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Growth rate, indicators of slaughter and quality of pork with the additional introduction of a chelated copper complex into the diet of pigs

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Abstract. The efficiency of conducting industrial competitive pig breeding in Ukraine depends on the level of feeding and provision of animals with the necessary biologically active substances. Lack of mineral substances leads to a decrease in growth rates, an increase in the duration of the fattening period, excessive feed consumption, and, accordingly, an increase in the cost of pork, which determines the relevance of the chosen subject. The purpose of the study was to identify the effect of the mineral additive of the copper chelate complex on the meat productivity of hybrid pigs and

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the quality of pork. the following methods are used to fulfil the purpose of the study: zootechnical (live weight dynamics, determination of average daily and relative gains), biochemical (analysis of chemical composition and microelement content in muscles, indicators of pork quality: moisture content, tenderness, marbling, colour intensity), morphological (slaughter yield parameters determination), and statistical (identification of substantial differences between values). The effectiveness of the chelated copper complex with glycine on the growth intensity of pigs, slaughter parameters, chemical and microelement composition of muscles, and pork quality indicators after cold storage is investigated. It is established that the additional introduction of a chelated copper complex into the diet increased the intensity of average daily weight gain of pigs by 9.1% and relative live weight gain by 4.5 percentage points. From pigs of this group, heavier carcasses were obtained by 4.5 percentage points with a smaller fat thickness over the 6-7 thoracic vertebra by 10.6% and an internal fat mass of 7.5%, and 9.7% more internal organs. Pork was obtained from animals of the experimental group with a lower fat content by 10.0 percentage points, a higher protein content – by 3.9 percentage points, and ash – by 12.1 percentage points. The diet with a chelated copper complex increased the moisture capacity and tenderness of pork after cold ageing, and helped reduce the caloric content of meat. The concentration of minerals in muscle tissue in the experimental group was higher in terms of copper, manganese, cobalt, iron, and zinc. Based on the obtained data, the possibility of effective feeding of the copper chelate complex with glycine to fattening pigs was established

Keywords: young pigs; live weight; microelement additive; chelated copper; slaughter yield; internal organ yield; meat quality

INTRODUCTION

It is necessary to provide proper feeding for the young animals, ensuring that they receive all the necessary nutrients to achieve the full genetic potential of meat breed pigs. This problem can be solved by using feed additives of various origins and therefore the diets of animals are determined depending on their physiological state and level of productivity, which proves the relevance of the chosen subject. The studies conducted by Ukrainian and foreign researchers A. Hutsol *et al.* (2018) and O. Skoromna *et al.* (2019) show that the use of feed with a sufficient amount of all the necessary nutrients contributes to the achievement of high rates in the reproduction, growth, development, and fattening of pigs. A variety of feed additives are used to improve feed consumption and increase the efficiency of its use, achieve maximum productivity, and obtain better quality products. Among feed additives, enzyme preparations, protein, amino acid, mineral and vitamin supplements, probiotics, prebiotics, and acidifiers are often used. Feed additives with antibacterial and immunostimulating properties, such as acidifiers, copper, and zinc, are added to the diets of pigs to maintain a balanced microbiota in the gastrointestinal tract and to control pathogens. Betaine and the trace element chromium, have a positive effect on energy and lipid metabolism in the pig body, which is described in the study by R. Fu *et al.* (2021). Animals are fed supplements containing enzymes to improve the absorption of nutrients and have a positive effect on the state of the gastrointestinal tract. However, the data obtained on the use of these additives and their impact on pig growth productivity vary from one researcher to another. They explain such discrepancies in the results obtained by the physiological state of development of animals, the period of their rearing and fattening.

O. Skoromna *et al.* (2019) noted that the importance of micronutrient supplements to the animal diet lies in the fact that they are involved in the formation of cells, tissues, organs, physiological, catalytic and regulatory functions in animals, and accordingly their inclusion in the animal diet is necessary. Mineral supplements are added to the pig's diet to improve health, digestion, and productivity (Myronenko & Usachova, 2022). Depending on the phase of pork production, a different amount of each mineral element is required in the animals' diet. The results of the study by N. Grushanska *et al.* (2018) and S. Villagómez-Estrada *et al.* (2020) confirm the positive effect of mineral supplements to improve the mineral status of piglets in rearing. They also established that in the case of excessive accumulation of these elements in the tissues, they are removed from the body. Maintaining 50% of the need for copper, iron, manganese, and zinc in a diet based on corn and soy meal is justified. A decrease in the content of certain trace elements (zinc, copper, manganese and iron) in the diets of pigs does not negatively affect the productivity of animals, but it causes a substantial decrease in the release of these minerals from the faeces. The main factor affecting the elimination of mineral elements is their concentration in feed and does not depend on the source of origin. J. Faccin *et al.* (2023) confirmed an increase in the use of alternative sources of chelated minerals, such as copper, manganese, selenium, and zinc. Feeding diets with organic trace elements included leads to an improvement in meat quality indicators. X. Bo *et al.* (2022) explain this by greater enzyme activity and protein biosynthesis. Under such conditions, pork is more resistant to protein oxidation, pork belly has a greater moisture-retaining ability. The concentration of complex minerals (calcium, zinc, copper, magnesium,

manganese, iron) in the diet of pigs improves the efficiency of feed use and meat quality, while not affecting the percentage of lean meat.

Copper is a component of metalloenzyme systems, and it can activate enzymes to better function in various biochemical processes. C. Espinosa & H. Stein (2021) argue that the growth-stimulating effect of copper occurs in pigs of different ages due to a decrease in the frequency of diarrhea and an increase in the efficiency of feed use by the body. They attribute this improvement to the effect of copper on enzymes involved in digestion and lipid metabolism. A number of authors, such as X. Li *et al*. (2022) state that the quality of meat is not affected by the dose of copper in the diet of animals.

After analysing the above studies, it was determined that the problem of proper feeding of young pigs has not been sufficiently examined, so the purpose of the study is to investigate the effect of copper chelate on the growth rate of pigs, slaughter indicators, and pork quality.

MATERIALS AND METHODS

The scientific-economic study was conducted at the "Plebanivskyi Sad" farm in Vinnytsia region, Ukraine, during 2022-2023, focusing on the hybrid piglets F1 (Velyka Bila×Landras). For this purpose, 24 pig heads with an average initial live weight of at least 32 kg were selected, which were divided into various feeding rations and raised to a final live weight of approximately 110-120 kg. The selected hybrid piglets were divided into 2 groups of 12 heads each. Groups of experimental animals were formed by the method of analogue groups, considering such factors as origin, age, gender, and live weight. The piglets involved in the study were obtained from sows of the Velyka Bila × Landras breed. In the course of studies related to feeding fattening pigs, a complete mixed feed was used that met the nutritional requirements for pigs and provided them with all the nutrients.

Piglets aged 75 days were selected for testing. At the beginning of the experiment, the pigs were given mixed feed "Grower", in the second period of fattening – mixed feed "Finisher". The period of feeding mixed feed "Grower" lasted 35 days, "Finisher" – 55 days. In the first period of fattening, piglets were fed mixed feed "Grower" until they reached a live weight of 65 kg. The composition of mixed feed "Grower" included: corn – 25%, wheat – 25%, barley – 23%, sunflower meal – 12%, wheat bran – 7%, soy cake – 3%, protein mineral vitamin supplements (PMVS) – 5%. The nutritional value of such a diet was 2173 Kcal in terms of metabolic energy, 157 g of digested protein. During the second fattening period, the pigs were fed mixed feed "Finisher" until they reached a live weight of 110 kg. The composition of this mixed feed included: barley – 38%, wheat – 24%, wheat bran – 12%, corn – 9%, sunflower meal – 9%, PMVS – 4%. In terms of nutritional value, mixed feed provided the body of pigs with 2051 kcal of metabolic energy, and 148 g of digestible protein. Pigs of the control and experimental groups were fed the main diet. Additionally, a mineral supplement was added to the diet of experimental pigs of the second group chelate complex copper, which contains 5% copper, 20% glycine. The test additive was given to pigs together with water, at the rate of 0.3 kg/ton of water. During the entire fattening period, pigs had arbitrary access to feed and water.

Pig growth was monitored by individual weighing at the beginning and end of each fattening period. Based on the results of weighing, the live weight of animals, average daily, absolute and relative weight gains during the experiment were determined. In the experiments, the consumed feed was recorded and the consumption of mixed feed per 1 kg of pork growth was calculated. Growth efficiency was evaluated by the average daily and relative live weight gain.

At the end of the experiment (day 110), 4 pigs were selected from each group that were not fed for 12 hours, and then slaughtered by electric shock (250 V, 0.5 A, for 5-6 seconds) to assess the effect of the copper chelate complex on slaughtering and pork quality. The long back muscle and internal organs (liver, spleen, kidneys, heart) were removed and weighed on an electric scale. In the muscle tissue of pigs, the physico-chemical parameters of the longest back muscle were determined: the level of initial moisture – by drying samples at a temperature of 60-65°C; hygroscopic moisture – by drying the suspension in a drying cabinet at a temperature of 103±2°C; protein content – by Kjeldahl's method; moisture retention capacity and tenderness-by pressing; caloric content-by mathematical calculation method based on chemical composition; acidity (ph) – by potentiometric method using a pH meter; colour intensity – using a photoelectrocolourimeter. Qualitative indicators of pork in terms of mineral content were determined by atomic absorption spectrometry on PRK-1M.

Data analysis was performed using variance analysis (ANOVA) using Excel 2010 software. The data is expressed as the average value of x±SD. Differences between the groups were considered statistically substantial at $P<0.05$ (adjusted for Bonferroni), comparisons were classified as substantial ($P<0.05$) or insubstantial ($p>0.10$). All experimental studies were conducted in accordance with modern methodological approaches and in compliance with the relevant requirements and standards, in particular, they meet the requirements of DSTU ISO/IEC 17025:2005 (2006). The keep of animals and all manipulations were conducted in accordance with the Order by the HCM of Ukraine No. 416/20729 on the "Approval of the Procedure of Animal Tests in Research Institutes" (Law of Ukraine No. 249, 2012), the European Convention for the Protection of Vertebrate Animals used for Experimental and other Scientific Purposes (European convention…, 1986).

RESULTS AND DISCUSSION

Studies conducted with additional administration of copper chelate complex show a positive effect on the

growth dynamics of pigs, slaughter indicators, and the quality of the resulting pork. The use of a chelated copper complex in the diet of fattening pigs (the second group) increased their live weight by 5.6% ($p<0.05$) in 110 days and by 6.5% ($p<0.05$) at 165 days in comparison with the indicators of animals of the control group (Table 1).

Table 1. *Growth rate of fattening pigs and feed payment for the introduction of a chelated copper complex into the diet, x±SD, n=12*

Indicator	Group	
	control (MD)	experimental (CC)
Live weight of pigs at the beginning of the feeding period of mixed feed "Grower" (75 days), kg	32.5±0.9	32.6±0.7
Live weight of pigs at the end of the feeding period of mixed feed "Grower" (110 days), kg	62.6±2.2	66.1±1.5
Absolute increase	30.1±1.1	33.5±0.96*
Average daily increase in live weight of pigs during the period of feeding mixed feed "Grower", g	860±24	957±22**
Relative increase in live weight of pigs during the period of feeding mixed feed "Grower", %	63.3±1.2	67.9±1.3*
Live weight of pigs at the end of the Finisher's mixed feed period (165 days), kg	112.5±8.4	119.8±7.9
Absolute increase	49.9±1.0	53.7±1.1*
Average daily increase in live weight of pigs during the period of feeding mixed feed to the Finisher, g	908±17	976±23
Relative increase in live weight of Pigs during the period of feeding mixed feed to the Finisher, %	57.0±2.1	57.8±1.9*
Average daily live weight gain for the study fattening period	888±19	969±25**

Note: ** – P<0.05; ** – P<0.01; *** – P<0.001 differences between the control and experimental groups; MD – the main diet, CC – copper chelate*
Source: *compiled by the authors*

Additional feeding of the copper chelate complex with mixed feed "Grower" increased the average daily growth in pigs by 11.3% ($p<0.01$), and during the period of feeding mixed feed "Finisher" – by 7.5% ($p<0.05$). For the entire study period of fattening animals, the average daily weight gain was higher in the second group by 9.1% ($p<0.01$). This accordingly had a positive effect on the relative increase in live weight of pigs. The supplement contributed to an increase in this indicator during the fattening period by 4.5 percentage points. Slaughter rates in pigs of both groups differed depending on the feeding diet. The use of a copper chelate complex in feeding fattening pigs increased the slaughter yield by 4.5 percentage points ($p<0.05$) compared to the animals of the control group. Pigs of the experimental group had a smaller fat thickness over the 6-7 thoracic vertebra by 10.6% ($p<0.001$). According to the indicator of the area of the "muscle eye", the best results were obtained in pigs for feeding the copper chelate complex, in which the advantage was 6.3% ($p<0.05$). Under the influence of a mineral supplement in the second group, the weight of internal fat decreased by 7.5% ($p<0.05$), the weight of the front legs increased by 4.2% (Table 2).

Table 2. *Indicators of pig slaughter with additional introduction of a chelated copper complex into their diet, x±SD, n=4*

Indicator	Group	
	control (MD)	experimental (CC)
Pre-slaughter weight, kg	111.2±3.8	115.6±3.2
Slaughter weight, kg	81.3±2.4	88.4±2.9
Slaughter yield, %	73.1±1.2	76.4±1.1*
Lard thickness over 6-7 thoracic vertebra, mm	32.1±0.9	28.7±0.8***
Internal fat, kg	1.74±0.06	1.61±0.04*
Area of the "muscle eye", cm^2	44.3±0.8	47.1±0.9*
Head weight, kg	4.2±0.07	4.7±0.03
Leg weight, g:		
front	763±24	795±28
rear	804±23	803.5±1.97

Note: ** – P<0.05; ** – P<0.01; *** – P<0.001 differences between the control and experimental groups; MD – the main diet, CC – copper chelate*
Source: *compiled by the authors*

The effect of a mineral supplement on the mass of internal organs was determined from the conducted studies. Under the influence of the test drug, liver weight increases by 12.7% ($p<0.001$), hearts – by 10.0% ($p<0.01$), lungs – by 10.0% ($p<0.001$). There was also a slight increase in kidney mass by 4.4% and a decrease in spleen mass by 4.3% compared to the control data (Table 3).

Table 3. *Weight (g) and slaughter yield (%) of internal organs of pigs with additional introduction of a chelated copper complex into their diet, g, x ± SD, n=4*

Indicator	Group	
	control (MD)	experimental (CC)
Liver, g	1832±46	2064±48***
%	1.65±0.08	1.78±0.05
Heart, g	378±17	416±19**
%	0.34±0.02	0.36±0.03
Lungs	485±12	542±18***
%	0.44±0.07	0.47±0.06
Kidneys	339±37	354±23
%	0.30±0.02	0.31±0.03
Spleen	188±34	161±27
%	0.17±0.01	0.14±0.02
Mass of internal organs, g	3226±47	3539±93**

Note: ** – P<0.05; ** – P<0.01; *** – P<0.001 differences between the control and experimental groups; MD – the main diet, CC – copper chelate*
Source: *compiled by the authors*

In general, 9.7% more internal organs were received from pigs of the experimental group ($p<0.01$). Feeding pigs a chelated copper complex in the diet increases not only the total slaughter yield but also the slaughter yield of internal organs. Correction of diets with trace elements increases the yield of the liver and heart by 7.8 percentage points and 5.9 percentage points, lungs – by 6.8 percentage points. There was a slight increase in renal yield by 3.3 percentage points and a decrease in spleen yield by 17.6 percentage points compared to the control data. Important indicators for fattening pigs are meat qualities, in particular, chemical composition, caloric content, marbling, and tenderness of meat. The nutritional value of meat depends on the quantitative ratio of moisture, protein, fat, mineral elements, and indicators of pork. The use of a copper chelate complex in pig feeding slightly increases the level of dry matter in meat of the second group. In meat samples of this group, the protein content and ash residue increased by 3.9 percentage points and 12.1 percentage points, respectively ($p<0.001$). Therewith, there is a decrease in the fat content in the meat of pigs that were fed the examined mineral preparation by 10.0 percentage points ($p<0.01$) (Table 4).

Table 4. *Chemical composition of pig meat with additional introduction of a chelated copper complex into their diet, % (x±SD, n=4)*

Indicator	Group	
	control (MD)	experimental (CC)
dry matter, %	91.6±2.4	92.3±2.7
Protein, %	64.8±2.6	67.3±2.4
Fat, %	22.8±0.7	20.5±0.9
Ash	3.3 ±0.1	3.7±0.1***

Note: ** – P<0.05; ** – P<0.01; *** – P<0.001 differences between the control and experimental groups; MD – the main diet, CC – copper chelate*
Source: *compiled by the authors*

The moisture-retaining properties of meat affect its technological characteristics, namely, juiciness and tenderness. When storing pork, these indicators vary depending on the shelf life and feeding factor of pigs. Moisture capacity is a substantial characteristic of meat and is determined by the amount of bound moisture in it. The more bound water contained in meat, the higher its technological properties will be. The action of the copper chelate complex leads to an increase in bound moisture in the muscles of pigs, which indicates an

increase in the juiciness of muscle fibres. When using the copper chelate complex, no changes were identified in the acidity, colour intensity, and tenderness of pig meat compared to the control sample. Marbling indicates the ratio of muscle to adipose tissue and is an important indicator that affects the taste and level of intramuscular fat in pork. It was established that feeding a mineral additive of the copper chelate complex led to a slight increase in the content of total and bound moisture in pig meat after daily exposure. The mineral supplement examined did not affect the active acidity value of the pH of meat (Table 5).

Table 5. *Indicators of pork quality after ageing with the additional introduction of a chelated copper complex into their diet, x±SD, n=4*

Indicator	Daily exposure time		30-day exposure time	
	Group			
	control (MD)	experimental (CC)	control (MD)	experimental (CC)
Total humidity, %	74.8±2.1	75.1±2.4	74.3±1.8	74.9±1.7
incl. bound, %	42.5±0.9	43.4±0.9	42.1±0.8	43.3±0.6
ph	5.6±0.2	5.6±0.2	5.4±0.2	5.4±0.2
colour intensity, E^{-100}	14.6±0.18	15.1±0.13	11.7±0.4	11.3±0.5
Tenderness, cm^2/g	287±12	328±13*	238±14	282±11*
Marbling	11.8±0.2	10.1±0.4***	9.6±0.2	8.2±0.3***
Caloric content, KJ	4818±43	4727±39*	4442±32	4193±64***

Note: ** – P<0.05; ** – P<0.01; *** – P<0.001 differences between the control and experimental groups; MD – the main diet, CC – copper chelate*
Source: *compiled by the authors*

The presence of adipose tissue gives pork tenderness and increased caloric content. However, a large amount of fat in meat leads to a decrease in protein levels, which in turn reduces its nutritional value. Due to the action of the copper chelate complex, there is an increase in the tenderness of meat by 14.3% (p<0.05) and a decrease in the level of marbling – by 14.4% (p<0.001) compared to the corresponding indicators in the control. According to the results of the calculation, it was identified that a decrease in the fat content in the meat of pigs of the experimental group affected a decrease in its caloric content by 1.9%.

Long-term storage of pork in a frozen state for 30 days has made some changes in its quality indicators. It has reduced the level of total and bound moisture. In addition, during the 30-day ageing of frozen pork, there was a decrease in its colour intensity in the control group by 19.8%, in the experimental group – by 25.1%, marbling – by 18.6% and 18.8%, respectively. In addition, long-term storage of pork made changes in the caloric content of meat, this indicator decreased in the control by 7.8%, in the experimental group – by 11.3%. Slightly better indicators were obtained in the experimental group, where a chelated copper complex was introduced into the diet of pigs. In terms of colour intensity in the samples of this group, compared with pork of animals that were fed the main diet, the decrease was by 21.2 percentage points, marbling – almost at the same level. The copper chelation complex also made changes in the caloric content of pork. Higher-calorie pork was obtained in the control group of animals.

Analysis of the chemical composition of pork identified changes in the selected samples depending on the diet of pigs. The additional introduction of a chelated copper complex into the diet of animals led to an increase in the content of zinc in the muscles of pigs by 7.7% (p<0.001), manganese – by 13.2% (p<0.001), copper – by 18.6% (p<0.001), cobalt – by 22.8% (p<0.01), and iron – by 8.4% (p<0.001) (Table 6).

Table 6. *Microelement composition of pig muscles with additional introduction of a chelated copper complex into the diet of animals (x±SD, n=4)*

Indicator	Group	
	control (MD)	experimental (CC)
Zinc, mg/kg	138.7±2.3	149.4±2.6***
Manganese, mg/kg	0.83±0.01	0.94±0.02***
Sulfur, mg/kg	7.78±0.11	9.23±0.12***
Cobalt, mg/kg	2.02±0.11	2.48±0.14**
Iron, mg/kg	72.5±1.4	78.6±1.5**

Note: ** – P<0.05; ** – P<0.01; *** – P<0.001 differences between the control and experimental groups; MD – the main diet, CC – copper chelate*
Source: *compiled by the authors*

Thus, high-quality pork in terms of the content of trace elements (zinc, copper, manganese, and cobalt) was established in the group of pigs that were additionally injected with a chelated copper complex in the diet. Pig breeding in Ukraine has been expanding in the area of industrial production in recent years and is becoming competitive on the world market. For this purpose, substantial efforts are being made to increase production volumes and improve the quality of pork. These data are consistent with other researchers who believe that chelated forms of trace elements are effective in feeding animals. According to the results of the study, it was established that the chelated complex of copper with glycine affects the growth rate of pigs, slaughter indicators, and pork quality. Indicators of animal growth intensity are influenced by a number of factors, among which the breed and feeding factors (Garmatyuk *et al.,* 2020). Interbreeding substantially increases the average daily live weight gain of pigs (Karpenko, 2020). In the conducted studies on examining the effect of additional administration of a copper chelate complex, hybrid young animals of Velyka Bila×Landras were used. Copper is used in pig feeding as an additive to stimulate animal productivity.Various sources of copper can alter the composition of the gut microbiota and improve gut health (Xiong *et al.,* 2023). The use of unconventional natural mineral additives in diets for fattening young pigs led to more efficient use of minerals in diets, which contributed to more intensive growth of animals and reduced feed costs per unit of production (Bomko & Baranyuk, 2017; Verbelchuk *et al.,* 2021). Given the limited amount of copper supplements in pigs' diets, the use of chelated copper may be an alternative to maintain the effect of stimulating growth and reducing exposure to the environment.

