and 1,699 ± 100 mg/100 g of dry weight contained varieties 'Boreal Beauty' and 'Boreal Blizzard', respectively. The data obtained are consistent with studies conducted in Slovakia, according to researcher T. Jurikova *et al.* (2012), berries *Lonicera caerulea* L. contain 1,470 mg/100 g of anthocyanins. Moreover, the above-mentioned scientists noted that the content of anthocyanins significantly depends on the type and conditions of cultivation, the limit of variation of the content is 400-1,500 mg/100 g.

The results of research have established that the fruits of varieties of Canadian selection – 'Boreal Blizzard', 'Boreal Bist', 'Boreal Beauty', in the drying process are enriched with anthocyanin content, and their amount in the finished product is – 2,350; 2,440; 2,420 mg/100 g of dry weight, respectively. Significantly higher amounts of anthocyanins in dried samples of 'Indigo Gem' blue honeysuckle (4,223.25 ± 120.10 mg/100 g of dry weight) were found by P.Y. Gökçe *et al.* (2022). R. Khattab *et al.* (2016) also noted a significant anthocyanin content in this variety – 4,033 mg/100 g of dry weight. In the 'Aurora' variety, the content of the above compounds was at the level of the data obtained in this study.

Drying at 65°C contributed to an increase in the anthocyanin content in blue honeysuckle berries by an average of 48%. J. Stojanovic & J.L. Silva (2007), W. Yuan *et al.* (2011), who studied another berry crop such as blueberries, noted a decrease in anthocyanin content. J. Stojanovic & J.L. Silva (2007) proved that the amount of anthocyanins in the berries of the above crop decreased by almost 60% compared to fresh, A. Wilkowska *et al.* (2016) reported a decrease in anthocyanin content in *Vaccinium myrtillus* berries by 57%, W. Yuan *et al.* (2011) also confirmed this claim that the anthocyanin content of eight different blueberry varieties also decreased by 60% after hot air drying. They evaluated the antioxidant activity and content of total phenols and anthocyanins in both fruits and leaves of 19 genotypes. Antioxidant activity, total phenols, and anthocyanin content remained virtually unchanged when stored at 4°C or -20°C for two weeks, but significantly decreased when the berries were oven-dried at 65°C for 48 hours.

Studies have shown that the amount of chalcones in fresh and dried blue honeysuckle fruits was stable. It was noted that the proportion of these substances in fresh blue honeysuckle fruits averaged 327 ± 32 mg/100 g of dry weight, in dried fruits – 1,142 ± 122 mg/100 g. As a result of the study, it was proved that the drying process contributed to an increase in the content of chalcones in blue honeysuckle berries by 190-335%. The highest amount of chalcones in both fresh and dried fruits was noted in the 'Boreal Beauty' variety – 367 ± 16 and 1,182 ± 123 mg/100 g of dry weight, respectively.

The conducted studies of the content of phytosubstances in fresh fruits of 4 varieties of blue honeysuckle and their changes during drying do not give a complete understanding of the effect of heat treatment on the preservation of ascorbic acid and polyphenolic components in them. Therefore, it will be advisable to conduct further research with other varieties of this crop.

CONCLUSIONS

As a result of the conducted studies, the materiality of degradation of bioactive substances (polyphenols, flavonoids, anthocyanins and chalcones) and the materiality of changes in sensory quality indicators (general appearance, circles and taste) in the fruits of blue Honeysuckle varieties 'Boreal Blizzard', 'Boreal Beauty', 'Boreal Bist' and 'Karina' during drying were established. The greatest amount of vitamin C was accumulated by the fruits of the varieties 'Boreal Blizzard' and 'Boreal Bist', polyphenolic substances – 'Boreal Blizzard', flavonoids – 'Boreal Beauty', anthocyanins – 'Boreal Bist'. The highest percentage of ascorbic acid retention (35%) was found in the 'Boreal Beauty' variety, and total polyphenols at the level of 50% were found in dried berries of the 'Boreal Beauty' variety. The amount of flavonoids up to more than 2,000 mg/100 g and anthocyanins up to more than 2,400 mg/100 g of dry weight during drying increased in the fruits of the mentioned variety and the 'Boreal Bist' variety.