Mineral supplement based on chelated trace elements (copper, zinc, iron, manganese), examined by M. Chorny *et al.* (2018) on young pigs, allowed for higher average daily gains with lower feed costs, which contributed to additional profits. The use of biomicroelement complexes in feeding enhances the metabolic processes and stimulates the growth rate of young pigs. Complexes containing copper and cobalt in combination with tryptophan have a more noticeable stimulating effect on the clinical and physiological state of animals (Espinosa *et al.,* 2019). The use of organic copper and zinc in pig feeding does not have a lasting effect on growth productivity. These trace elements can maintain their serum concentrations and substantially reduce the faecal excretion of these elements. The wide spectrum of action of chelated compounds of trace elements causes an increase in multiple pregnancies, nest weight, improved pig viability, increased pig weight, improved slaughter yield and physical and chemical properties of meat. Accordig to M. Chorny *et al.* (2018), additional levels of microminerals (copper, iron, and manganese) do not affect the activity of liver enzymes, but severe intoxication with copper and zinc compounds leads to metabolic disorders and irreversible pathological processes in the liver. The use of a chelated form of copper with glycine in our studies is confirmed by other data from researchers on the stimulating effect of micromineral supplementation on the growth rate of fattening pigs. J. Zhao *et al.* (2014) investigated the feasibility of replacing $CuSO_4$ on chelated copper as a growth stimulator in pigs. They established that pigs fed chelated copper were 6.0% heavier at the end of the experiment, they used feed more efficiently and obtained heavier carcasses from them. The authors' study confirms the data of previous researchers on the positive effect of the copper chelate complex on the increased yield of carcasses and internal organs.

The use of mineral supplements containing various forms of trace elements increases the growth and development of young animals, which further increases the profitability of pork production (Korobka *et al.,* 2018). Therewith, the introduction of carbon dioxide and chelated forms of salts into the diet of pigs has substantially better indicators. The introduction of copper, even in low doses, into the diet of pigs contributes to healthy changes in the composition of intestinal bacteria and increases growth productivity (Li *et al.,* 2021). Enriching the diets of pigs with mineral additives of natural origin contributes to better preservation of livestock, increases the mineral content in slaughter products, ensuring high-quality pork. The use of mineral supplements in feeding improves the quality and biological value of meat (Razanova *et al.,* 2022). With the introduction of the protein-vitamin-mineral supplement "Minactivit", the slaughter yield of pigs increased, and the physico-chemical parameters of muscle tissue (water retention capacity, protein content) improved, the yield of fat in the carcass decreased (Suprovych *et al.,* 2019). Similar results were obtained for feeding LG-MAX and Sal-Plex additives in feeding pigs during rearing and fattening, but in this study, the fat content of pork (Tkachik & Tkachuk, 2019). The results of this study also showed that a chelated copper complex can improve the chemical and mineral composition of pork, and its quality indicators after cold ageing. Studies of the feeding factor of introducing a chelated copper complex into the diet of fattening pigs contributed to more intensive growth of animals, obtaining a higher slaughter yield of carcasses and high-quality pork.

CONCLUSIONS

In the course of the study, the intensity of pig growth was determined and indicators of slaughter and quality of pork with the additional introduction of a chelated copper complex into the diet were measured and determined. The results fully fulfil the set goal of the study. Additional feeding of the copper chelate complex increased the live weight of pigs in 110 days by 5.6%, 165 days – by 6.5% compared to the control, increased the average daily weight gain for the study fattening period

by 9.1%, and the relative increase in live weight – by 4.5 percentage points.

Under the influence of the examined drug in the experimental group, the slaughter yield is higher by 4.5 percentile points and the area of the "muscle eye" – by 6.3%, the thickness of lard over the 6-7 thoracic vertebra is smaller by 10.6%, the mass of internal fat is increased by 7.5%, the mass of internal organs (liver, heart, lungs, and kidneys) increases by 9.7%. In the meat samples of the second group, the protein and ash residue content was increased by 3.9 percentage points and 12.1 percentage points, respectively, and the fat content was reduced by 10.0 percentage points. Under the action of the copper chelate complex, there is an increase in meat tenderness by 14.3%, a decrease in marbling – by 14.4%, and caloric content – by 1.9%. Long-term storage of pork made some changes in its quality indicators and the best indicators were obtained in the experimental group, where a chelated copper complex was introduced into the diet of pigs. The additional introduction of a chelated copper complex into the diet of animals led to an increase in the content of zinc in pig muscles by 7.7%, manganese – by 13.2%, copper – by 18.6%, cobalt – by 22.8%, and iron – by 8.4%.

Future research in this area should be aimed to further improve understanding of the effects of the copper chelate complex on pork growth rate, slaughter rates, and quality. It is important to conduct a more detailed study of the molecular and biochemical mechanisms underlying improved feed growth and conversion using this complex. The research may also include an analysis of the effects of the copper chelate complex on pig metabolism and hormone levels to better understand the underlying mechanisms.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Інтенсивність росту, показники забою та якості свинини за додаткового введення до раціону свиней хелатного комплексу міді

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Анотація. Ефективність ведення промислового конкурентоспроможного свинарства в Україні залежить від рівня годівлі і забезпеченості тварин необхідними біологічно активними речовинами. Недостатність мінеральних речовин спричиняє зниження темпів росту, збільшення тривалості періоду відгодівлі, надмірне споживання кормів і, відповідно, підвищення вартості свинини, що зумовлює актуальність обраної теми. Метою дослідження було виявити вплив мінеральної добавки хелатного комплексу міді на м'ясну продуктивність гібридних свиней та якість свинини. Для виконання мети досліджень використані наступні методи: зоотехнічні (динаміка живої маси, визначення середньодобових і відносних приростів), біохімічні (аналіз хімічного складу та вмісту мікроелементів у м'язах, показників якості свинини: вміст вологи, ніжність, мармуровість, інтенсивність забарвлення), морфологічні (визначення показників забою), статистичні (визначення достовірної різниці між значеннями). Досліджено ефективність хелатного комплексу міді з гліцином на інтенсивність росту свиней, показники забою, хімічний та мікроелементний склад м'язів, показники якості свинини після холодної витримки. Встановлено, що додаткове введення до раціону хелатного комплексу міді підвищувало інтенсивність середньодобових приростів свиней на 9,1 % та відносного приросту живої маси на 4,5 п.п. Від свиней даної групи отримано важчі туші на 4,5 п.п. з меншою товщиною шпику над 6-7 грудним хребцем на 10,6 % та масою внутрішнього жиру на 7,5 %, а також на 9,7 % більше внутрішніх органів. Від тварин дослідної групи отримано свинину з меншим на 10,0 п.п. вмістом жиру, більшим вмістом білку – на 3,9 п.п та золи – на 12,1 п.п. Раціон з хелатним комплексом міді підвищував після холодної витримки вологоємність та ніжність свинини, сприяв зниженню калорійності м'яса. Концентрація мінеральних речовин у м'язовій тканині у дослідній групі була вищою за вмістом міді, марганцю, кобальту, заліза, цинку. На підставі отриманих даних досліджень встановлено можливість ефективного згодовування хелатного комплексу міді з гліцином свиням на відгодівлі

Ключові слова: молодняк свиней; жива маса; мікроелементна добавка; хелатна мідь; забійний вихід; вихід внутрішніх органів; якість м'яса

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The course of the postpartum period in cows in the presence of concomitant pathology

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Abstract. The decrease in productivity in cows is directly related to the pathologies of the organs of the reproductive system that occur at the end of the transit period, therefore it is important to improve the methods of diagnosis and preventive therapy of cows in this period. The purpose of the work was to establish the forms of pathologies that occur in the transit period in cows, their interrelationship and the causes that cause them in terms of seasonal dynamics. When conducting research, morphological, clinical (examination, palpation), laboratory (bacteriological studies of the uterus), and

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statistical (statistical reliability) methods were used. The research was conducted in the limited liability company "Milk of the Fatherland" in 2 departments where unattached housing is used. The occurrence of subinvolution of the uterus against the background of litter retention and persistent corpus luteum was established by 9.5% more in the 1st department. A 43.5% correlation of the prevalence of delayed involution with endometritis was revealed. An increase, 12.8% in January and up to 14.1 in February, of cases of subinvolution of the uterus was established, while in May the similar indicator was 5.0%. The prevalence of persistent corpus luteum was established up to 16.8%, luteal cyst – up to 1.7%, ovarian follicular cyst – 2.1%. The presence of microflora in the uterine cavity (*E. coli, Ps. aeruginosa* and *S. aureus* – 49.8% *S. aureus* and *E. coli* – 33.5%, *Pr. vulgaris* and *E. coli* – 16.7%) provoked the occurrence inflammatory processes: chronic endometritis – 10.4%, vulvovaginitis – 18.1%, cervicitis – 21.4%. Research results can be used to develop new and improve existing methods of treatment of cows with pathology of genital organs in the transit period in farms of different forms of ownership

Keywords: transit period; inflammatory processes; subinvolution of the uterus; endometritis; cervicitis; salpingitis

INTRODUCTION

The processes of restoration of the uterus after parturition to the state characteristic of a non-pregnant cow are an important factor for further reproductive capacity. The delay in the involution of the organs of the reproductive system of cows is the main factor in the development of inflammatory and destructive processes, which subsequently lead to infertility and early culling of cows. At the same time, the cost of the obtained products increases due to overspending of feed and a decrease in herd productivity in general as a result of the use of repair cows (heifers), which, as a rule, have lower milk yields compared to cows aged 4-6 years.

Researchers O.V. Pascottini *et al.* (2022) claim the development of maladaptive mechanisms in cows in the postpartum period due to a negative energy balance, characterized by increased resistance of uterine tissues to insulin and excessive formation of adipose tissue. Another researcher, D.C. Wathes (2022), came to similar conclusions, but he also emphasizes the importance of genetic programming during pregnancy for structural and physiological modifications to the future female's fertility.

In addition, it is known that a large number of cows have a postpartum period of more than 30 days, which is due to the development of subinvolution of the uterus and requires stimulation of the organs of the reproductive system (Chen *et al.,* 2023). Most authors indicate vitamin E and selenium deficiency as a contributing factor to the development of uterine subinvolution (Dresen *et al.,* 2023). In addition, researchers Y.M. Somagond *et al.* (2023) obtained positive results when using multivitamin and multimineral products to prevent transit period pathologies in cows. As a result of research by B.R. Crites *et al.* (2022) is the establishment of a correlation between a low level of selenium in the blood serum of cows and a delay in the resorption of the corpus luteum in cows in the postpartum period, which causes not only the development of subinvolution of the organs of the reproductive system in cows, but also provokes the creation of prerequisites for the development of inflammatory processes in the uterus, and the mammary gland.

Important is the report of the authors P. Taechamaeteekul *et al.* (2022) that with subinvolution of the uterus caused by an insufficient amount of prostaglandin F2a, the amount of colostral antibodies in colostrum decreases. And as noted by R. Rekawiecki *et al.* (2020), during subinvolution, a decrease in the activity of the releasing hormone was observed, which indirectly affects the level of progesterone and the regression of the corpus luteum. The results of the study on the negative impact of oxidant stress are described in the work of M. Zachut & G.A. Contreras (2022). Other scientists indicate the development of postpartum pathology as a result of the action of mycotoxins, in particular zearalenone (Chekan *et al.,* 2022).

Along with this, researchers N.F. Krivoy & L.A. Franchuk (2018) suggest, along with clinical studies, for the diagnosis of postpartum endometritis, the use of laboratory tests with Benedict's reagent, which, according to the authors, increases the effectiveness of diagnosing subclinical endometritis. Other scientists L. Fedonyuk *et al.* (2021) point out the crucial importance of the disruption of metabolic processes in late dryness, which leads to the development of postpartum pathologies, in particular, endometritis and subinvolution, and suggest the use of supplements containing anionic salts of a new generation for the purpose of prevention

Effective work on the development of new and improvement of existing methods of diagnosis and treatment of cows with pathologies of the genital organs requires the establishment of correlational relationships between pathologies (cause-effect), as well as provoking and contributing factors (seasonality, disruption of homeostasis) determined the purpose of these studies. The aim of the work was to establish the causes and prevalence of gynecological and accompanying pathology in cows in the postpartum period, taking into account seasonal dynamics in a comparative aspect.

MATERIALS AND METHODS

The research was carried out on the basis of the Limited Liability Company of the Agricultural Company (LLC)

"Moloko Vitchyzny" in 2 departments with a non-affiliated system of maintenance in the period from 2020 to 2022. In both departments, a flow-shop keeping system has been implemented, the grouping of animals is carried out based on the productivity and physiological state of the animal. In the 2nd department, one-moment start-up is used, with the subsequent transfer of animals to a separate room and their separation into early and late dry periods. During the dry season, animals are kept on deep litter. There is a separate maternity room with two individual boxes. The milk productivity of animals per lactation is 6000-6500 kg., the 2nd department and 5000-5500 kg in the 1st department. In the 2nd department, synchronization and stimulation of the sexual cycles of cows is used, in the 1st – insemination of animals is used to determine the optimal time of sperm injection.

At the same time, the study of obstetric pathology (calving period) was conducted on the cattle of cows of the first department (n=62) and the second (n=78). Clinical signs of diseases were taken into account: delayed litter was considered when the placenta did not separate within 8 hours, endometritis was characterized by the release of purulent exudate from the genitals. Diagnosis of subinvolution of the uterus is carried out by visual control of the nature of lochia and a rectal examination on the 10-14th day after childbirth, using palpation (the size of the uterus is more than 40 cm in diameter), as well as observation of the clinical condition of the animals. To clarify the diagnosis and monitor the recovery of animals with postpartum subinvolution of the uterus, tests of Katerynov and Dyudenko with lochia were used. Pankov's obstetric and gynecological spoon (ALP) was also used for diagnosis.

The study of the anatomical and topographic state of the uterus (sonographic examination of the genitals, contractility of the uterus, its size, presence of contents, topography of the uterus) was carried out using a sonographer – Tringa Vet 50S with a linear sensor. In cows with subinvolution of the uterus, the content of cervical mucus was studied on the 5-7th day after childbirth. The content of the cervix was obtained, after the previous dry treatment of the external genitalia, by the rectocervical method using a plastic catheter (pretreated with rectified alcohol), a sanitary cover and a Jeanette syringe. Later, the lochia was placed in sterile plastic tubes for washing and sent to the Sumy Regional State Laboratory of Veterinary Medicine to find out microbiocinosis of the uterus due to subinvolution.

Vulvovaginitis was diagnosed using a vaginal examination (examination) and the presence of serous exudate. Cervicitis was established on the basis of a rectal examination (a pear-shaped increase in the cervix from 7 to 12 cm was detected). For the diagnosis of gynecological pathology, a rectal examination was performed according to the generally accepted method (palpation) and the use of ultrasound diagnostics (USD) using a sonograph – Tringa Vet 50S with a linear sensor. The size (subclinical endometritis, salpignitis, hypotrophy of the ovaries), presence of formations (persistent corpus luteum, luteal and follicular cysts), response to contraction massage (uterine atony, rebirth) were taken into account.

In order to establish the fecundity of cows in a seasonal aspect, a pregnancy study was carried out with the help of a sonographer – Tringa Vet 50S with a linear sensor and pregnancy was established. Thus, in the first department, 295 cows were examined in winter, 368 in spring, 356 in summer, and 296 in autumn. Similarly, cows in the second department were examined: 365 cows in winter, 215 in spring, 270 in summer, and 285 in autumn.

All experimental studies were conducted according to modern methodological approaches and in compliance with the relevant requirements and standards, in particular, they meet the requirements of DSTU ISO/IEC 17025:2005 (2006). Keeping of animals and all manipulations were carried out in accordance with the provisions of the Procedure for Conducting Experiments and Experiments on Animals by Scientific Institutions (Law of Ukraine No. 249, 2012), the European Convention on the Protection of Vertebrate Animals Used for Experimental and Other Scientific Purposes (1986).

RESULTS AND DISCUSSION

Among the cows of farms in the northern region, the prevalence of uterine subinvolution depended on the seasonality of calving, housing conditions (namely, a high concentration of animals in a limited area, group sectional housing, limited exercise and insolation), feeding technology (insufficient energy in the diet and balancing it at the expense of concentrated feed, presence of mycotoxins in feed). Thus, in a farm with an acceptable and average level of micromycete contamination of fodder, uterine subinvolution did not exceed 20-30%, acute postpartum metritis 25%, and subclinical metritis 35%. At the same time, obstetric and gynecological diseases were registered 2-3 times more often in animals from farms with a high level of feed contamination by mold fungi and their toxins (Chekan *et al.*, 2022). The structure of obstetric pathology in the 1st and 2nd departments of LLC AF "Moloko Vitchyzny" is shown in Table 1.

Table 1. *The structure of obstetric pathology causing complications in the postpartum period (n=140)*

Causes of gynecological pathology	Milk of the Fatherland JSC			
	1 department		2 departments	
	Number of heads	%	Number of heads	%
Litter retention	4	5.2	3	3.8

Table 1, Continued

Causes of gynecological pathology	Milk of the Fatherland JSC			
	1 department		2 departments	
	Number of heads	%	Number of heads	%
Subinvolution of the uterus	19	17.4	12	7.9
Endometritis	26	21.7	35	23
Vulvovaginitis	7	7.6	18	11.8
Cervicitis	6	4.9	10	6.6
In total	62	56.8	78	51.3

***Source**: developed by the authors*

The prevalence of obstetric pathology in the 1st department prevailed over the indicators of the 2nd department. Thus, the retention of manure increased by 1.5% compared to other farms. The subinvolution of the uterus, which developed both against the background of litter retention and independently in the first department, was 9.5% higher compared to the 2nd department. Subsequently, in the 1st department, 37.3% of sick cows and 43.5% of animals in the 2nd department had subinvolution of the uterus complicated by endometritis, the course of which in the 1st department decreased by 1.3%, compared to the other department.

The frequency of vulvovaginitis and cervicitis in the 2nd department exceeded the incidence in the 1st department by 4.2% and 1.7%, respectively. The prevalence of general obstetric pathology in the 1st department was 5.5% higher than the indicators of other farms. The next stage of research was the study of the prevalence of subinvolution of the uterus in the seasonal aspect (Table 2).

***Table 2.** Seasonal dynamics of the spread of uterine subinvolution (n=55)*

Period	January	February	March	April	May	June	July	August	September	October	November	December	everything
In total hotel heads	39	71	67	54	40	37	36	35	41	59	89	42	610
subinvolution	5	10	6	3	2	2	2	3	4	5	10	3	55
%	12.8	14.1	9.0	5.6	5.0	5.6	5.6	8.6	9.8	8.5	11.2	7.1	9.0

***Source**: developed by the authors*

The most cases of the disease were registered in February 14.1%, January 12.8% and November 11.2%, and in March it decreased to 9.0%. Uterine subinvolution was the least recorded in cows at the end of spring and summer, from April to July its percentage did not exceed 5.6%. An upward trend has been observed since August. Such a seasonal manifestation of subinvolution in the economy is associated with mass calving of cows and the influence of adverse environmental factors (accumulation of animals in one sector after birth, movement of cows to stalls and contamination of open birth canals, low level of carotene and microelements of copper (Cu) and zinc (Zn) in blood serum of animals, contamination of feed with molds).

After analyzing the reasons that lead to the development of subinvolution of the uterus in cows in these farms, the main and mediating factors were established: the crowding of animals in one sector after childbirth, moving cows to stalls and contamination of open birth canals, feeding poor-quality feed containing aflatoxins, low level carotene and microelements Cu and Zn in animal blood serum, the presence of heavy metal salts in colostrum (exceeding the maximum permissible levels of arsenic (As), mercury (Hg) and lead (Pb), overstretching of the uterus in multiple pregnancy, large fetus, violation of steroidogenesis in pregnant cows, the presence of accompanying pathologies and complications during pregnancy, improper delivery, in particular, premature extraction of the fetus, which leads to a violation and weakening of the rhythm of uterine contractions, pathological births and injuries of the birth canal, previous abortions and chronic inflammatory processes of the uterus, delayed litter.

As a result of the complication of pathologies during childbirth, there is the development of gynecological pathology, which in the vast majority blocks the fertility of cows and is a primary criterion for the development of methods of treatment and prevention of infertility in the postpartum and service periods. At the same time, the following gynecological pathologies of a functional and inflammatory nature were detected (Table 3).

***Table 3**. Analysis of gynecological pathology*

Causes of gynecological pathology	Milk of the Fatherland JSC				In general, for these departments	
	1st department		2nd department			
	Goal	%	Goal	%	Goal	%
Vulvovaginitis	77	18.1	17	8,9	94	15.2
Cervicitis	91	21.4	16	8.4	107	17.3
Chronic metritis	40	9.4	20	10.5	60	9.7
Subclinical metritis	30	7	31	16.2	61	9.9
Salpingitis	4	0.9	2	1	6	1.0
Persistent yellow body	42	9.9	32	16.8	74	12.0
Ovarian hypotrophy	55	12.9	28	14.7	83	13.5
Luteinous cyst	7	1.7	3	1.6	10	1.6
Follicular cyst	4	0.9	4	2.1	8	1.3
Clinical norm	34	8	18	9.4	52	8.4
Atony of the uterus	12	2.8	11	5.7	23	3.7
Degeneration	30	7	9	4.7	39	6.4
Total infertile animals	426	100	191	100	617	100.0

***Source**: developed by the authors*

The frequency of inflammatory processes of reproductive organs in cows in both farms ranged from 46.6 to 58.5% of the total number of gynecological pathologies. Inflammatory processes of genital organs in cows registered in the 1st department exceeded the indicators of animals of other farms by 12%. In this farm, acute inflammatory processes, such as cervicitis and vulvovaginitis, prevailed among the gynecological pathology of cows accompanied by inflammatory genesis. Their prevalence was 2.3 and 1.9 times higher compared to chronic metritis and 3.1 and 2.6 times higher compared to subclinical inflammatory processes of the uterus. The frequency of salpingitis in both farms was almost the same and did not exceed 1%.

In addition to inflammatory processes of reproductive organs in cows, a significant share of the total number of gynecological pathologies was ovarian dysfunction. The prevalence of ovarian dysfunction in both farms ranged from 28.5 to 35.2%. The main number among ovarian dysfunction was persistent luteal corpuscle and ovarian hypotrophy, which exceeded the frequency of luteal cysts by 5.8 and 7.6 times and the number of follicular cysts in the 1st department by 9 and 12%. A similar trend was observed in the 2nd department. Persistent corpus luteum and ovarian hypotrophy exceeded the frequency of luteal cysts by 10.5 and 9.2 times, respectively. The number of follicular cysts was lower by 14.7 and 12.6% compared to persistent corpus luteum and ovarian hypotrophy.

Among barren cows, the number of clinically healthy cows did not exceed 10% in both farms. Violation of the rigidity of the uterus was 2.8 and 5.7%, respectively, and was 2 times greater in the 2nd department, compared to other farms. Among ovarian rebirths, sclerotic processes prevailed and accounted for 7 and 4.7% of the total gynecological pathology. In the first two days after birth, 81.7% of the animals, which later developed acute subinvolution of the uterus, had abundant discharge of liquid bloody lochia, while the mucous plug in the cervical canal was absent in 87.6% of the animals. During the normal course after the hotel period, in 43.1% of animals, lochia is represented by a small amount of thick, cloudy, viscous mucus of a straw-yellow or light brown color, which is located in a small amount both in the vaginal cavity and in the cervical canal, forming mucous cork, which is a kind of protective barrier that prevents the penetration of microflora into its cavity.

During the study, intensive contamination of the uterine cavity with conditionally pathogenic microflora was established. And by the 7th day of the experiment, 100% of the test animals had different strains of microorganisms isolated from the cervical mucus samples. However, the introduction of the tested means already during this period contributed to positive changes in the microbial ecosystem of the reproductive organs. Among 15 samples of contents taken from the cervix of cows suffering from subinvolution, *Escherichia coli was isolated in 64% of the animals*. Contamination of the uterus *by Staphylococcus aureus* and *Pseudomonas aeruginosa* was diagnosed in 33.3% and 20% of cows. The smallest microbial contamination of the uterus was *Proteus vulgaris*, it was isolated in only 6.7% of animals.

In all animals, the microbial landscape of the uterus was represented by an association of

microorganisms. The association with *E. coli, Ps. aeruginosa* and *S. aureus* – 49.8% of the total number of cases. The association with *S. aureus* and *E. coli was determined as the next most common*, which was 33.5%. The association of the following microorganisms was the least common among the farm's cows – *Pr. vulgaris* and *E. coli* (16.7%). Thus, the leading role in the development of subinvolution is played by pathogenic microflora, which contaminates the uterine cavity up to 7 days after delivery and complicates the course of the pathological process. The general condition of cows with subinvolution of the uterus is depressed, appetite and productivity decrease. In some animals, there is a subfibrillar increase in body temperature and slowing down of scar contractions.

When conducting a rectal examination in the first two days after calving in the majority of animals that later developed acute subinvolution of the uterus, 47.1% of the animals did not have any discharge of lochia, and 52.9% of the cows showed abundant discharge of liquid blood lochia, while the mucous plug in the cervical canal was absent in 88.2% of the animals. The rigidity of the uterus is weakly expressed, the folds of its surface are insignificant, while when examining clinically healthy cows 2-3 days after calving, pronounced transverse and longitudinal folds were found on the surface of the uterus, during massage it became a bumpy, dense consistency.

In case of subinvolution in cows, on the 6-7th day after childbirth, the uterine horns hang over the edge of the pubic bones, which cannot be reached by hand, the uterus does not respond to contraction during palpation, there is fluctuation, the walls are loose, without pronounced folds, after the massage, lochia of a liquid consistency may be released. dirty-gray color and a slightly similar mass with impurities of the decay of caruncles or pieces of caruncles with areas of the choroid. In the normal course of the postpartum period, lochia has a thick homogeneous mass with an admixture of red-brown mucus.

When examining cows with subinvolution on the 10-11th day after calving, the uterus has dimensions' characteristic of a 3.5-4.0 month pregnancy, is located in the abdominal cavity, responds poorly to massage, after which lochia of a liquid or semi-liquid dark consistency is released from the genitals. brown with admixtures of a small amount of mucus, while with the normal course of involutional processes, the uterus has a size characteristic of a 2.5-3.0 month pregnancy with the release of homogeneous lochia of brown or straw-yellow color. The criteria for the completion of the involution of the uterus are: a decrease in its size, when it is freely grasped by the hand, is located in the pelvic cavity, its horns are relatively symmetrical, elastic and elastic in consistency and respond to massage (Table 4).

Table 4. *Indicators of genital involution in cows depending on the course of the postpartum period*

Indexes	Physiological course of the postpartum period, n=17	Subinvolution of the uterus, n=19
Periods of cessation of vibration of the middle uterine arteries, days	2.5±0.13	4.9±0.17**
Thickening of sacro-gluteal ligaments, days	2.7±0.23	5.2±0.31**
Periods of cessation of lochia discharge, days	14.7±1.2	24.9±0.8**
Completion of genital involution, days	24.6±2.4	32.6±1.6*

Notes: ** – p<0.05, ** – p<0.001*
Source*: developed by the authors*

The vaginal part of the cervix is reduced in size, designed in the form of a rosette, protrudes into the vaginal cavity by 2.0-2.5 cm, there is no swelling of the folds. The mucous membrane of the vagina is pale pink, smooth, shiny, moderately moistened, the discharge of lochia from the cervical canal stops. It was established that in cows with acute postpartum subinvolution of the uterus, the vibration of the middle uterine arteries is 2 times longer ($p<0.001$) than in animals with a normal course of the postpartum period, and sacro-gluteal ligaments tighten 1.93 times ($p<0.001$) later. joints The nature and amount of lochia released from the genital tract is significantly different. During subinvolution, the cessation of lochia secretion is delayed by 10.2 days ($p<0.001$) and the completion of involutional processes by 10.2 days ($p<0.05$).

The level of protein-carbohydrate compounds (hexose bound to protein, seromucoids, ceruloplasmin, and sialic acids) and sex steroids (progesterone and estradiol) in the blood of sick animals also has diagnostic value for subinvolution of the uterus. The results of the research indicate that there are significant differences between the course of the postpartum period in normal conditions and with acute subinvolution of the uterus in cows in terms of indicators of the state of the genital organs, the nature and amount of secreted lochia, depending on the timing of the research, the time of cessation of lochia secretion and the completion of the involution processes. The next stage of research was to find out the fertilizing ability of cows at different times of the year (Table 5).

Table 5. *Fertilization of cows during the year in experimental farms*

	Season											
	winter			spring			summer			autumn		
	wasps	add		wasps	add		wasps	add		wasps	add	
		n	%		n	%		n	%		n	%
1 department	295	91	30.8	368	134	36.4	356	93	26.1	296	107	36.2
2 departments	365	128	35.1	215	91	42.3	270	91	33.7	285	136	47.7

Notes: *– number of inseminated animals, pl. – the number of pregnant animals after insemination*
Source*: developed by the authors*

The lowest number of fertilizations was obtained in the 1st department in the summer season, which is caused by temperature stress. At the same time, this indicator was 15.3% higher in winter, 28.3% in spring, and 27.9% in autumn. The largest number of fertilizations was received in the autumn period in the 2nd department. It was 26.4% higher than the similar figure in winter, 11.3% in spring and 29.6% higher. At the same time, fertilization in all seasons of the year in the 2nd department was significantly higher than the similar indicators of the 1st department. The course of the postpartum period, and thus the fertility of cows, directly depends on the course of childbirth, in particular, the delay of litter and the introduction of microflora during delivery. At the same time, rare cases of simultaneous manifestation of inflammatory processes in different parts of the reproductive system (pathologies of the ovaries, oviducts, uterus and vagina) are important. All this leads to overgrazing and reduced productivity, which in turn leads to economic losses and higher prices of livestock products.

It was established that the subinvolution of the organs of the reproductive system in cows in the postpartum period occurred against the background of endometritis from 37.3% in the first department to 43.5% in the second department. Other researchers P. Nyabinwa *et al.* (2020) indicate that postpartum endometritis is recorded at the level of 23.5% of the total number of cows that have calved, which leads to a decrease in productivity. Some authors, N. Pascal *et al.* (2021), indicate that often endometritis occur in a complex with subinvolution of the uterus after delivery assistance and litter retention within 21-60 days after delivery. However, during the research, data was obtained that after giving birth assistance, the manifestation of cervicitis in cows was registered at the level of 4.9% in cows of the 1st department to 6.6% in cows of the 2nd department in a complex with subinvolution of the organs of the reproductive system of cows.

Characterizing the seasonal dynamics of uterine subinvolution, most researchers associate the increase in the number of diagnosed cases with mass calvings, while paying attention to the fact that in the winter-spring period, the insufficiency of vitamins and trace elements in the diets of cows is common, which coincides with the results of studies (Lin *et al.,* 2021). It was established that in the postpartum period and in cows against the background of the development of subinvolution, cervicitis was recorded in 17.3% and vulvovaginitis in 15.2%. Researchers D.A. Vallejo-Timarán *et al.* (2021) claim that about 23% of cows have clinical or subclinical cervicitis or vulvovaginitis, while the amount of interleukins IL 1 and IL 8 and cytokines in the vaginal mucus increases, indicating the development of inflammatory processes. According to T.O. Cunha *et al.* (2021) a high level of progesterone, reducing the local protective capacity of the mucous membrane of both the cervical canal and the vagina, provokes the development of microorganisms, and therefore the development of inflammatory processes.

P. Skliarov & O. Zubkov (2021) note the importance of using an algorithm for predicting the course of the postpartum period, which consists of a number of indicators of both homeostasis (the main markers of inflammation) and clinical condition, which fully coincides with the data obtained during the study. However, the authors point out the importance of the completeness of the fetoplacental complex. Along with this, it is important to complicate the course of the postpartum period as a result of overdistention and improper joint placement of the fetus, as noted by L.V. Koreyba (2014). At that time, the authors A.Y. Kraevskyi & A.G. Seredzhimova (2018) note that litter retention is more common in first-born cows, and injuries during childbirth are the cause of postpartum complications. The data are consistent with the research concept and will be part of further research.

Researchers O.B. Pascottini *et al.* (2023) indicate the presence of young neutrophils in large numbers in the cervical and uterine mucus and claim that the main representatives of the exudate microflora in endometritis are *E. coli, Streptococcus uberis and Trueperella*, which is confirmed by the data obtained during current research. Y. Yi *et al.* (2022), who claim that during inflammation of the endometrium, microvilli of the epithelium are destroyed, necrobiosis of cells and edema of the epithelium is observed, and the presence of a large number of microorganisms on the surface of the mucous membrane. This practically coincides with the results obtained during research.

Based on the above, we can say that postpartum complications are common pathologies in farms of various forms of ownership both in our country and abroad. However, given the large number of publications, the problem remains relevant and requires further research.

CONCLUSIONS

Subinvolution of the organs of the reproductive system is from 7.9% to 17.4% and is a consequence of litter retention, which is from 3.8% to 5.2% and the imbalance of individual hormones in the postpartum period and is a prerequisite for the development of such inflammatory processes as endometritis from 21.7% to 23.0%, vulvovaginitis from 7.6% to 11.8% and cervicitis from 4.9% to 6.6%. Delayed uterine involution has a seasonal pattern, so the highest percentage of 14.1% is diagnosed in February and 12.8% in January, and the lowest in May is 5.0%, which is associated with mass calvings and poor rations.

As a complication of subinvolution of the uterus, a violation of the secretion of both local hormones – persistent corpus luteum from 9.9% to 12.0%, and chronic inflammatory processes – metritis from 9.4 to 9.7% was noted. In the seasonal aspect, subinvolution of the organs of the reproductive system in cows most often occurs in January (12.8%) and February (14.1%), and the least this pathology was diagnosed in May (5.0%) and April, June and July (5.6%). Subinvolution of the organs of the reproductive system is a consequence of the development of gynecological pathology of an inflammatory nature (vulvovaginitis – 15.2%, cervicitis – 17.3%, salpingitis – 1.0%), a violation of the hormonal background (persistent corpus luteum – 12.0%, luteal cyst – 1.6%, follicular cyst - 1.3%), and non-inflammatory (uterine atony – 3.7%, rebirth – 6.4%).

With subinvolution of the organs of the reproductive system, the involution lasts 1.33 times longer (the period of cessation of uterine artery vibration is 1.96 times, thinning of the uterine ligaments is 1.93 times, the period of cessation of lochia discharge is 1.69 times). Fertilization in the seasonal aspect was the highest in spring (36.4%) in the first compartment and in autumn (47.7%) in the second, and the lowest in summer (26.1% in the first compartment and 33.7% in the second). In further research, it is planned to develop prognostic tests for the occurrence and complexity of transit flow in cows and to test effective treatment schemes for cows with this pathology.

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CONFLICT OF INTEREST

The authors indicate the absence of any conflicts of interest during research, data analysis and publication of the material.

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Перебіг післяродового періоду у корів за наявності супутньої патології

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Анотація. Зниження продуктивності у корів безпосередньо пов'язано із патологіями органів статевої системи, що виникають наприкінці транзитного періоду, тому важливим є удосконалення методів діагностики та превентивної терапії корів у даному періоді. Метою роботи було встановити форми патологій, що виникають у транзитному періоді у корів, їх взаємозв'язку та причин, що їх викликають у розрізі сезонної динаміки. При проведенні досліджень застосовували морфологічні, клінічні методи (огляд, пальпація), лабораторні (бактеріологічні дослідження вмістимого матки), статистичні (статистична достовірність). Дослідження проводили в товаристві з обмеженою відповідальністю «Молоко Вітчизни» на 2-х відділеннях, де використовується безприв'язне утримання. Встановлено виникнення субінволюції матки на фоні затримки посліду та персистентного жовтого тіла на 9,5 % більше у 1-му відділенні. Виявлено кореляцію поширеності затримки інволюції із ендометритом у 43,5 %. Встановлено підвищення, 12,8 % у січні та до 14,1 у лютому випадків субінволюції матки, тоді як у травні аналогічний показник склав 5,0 %. Встановлено поширення персистентного жовтого тіла до 16,8 %, лютеїнової кісти – до 1,7 %, фолікулярної кісти яєчників – 2,1 %. Наявність у порожнині матки мікрофлори (*E. coli, Ps. aeruginosa* та *S. aureus* – 49,8 % *S. aureus* та *E. Coli* – 33,5 %, *Pr. vulgaris* та *E. coli* – 16,7 %) провокувало виникнення запальних процесів: хронічного ендометриту – 10,4 %, вульвовагініту – 18,1 %, цервіциту – 21,4 %. Результати досліджень можуть бути використані для розробки нових та удосконалення існуючих методів лікування корів із патологією статевих органів у транзитному періоді у господарствах різної форми власності.

Ключові слова: транзитний період; запальні процеси; субінволюція матки; ендометрит; цервіцит; сальпінгіт

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Influence of age and breed of dogs on tumour development

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Abstract. The increase in the number of dogs as pets poses the challenge for veterinary specialists to find new approaches to prevent their morbidity and early mortality. Age and breed are considered to be the main risk criteria for the formation of tumours in dogs, so the aim of this study was to investigate the impact of these and a number of other factors on the susceptibility to cancer in this species. The research was based on the analysis of a single database of veterinary clinics in Bishkek, which includes 328 confirmed cases of cancer in dogs. The most common breeds were German (n=48) and Central Asian Shepherds (n=23), Rottweilers (n=18), Dachshunds (n=18), Poodles (n=17), Shar Pei (n=14), Pekingese (n=14), and a group of outbred dogs (n=70). Benign neoplasms were recorded in 140 cases, accounting for 54.3% of the total number of tumours in pure-bred dogs. Benign tumours predominated in large breed dogs (n=75), or 53.6% of the total number of benign tumours, and the highest growth of malignant tumours was detected in small breed dogs (59%) (n=29). Dogs, regardless of breed, were more vulnerable to tumour formation between the ages of 6 and 12 years. The

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database analysis revealed that females were more likely to develop cancer than males, with mammary tumours being the main diagnosis in females (36.3%). Small dog breeds had a higher risk of developing mammary tumours than large dogs. The obtained results revealed breed-specific features of the manifestation of morphological types of tumours in dogs and made it possible to determine the critical periods of their formation

Keywords: new formations; oncological pathology; predisposition; database; statistical analysis

INTRODUCTION

The domestication of dogs and their use for human benefit as part of animal husbandry was one of the first to develop, so today there is a considerable variety of dog breeds, which are divided into service, hunting, indoor and decorative. Other classifications have seven to ten groups of dog breeds depending on their origin, size, or use. According to other classifications, there are seven to ten groups of dog breeds depending on their origin, size, or direction of use (Lehari, 2022). But despite this diversity of dogs, their main purpose in the animal world is as a companion for humans. In the work of J. Benz-Schwarzburg *et al.* (2020), it is indicated that human relationships with domestic dogs are very common and often result in a strong shared attachment and in treating these dogs as family members or even children. Such relationships are biopsychosocial in nature indicates that dogs are able to sense their owner's emotional state and respond to their owner's social gestures, and this allows them to form complex attachment relationships with humans. This is confirmed in the studies of A.M. Chira *et al.* (2023) conducted with dogs of different breeds and in different countries. Therefore, when a person gets a dog, he/she assumes the responsibility to take care of it, to monitor its health, to protect it from dangers.

One of the most dangerous and difficult-to-treat diseases of pets is cancer. In the Kyrgyz Republic, according to A.Sh. Irgashev *et al.* (2016), oncological diseases in animals are poorly studied from a scientific point of view, while veterinary clinics have established diagnosis and treatment of sick animals. Modern knowledge of physiology, feeding, and treatment of dogs has allowed increasing the life expectancy of these pets for a significant period of time. But, the flip side of this phenomenon, has been an increase in the incidence of cancer diagnosis in adult dogs, as confirmed by the findings of D.H. Thamm (2019), who indicates that 30% of dog mortality is caused by different types of tumours diagnosed mainly in older animals. Histological studies confirm the similarity of cancerous masses in dogs to human tumours. The most common tumours are lymphoma, melanoma, osteosarcoma, bladder carcinoma and multiple types of brain cancer. Considering the similarities between cancers in dogs and humans, makes these pets, according to T.G. Guimarães *et al.* (2022), the best biological subjects to study the therapeutic effects of different treatments on the body for their subsequent application in human therapy.

Studies of oncological diseases in dogs in Kyrgyzstan, despite their relevance, are rather limited. The main directions over the last few years have been the study of skin tumours and mammary gland tumours by S.N. Ishenbaeva and A.Sh. Irgashev (2022). A difference of these studies is the small number of control animals. Although in the robot D. Steven (2020) points out that a high inbreeding coefficient in most dog breeds, may be responsible for the development of tumours, and such results can only be obtained on a larger number of animals with known heritability. Such works will allow studying and carrying out mapping of separate loci of genes responsible for the development of tumours of different types in the organism of not only dogs, but also humans. Moreover, the similarity and adequacy of the immune system response, at spontaneous development of oncology in dogs, allows studying the mechanisms of cytological response at the early stage of the disease and analysing the immunogenetic influence of drugs and physical approaches in treatment on the human organism.

Based on the insufficient study of canine oncological diseases in Kyrgyzstan, as well as taking into account the social aspects of companion relationships between dogs and humans, and physiological and immunological similarity of oncological processes in the organism of these species, makes the study of genetic and paratypical factors of tumour development in dogs an actual direction of scientific work. Therefore, the aim of this article was to study the prevalence of cancer pathology in dogs depending on their breed and age in Bishkek city.

LITERATURE REVIEW

Recently, the number of cancers in dogs has increased; this trend in companion animals is related to their accumulation of significant fatty tissue stores. According to the observations of P.H. Marchi *et al.* (2022), overweight is one of the reasons for the increase in cancers in dogs. Mostly cancerous neoplasms are diagnosed in epithelial and lymphoid tissues. Thus, in the work by J.S. Munday *et al.* (2019), tumours were detected in the tissues of the outer skin, B. do Nascimento Borges (2022) and H.Y. Lim *et al.* (2022) in the mammary gland, B. Clerc-Renaud *et al.* (2021) and Q. Gao *et al.* (2019) – in the urogenital tract, K. Kliczkowska-Klarowicz and R. Sapierzyński (2019) and M. Cray *et al.* (2020) in oral soft tissues, and K.M. Makielski *et al.* (2019), D.G. O'Neill *et al.* (2023), J. Beck *et al.* (2022), G.L. Edmunds *et al.*

(2021), and L. Leonardi *et al.* (2021) significant numbers of tumours have been found in bone tissue.

The growth of tumours occurs as a consequence of genetic or other changes in the cells of animals, which, according to P.H. Marchi *et al.* (2022) is a consequence of DNA damage due to various gene mutations. The causes of genome damage can also be chemical, physical and biological agents such as viruses, hormones, carcinogens and other factors. In the studies of M.I. Crescio *et al.* (2022) in dogs, the main disposing factors for the development of oncology are breed, age, sex, as well as various surgical interventions in the body of animals that lead to hormonal shifts (castration).

According to A.M. Oberbauer *et al.* (2019), the predisposition to oncological diseases in dogs of different breeds depends on their heredity. This is primarily due to a rather close inbreeding in the breed to some prominent progenitor. But, sometimes, a high genetic predisposition, even in unrelated groups of dogs within the same breed, may depend on genetic selection used to meet breed standards. Castration of males and females reduces the risks of mammary and genitourinary cancers, but increases the likelihood of osteosarcoma, lymphosarcoma, haemangiosarcoma and mast tumours. C. Kraus *et al.* (2023) confirm the breed dependence of cancer mortality in dogs. In studies on 118 breeds and more than 40 thousand dogs, reliable results were obtained that in small breed animals, the development of cancerous tumours was observed less frequently in comparison with large breeds, and at this time the life expectancy in old age decreased with increasing body size of the animals. The life expectancy of dogs dying of cancer showed the same trend. J. da Silva and B.J. Cross (2023) in their work also conclude that the main cause of mortality in dogs is cancer pathology. Which may be related to the accelerated increase in body size of the animal at an early age. Also in the work of K. Pinello *et al.* (2022), it is indicated that statistical information based on a sample of 16272 oncology records shows that the formation of malignant tumours in dogs and cats occurs 8-9 months later than benign tumours. Females had a higher risk of developing cancer than males. In addition, the place of residence of animals did not affect the frequency of pathology, but the risk of malignant neoplasms increased by about 20% every three years of life.