It is established that during the drying process, the fruits of blue honeysuckle lose their attractiveness and their taste qualities deteriorate. In particular, dried berries of the 'Karina' variety were the least attractive in terms of appearance and colour. Best of all, according to the definition of tasters, the score is 8 points, the taste during drying was preserved by the fruits of the variety 'Boreal Blizzard'. Considering the data obtained, namely the assessment of the preservation of sensory indicators of quality and biological activity, the most suitable for processing by drying method are fruits of Canadian selection, 'Boreal Blizzard', 'Boreal Beauty', and 'Borial Bist'.

The obtained data will be useful for further scientific research on the creation of new varieties with a high content of phytosubstances. The varieties 'Boreal Blizzard' and 'Boreal Beauty' will be involved in hybridisation, since the first of these varieties, when grown in the forest-steppe of Ukraine, accumulates the most total polyphenols, and the second anthocyanins. The next research will be to expand knowledge about the impact of blue honeysuckle consumption on human health, and to create new products and technologies to maximise the use of blue honeysuckle fruits in various industries and medicine. In the future, it is possible to study the possibilities of using blue honeysuckle fruits in various industries, including the food and pharmaceutical industries. This may include creating new products, supplements, or pharmaceuticals based on this plant, determining the content of vitamins (such as vitamin C, vitamin E), minerals (such as potassium, magnesium), and antioxidants (such as flavonoids, anthocyanins) in different parts of the fruit and their changes during drying.

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CONFLICT OF INTEREST

None.

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Сенсорні та біоактивні показники якості свіжих та сушених плодів жимолості голубої (*Lonícera caeruléa* L.)

Анотація. Актуальність досліджень базується на особливій цінності ягід жимолості голубої, оскільки вони містять значну кількість біологічно активних речовин, котрі наділені антиоксидантними властивостями. але мають нетривалий період споживання.

Для його подовження та забезпечення населення нутрієнтноцінною продукцією було поставлено мету виділити сорти, плоди яких є найбільш придатними для пероброблення способом сушіння. Було використано лабораторні методи для біохімічного дослідження плодів та статистичні методи (з допомогою програми STATISTICA та дисперсійного аналізу ANOVA розглядалися сенсорні показники якості та вміст фіторечовин, а саме: вітаміну С, поліфенолів, флавоноїдів, антоціанів і халконів у свіжих та сушених плодах сортів 'Boreal Blizzard', 'Boreal Beauty', 'Boreal Bist' і 'Каріна'). В результаті проведених досліджень було виділено сорти, котрі в процесі термічної обробки максимально, по відношенню до свіжого аналогу, зберегли сенсорні та споживчі показники якості. Встановлено діапазон варіювання поліфенольних речовин, який знаходився в межах мінімуму 7370 ('Каріна') та максимуму 7336 мг/100 г сухої маси ('Boreal Blizzard'), відсоток їх збереження у сушених ягодах найвищий був у сорту 'Boreal Beauty'. Середній вміст флавоноїдів у свіжих плодах досліджуваних сортів становив 1064 ± 240 мг/100 г, антоціанів – 1520 ± 289 мг/100 г сухої маси. Сушіння ягід сприяло збільшенню кількості даних речовин на 55-110 % – флавоноїдів та на 48 % – антоціанів. Доведено, що в процесі сушіння плоди жимолості голубої втрачають вітамін С, втрати залежно від сорту становлять 65-72%. Результати досліджень стануть корисними при підборі батьківських форм для створення сировинних сортів та при виборі сорту для сушіння і виготовлення натуральних плодових порошкових концентратів з підвищеним вмістом біологічно активних речовин

Ключові слова: органолептичний аналіз плодів; сушіння; поліфеноли; флавоноїди; антоціани; халкони

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