MATERIALS AND METHODS

The source of materials for the study was a joint database of veterinary clinics in Bishkek, which included 328 diagnostic records of oncologically ill dogs with tumours of various localizations. Oncological material for the study was provided by the veterinary clinics "Samson", "Gauhar" and "Animal Planet", as well as by Faculty of Veterinary Medicine at the Kyrgyz National Agrarian University named after K.I. Skryabin. Histological samples of dog tumours obtained by different methods of investigation: autopsy and biopsy were subjected to further histopathological examination in the histology laboratory of the Department of Veterinary and Sanitary Expertise, Histology and Pathology at the Kyrgyz National Agrarian University named after K.I. Skryabin. All canine cases were classified according to the International Histological Classification of Tumours of the World Health Organization (WHO) (Roccabianca *et al.*, 2021).

In each case of confirmed oncological pathology, a complete animal history was collected whenever possible. It was mandatory to record information about the dog's breed, age, sex, sterilization status and other factors that could influence the predisposition to the disease. Depending on the age of the animals were divided into five groups: the first was 0-3 years, the second 3-6 years, the third 6-9 years, the fourth 9-12 years and the fifth included dogs that were 12 years of age or older at the time of diagnosis. The age of the animals was established by subtracting the date of birth from the date of diagnosis. The breed of the dogs was determined by the records in the animal's passport, or in case of its absence – by the relevant breed traits. Unbred animals were singled out in a separate group. When studying the influence of body size on tumour development, animals were divided into three groups: small, medium and large. Animals of small dog breeds (weighing up to 12 kg and growing up to 28 cm) were automatically included into the small group. Such breeds included Toterriers, French Bulldogs, Bolognese, Chihuahua, Yorkshire Terriers, Russian Toy, Spitzes. The medium-sized animals – breeds, whose average weight of representatives was 12-25 kg, and the height at the withers was within 28-60 cm – dachshunds, poodles, Shar Pei, boxer, cocker spaniels were included. The group of large dogs included breeds with the weight of adult animals exceeding 25 kg and having a height above 60 cm – German Shepherd, Rottweiler, Doberman, Labrador, Central Asian Shepherd. In cases with mongrel dogs, they were assigned to a certain group depending on the weight and height established at the diagnosis of the disease.

According to the results of external signs and histological studies of tumours, all cases were grouped according to the new WHO classification adapted for small animals in the work of M.A.M Sharif (2006), and for convenience of further analysis they were divided into benign and malignant tumours. The obtained results of the studies were subjected to mathematical processing using TIBCO Statistica v 14.0.0.15 software (USA). Statistical analysis was performed by genetic-mathematical and biometric methods using descriptive statistics tool and analysis of variance. Sample averages and the strengths of influence of individual indicators on the propensity of dogs to cancer were calculated.

RESULTS

The main focus of the research work was to conduct a statistical analysis of records from an information database of cancer in cats and dogs compiled by veterinary clinics

that practice the diagnosis and treatment of neoplasms in pets. The information database included records of 328 dogs that belonged to up to 46 different breeds and were diagnosed with neoplasms between 2017 and 2022. A prerequisite for entering animals into the database was confirmation of the cancer diagnosis by the results of histological diagnosis of tumours. The majority of information entries in the database referred to female cases – 63%, indicating a significant difference ($P<0.05$) in the susceptibility to oncology specifically in females.

This situation could be caused by a significant number of dogs with mammary gland pathology, which appears only in females and accounted for 36.3% of all tumours in animals. At the same time, the mean age of animals of both sexes at the time of cancer diagnosis was approximately the same and was about 8 years. The database contained records of pets and shelter dogs treated or autopsied at these institutions. The breed composition of the animals whose information was used in the study is presented in Figure 1.

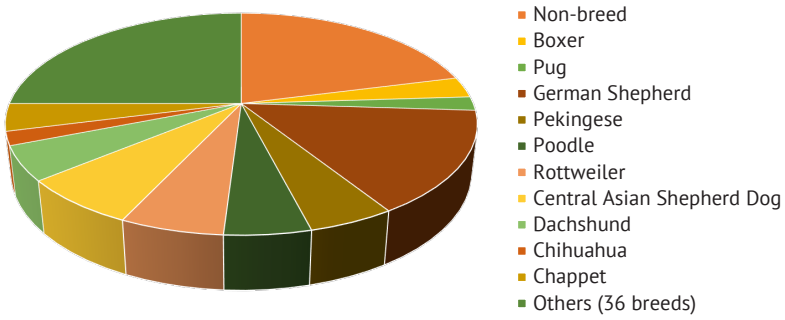

Figure 1. *Breed composition of oncologically ill dogs in Bishkek for the period 2017-2022*
Source: *compiled by the authors*

The proportion of dogs from other breeds with cancer, the number of which was more than 1%, belonged to the breeds Basset Hound – 1.2%, Cane Corso – 1.2%, Kurtshaar – 1.2%, Jack Russell Terrier – 1.5% and Husky – 1.5%, while representatives of the other 32 breeds that were present in the database were less than 1%. This distribution of animals may have been due not so much to the genetic predisposition of animals to cancer, but to the significant number of animals of these breeds in Bishkek. Due to the lack of reliable information on the number of animals of each breed in the service area of veterinary clinics, it is possible to consider the results obtained only as an established trend that needs further confirmation. But the number of animals in separate breeds allows studying the influence of separate genetic and paratypical factors on oncological predisposition of animals. Therefore, further research work was conducted mainly on breeds with significant number of records in the database, namely German Shepherd Dog (n=48), Central Asian Shepherd Dog (n=23), Rottweiler (n=18), Dachshund (n=18), Poodle (n=17), Shar Pei (n=14) and Pekingese (n=14), and also in statistical processing were included mongrel dogs (n=70), the number of which prevailed in the sample.

One of the main parameters that the researchers believe has a predisposition to the occurrence of cancer is the size of the animals. The study distributed and analysed the incidence of disease in both pure-bred and mongrel animals according to their size. While in the case of pure-bred animals, the distribution of animals was based on breed classification, in the case of mongrel dogs they were assigned to one group or another according to their height and body weight at the time of diagnosis. The results of this distribution are presented in Figure 2.

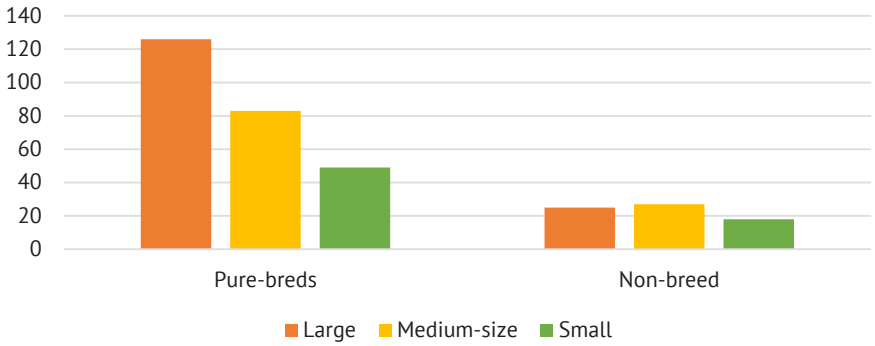

Figure 2. *Distribution of dogs with oncology depending on the size of the breed*
Source: *compiled by the authors*

In controlled pure-bred animals, the highest number of patients was among large-sized dogs – 48.9% (P<0.05) of the whole population, which is significantly higher compared to medium and small animals, while no significant difference between animals of different sizes with oncological diagnosis was observed among pure-bred dogs.

Further analysis of the prevalence of tumours of different types showed that in pure-bred dogs the incidence of malignant and benign tumours was almost at the same level, with a slight increase in the incidence of benign neoplasms. Whereas in mongrel dogs, the incidences were at a lower level, with higher incidences of malignant pathology. Benign neoplasms were recorded in 140 cases out of the total number of tumours in pure-bred dogs, accounting for 54.3%, while malignant tumours were detected in 118 pure-bred animals, accounting for 45.7%. The incidence of oncological diseases in dogs of different breeds is presented in Figure 3.

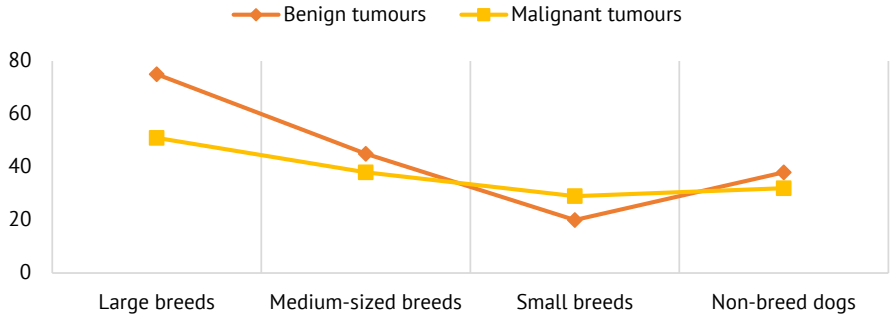

Figure 3. *Oncology incidence in dogs depending on breed size*
Source: *compiled by the authors*

In the pure-bred population, there was a prevalence of animals with a confirmed diagnosis of benign tumours. Among large and medium breeds of dogs, the difference between different types of neoplasms was 19% and 8%, respectively, in favour of benign pathology. The highest increase of malignant tumours was found in small breed dogs, 59% (n=29). In the case of mongrel animals, the incidence of malignant tumours was higher than benign tumours. This may be a consequence of owners' failure to refer tumour problems of animals to clinics in a timely manner, as, in most cases, diagnoses of cancer were made shortly before the animals themselves died. This may suggest that the owners of such dogs do not pay proper attention to these pathologies until they affect the general condition of the dog. And considering that the majority of mongrel animals came to clinics from shelters for homeless animals – it confirms this assumption. The small number of animals with benign tumours in the group of mongrel animals can also be argued by this approach, as their impact on the animal's body is minimal. Another probable explanation for the increase in the number of dogs with malignant cancer in the group of pedigree animals is the increase in the proportion of small and medium-sized dogs, in which, similarly to pure-bred animals, this type of tumour predominates. The strength of influence of the indicator of the size of animals in the breed on the probability of benign or malignant tumour development in pure-bred animals was 18% (P<0.01), while in the population of mongrel dogs the insignificant number of animals in the groups did not allow obtaining a reliable result.

The next factor whose influence was analysed on the predisposition to tumour development in dogs was their age. For this purpose, only pure-bred animals whose exact age was documented were included in the study group, in order to reduce the statistical error of using possible or approximate age in mongrel dogs. The results of grouping dogs, according to the two factors investigated, age and body size, are shown in Figure 4.

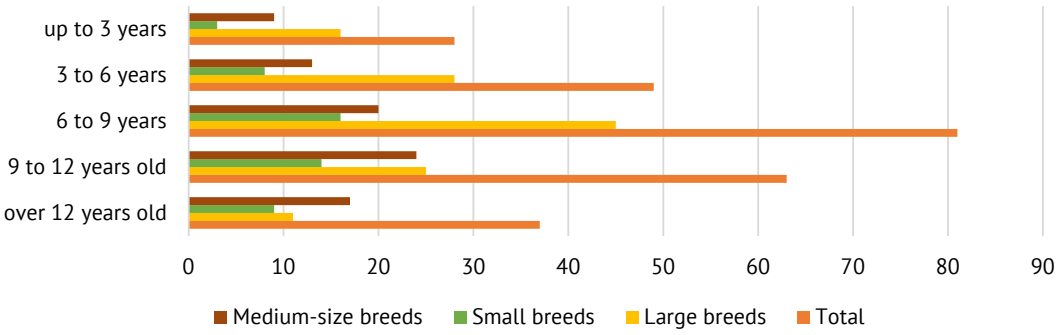

Figure 4. *Distribution of oncologically ill pure-bred dogs by age criterion at the time of diagnosis*
Source: *compiled by the authors*

The incidence of oncology in dogs, depending on age, falls under a normal distribution with maximum manifestation of pathology in the interval from 6 to 9 years. It is during this period that the maximum number of diseased animals of both large and small breeds manifests itself. In dogs of medium breeds, the peak of morbidity is slightly shifted to a later period – from 9 to 12 years. Depending on the age, animals from 6 to 12 years of age have a much higher probability of developing malignant tumours during this period than young dogs. Thus, malignant tumours were diagnosed in young animals up to 3 years of age only in 10 cases (36%), whereas in later periods this diagnosis only increased, so at the age of 3 to 6 years they were detected in 21 dogs (43%), from 6 to 9 years in 49 (60%), from 9 to 12 years in 36 (57%), and in animals over 12 years of age only in 11 cases (28%). Whereas benign tumours were mostly manifested in older animals. This tendency can only be explained by the increased probability of tumour formation, including malignant tumours, during the period of intensive growth of animals. Only malignant tumours, due to more active metastasis, are able to manifest in the organism much earlier than benign ones. Therefore, diagnosis of such neoplasms occurs at a later age, which was observed in the conducted studies.

Large breed dogs were more vulnerable at the age of 6 to 9 years, during this period, tumours were diagnosed in 45 animals, which was 55.5% of the total number of cases in this age group. Whereas in the same animals, only at the age of over 12 years, the incidence of cancer is almost halved. In young dogs of small breeds up to 3 years of age, tumours were found very rarely, and mostly they were malignant neoplasms. With increasing age, the number of neoplasms only increased, but the ratio of different types of tumours was on the side of malignant pathology. The strength of the effect of the dog's age on oncological susceptibility, calculated by single factor analysis of variance, was found to be 21% ($P<0.05$). The analysis of breed dependence of oncological pathology manifestation revealed that no neoplasms were detected in poodles under 3 years of age, but the main number of tumours was diagnosed in animals over 9 years of age – 82% of cases. In dogs of the Shar Pei breed, epithelial skin lesions were most often observed in 57% of cases. In Boxers, tumours were localized in the head region – 40% and were predominantly benign neoplasms in up to 80% of cases and were diagnosed before the age of 8 years. In Pekingese dogs, the main diagnosis was malignant mammary tumours in 71% of cases.

When analysing the manifestation of oncological pathology depending on the sex of animals, it was revealed that in males the most frequent neoplasms were skin tumours up to 25% and genital organs 3.9%, and in females the main site of localization was the mammary gland – 36.3%, at that the most frequent epithelial neoplasms of the mammary gland were diagnosed in German shepherd dogs – 22 cases, which made 8.5% of all cases of oncology in this breed. No such pathology was detected in female Shar Pei and Labrador breeds. Due to the small number of sterilized animals, mostly from the number of mongrels, the results of the analysis for this indicator were not reliable and will be investigated in detail in subsequent works. Also, if possible, it is planned to carry out genetic and selection analysis of the influence of paternal breeds on the manifestation of diseases in mongrel animals and correlation analysis of the manifestation of cancer pathology in different generations.

DISCUSSION

Veterinary oncology, especially in the context of small, domestic animals, is becoming a major focus of most clinical facilities that practice animal medicine. The significant use of dogs for business purposes in pure-bred breeding or their use as human companions brings a new level of veterinary care to these animals. And with current knowledge and diagnostic capabilities, the real causes of disease and death in dogs are coming to the fore. Therefore, the results obtained need revision and more in-depth knowledge. Such a direction, which is developing at a very fast pace, is veterinary oncology. Research in this direction is carried out both to improve the treatment of different types of neoplasms and to investigate predisposition factors in the development of such pathology. The results of genetic and statistical analysis, which are presented in this paper, are also one of the directions of accumulation of knowledge base in veterinary oncology. The results obtained should help dog owners to identify critical moments in the life of their pets in order to ensure their long and healthy existence.

In the study conducted, the main focus of the research work was to investigate the influence of breed and age of dogs on their predisposition to develop cancer pathology. At the same time, the breed aspect was studied with the involvement of additional factors: body size and gender identity. The obtained results of predisposition to tumour formation in the controlled animals allowed ranking the breeds of dogs by intensity of the disease in the following descending order: German and Central Asian shepherd dogs, Rottweiler, Dachshund, Poodle, Shar Pei and Pekingese. In contrast, breeds such as Bulldogs, Dalmatians, Taigans, St Bernards, Yorkshire Terriers, Jack Russell Terriers and Riesenschnauzers showed a lower risk of developing tumours. In studies conducted by N.R. Senthil *et al.* (2020) observed quite different incidence rates among animals of individual breeds. Thus, the incidence of German Shepherd dogs was minimal – 3.9%, and the highest incidence of tumours was found in mongrel dogs, which is confirmed by the results of studies by A.L. Martins *et al.* (2022). The difference in results obtained between different researchers could be due to the difference in the population size of a particular breed in the area where the

experiments were conducted. The probability of an increase in the number of animals with cancer was found to be directly proportional to the population size. But, despite the number of breeds in all studies, the breeds that are more susceptible to cancer have fallen into the risk group. These include the Golden Retriever and the Rottweiler. In addition to the previous authors, information about the high predisposition to the disease in such animals is also given in their studies by M. Cray *et al.* (2020).

The age dynamics of oncological diseases in dogs of different breeds indicates that the maximum manifestation of pathology occurs between 6 and 9 years of life. At the same time, the number of diseased animals in the conducted studies fall under the normal distribution, which indicates its natural nature, which is not influenced by any side or unnatural conditions. On this basis, it can be stated that similar results can be expected in other studies where there was no artificial selection of control animals. This was confirmed by the results of cancer screening presented in the work by J. Rafalko *et al.* (2023) on a group of dogs numbering 3452 animals diagnosed with cancer. In this work, the average age of dogs at initial diagnosis was 8.8 years, which corresponds to the results obtained when analysing the database of oncologically diseased animals in Bishkek. In the work of these authors, it is also indicated that in pure-bred dogs, oncological diseases were diagnosed at a much earlier age in comparison with non-breed animals. In this case, the weight of animals was inversely proportional to their age at the time of diagnosis of the disease. In the studies referenced in this paper, large breed dogs were also diagnosed with tumours at an earlier age than small breeds.

Similar results were obtained in the work of A. Doherty *et al.* (2020), in which, when analysing information on genotypic and phenotypic characteristics of more than 72,000 dogs, it was concluded that breeds with high average body weight had higher mortality rates from cancer problems and shorter life expectancy. Although the work of A.M. Oberbauer *et al.* (2019) makes some distinction on the propensity to develop tumours between the natural body weight of an animal that meets breed traits and overweight that is a consequence of spaying or overfeeding animals. Initially, when carrying out the work, it was also planned to analyse materials on the influence of castration of males and females on the morbidity of animals. But in the process of its implementation, it turned out that among the sterilized animals there were only mongrel animals, and in insignificant quantity. Such a sample did not allow obtaining representative results, so this research was postponed until the next work.

Analysis of the information database of veterinary clinics in Bishkek on oncological problems of dogs showed that neoplasms were more often registered in large breeds of dogs. Moreover, the ratio of different types of tumours changed with age. In older dogs, the probability of diagnosing a malignant neoplasm decreased and the frequency of benign tumours increased. The logical explanation for this trend is the lack of early diagnosis of neoplasms in dogs in Kyrgyzstan, and the diagnosis of oncology is made already at physiological disorders in animals, when clinical signs appear. Preventive screening of animals for early diagnosis of oncological problems, even in pure-bred animals, which are used in breeding for profit, is not carried out, and the detection of tumours occurs as a result of the manifestation of dysfunction of the body, or with obvious clinical signs. Since malignant neoplasms in the organism progress much faster than benign ones, they are detected at an earlier age. This can explain the current dynamics of the detection of neoplasms in dogs in Bishkek.

The analysis of the influence of sex on the predisposition to oncological problems indicated a significantly higher probability of tumour development in female dogs compared to males. The difference between the sexes in the studies was 26%. The studies of A.M. Koterbay *et al.* (2020) on Chow Chow animals and of K. Pinello *et al.* (2022) on a population of 13006 dogs of different breeds indicate that there is a greater likelihood of tumours being found in female individuals. In the case of the animals from Bishkek, this significant preponderance in the incidence in females was associated with the prevalence of tumours in the mammary gland, which accounted for more than 36% of all tumours in this sex.

The analyses conducted support the hypothesis that age and breed factors both separately and in combination influence the susceptibility of dogs to oncological pathology. These observations allowed identifying the peculiarities of the manifestation of some morphological types of tumours in dogs of different breeds and to determine the critical periods of their formation. The results obtained confirm the importance of annual examinations in dogs for the prevention of oncology, as well as the need to register cases of cancer in animals, which will facilitate the development of new approaches for the prevention of diseases in dogs, as well as increase their life expectancy.

CONCLUSIONS

Based on the materials of the unified information database of veterinary clinics of Bishkek on cases of dogs with oncological diseases, as well as on the results obtained during its statistical analysis, the following conclusions and suggestions for future scientific work can be made. In pure-bred dogs, the ratio of morphological types of tumours was approximately at the same level, with a slight increase of benign neoplasms 54%. The influence of sex on the predisposition to tumour formation in dogs, in the studies carried out, revealed a significant increase in this pathology in females – 63%, the reason for this was the high level of neoplasms

in the mammary gland, the proportion of which was 36.3% of all tumours in this sex. The most predisposed breeds to oncological pathology were dogs of large breeds, namely German (n=48; 14.6%) and Central Asian shepherd dogs (n=23; 7%). In representatives of these breeds, benign tumours prevailed (n=75), or 54% of the total number of benign masses. Whereas malignant tumours were predominantly detected in small breed dogs, 59% (n=29). The maximum manifestation of oncological pathology in dogs, regardless of breed, was observed between 6 and 12 years of age. At the same time, with increasing age, the probability of diagnosing malignant neoplasm decreased.

To reduce the negative effect of oncological pathology on dogs, it is recommended to carry out annual screening of dogs from the age of 6 years. This will facilitate timely diagnosis of neoplasms in the body and increase the effectiveness of treatment procedures. Firstly, such screening is recommended for dogs used for pure-bred breeding and service companion dogs. In order to accumulate knowledge about the manifestation and predisposition of dogs to oncological pathology in future studies it is planned to conduct research on the influence of sterilization of animals of both sexes on the development of tumour neoplasms in them, and to conduct genetic and selection analysis on the manifestation of oncology in related animals in different generations.

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CONFLICT OF INTEREST

None.

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Вплив віку та породи собак на розвиток пухлини

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Анотація. Збільшення чисельності собак як домашніх тварин ставить перед ветеринарними фахівцями завдання пошуку нових підходів для профілактики їх захворюваності та ранньої смертності. Вік і породу вважають основними критеріями ризику утворення пухлин у собак, тому метою цього дослідження було вивчення впливу цих і низки інших чинників на схильність розвитку онкологічної патології в цього виду тварин. Дослідження ґрунтувалися на аналізі єдиної бази даних ветеринарних клінік міста Бішкек, що включає 328 підтверджених випадків онкологічної патології у собак. Найпоширенішими породами були німецькі (n=48) і середньоазіатські вівчарки (n=23), ротвейлери (n=18), такси (n=18), пуделі (n=17), шарпеї (n=14), пекінеси (n=14), а також група безпородних собак (n=70). Доброякісні новоутворення були зафіксовані в 140 випадках, що становило 54,3 % від загальної кількості пухлин чистопородних собак. Доброякісні пухлини переважали у собак великих порід (n=75), або 53,6 % від загальної кількості доброякісних утворень, а найбільший ріст злоякісних пухлин виявили в собак маленьких порід 59 % (n=29). Собаки, незалежно від породної приналежності, виявилися більш уразливими до утворення пухлин у віці від 6 до 12 років. Під час аналізу бази даних виявилося, що у самок ймовірність онкологічної патології була вищою, ніж у самців, при цьому основним діагнозом у самок були пухлини молочної залози – 36,3 %. У дрібних порід собак ризик розвитку пухлин молочних залоз був вищим, ніж у великих собак. Отримані результати виявили породні особливості прояву морфологічних типів пухлин у собак і дали змогу визначити критичні періоди їх утворення

Ключові слова: новоутворення; онкологічна патологія; схильність; база даних; статистичний аналіз

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Economic efficiency of growing winter barley in the Southern Steppe zone of Ukraine under the influence of variety and biological preparations

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Abstract. The relevance of the article lies in the determination of the most optimal varieties and biopreparations that ensure high yield and profitability of growing winter barley. The purpose of the research was to determine the main indicators of the economic efficiency of the elements of the technology of growing winter barley for foliar fertilizing of plants in the main periods of vegetation with biological preparations. When conducting research, generally accepted methods were used: systematic approach and systematic analysis, field and statistical. The article provides data on the economic efficiency of the elements of winter barley cultivation technology based on the results of research conducted with four varieties of the crop in the conditions of the Educational and Scientific Practical Center of the Mykolaiv National Agrarian University in 2016-2019. The impact of variety selection, foliar fertilizing with modern bacterial preparations on the main indicators of the economic efficiency of growing winter barley was analysed. It was established that the cost of the grown grain depended on and changed under the influence of the features of the variety, biological preparation and the number of fertilizing. Obtaining the maximum cost of grain ensured the cultivation of winter barley varieties Valkyrie and Oscar for carrying out foliar feeding in the phase of tillering and emergence of plants in the tube with the biological preparation Organic Balance: 26.5 and 26.3 thousand hryvnias/ha, respectively. The same varieties, in case of two-time fertilization with Azotophyt, formed the value of grain at 25 thousand UAH/ha, and in controls – 20.1 and 21.1 thousand UAH/ha, respectively. Indicators of conditional net profit and level of profitability also changed with a similar dependence. Values of the cost of growing a unit of production of winter barley had the opposite dependence. The obtained scientific research results and definitions will contribute to the cultivation of winter barley on the basis of resource conservation with the use of biological preparations to increase productivity and the main factors of economic efficiency

Keywords: cost of grown grain; conditional net profit; level of profitability; cost of growing a unit of production

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INTRODUCTION

Technological measures in the cultivation of any culture should ensure economy, ease of use, obtaining stable productivity while simultaneously forming optimal indicators of economic efficiency. The specified factors, the selection of varieties and the possibility of optimizing nutrition on a resource-saving basis determine the relevance of this article. Winter barley in Ukraine, and in particular in the Southern Steppe zone, is an important crop of the grain wedge, it significantly increases productivity by optimizing nutrition, which in turn affects the overall costs and profitability of cultivation.

It is possible to significantly improve plant nutrition, to obtain a high yield with at the same time high-quality indicators of grain at low costs. It is appropriate to effectively manage the processes of forming the productivity of winter barley on a resource-saving basis through the use of optimization of nutrition with modern biological preparations in the main periods of plant growth and development. In addition to having a beneficial effect on growth processes and increasing the yield level, each element of cultivation technology must be economically feasible and ensure profitability and profitability, that is, not significantly increase costs and unit cost of production.

O. Vinyukov *et al.* (2021) have established with their own studies that inoculation of seeds with a microbiological preparation in the technologies of growing winter wheat helps to increase the supply of nutrients to plants that stimulate the development of plants during the growing season, and, as a result, increased the parameters of the crop structure. Based on the results of research by I. Mosiychuk *et al.* (2022), who conducted research with biological preparations Oracle multicomplex, Vimpel 2 and a mixture of preparations Vimpel 2 + Oracle multicomplex, formed the opinion that biological preparations significantly affect the sowing quality of spring barley seeds of the Sebastian and Helios varieties. The most effective is the use of a mixture of drugs Vimpel 2 + Oracle multicomplex, that is, the use of biological drugs in a complex increased growth processes, and also increased the energy of germination and laboratory germination of seeds.

Yu. Mashchenko *et al.* (2023) believe that the yield of winter wheat in grain-steam-row crop rotation when using the organo-mineral fertilization system with the biopreparation Mikofrend was 6.18 t/ha, and the increase from mineral fertilizers was 0.56 t/ha. A significant increase in yield was obtained due to the biological preparation, which was recorded in the version without fertilizers – 0.45 t/ha. That is, scientists have confirmed that the use of a biological preparation significantly increased the yield. A number of authors, I. Kohut *et al.* (2021) determined the influence of growth regulators on the productivity of winter barley sowing Highlight in the conditions of the Southern Steppe of Ukraine. Thus, the use of the scheme with Chlormequat chloride at a dose of 1.5 l/ha and Terpal at a dose of 1.0 l/ha led to a lengthening of interphase periods, which in turn led to the longest vegetation period of winter barley in this experiment – 169 days. Application of Terpal at a dose of 2.0 l/ha shortened the vegetation period by 2 days compared to the first scheme. Winter barley completed the growing season the fastest in the control variant, where the length of the growing season was 156 days.

The author O. Makuha (2021) reports in her research that when spring barley seeds are treated with the phosphate-mobilizing biopreparation albobacterin, the increase in net profit compared to the control variant varied from UAH 851/ha in the Sovira variety to UAH 1,011/ha in the variety Helot. At the same time, the increase in profitability ranged from 4.9% to 5.6%, depending on the variety. Under the influence of the biological preparation polymyxobacterin, an even higher increase in net profit was observed for the specified varieties, namely UAH 1,303/ha and UAH 1,704/ha, respectively. The level of profitability also increased, being 7.6% and 9.5%, respectively, for these varieties.

Among the most cost-effective components of the cultivation technology of any crop should be the selection of the variety. It should be adapted to a certain zone, provide a high yield potential, and for winter barley also be frost-resistant, have signs of resistance to adverse environmental conditions and changes in soil and climatic conditions. After all, under absolutely identical growing conditions, the realization of the genetic potential of productivity within varieties can manifest itself and differ significantly. The listed studies contributed to the development of the topic, but the most productive varieties and biological preparations for foliar feeding of plants during important phases of their vegetation have not yet been determined. That is why the purpose of the research was to substantiate the economic aspects of the introduction of the use of biological preparations on winter barley varieties during the main periods of plant growth and development.

MATERIALS AND METHODS

The research was conducted with winter barley during 2016-2019 at the Educational and Scientific Practical Center of the Mykolaiv National Agrarian University. The scheme of the experiment included the following options: Factor A – varieties of winter barley: Worthy, Valkyria, MIP Oscar and MIP Yason; Factor B – biological preparations: control (water treatment), Azotophyt, Mycofriend, Melanoriz, Organic balance (Table 1).

Table 1. *Scheme of the experiment*

Factor A – varieties:	**Factor B – biologics:**
Worthy (st)	Control (water treatment)
Valkyrie	Azotophyt
MIP Oscar	Mycofriend
MIP Yason	Melanoriz
	Organic balance

Source: *developed by the authors*

The research material was four varieties of winter barley presented by leading institutions of Ukraine: Dostoiny and Valkyrie from the Breeding and Genetic Institute – National Center for Seed Science and Varietal Research in Odesa, which are recommended for all zones of Ukraine since 2014. Additionally, MIP Oscar and MIP Yason are represented by the Myroniv Wheat Institute named after V.M. Crafts of the National Academy of Agrarian Sciences of Ukraine and included in the register of plant varieties of Ukraine in 2016-2017 (State register of plant varieties, 2023). In the experiment, the effect of four biopreparations, namely Azotophyt, Mycofriend, Melanoriz, and Organic Balance, was studied on the specified varieties of winter barley.

Azotophyt is a systemically acting biological preparation that contains natural *Azotobacter bacteria chroococcum* and biological products of their vital activity. It stimulates the development of the root system of plants, strengthens their immune system, improves the quality of the soil, helps to increase the yield and increases the nitrogen content in the soil. Mycofriend is a mycorrhizal biopreparation containing *Glomus fungi sp.*, rhizosphere microorganisms that contribute to the formation of mycorrhizae. Also included are phosphate-mobilizing bacteria and bacteria with fungicidal properties. Melanoriz is a complex mycorrhizal preparation created to nourish plants and protect them from diseases. It contains mycorrhizal fungi *Glomus, Aspergillus terreus, Trichoderma lignorum, Trichoderma viride,* which help plants absorb nutrients and protect them from diseases. Organic balance is a biological preparation that stimulates the growth and development of agricultural crops, provides stress resistance and balanced nutrition. It contains a concentrated mixture of live producer bacteria that provide plants with nitrogen, phosphorus and potassium, and also have fungicidal properties to protect plants from bacterial and fungal diseases. The research was conducted during 2017-2018 and 2018-2019, and the drugs were used at a dose of 200 g/ha, while the working solution was 200 l/ha.

Foliar fertilizing of winter barley was carried out at specific moments of the growing season. The first additional feeding took place during the spring tillering of the plants, and the second and third feeding took place after tillering, at the beginning of the emergence of the plants in the tube. The soil on the experimental sites was southern chernozem, with an average concentration of mobile nutrients. The content of organic matter in the 0-30 cm soil layer was 2.9-3.2%, and the pH ranged from 6.8 to 7.2. The area of the sowing plot was 72 m^2, while the area of the accounting plot was 30 m^2, and the experiment was conducted using four times repetition. The predecessor for sowing winter barley was peas. All varieties of barley were sown in accordance with the optimal terms for this climatic zone. Taking into account information about the predecessor and the level of soil nutrition, no mineral fertilizers were used, and the method of growing winter barley corresponded to the generally accepted for the Southern Steppe of Ukraine, except for the factors that were the object of study.

The cost of gross production was determined by multiplying the yield of the crop by the price of 1 ton of grain. The cost of cultivation was determined by dividing production costs by yield. Conventionally, the net profit was determined by the difference between the cost of gross products and production costs. The level of profitability is by dividing net profit by production costs. In order to assess the economic efficiency of growing winter barley varieties under the influence of foliar fertilizing with biological preparations and justifying the expediency of the researched factors, technological maps were drawn up and calculations were made of the cost of products, production costs for cultivation, cost price, conditional net profit and the level of profitability (at the prices of 1.12. 2022).

Experimental plant studies, including the collection of plant material, conformed to the principles established by the relevant institutional, national or international standards. The authors followed the requirements and provisions of the Convention on the Conservation of Biological Diversity (1992), as well as the Convention on Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS AND DISCUSSION

The economic efficiency of the use of biological preparations for the researched varieties of winter barley was determined: the cost of gross production, the cost of growing a unit of production, the level of profitability of production. It has been established that the use of complex biological preparations twice in the main periods of winter barley plant development (in the phase of spring tillering and at the beginning of the emergence

of plants into the tube) increases the efficiency of crop cultivation and ensures an increase in the level of profitability. During the research, there was also determined that the cost of gross production for the cultivation of winter barley varied to a certain extent depending on the varietal composition and biological preparations, which is associated with fluctuations in the levels of grain yield according to the variants. With fertilizing, and especially in both phases, this indicator increased regardless of the variety (Table 2).

Table 2. *The cost of gross production when growing winter barley grain depending on the variety and biological preparations (average for 2017-2019), thousand UAH/ha*

Feeding option (factor B)	Variety (factor A)				
	Worthy	Valkyrie	Oscar	Jason	the average factor B
CONTROL (water treatment)	18.7	20.1	21.1	18.4	19.6
Azotophyt I	21.4	24.0	24.2	20.6	22.5
Azotophyt I+II	22.6	25.0	25.0	22.3	23.7
Mikofrend I	21.2	22.8	23.1	20.1	21.8
Mycofriend I+II	21.6	23.7	24.5	20.8	22.7
Melanoriz I	19.8	21.3	22.3	19.2	20.6
Melanoriz I+II	20.3	22.5	22.8	20.3	21.5
Organic balance I	20.4	25.2	25.8	22.6	23.5
Organic balance I+II	21.4	26.5	26.3	23.5	24.4
Average factor A	20.8	23.4	23.9	20.9	22.3

Notes: *Period of foliar fertilization: I – in the phase of spring tillering; I+II – in the phase of tillering and at the beginning of the emergence of plants into the tube*
Source: *developed by the authors*

In the control, and especially with the cultivation of the Yason variety, this indicator was the lowest – 18.4 thousand UAH/ha, and when using the biological preparation Organic-Balance on sowing the Valkyria variety in both phases, it increased to 26.5 thousand UAH/ha or by 44 .0% and was the maximum. Cultivation of the Oscar variety provided these indicators at the levels of 26.3 thousand UAH/ha and 42.9%. The highest value of gross production on average for all variants over the years of research – 23.9 thousand hryvnias/ha was provided by the cultivation of the Oscar winter barley variety. In the Valkyrie variety, it was 23.4 thousand hryvnias/ha, and in the Dostoiny variety, it decreased to 20.8 thousand hryvnias/ha, or by 14.9%. It was determined almost the same for the cultivation of Yason winter barley – 20.9 thousand hryvnias/ha.

Fertilization with Organic-Balance biological preparation twice during the growing season ensured an increase in the value of gross production for all varieties to UAH 24.4 thousand/ha, which is 24.5% more compared to the control option (treatment of crops with water). The effectiveness of the use and advantages of biological preparations, which are taken for research, is illustrated in Fig. 1, which shows the average values of the cost of grown products for carrying out one and two treatments of weeding plants.

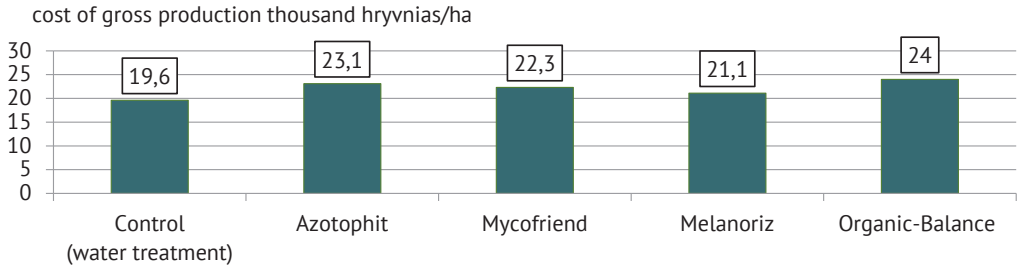

Figure 1. *Cost of gross production under the influence of biological preparations (average by varieties for 2017-2019), thousand UAH/ha*
Note: **Organic balance for 2018-2019*
Source: *developed by the authors*

The cost of growing 1 ton of winter barley grain is a minimum of UAH 1.7 thousand. determined by the Valkyrie variety after a one-time sowing treatment with the drug Azotophyt (Table 3).

This indicator increased to 2.29 thousand hryvnias/t or by 32.9% when growing the Yason variety treated with the same biological preparation in the spring budding phase.

Table 3. *Cost of growing 1 ton of winter barley grain depending on the influence of the studied factors (average for 2017-2019), thousand UAH*

Feeding option (factor B)	Variety (factor A)				
	Worthy	Valkyrie	Oscar	Jason	The average factor B
CONTROL (water treatment)	1.99	1.87	1.80	2.02	1.92
Azotophyt I	2.20	1.70	1.98	2.29	2.04
Azotophyt I+II	2.21	1.74	1.72	2.23	1.98
Mikofrend I	2.06	1.92	1.90	2.16	2.01
Mycofriend I+II	2.14	1.97	1.91	2.22	2.06
Melanoriz I	2.19	2.05	1.96	2.25	2.11
Melanoriz I+II	2.27	2.07	2.04	2.27	2.16
Organic balance I	2.13	1.76	1.72	1.94	1.89
Organic balance I+II	2.16	1.78	1.79	1.99	1.93
Average factor A	2.15	1.87	1.87	2.15	2.01

Notes: *Period of foliar fertilization: I – in the phase of spring tillering; I+II – in the phase of tillering and at the beginning of the emergence of plants into the tube*
Source: *developed by the authors*

According to the varietal composition, the Valkyria and Oscar varieties provided the advantage in forming the minimum values of the cost of production of 1 ton of grain at the level of UAH 1.87 thousand. For the cultivation of other researched varieties, this indicator increased to UAH 2.15 thousand/t or by 14.9%. On average, based on the nutritional background (factor B), the lowest cost of growing 1 ton of grain of the studied crop at the level of UAH 1.89 thousand was determined by the option of using the drug Organic-Balance once in the tillering phase. This indicator increased by 14.2% (up to 2.16 thousand hryvnias/t) during two-time feeding with the drug Melanoriz. In the conditions of a market economy, one of the main criteria for the economic efficiency of technological processes is the obtaining of conditional net profit and the level of profitability. A comparison of indicators of conditional net profit shows that it was the lowest (10,000 hryvnias/ha) when growing the Yason variety with a one-time feeding with the biopreparation Melanoriz during the tillering phase (Table 4). A significant increase of this indicator to 16.4 thousand hryvnias/ha or by 64.0% was provided by the Valkyrie variety after two-time treatment of crops with the biological preparation Organic-Balance.

Table 4. *Conditionally net profit when growing winter barley grain depending on the variety composition and biological preparations (average for 2017-2019), thousand UAH/ha*

Feeding option (factor B)	Variety (factor A)				
	Worthy	Valkyrie	Oscar	Jason	the average factor B
CONTROL (water treatment)	10.8	12.1	13.0	10.5	11.6
Azotophyt I	11.4	15.3	14.0	10.6	12.8
Azotophyt I+II	12.0	15.7	15.8	11.7	13.8
Mikofrend I	11.9	13.5	13.8	10.9	12.5
Mycofriend I+II	11.8	13.8	14.6	11.0	12.8
Melanoriz I	10.6	12.0	13.0	10.0	11.4
Melanoriz I+II	10.5	12.6	12.9	10.5	11.6
Organic balance I	11.1	15.8	16.3	13.2	14.1
Organic balance I+II	11.6	16.4	16.3	13.5	14.4
Average factor A	11.3	14.1	14.4	11.3	12.8

Notes: *Period of foliar fertilization: I – in the phase of spring tillering; I+II – in the phase of tillering and at the beginning of the emergence of plants into the tube*
Source: *developed by the authors*

The average factorial values proved the advantage of growing the Oscar variety, which provided an increase in conditional net profit to UAH 14.4 thousand/ha, which was 27.4% higher than the level of the Dostoiny and Yason varieties, which generated a profit of UAH 11.3 thousand/ha Ha. With regard to factor B (nutritional background), the advantage of two-time feeding of crops with the preparation Organic-balance, which contributed

to the growth of the studied indicator to 14.4 thousand hryvnias/ha, was substantiated. The minimum level of conditional net profit (11.4 thousand hryvnias/ha) was provided by one-time feeding with the biological preparation Melanoriz. A clear confirmation of the advantages of the biological preparation Organic-Balance and, conversely, the lowest efficiency in ensuring the conditional net profit from Melanoriz, are the data in Figure 2.

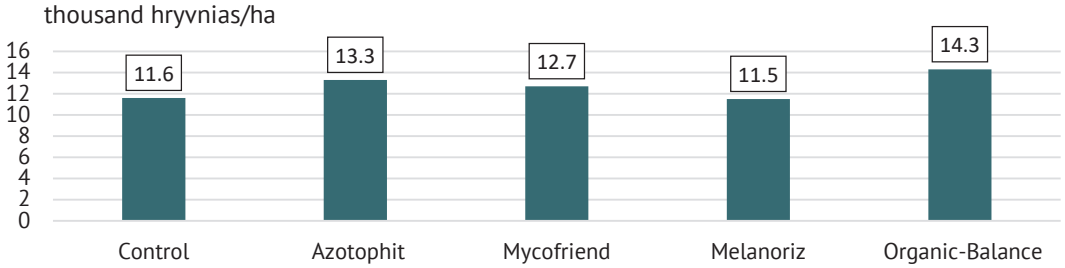

Figure 2. *Conditional net profit depending on the biological preparation (average by varieties for 2017-2019), thousand UAH/ha*

Source: *developed by the authors*

An important indicator of economic efficiency is the profitability of culture production. The level of profitability of the elements of the winter barley grain cultivation technology, depending on the varietal composition and biological preparations, ranged from 105.4% in the version with the Yason variety for a one-time sowing treatment with the biological preparation Azotophyt. In the Valkyrie variety, in the same variant, it increased to 177.1%, or the difference between these identical variants of feeding with Azotophyt in the phase of spring tillering was 68.0 relative percent (Table 5).

Table 5. *The level of profitability of winter barley grain cultivation technology depending on the variety composition and biological preparations (average for 2017-2019), %*

Feeding option (factor B)	Variety (factor A)				
	Worthy	Valkyrie	Oscar	Jason	average by factor B
CONTROL (water treatment)	136.2	150.9	160.5	133.2	145.2
Azotophyt I	113.4	177.1	136.8	105.4	133.2
Azotophyt I+II	113.0	170.7	172.7	110.3	141.7
Mikofrend I	128.2	144.2	147.4	118.0	134.5
Mycofriend I+II	119.4	138.8	146.0	111.9	129.0
Melanoriz I	114.8	129.6	139.2	108.7	123.1
Melanoriz I+II	107.1	127.6	130.6	107.1	118.1
Organic balance I	120.4	167.6	172.5	142.0	150.6
Organic balance I+II	117.6	163.3	162.1	136.2	144.8
Average factor A	118.9	152.2	152.0	119.2	135.6

Notes: *period of foliar fertilization: I – in the phase of spring tillering; I+II – in the phase of tillering and at the beginning of the emergence of plants into the tube*

Source: *developed by the authors*

On average, in relation to the varietal composition, the studied indicator reached the highest level of 152.0 and 152.2% for the cultivation of Oscar and Valkyria varieties, respectively. The Dostoiny and Yason varieties have a significantly lower profitability level of 118.9; 119.2% or 27.5-28.0 relative percent less compared to the Valkyrie and Oscar varieties. According to feeding options, the lowest level of profitability was determined on an average of 118.1% for two-time use for feeding the drug Melanoriz. This indicator exceeded 150% for a one-time feeding with the biological preparation Organic-Balance. This testifies to the high economic efficiency of foliar fertilizing of plants of winter barley varieties with the biological preparation Organic-Balance, and the use in both phases is 144.8%.

It should also be noted that the use of Organic Balance for top dressing, especially in the spring tillering phase, increased the profitability levels of the production of all studied varieties of winter barley, except for the Dostoiny variety, the cultivation of which achieved the highest profitability in the control option for the treatment of sowing plants with water without the use of biological preparations. The reaction of winter barley varieties to foliar fertilizing is presented in Figure 3.

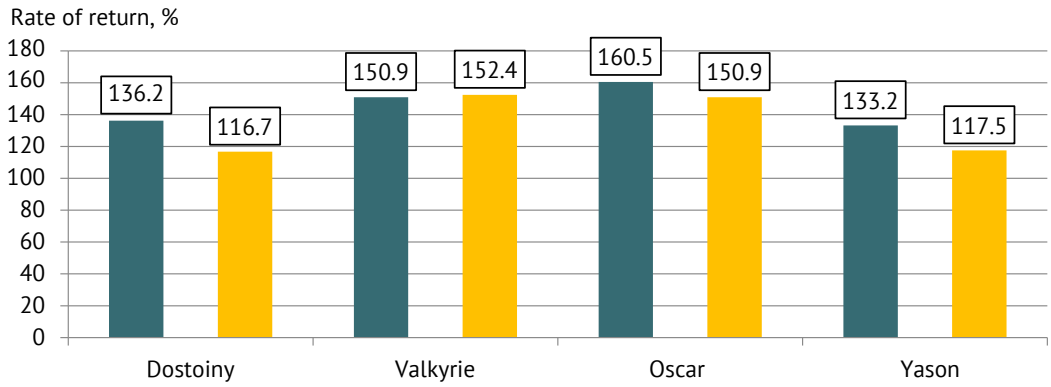

Figure 3. *The level of profitability of growing winter barley varieties depending on foliar fertilizing with biological preparations (average for 2017-2019), %*

Notes: *control (water treatment); Average values for variants of feeding with biological preparations*

Source: *developed by the authors*

At the same time, despite a certain decrease in the profitability of growing winter barley varieties in the case of seed fertilization, and vice versa, a certain increase in the cost price compared to the control, the conditional net profit at the same time increases in most variants of the experiment, which indicates the expediency and payback of the incurred costs and generally confirms the economic efficiency of this technological measure. Studies and calculations have confirmed that a certain agricultural measure, which is included in the technology of growing an agricultural plant, should be distinguished by positive results in relation to the main economic indicators. It should not be highly expensive in terms of the total cost of cultivation, provide conditional net profit and level of profitability, and not significantly increase the cost price.

The most important factors of the agro-economic efficiency of growing winter barley, which were determined under the influence of the use of such an element in technology as foliar feeding with modern biological preparations to optimize plant nutrition on the basis of resource conservation, are consistent with the previously obtained results of many scientists conducted with winter crops (Vozhegova & Krivenko 2019; Pozniak, 2019; Gamayunova & Kuvshinova 2021).

A number of studies by H. Huang *et al.* (2019) testify to a significant increase in yield levels with the use of mineral fertilizers to feed grain crops. However, growing costs due to the high cost of both the fertilizers themselves and their direct application are increasing. The introduction of resource-saving measures in cultivation technology, in particular biological preparations and re-regulating substances, has a favourable effect both on the growth processes and yield of plants, and on indicators of economic efficiency. According to the results of research by A. Krivenko (2019) and comparing the use of mineral fertilizers and biological preparations on winter wheat after black steam at the Odesa Agricultural Research Station, the advantage of the latter was noticeable: the level of profitability in the option of using N_{60} was 115.1%, and Azotophyta – 154.2%. The grain yield was at the levels of 4.06 and 3.97 t/ha, respectively, production costs were 9.9 and 8.2 thousand UAH/ha, conditional net profit was 11.4 and 12.6 thousand UAH/ha, and the cost of production 2.44 and 2.06 thousand UAH/t, respectively. In the studies of the same author, grain yield from the use of complete mineral fertilizer $N_{64}P_{64}K_{64} + N_0$ was formed at the level of 5.41 t/ha, or significantly higher, but the level of profitability decreased to 95.7% and the cost of cultivation increased to 2.68 thousand hryvnias/t.

Research by D. Lovarelli *et al.* (2019) also confirmed that, compared to other technological factors, mineral fertilizers or optimization of plant nutrition, including on the basis of resource conservation, affect the level of harvests to a much greater extent. For nutrition, it is important to create other favourable conditions for each culture. In the conditions of climate change, particularly the increase in its aridity, it is expedient to pay considerable attention to soil cultivation measures. This element in plant growing technology is quite expensive and affects the water-physical properties of the soil.

The issue of growing winter barley in crop rotation on irrigated dark-chestnut soil in the conditions of Southern Ukraine was investigated by the authors of M. Malyarchuk *et al.* (2022) established that the maximum efficiency of grain – 6.96 t/ha was formed by the crop with a combination of long-term disk tillage (12-14 cm) and fertilization with $N_{120}P_{40}$ per 1 ha of the crop rotation area against the background of making sideral fertilizer (spring mustard) and use of crop rotation by-products. In the specified variant, in addition to the highest grain yield, the authors also obtained the maximum level of profitability – 242.8% at the same time the lowest cost price – UAH 2,042/t. They also report that the level of grain yield was significantly influenced by the fertilization system in crop rotation, compared to the methods of cultivation.

Research by L. Kolomiets *et al.* (2022), carried out on the basis of organic technology for growing winter

wheat and spring barley in the conditions of the Right Bank Forest Steppe of Ukraine, established the effectiveness of the combination of no-till soil cultivation with the use of biological preparations. This ensured an increase in the grain yield of winter wheat by 28% and spring barley by 15% and was economically efficient. In particular, the costs of growing spring barley with the use of tillage and biological preparations were reduced by 10% for a profitability level of 159%. In addition to favourable economic factors, agricultural production under this approach is based on ecological principles of natural resource protection.

Research by I. Vogeler *et al.* (2023) confirmed that growing catch crops effectively reduces nitrogen leaching costs in farming systems. This becomes possible due to the fact that these crops absorb post-harvest mineral nitrogen from the soil before the onset of the main winter percolation season. Modelling shows that catch crops can reduce nitrogen leaching costs by 38-64% if grown annually and by 21-39% if grown biennially. The replacement value of nitrogen fertilizers varies on average from 28 to 44 kilograms of nitrogen per hectare, but they show high annual variability. It is important to note that indicators of nitrogen replacement by fertilizers do not always correlate with the nitrogen content consumed by the catch crop before its harvest. This may be due to the long-term effect of the process of nitrogen mineralization from the catch crop residues, as well as the competition for nitrogen resources from the catch crop.

Thus, on the basis of a review of literary sources and the results of own research, the importance of plant nutrition as one of the defining elements of technology is highlighted. At the same time, it is also substantiated that this measure can be carried out with minor additional investments. The use of biological preparations can increase the yield and quality of agricultural crops, ensure rational use of nature and economic expediency, because the output of products increases to a greater extent, compared to the incurred costs of resources. This is extremely important for the effective functioning of the agricultural sector, which provides more than 50% of the income of the Ukrainian economy and is a priority (Vakulenko, 2022). A certain record in relation to the gross collection of grain and leguminous crops, which in 2021 was collected by 33.5% more compared to the previous year 2020, was provided by the agrarians of Ukraine (Miroshnyk & Baglai 2022).

Authors V. Gamayunova *et al.* (2019) testify that the issue of increasing the level of grain production efficiency should be resolved both at the state and regional levels. At the same time, the area of winter grain crops in the Mykolayiv region varies from 65.1 to 71.7% in most years, and according to methodological recommendations, their specific weight should not exceed 60% of the arable area. However, there is currently a war going on in Ukraine, the acreage of crops is decreasing, and there are difficulties with the material and technical support of farms. In this regard, the effectiveness of the production of agricultural crops in the war and post-war periods, to increase the output of products, it is necessary to contribute to this on the basis of resource conservation, and the research and proposals of the current research.

CONCLUSIONS

Determining the economic efficiency of growing winter barley with the inclusion in the technology of the element of optimizing nutrition on the basis of resource conservation and environmental friendliness, namely the use of modern biopreparations, proved their positive impact. The cost of gross production for all varieties during the years of cultivation without the use of biological preparations for feeding amounted to 19.6 thousand hryvnias/ha on average, and in the most optimal variants of the experiment it increased to 23.7-24.4 thousand hryvnias/ha. Conditionally net profit, respectively, is defined as: 11.6 and 13.8-14.4 thousand hryvnias/ha. The cost of a unit of production for fertilizing with biological preparations in most variants of experiments on average varied insignificantly by variety, and the cultivation of Valkyrie and Oscar varieties, which formed the highest yield, even decreased compared to the control.

The level of profitability also changed with a similar dependence. In the control, it was 145.2% on average by variety, with fluctuations from 133.2 (Yason variety) to 160.5% (Oscar variety). Foliar fertilizing with biological preparations of Dostoiny and Yason varieties led to a decrease in the profitability of cultivation, and Valkyrie and Oscar varieties to growth, especially with the use of Organic Balance and Azotophyt. Thus, according to the results of research and calculations, farms in the Southern Steppe zone of Ukraine, engaged in the cultivation of winter barley, are advised to place it after the best predecessors, in particular after peas, to sow high-yielding varieties Oscar and Valkyrie, and to process the crops of plants in the phases of tillering and emergence into the tube biological preparations Organic Balance and Azotophyt. This will ensure the formation of stable levels of grain harvest and profitability and profitability of production.

Prospects for further research in the field of economic efficiency of growing winter barley may include a more in-depth analysis of the impact of different varieties of barley on the yield and quality of products in view of the conditions of different regions, as well as research on optimal doses and methods of using biological preparations to increase productivity and reduce costs for chemical fertilizers and plant protection. In addition, an important direction can be the assessment of the influence of environmental factors on the cultivation of barley and the development of recommendations for sustainable and stable cultivation of the crop in conditions of climate change and preservation of soil fertility.

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None.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Економічна ефективність вирощування ячменю озимого у зоні Південного Степу України за впливу сорту і біопрепаратів

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Анотація. Актуальність статті полягає у визначенні найбільш оптимальних сортів і біопрепаратів, які забезпечують отримання високої прибутковості та рентабельності вирощування ячменю озимого. Метою досліджень було визначити основні показники економічної ефективності елементів технології вирощування ячменю озимого за проведення позакореневих підживлень посіву рослин в основні періоди вегетації біопрепаратами. При проведенні досліджень використовували загальноприйняті методи: системний підхід і системний аналіз, польовий та статистичний. У статті наведено дані економічної ефективності елементів технології вирощування ячменю озимого за результатами досліджень, проведених з чотирма сортами культури в умовах Навчально-науково практичного центру Миколаївського національного аграрного університету у 2016-2019 рр. Проаналізовано вплив добору сорту, проведення позакореневих підживлень сучасними бактеріальними препаратами на основні показники економічної ефективності вирощування ячменю озимого. Встановлено, що вартість вирощеного зерна залежала і змінювалась за впливу особливостей сорту, біопрепарату та кількості проведених підживлень. Отримання максимальної вартості зерна забезпечило вирощування сортів ячменю озимого Валькірія та Оскар за проведення позакореневих підживлень у фази кущіння і виходу рослин у трубку біопрепаратом Органік-баланс: 26,5 та 26,3 тис. грн/га відповідно. Ці ж сорти у разі дворазового підживлення Азотофітом сформували вартість зерна по 25 тис. грн/га, а у контролях – 20,1 і 21,1 тис. грн/га відповідно. З аналогічною залежністю змінювались і показники умовно чистого прибутку та рівня рентабельності. Значення величини собівартості вирощування одиниці продукції ячменю озимого мали протилежну залежність. Отримані наукові результати досліджень та визначення сприятимуть вирощуванню ячменю озимого на засадах ресурсозбереження з використанням біопрепаратів для підвищення продуктивності та основних чинників економічної ефективності

Ключові слова: вартість вирощеного зерна; умовно чистий прибуток; рівень рентабельності; собівартість вирощування одиниці продукції

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Peculiarities of plant adaptation of interspecific hybrid *Betula ex vitro*

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Abstract. Microclonal propagation as one of the methods of biotechnology allows obtaining genetically homogeneous plants during the year from a minimum amount of donor material. Adaptation of plants *ex vitro* to environmental conditions is the final and important stage of microclonal propagation. The purpose of the study is to determine the optimal mode of plant adaptation of triploid interspecific hybrid *Betula ex vitro* to environmental conditions. Biotechnological (microclonal propagation) and statistical (arithmetic mean, standard error, one-way analysis of variance (ANOVA)) methods were used for research. The study was carried out in the research of Plant Biotechnology Laboratory of the Separated Subdivision of National University of

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Life and Environmental Sciences of Ukraine "Boyarka Forest Research Station" during 2019-2023. According to research, the MS nutrient medium with the addition of 0.25 mg·l^{-1} of kinetin stimulated the active proliferation of microshoots and root system. Optimum plant development took place on the nutrient medium *vitro* for a 25-30-day cycle of cultivation, which contributed to successful adaptation to environmental conditions. The proportion of adapted *Betula ex vitro* hybrid plants on agroperlite substrate was more than 60% for 30 days. Significant plant viability (more than 80%) was obtained under the conditions of preliminary exposure of the plant root system in auxin solution (1.0 mg/l IAA, 1.0 mg/l NAA, 1.0 mg/l IBA) for 25-30 minutes followed by daily spraying of leaves with 20% glycerin for 15-20 days. Adapted plants had typical pigmentation without signs of chlorosis and vitrification. In the spring, the survival rate of plants under environmental conditions was more than 80% and indicated a high level of adaptability after *in vitro*. The developed protocol for the adaptation of the *Betula ex vitro* hybrid allows obtaining high plant survival in environmental conditions. The practical value of the research is obtaining plants adapted to environmental conditions *ex vitro,* which in the future can be used to qualitatively enrich the range of artificial plantings in settlements

Keywords: culture *in vitro*; birch; microclonal propagation; substrate, viability

INTRODUCTION

Microclonal propagation is considered as a component of intelligent management of natural resources, which emphasizes the use of high-quality plant material *in vitro*. Application of technologies *in vitro* allows you to save and multiply valuable plant genotypes, create a plant bank, carry out cryopreservation, improve health and obtain plants with the necessary quality parameters. Such technologies are an effective way of obtaining high-quality plant material of forest-forming species. Obtained plant tissues *in vitro* – a model for genetic and cellular engineering. In this context, microclonal propagation of the triploid interspecific hybrid *Betula ex vitro,* which has a high growth rate and resistance to adverse environmental factors, is an extremely urgent task. Such propagation allows obtaining genetically homogeneous plants throughout the year from a minimum amount of donor material. Adaptation of woody plants *ex vitro* as the final and important stage of microclonal propagation shows how much the protocol *in vitro* is effective and can be used in large volumes for mass cultivation and high-quality enrichment of artificial plantations.

In the world practice of research with tissue culture of woody plants *in vitro* aimed at the study of plant material's juvenileness and the expression of target genes; intraspecific reaction of plants to LED lighting; development of a protocol for microclonal propagation, study of the regenerative capacity of tissues under the action of the components of the nutrient medium; determination of the anatomical, biochemical and physiological state of tissues; study of plant adaptation *ex vitro*.

In particular, the authors of M. Zeps *et al.* (2022) studied the intraspecific response of plants *in vitro* silver birch (*Betula pendula* Roth.) and clones of hybrid aspen (*Populus tremuloides* Michx. × *Populus tremula* L.) from the eastern Baltic to LED artificial lighting (LED). It was established that the studied light treatments did not affect the density of stomata and the secondary cell wall of xylem in birch stems, as well as the length of stomata, stem radius and phloem width of hybrid aspen. In the study, scientists B. Krivman *et al.* (2023) evaluated the expression of the target genes responsible for the juvenile microRNAs during the micropropagation of white birch, and also determined the factors affecting the juvenile genotypes and their different morphogenic ability *in vitro*.

Researchers S. Välimäki *et al.* (2021) studied the regenerative capacity *of in vitro* of dormant plant buds *of Ulmus laevis* Pall. and *Ulmus glabra* Huds. after cryopreservation. The authors also studied tissue initiation on DKW nutrient medium with the addition of growth regulators and tested the rooting of microshoots during short-term induction in a liquid nutrient medium followed by adaptation. P. Chmielarz *et al.* (2023) developed a protocol for microclonal propagation of 800-year-old *Quercus robur* L. plants using WPM and QL nutrient medium based on previous studies of M. Quorin & P. Lepoivre (1977).

Scientists J. Martins *et al.* (2022) investigated the effect of BA and kinetin (6-furfurylaminopurine) in WPM nutrient medium on the anatomical, biochemical and physiological condition of *Q. robur* shoots. Authors N. Dimitrova *et al.* (2021) note that plant adaptation *ex vitro* is a rather important stage that generally determines the success of micropropagation. It was established that the biostimulant Lumbrical (1:16, v:v), which was added to the substrate (peat, perlite, 1:1; peat-perlite, 1:1, v/v), increased the efficiency of plant adaptation *ex vitro Pyrus communis* L., improved vegetative growth and photosynthetic characteristics. H. Ribeiro *et al.* (2022) to adapt microshoots of walnut hybrid rootstock 'Paradox' (*Juglans hindsi* × *Juglans regia*) cl. 'Vlach' used rhizogenesis *ex vitro* using a substrate (coconut fibre, perlite, vermiculite, 80:10:10%). Researchers M. Capuana *et al.* (2022) established that for the adaptation of *Salix acmophylla* (Boiss.) *in vitro,* it is advisable to use an autoclaved substrate consisting of garden soil, peat, and sand (3:2:1).

N. Sharma *et al.* (2023) investigated various strategies (hydroponics, photoautotrophic acclimation, biotization) to achieve successful acclimation of plants *ex vitro*. Authors O. Chornobrov & O. Tkachova (2020) note that to prevent dehydration of *Fragaria vesca* L. *ex vitro* effectively apply the method of daily spraying of leaves with 30% glycerin solution for 30 days. They also note the influence of the length of time plants are kept in conditions of high relative humidity (85-90%) on the efficiency of adaptation of *F. vesca,* because its sudden change is a stress for plants.

Analysis of the literature indicates that the effectiveness of the adaptation of woody plants *ex vitro* to environmental conditions depends on a complex of internal and external factors, and quite often a significant percentage of waste is recorded. This, in turn, determines the need to develop an individual adaptation protocol and carefully select cultivation conditions for successful plant survival *ex vitro*. That is why the goal of the study was to develop an optimal protocol for the adaptation of plants of the triploid interspecies hybrid *Betula ex vitro* to environmental conditions. Research objectives: 1) to analyse the effect of various substrates on the efficiency of adaptation of hybrid plants; 2) to establish the viability of hybrid plants under the conditions of keeping the root systems in different auxin solutions; 3) to investigate the effect of different concentrations of glycerol on the growth characteristics of hybrid plants.

MATERIALS AND METHODS

The research was carried out at the Plant Biotechnology Laboratory of the Separated Subdivision of National University of Life and Environmental Sciences of Ukraine "Boyarka Forest Research Station" during 2019-2023. Aseptic regenerating plants of the triploid interspecific hybrid *Betula* were used for the research. This hybrid was obtained at the Scientific and Research Institute of Forestry "Silava" (Latvia) by artificial pollination of a suspended birch with downy birch pollen. The *Betula* hybrid has a high growth rate and resistance to adverse environmental factors. Plants *in vitro* were cultivated on MS nutrient medium according to T. Murashige & F. Skoog (1962), with the addition of growth regulators of the cytokinin type of action according to the method of M. Melnychuk *et al.* (2003), V. Kunakh (2005), S. Park (2021). 100 mg·l^{-1} myo-inositol, 30 g·l^{-1} were added to the nutrient media sucrose and 7.0-7.3 g·l^{-1} microbiological agar. The indicator of acidity of the environment (pH) was adjusted to the level of 5.7-5.8. The plant material was cultivated in a light room at a temperature of 24±1°C and illumination of 2.0-3.0 klx with a 16-hour photoperiod and a relative humidity of 70-75%. Aseptic conditions were created according to methods generally accepted in biotechnology (Slater *et al.*, 2003; Smith, 2012; Clark & Pazdernik, 2015).

Regenerants with a cultivation cycle of 25 days were adapted to the conditions of *ex vitro* in a stepwise manner, which consisted of adaptation to the conditions of the adaptation room and environment. Plants were removed from the test tubes with tweezers, the root system was washed from the remnants of the nutrient medium in tap water with subsequent transfer to 0.001% $KMnO_4$ (2-3 min). Plants were planted in plastic containers with a volume of 0.25 l, 1 pc. in the following substrates: river sand; coarse-grained agroperlite; horse peat, agroperlite, vermiculite (1:1:1); coconut fibres; coconut fibres, agroperlite (1:1). After planting, the plants were sprayed with water. Regenerants were fed once every 30 days with a solution of macro- and microsalts for ½ MS. The plants were kept in conditions of high relative humidity (HRH) (85-90%) for 3-5 days. HRH was determined using a digital thermohygrometer. Planting material was placed in glass containers. The main methods of gradual adaptation of plants were performed according to the method of H. Kushnir & V. Sarnatska (2005).

The HRH was gradually reduced to the level of 60-70% by means of artificial ventilation. Plants were sprayed with water when signs of wilting appeared. To increase the number of transplanted plants, the root system was kept for 15-20 minutes in a solution of auxins (1.0 mg/l IAA (indole-3-acetic acid), 1.0 mg/l NAA (1-naphthylacetic acid), 1.0 mg/l IBA (indole-3-butyric acid). Plants not treated with auxins were used as a control. We determined the effect of concentrations of glycerol solution (10%, 20%, 30%, 60%) on the morphometric parameters of plants, which were previously kept for 15-20 minutes in auxin solution and planted on an agroperlite substrate. Spraying of leaves with glycerin solution was carried out for 15-20 days. Plants were grown in an adaptation room under Osram Fluora phytolamps (illumination 3.0-4.0 klx, 16-hour photoperiod) at a temperature of 21±2°C. Plant viability was recorded after the appearance of new leaves (30 days of adaptation).

60 days after adaptation, the plants were transplanted into containers with a volume of 0.33 l in a substrate (agroperlite, coconut fibres, peat, 2:1:1). Starting from May and ending in September, container culture of plants lasts 2-8 hours. was in environmental conditions. In autumn, the plants were transplanted into containers with a volume of 1.0-1.5 l in a substrate (peat, agroperlite, coconut fibres, vermiculite, 4:1:1:1). In autumn 2021, the plants were planted in the environment. In winter, at temperatures below -10°C, plants *ex vitro* covered with agrofibre. Plant viability was determined in the spring.

Biotechnological methods, such as microclonal propagation, as well as statistical approaches, including arithmetic mean, standard error, and one-way analysis of variance (ANOVA), were used for the research. Statistically, the experimental data were processed using the MS Excel analysis package. Results are presented as M±m (M – arithmetic mean, m – standard error). To analyse the effect of substrates, auxins, and glycerol on the efficiency of plant adaptation, a one-way analysis of

variance (ANOVA) was performed. When conducting the research, the requirements of the Convention on Biological Diversity (1992) were observed.

RESULTS AND DISCUSSION

Active proliferation of explants by activating the growth of existing meristems, forming the root system, and obtaining *Betula* hybrid plants was obtained on MS with the addition of 0.25 mg/l kinetin (Fig. 1, a). According to the results of the study, the MS nutrient medium modified with 0.25 mg/l kinetin (6-(furfuryl-amino)purine) simultaneously stimulated the development of the microshoots and the roots of interspecific hybrid *Betula plants* (Fig. 1, b). On the 30th day of cultivation, plants were obtained *in vitro* with the following morphometric parameters: the share of regeneration-capable explants – 93.4±2.5%, microshoot length – 5.8±0.3 cm, the share of rooted microshoots – 96.4±1.6%, root length – 4.2±0.3 cm. Plants *in vitro* had pigmentation characteristic of the hybrid, signs of chlorosis and vitrification were not fixed (Fig. 1, c).

The substrate is of great importance for the survival of regenerating plants, and the efficiency of adaptation depends on its correct selection (Table 1).

Figure 1. *Betula interspecific hybrid plants in vitro on the nutrient medium and adaptation to conditions ex vitro*
Note: *a) plant in vitro; b) roots of plants, 30 days of cultivation; c) plants in a culture room on MS with the addition of kinetin; d) ex vitro plants on agroperlite substrate in glass containers in an adaptation room; e) plants ex vitro in distilled water with auxins; birch container culture, 63 days (f) and 95 days of adaptation (g); h) plants ex in vitro under environmental conditions*
Source: *photographed by the authors*

Table 1. *Efficiency of plant adaptation of interspecific hybrid Betula ex vitro to the conditions of the adaptation room and their growth on substrates, 30-day cultivation*

Version	Composition of substrates	The efficiency of plant adaptation *ex vitro* [1], %	The beginning of the formation of new leaves, era	Linear growth[2]	Pigmentation of shoots
1	river sand	0	–	–	–
2	agroperlite	64.0±5.1	14-18	active	green

Table 1, Continued

Version	Composition of substrates	The efficiency of plant adaptation *ex vitro* [1], %	The beginning of the formation of new leaves, era	Linear growth[2]	Pigmentation of shoots
3	horse peat, agroperlite, vermiculite (1:1:1)	27.0±3.0	35-38	weak	light green
4	coconut fibres	32.0±4.1	35-38	weak	light green
5	coconut fibres: agroperlite (1:1)	42.0±3.0	25-30	average	-//-

Notes: *1. mean ± standard error; 2. linear growth: active (more than 3 cm), medium (2.0-2.9 cm), weak (less than 1.9 cm), absent (–)*
Source: *developed by the O. Chornobrov*

Insignificant plant growth was recorded on substrates containing peat, agroperlite, and vermiculite (option 3); coconut fibres (option 4); coconut fibres, agroperlite (option 5). Such variants of substrates contributed to weak and medium growth of plants, which mostly had light green pigmentation. To adapt plants *ex vitro* for each genotype, it is necessary to select the substrate individually. According to the research results, agroperlite substrate was optimal for the growth and survival (more than 60%) of *Betula* hybrid plants *ex vitro* (Fig. 1, d). The composition of the substrate had a significant effect on the viability of plants (Table 2).

Table 2. *Final results of one-way analysis of variance plants for Betula interspecies hybrid plants ex vitro in the conditions of the adaptation room*

Analysis of variance						
Source of variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Effectiveness of adaptation of plants on different substrates						
Between groups	11653.75	3	3884,5833	64.0756	3.92	3.2389
Viability of plants due to the endurance of roots in auxins						
Between groups	3800	3	1267	38	4.43	4.0662
Liveability plants by spraying with glycerin solution						
Between groups	5625	3	1875	17.3077	0.0007	4.0662

Notes*: SS – level of reliability; df – the number of degrees of freedom; MS – variances; F is the estimated value of Fisher's test; P-value – calculated value of minimum significance; F_{crit} is the critical value of Fisher's test*
Source: *developed by the O. Chornobrov*

To increase the number of viable plants of the hybrid *Betula ex vitro* the roots before planting in the substrate was kept for 25-30 minutes in auxin solutions (IAA, NAA, IBA, Fig. 1, e) (Table 3).

Table 3. *Characteristics of plant growth of hybrid Betula ex vitro in the conditions of an adaptation room for roots in auxins on an agroperlite substrate, 30 day*

Auxin	Survival of plants *ex vitro*[1] %	The beginning of the formation of new leaves, day	Linear growth[2]	Pigmentation plants	Other signs
IAA	53.3±3.3	22-25	average	light green	signs of chlorosis
NAA	26.7±3.3	28-30	weak	-//-	-//-
IBA	56.7±3.3	22-25	average	-//-	-//-
IAA, NAA, IBA	76.7±3.3	18-20	active	green	no signs of chlorosis and vitrification were detected

Notes: *1. mean ± standard error; 2. linear growth: active (over 2.0 cm), medium (1.0-1.9 cm), weak (less than 0.9 cm), absent*
Source: *developed by the O. Chornobrov*

Maintenance of plant roots *Betula* hybrid *ex vitro* in different versions of auxin solutions reliably influenced their viability. The difference in survival rates of regenerants with the use of different auxins was statistically significant ($F_{calc.}$=38, $F_{crit.}$=4.0662; $F_{calc.}$>$F_{crit.;}$ Table 2). Under the conditions of the use of several auxins, more than 70% survival rate, active growth was obtained, the plants had pigmentation typical for the hybrid without signs of chlorosis and vitrification. For to prevent dehydration of regenerants, various methods are used, in particular, spraying

with a glycerin solution. The results of the effect of glycerin concentrations on the viability of plants (the root systems were pre-treated with a mixture of auxins and planted in an agroperlite substrate) are shown in Table 4.

Table 4. *Growth characteristics of hybrid Betula ex vitro for spraying with glycerin solution on agroperlite substrate, 30 day*

Glycerin concentration, %	The viability of plants in the conditions of the adaptation room[2], %	The beginning of the formation of new leaves, era	Linear growth[3]	Pigmentation plants	Other signs
K [1]	76.7±3.3	18-20	active	green	no signs of chlorosis and vitrification were detected
10	5 6.7±6.7	22-25	average	green	-//-
20	83.3±3.3	16-21	active	-//-	-//-
30	36.7±8.8	22-25	average	light green	signs of chlorosis
60	26.7±3.3	26-31	weak	-//-	-//-

Notes. *1. control; 2. mean value ± standard error; 3. linear growth: active (over 2.0 cm), medium (1.0-1.9 cm), weak (less than 0.9 cm), absent*
Source: *developed by the O. Chornobrov*

Based on the results of the research, a reliable influence of the concentration of glycerol on the viability of *Betula ex vitro* hybrid plants was established. In the case of using a 20% solution of glycerin, more than 80% of viable *Betula* hybrid plants with active growth and new leaves were obtained. The plants had the typical hybrid morphology and pigmentation (Fig. 1, f, g). The plants in the containers adapted well to the environmental conditions and were characterized by active growth: at the beginning of May, the height of the plants was 34.4±1.3 cm, the proportion of adapted ones was more than 95.2±1.8% (Fig. 1, h). Hybrids planted in open ground in autumn showed 86.0±1.7% survival rate in spring, which indicated a high level of adaptation of plants *in vitro* to environmental conditions.

So, the artificial solid universal nutrient medium MS was used for the initiation and regeneration of *Betula* hybrid explants. R. Rathwell *et al.* (2016) investigated the regeneration of *B. lenta* plants also on solid nutrient medium, but preferred WPM. O. Chornobrov *et al.* (2019) introduced into culture *in vitro* endangered plant *Salix retusa* L. and *Salix alpine* Scop. using nutrient medium, MS with the addition of 0.25-0.50 mg/l kinetin and 2.0 g/l of activated carbon (regeneration frequency over 80%). The selection of different basic environments is determined by the study of tissues of different genotypes *of Betula in vitro* and, accordingly, their different necessity in inorganic and organic substances.

R. Rathwell *et al.* (2016) used ½ DKW with the addition of auxin (20 μM IBA) for active rhizogenesis of *B. lenta* plants with 80% of rooted microshoots. L.K. Simola (1985) for obtaining *B. pendula* plants *in vitro* used a nutrient medium with the introduction of cytokinins and auxins, in particular 5-10 mg/l zeatin and 0.1-0.2 mg/l NAA. S. Välimäki *et al. (2021)* used semi-solid or liquid nutrient medium ½ DKW with 3-5 mg/l IBA for 2-3 days in the dark for rooting microshoots of *U. laevis* and *U. glabra*. According to the results of this study, the proportion of rooted microshoots of interspecific hybrid *Betula* on nutrient medium with cytokinin was more than 90%. Plants of different genotypes are cultivated on different types of nutrient media and use different consistencies.

According to the results of this study, the relatively low survival rate of plants of interspecies hybrid *Betula* on such types of substrates (peat, agroperlite, vermiculite; coconut fibres; coconut fibres, agroperlite) is due to the stress that occurs during the transition from heterotrophic to autotrophic nutrition. Each genotype of plants involves the use of an individual approach to the selection of the substrate for adaptation. In particular, according to L.K. Simola (1985) it was found that peat humic substrate is optimal for the survival of *B. pendula* plants*;* according to N. Dimitrova *et al.* (2021) for *P. communis* plants, it is – peat-perlite substrate; according to M. Capuana *et al.* (2022) for *S. acmophylla* – a mixture of garden soil, peat, and sand; according to S. Välimäki *et al.* (2021) for *U. laevis* and *U. glabra* – light sphagnum peat. According to the results of this study, it is advisable to adapt *Betula ex vitro* hybrid plants on an agroperlite substrate (over 60% survival rate).

To increase the survival rate of woody plants, various methods are used, in particular, auxins, biostimulants, glycerin, etc. are used. In particular, according to the results of this study, more than 70% survival rate was obtained using the procedure of keeping the root system of *Betula* interspecies hybrid plants in auxin solution (IAA, NAA, IBA). Research by N. Dimitrova *et al.* (2021) showed the positive effect of using biostimulants, in particular, Lumbrical, to improve vegetative growth and photosynthetic characteristics of *P. communis ex vitro* plants.

Authors S. Välimäki *et al.* (2021) tend to improve the adaptation of *U. laevis* and *U. glabra* recommend the use of short-term induction of microshoots in a nutrient

medium with auxin, followed by planting in sphagnum peat in mini-greenhouses. The proportion of rooted and adapted plants was 18% for *U. laevis* and 64% for *U. glabra* at 41 days. It is also noted that the use of a liquid nutrient medium reduces injury to the roots and is less time-consuming, as it does not need to be washed from the remains of the nutrient medium.

O. Chornobrov & E. Tkachova (2020) established in the study the expediency of spraying *F. vesca ex vitro* with a 30% solution of glycerin for 30 days, the treatment of which reduced the dehydration of plants and made it possible to obtain more than 70% survival rate. According to the results of this study, in the case of applying the following procedure: using a 20% glycerin solution, keeping the roots in auxin solution followed by planting on an agroperlite substrate, more than 80% of viable plants of the *Betula* interspecies hybrid were obtained. For comparison, the indicator of survival of plants *ex vitro* for other species is: *B. lenta* – 37% for R. Rathwell *et al.* (2016); *B. pendula* – 95% for L.K. Simola (1985); *U. laevis* – 18% and *U. glabra* – 64% for S. Välimäki *et al.* (2021); *S. acmophylla* – 90% according to M. Capuana *et al.* (2022); walnut hybrid rootstock 'Paradox' – 84% by H. Ribeiro *et al.* (2022).

In general, the efficiency of plant adaptation *ex vitro* depends on a complex of internal and external factors, therefore a careful selection of the protocol, which includes the technology of microclonal propagation and acclimatization, is the key to the success of obtaining viable plants. The procedure for the adaptation of a triploid interspecific *Betula* hybrid was developed in this study *ex vitro* provides a new tool that allows obtaining high viability of healthy planting material under environmental conditions and provides a platform for further research.

CONCLUSIONS

Betula interspecies hybrid has been developed *ex vitro* using agroperlite substrate, auxins and glycerin solution, which allows obtaining more than 80% survival in environmental conditions. The optimal conditions for the proliferation of microshoots and the roots were the use of nutrient medium MS with the addition of 0.25 mg/l kinetin during a 30-day cultivation cycle.

The composition of the substrate had a significant effect on the viability of *Betula* hybrid plants *ex vitro* in the conditions of the adaptation room. Weak growth of plants was recorded on substrates containing horse peat, agroperlite, and vermiculite; coconut fibers; coconut fibres, agroperlite. According to research, the agroperlite substrate is optimal for growth and survival (over 60%) of plants. Endurance of root systems of *Betula* hybrid plants *ex vitro* in auxin solutions reliably affected survival. Under the conditions of keeping plant roots in a mixture of 1.0 mg/l IAA, 1.0 mg/l NAA and 1.0 mg/l more than 70% received IBA within 25-30 minutes survival with active growth and typical pigmentation.

A reliable influence of experimental concentrations of glycerol on the viability of the hybrid was established, *Betula ex vitro*. In the case of daily spraying of plants 20% glycerin solution for 15-20 days, more than 80% were obtained of viable plants. Spring viability of hybrid plants *Betula ex vitro,* planted in autumn under environmental conditions, was more than 80%. Further research can be directed to a detailed study of the genetic and molecular mechanisms that underlie the adaptation of the hybrid *Betula ex vitro* to variable environmental conditions. Additional studies may include the analysis of physiological and morphological features of these plants under the influence of various factors, such as soil conditions, climatic conditions and competition with other species.

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CONFLICT OF INTEREST

None.

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Особливості адаптації рослин міжвидового гібриду *Betula ex vitro*

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Анотація. Мікроклональне розмноження як один із методів біотехнології дозволяє одержати генетично однорідні рослини упродовж року з мінімальної кількості донорного матеріалу. Адаптація рослин *ex vitro* до умов довкілля – заключний і важливий етап мікроклонального розмноження. Мета дослідження – визначення оптимального режиму адаптації рослин триплоїдного міжвидового гібриду *Betula ex vitro* до умов довкілля. Для досліджень використовували біотехнологічні (мікроклональне розмноження) та статистичні (середнє арифметичне, стандартна похибка, однофакторний дисперсійний аналіз (ANOVA)) методи. Дослідження здійснено у науково-дослідній лабораторії біотехнології рослин Відокремленого підрозділу Національного університету біоресурсів і природокористування України «Боярська лісова дослідна станція» упродовж 2019-2023 р. За дослідженнями живильне середовище MS з додаванням 0,25 мг·л$^{-1}$ кінетину стимулювало активну проліферацію мікропагону і кореневої системи. На живильному середовищі відбувся оптимальний розвиток рослин *in vitro* за 25-30-добовий цикл культивування, що сприяв успішній адаптації до умов довкілля. Частка адаптованих рослин гібриду *Betula ex vitro* на агроперлітовому субстраті становила понад 60 % на 30-добу. Значну приживлюваність рослин (понад 80 %) одержано за умов попереднього витримування кореневої системи рослин у розчині ауксинів (1,0 мг·л$^{-1}$IAA, 1,0 мг·л$^{-1}$ NAA, 1,0 мг·л$^{-1}$ IBA) упродовж 25-30 хв із наступним щоденним обприскуванням листків 20 % гліцерином упродовж 15-20 діб. Адаптовані рослини мали типову пігментацію без ознак хлорозу та вітрифікації. Навесні приживлюваність рослин в умовах довкілля становила понад 80 % і свідчила про високий рівень пристосованості після *in vitro*. Розроблений протокол адаптації гібриду *Betula ex vitro* дозволяє одержувати високу приживлюваність рослин в умовах довкілля. Практичною цінністю дослідження є одержання адаптованих до умов довкілля рослин *ex vitro*, які в подальшому можуть використовувати для якісного збагачення асортименту штучних насаджень населених пунктів

Ключові слова: культура *in vitro*; береза; мікроклональне розмноження; субстрат; приживлюваність

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Microsphaera viburni (Duby) S. Blumer: Ecological and biological features, methods of control in the system of ornamental and fruit horticulture

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Abstract. The research relevance is determined by the need for a comparative assessment of different viburnum species in terms of resistance to powdery mildew, a disease that inhibits physiological processes in plants, negatively affecting growth, development, and yield, as well as decorative effect. The research aims to study the bio-ecological characteristics of *Microsphaera viburni* (Duby) S. Blumer and to develop measures to control powdery mildew in viburnum orchards. During the experiment, methods and techniques were used to conduct phenology, create provocative backgrounds, assess

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the level of damage to the ground part, and determine the degree of damage and resistance of viburnum plants. Recommendations for avoiding or reducing the risks of powdery mildew in viburnum orchards are provided. Nitrogen fertilisers should be applied in early spring and avoided in late summer to limit the growth and development of annual shoots, the tissue of which is more sensitive to the powdery mildew pathogen. It has been shown that formative, regulatory, and sanitary pruning in early spring can improve lighting and air circulation in the basal part of viburnum plants, intensify the growth of permanent shoots and form the desired type of bush (tree) in the system of fruit or ornamental horticulture. It has been proved that in the conditions of the Northern Forest-Steppe of Ukraine, it is advisable to grow highly resistant (Anya, Osinnia, Elina, Omriana) and resistant (Kralechka, Plododekorna, Sonetta, Horikhova, Yaroslavna) varieties (forms) of European cranberrybush of the Institute of Horticulture of the National Academy of Agrarian Sciences of Ukraine against powdery mildew. It is recommended to use resistant and medium-resistant varieties of common dwarf viburnum 'Eskimo' and common 'Roseum' for ornamental gardening (*Viburnum opulus* Roseum). The practical value was in a determination that powdery mildew of European cranberrybush 'Roseum' does not affect other species of the genus *Viburnum* L. under artificial inoculation; it was confirmed that the susceptibility of viburnum plants to this disease can be significantly reduced by low-susceptible and resistant varieties and species of the genus *Viburnum* L. and timely agronomic measures

Keywords: species (varieties, forms) of the genus *Viburnum* L.; powdery mildew; fungal disease; species assessment; control measures

INTRODUCTION

Diseases constantly accompany biological objects, including plants. Up to 40% of direct losses are incurred by major crops as a result of biotic stress, and in some years, crops such as wheat, potatoes and others have been affected by pathogens and have fallen out of the crop structure by almost 100% (Backyard Garden Information Source, 2023). Often, the environmental factors that cause crop losses are incorrect strategies for managing and controlling phytopathogens, which include forecasting, cultural, biological and agrochemical management. Biological control is becoming increasingly important due to its environmental friendliness compared to chemical control. However, the poor quality and timeliness of the implementation of agricultural management elements in the phytocenosis management system led to the large-scale use of fungicides. Plant tolerance and resistance are of great importance, which is the best option for preventing disease damage and increasing their range. This is achieved through the development of genetics, plant breeding and biotechnology. Reduced genetic diversity promotes the emergence and spread of pathogens to the point where diseases become both local and widespread.

T. Moskalets *et al*. (2019) state that direct losses from pathogens amount to about 20-40%. Representatives of the multispecies genus *Viburnum* L. are no exception, and among the complex of unfavourable biotic environmental factors, they suffer significantly from several diseases, including fungal diseases, which inhibit the processes of increasing the number of viburnum orchards. One of the most dangerous fungal diseases of viburnum is powdery mildew, one of the most common diseases in Europe, North America and elsewhere. Powdery mildew is host-specific, meaning that a certain type of pathogen cannot survive without a proper host plant (Morini, 2020). N. Pinchuk *et al.* (2018) reported that the causative agent of powdery mildew of plants of the genus Adoxaceae is the monophage *Microsphaera viburni* (Duby) S. Blumer, 1933 (homotypic synonym of *Erysiphe viburni* Duby, 1830), which affects and reduces the productivity and decorative value of infected plants, inhibiting their growth and development, the number of inflorescences and fruits.

V.P. Heluta and I.M. Anishchenko (2021) reported that in Ukraine, the damage to common viburnum (*Viburnum opulus* L.) plants is mainly observed in the western and northern regions, which manifests itself locally or as an epiphytotic disease, in particular, the manifestation of which was noted in 1989. Wijayawardene *et al*. (2022) note that the powdery mildew pathogen is unique because, in the absence of free water on the leaf surface, which often inhibits spore germination, it is capable of rapid functional activity, usually in partial shade and strong thickening, in particular, germination and infection of a larger plant surface with spores.

J. Kubina (2017) states that the pathogen mainly affects young leaves of viburnum (old leaves are almost not damaged) and affects the distribution of carbohydrates and other nutrients in the plant, creating a powerful local sink in places where leaves are affected by fungal infections. S. Martin (2019) reports that powdery mildew reduces the radial growth of tree species with a cumulative and delayed effect over many years. The significant impact of powdery mildew on plants is associated with altered growth patterns, either environmental factors (pests, critically low and high air temperatures, etc.) or elements of agronomic practices (e.g., the formation of a viburnum plant by a tree or bush). According to J. Williamson (2021), in many cases, powdery mildew progresses, and the affected areas may increase, often covering the entire leaf, branch or stem (in particular those closest to the soil surface), and chlorosis

or necrosis of the affected leaf tissue is observed. Pane *et al.* (2021) argue that downy mildew fungal infections can often reduce the overall cold tolerance of plants.

As noted by R. Panstruga and H. Kuhn (2019), powdery mildew fungal colonisation of plants can disrupt local microbial community structures associated with the root/rhizosphere, and other (foliar) phytopathogens can interact with powdery mildew and mycoparasites can influence the outcome of plant-powdery mildew interactions. Successful colonisation by powdery mildew will affect pre-existing foliar and possibly even microbial communities. A. Gross *et al.* (2021) believe that in any case, powdery mildew will have a significant impact on plants in both cultivated and natural coenoses and will determine the duration of vegetation existence, in particular under global climate change, which will determine the severity of the disease, mainly by changing the phenological synchrony of the pathogen-host plant.

Therefore, the epidemiological detection and management of phytopathogenic foci to reduce the risks and scale of their manifestation in the context of global food and environmental security is relevant. The research aims to investigate the ecological and bioecological features of powdery mildew on viburnum plants and develop measures for its control.

MATERIALS AND METHODS

Viburnum powdery mildew damage was monitored at the experimental plots of the Institute of Horticulture of the National Academy of Agrarian Sciences of Ukraine (NAAS) and its research network during 2018-2021. Varieties/breeding forms of common viburnum (*Viburnum opulus* L.) of Ukrainian selection were involved in the study of the degree of plant damage: Anya, Ulyana, Yaroslavna, Elina, Horikhova, Omriana, Sonetta, Kralechka, Osinnia, Plododekorna and viburnum species: *V. hordovina*; *V. carthyphyllum*; *V. rhytidophylloides* (*Viburnum* × *rhytidophylloides*); *V. Burkwood*; *V. wrinkled viburnum* (*Viburnum rhytidophyllum* Hemsl.); *V. opulus Roseum*; *V. sargentii* Koehne Onondaga; *V. opulus* L., variety Eskimo (Fig. 1).

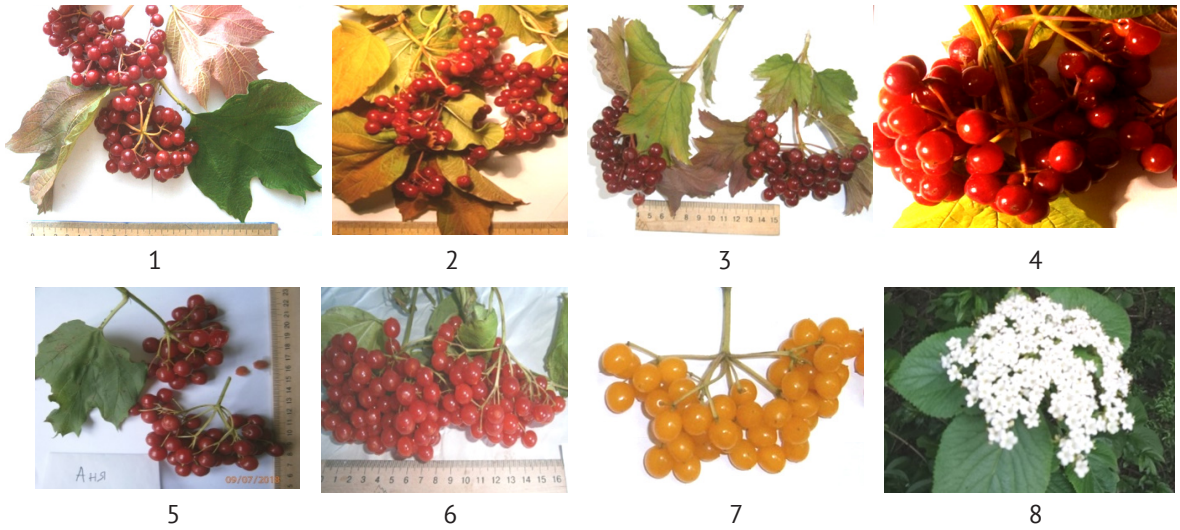

Figure 1. *Photos of individual samples of Viburnum officinale and Viburnum hirsuteum were used in the study*
Note: *1 – Kralechka; 2 – Plododekorna; 3 – Horikhova; 4 – Soneta; 5 – Anya; 6 – Elina; 7 – Yaroslavna; 8 – Viburnum lantana*
Source*: photographed by the authors*

Observations and records of plants were carried out during May and September (Methods of qualification..., 2023). Leaves of the studied varieties were collected twice during the growing season. During the vegetation of viburnum plants, 10-15 leaves were taken from 3 trees (bushes) of each variety/species (5 leaves × 3 replications) to determine the area affected by powdery mildew.

Plant material was collected in parchment bags. Each sample of a particular viburnum plant variety/species was labelled with the sample number, place, and time of collection. Visual examinations were carried out in the basal part and on the periphery along the entire vertical crown of the plants. The assessment of viburnum plant resistance was performed in three periods: the first one – 10 days after the first diseased plants were detected in the experiment, the second one – 2-3 weeks after the first one, i.e., during the period of the greatest development of the disease, the third one – at the end of harvesting.

The degree of powdery mildew damage to viburnum leaves was determined on a scale of points. Processing the data obtained, the percentage of disease development or damage to plant organs (P) was calculated using the formula:

$$P = \frac{a}{b \times 9} \quad (1)$$

where: a – sum of damage scores of all plants in the replication; b – number of plants in the replication; 9 – maximum damage score. The lower the degree of damage, the higher the resistance of plants of a particular variety (Table 1).

***Table 1**. Methods for assessing the level of damage and resistance of viburnum plants to the disease caused by Microsphaera viburni (Duby) S. Blumer*

Damage scale	Damage stage	Damage to the surface of plant organs, %	Resistance scale	Resistance score
0-1	Absent or exceptionally weak	<5	High	9
2-3	Weak	5-25	Resistant	7
4-5	Average	26-50	Average	5
6-7	High	51-75	Weak	3
8-9	Highly resistant	>75	Exceptionally weak	1

***Source**: Methods of qualification... (2016)*

The average damage score of viburnum plants was determined by the formula:

$$B = \frac{\sum(a \times b)}{N}$$

where B is the average plant damage score; ∑(a×b) is the sum of the products of the number of affected plants and the corresponding damage score; N is the total number of plants under study.

The plant damage coefficient was determined by the formula:

$$K = \frac{A \times B}{100}$$

where K is the damage coefficient (in our conditions, it ranges from 1.07 to 2.41, with an average of 1.5); A – percentage of affected plants; B – average lesion score.

To facilitate the work on accounting for foliar diseases on viburnum plants (Methods of qualification..., 2023), a corresponding calendar for phytopathological accounting was developed, part of which is presented in the methodological part of the article (Table 2).

***Table 2**. Calendar of phytopathological inspections of viburnum plants*

Time of monitoring	Disease	Damage type	Indicator of monitoring
At noticeable damage	Powdery mildew	It affects leaves and shoots. The affected organs have a greyish-whitish, spidery, or powdery coating, which later becomes red or brown, and in late summer with dotted black cleistothecia. Affected leaves curl, harden, and fall off prematurely. Annual shoots do not grow, or have weak growth, often bend, and gradually die.	Stage of damage of leaves and shoots, %

***Source**: Methods of conducting phytopathological studies for artificial infection of plants (2016)*

In parallel with the diagnostics of viburnum plants, an experiment was set up that included variants of foliar inoculation of two-year-old viburnum plants with a suspension of conidia or particles of powdery mildew mycelium according to the accepted methodology (Methods of conducting phytopathological studies for artificial infection of plants, 2016). The experimental design included two variants: 1 – without inoculation (control), and 2 – with inoculation. Among the experimental plants, samples of viburnum *Viburnum opulus* L. varieties Yaroslavna, Elina, Omriyana, Autumn, Kralechka, Plododekorna, Horikhova and Anya; *V. opulus* Roseum; *V. opulus* L. Eskimo variety; *V. rhytidophyllum* Hemsl.; *Viburnum* × *carlcephalum*; *V. lantana*; *V. lantana* var. *variegatum*; *Viburnum* × *rhytidophylloides*; *Viburnum* × *burkwoodii*; *V. sargentii* Koehne. The number of plants of the studied species (variety) of viburnum was 3 copies, which was perceived as a 3-fold replication of the experiment. The extent and score of damage were determined based on the data in Table 1.

To test the resistance of the new forms of Viburnum vulgare plants, an experiment was conducted that involved artificial infection of young plants (the average height of which did not exceed 1 m) with the powdery mildew pathogen by spraying a special inoculum from the affected leaves with spores of the fungus *Microsphaera viburni*. For this purpose, the most favourable conditions for infection were chosen, which are created at a temperature of +18-25°C and high air humidity of about 60-80% (third decade of May). Statistical data processing was carried out using Statistica-6.0 computer software. The study complied with the requirements of the Convention on Biological Diversity (1992).

RESULT

Regular inspections revealed that white powdery spots appear on the leaves and stems of affected viburnum plants. During 2018-2019, thorough examinations of viburnum plants in the collection nursery were carried out and it was found that the first visible symptoms of powdery mildew are raised bubbly areas on young leaves, which eventually cause them to curl, exposing the lower surface of the leaves. At the same time, the affected leaves are covered with a white (May-June), later (July-August) light grey or grey-white, like talcum powder, powdery coating (loose mycelium), mostly on the upper part of the leaf blade (Fig. 2).

A B

***Figure 2**. Part of viburnum leaf*
***Note:** not affected (A) and affected (B) by powdery mildew*
***Source**: photographed by the authors*

Young leaves of the lower tier were often noted to be the most affected, and as the disease progressed, leaf spots increased in size, accompanied by the formation of a large number of asexual spores, as a result, moulds could often appear on the leaves, which, in particular on plants with generative buds, made it impossible for them to open. In the second part of summer, the leaves of severely affected plants developed brown spots with purple or red colouration around the infection. The disease usually appears in the summer and reaches its peak at the end of the summer period. In 2018-2019 in the northern part of Ukraine, environmental factors contributed to the manifestation of powdery mildew on common viburnum plants, and according to Table 3, varieties and forms of common viburnum Anya, Elina, Omriana and Osinnia are highly resistant, the degree of damage was 1 point, fruit varieties and forms Yaroslavna, Sonetta, Horikhova, Kralechka, Plododekorna and decorative variety Eskimo were resistant (7 points), and *Viburnum opulus* Roseum was medium resistant (5 points) (Table 3).

***Table 3.** Results of the assessment of the degree of damage and resistance of viburnum plants to powdery mildew, average value for 2018-2019*

Name of the species/variety (breeding form)	Degree of damage, points	Resistance scale	Damage scale
V. opulus L. Anya variety *V. opulus* L. Elina variety *V. opulus* L. Omriana variety *V. opulus* L. Osinnia variety	1	Highly resistant	9
V. opulus L. Kralechka variety *V. opulus* L. Plododekorna variety *V. opulus* L. Eskimo variety *V. opulus* L. Sonetta variety *V. opulus* L. Horikhova clone *V. opulus* L. Yaroslavna variety	3	Resistant	7
V. opulus Roseum	5	Average	5
None of the species/varieties received this number of points	7	Weak	3
	9	Exceptionally weak	1

***Source**: compiled by the authors*

Plants of other species of the genus *Adoxa* L. *(Adoxaceae* Trautv.*)* (*V. rhytidophyllum* Hemsl.; *Viburnum* × *carlcephalum*; *V. lantana*; *V. lantana* var. *variegatum*; *Viburnum* × *rhytidophylloides*; *Viburnum* × *burkwoodii*; *V. sargentii* Koehne) hadnosigns of powdery mildew damage. It was noted that the incubation period largely depends on weather conditions and the resistance of the variety to the disease. At 5-10 days, a powdery white coating was observed on the plants of certain species (varieties), which is nothing more than the surface mycelium and conidial sporulation of the fungus. However, conidial sporulation became widespread after the visual presence of plant damage by the disease. The growth of new shoots of affected plants occurred, but less intensively than in the control variant. Spreading through the affected plant, conidia got on young leaves and caused a secondary infection, which manifested itself shortly before the end of the growing season.

It is worth noting that dry hot weather (up to +27-30°C) during the summer period caused a decrease in the resistance of a certain species (variety) of viburnum plants to the disease (wilting of plant shoots, which contributed to their damage, as the fungus penetrates more easily into the plant, which is close to plasmolysis), and, consequently, massive conidial sporulation of the fungus and an increase in the area of damage.

Thus, it can be assumed that the harmfulness of powdery mildew is due to increased transpiration of plants, disruption of the synthesis of organic compounds, the impaired outflow of plastic substances into the stems and roots, and rapid ageing of leaves.

A noticeable outbreak of secondary infection was observed during re-growth, with the affected leaves hardly drying out as compared to the primary infection. It should be noted that the secondary infection manifested itself mainly on the underside of the leaf, with the leaves becoming coarser, acquiring a felt-like appearance and in places of significant accumulation of mycelium, mainly on the surface of annual shoots, fruiting bodies of the fungal pouch stage – cleistothecia – were formed, in which one bag with eight sackspores was formed by the end of the growing season. At the same time, mature cleistothecia remain overwintering on the affected shoots.

It is worth noting that the marsupial stage does not play a role in the maintenance and development of fungal infection. For example, in temperate climates, the pathogen overwinters in leaf and fruit buds with mycelium, which it penetrates in summer during their formation. It was found that after foliar inoculation, powdery mildew appears only on common viburnum in the period from the budding phenophase with damage to 5% of leaves and increases the level of its development by about 22% in the phase of growth and fruit filling after a decrease in the average daily air temperature of about 20°C and an increase in air humidity of more than 70% (III decade of August-I decade of September) (Table 4).

***Table 4**. Damage and resistance level of Viburnum vulgare plants depending on artificial inoculation with powdery mildew fungus*

Type (variety, form, cultivar) of viburnum	Damage to the surface of plant organs, %			Damage stage	Resistance level
	before inoculation	after inoculation			
	vegetative budding phase	budding phase	fruit growth and ripening phase		
Viburnum opulus L. Yaroslavna variety	0	9	18	weak	resistant
Viburnum opulus L. Anya variety	0	5	5	exceptionally weak	highly resistant
Viburnum opulus L. Elina variety	0	3	3	exceptionally weak	highly resistant
Viburnum opulus L. Omriana variety	0	10	23	weak	resistant
Viburnum opulus L. Sonetta variety	0	3	5	exceptionally weak	highly resistant
Viburnum opulus L. Horikhova clone	0	5	5	exceptionally weak	highly resistant
Viburnum opulus L. Osinnia variety	0	5	5	exceptionally weak	highly resistant
Viburnum opulus L. Kralechka variety	0	12	27	average	average
Viburnum opulus L. Plododekorna variety	0	3	4	exceptionally weak	highly resistant
Viburnum opulus Roseum	0	13	29	average	average
Viburnum opulus L. Eskimo variety	0	16	19	weak	resistant
Viburnum rhytidophyllum Hemsl.	0	0	0	none	-*
Viburnum × carlcephalum	0	0	0	none	-
Viburnum lantana var. Aureum	0	0	0	none	-
Viburnum lantana var. *Variegatum*	0	0	0	none	-
Viburnum × rhytidophylloides	0	0	0	none	-
Viburnum x burkwoodii	0	0	0	none	-
Viburnum sargentii Koehne Onondaga variety	0	0	0	none	-

***Note:** *The powdery mildew pathogen did not manifest itself as it is not specific to the host plant*
***Source**: compiled by the authors*

After inoculation, Viburnum vulgare varieties Anya, Elina, and forms Sonetta, Plododekorna, and Horikhova had a very low degree of damage (⩾5) and were noted as highly resistant. Cultivar Yaroslavna, from Omriana and *V. opulus* L. variety Eskimo, are characterised as resistant, and a form of common viburnum Kralechka *V. opulus* Roseum – as medium resistant. No signs of lesions after inoculation on viburnum plants of *V. rhytidophyllum* Hemsl, *V.* × *carlcephalum*, *V. lantana var. Aureum*, *V. lantana* var. *Variegatum, V.* × *rhytidophylloides*, *V.* × *burkwoodii* and *V. sargentii* Koehne of Onondaga cultivar were not found, which confirms the high species specificity of the pathogen to the host plant. Biometric studies carried out in the middle and at the end of the growing season revealed that shoot growth in viburnum plants affected by powdery mildew decreased by 1.3-1.6 times (Table 5).

***Table 5**. Comparative assessment of annual shoot growth of two-year-old viburnum plants on variants without inoculation and inoculation with powdery mildew fungus, average value for 2019-2020*

Type (variety, form) of viburnum	Variant	The average length of an annual shoot, cm		Deviation of data from the variant with an inoculation to the variant without inoculation (±, cm)
		middle of the vegetation period	vegetation period ending	
Viburnum opulus L. Elina variety	No inoculation	25.4	41.6	
	Inoculation	28.5	39.4	-2.2
Viburnum opulus L. Anya variety	No inoculation	49.7	63.5	
	Inoculation	48.6	58.5	-5
Viburnum opulus L. Sonetta variety	No inoculation	33.8	49.5	
	Inoculation	35.3	51.5	2
Viburnum opulus L. Horikhova clone	No inoculation	52.7	81.5	
	Inoculation	50.4	78.5	-3
Viburnum opulus L. Osinnia variety	No inoculation	21.6	42.8	
	Inoculation	23.5	39.5	-3.3
Viburnum opulus L. Plododekorna variety	No inoculation	18.4	63.5	
	Inoculation	17.5	68.9	5.4
Viburnum opulus L. Yaroslavna variety	No inoculation	49.9	61.8	
	Inoculation	35.5	52.6	-9.2
Viburnum opulus L. Omriana variety	No inoculation	30.4	63.3	
	Inoculation	27.7	60.2	-3.1
Viburnum opulus L. Eskimo variety	No inoculation	15.3	39.1	
	Inoculation	16.5	31.2	-7.9
Viburnum opulus L. Kralechka variety	No inoculation	39.5	54.7	
	Inoculation	32.5	49.0	-5.7
Viburnum opulus Roseum	No inoculation	23.7	58.5	
	Inoculation	18.5	31.7	-26.8

***Source**: compiled by the authors*

As noted, the occurrence of powdery mildew was noted only on plants of the species *Viburnum opulus* L. It was found that for varieties Sonetta and Plododekorna on the variants of inoculation, the growth of annual shoots was not inhibited. For the varieties Elina, Anya, Horikhova, Osinnia, Omriana and Kralechka, the inoculation variant showed a decrease in the length of the annual shoot by 2.2-5.7 cm compared to the control (without inoculation). However, the greatest effect of powdery mildew on shoot growth was for common viburnum cultivars Yaroslavna and *Viburnum opulus* Roseum, 9.2 and 26.8 cm, respectively.

The types of fertilisers and methods of their application were determined to have a significant impact on the manifestation of the powdery mildew pathogen. In particular, nitrogen fertilisers (in the form of ammonium, potassium, or calcium nitrate) should be applied in early spring and avoided in late summer to limit the growth and development of annual shoots, whose tissue is more susceptible to fungal infection. It has been shown that pruning measures to remove excess and damaged shoots in the summer can improve lighting and air circulation in the basal part of viburnum plants, intensify the growth of permanent shoots and form the desired type of bush (tree).

During viburnum planting, it is necessary to ensure sufficient distance between plants and to thin out individual bushes (trees) every spring to ensure air circulation in the ground part. In the irrigation system of mother and cuttings nurseries, and hybrid nurseries, if necessary, it is advisable to use only drip irrigation, avoid water getting on the leaves, and prevent contact of the ground part of viburnum plants with wet soil. It is recommended to use cultural control: fruit change and selection of resistant varieties. It is recommended to alternate resistant varieties with those that are more or less susceptible to powdery mildew. Summarizing the above, we can say that measures for early diagnosis of viburnum plants for fungal diseases, timely preventive measures, selection of resistant varieties adapted to a particular area, compliance with the elements of agricultural technology, control in the nursery, etc. will

reduce the manifestation of powdery mildew in the orchards of the crop under study.

DISCUSSION

Powdery mildew, which is an obligate biotrophic phytopathogen, forms mycelium (fungal filaments), which, unlike the perinosporosis pathogen, which functions on the lower part of the leaf, grows only on the leaf surface, spreading haustoria, or root-like structures, into the epidermal (upper) cells of the plant without affecting the tissue. The downy mildew fungus overwinters on plant debris in the form of cleistothecia or mycelium and in spring the cleistothecia form spores that are transferred to the host plant by rain, wind or insects (Host and Disease Descriptions, 2023).

As noted by V. Heluta (2022), the obligate fungus of powdery mildew grows as thin layers of mycelium on the surface of infected plant organs, feeding on epidermal cell products using suckers. The formed asexual spores, known as conidia, are formed in chains on the affected surface of the plant. The presence of mycelium and conidia on the affected surface, such as a leaf, looks like a white or grey powdery mass. As noted by H.D. Shin *et al.* (2019), the spores are transported by abiotic environmental factors to healthy areas of the plant or other plants.

J. Drago (2023) notes that when the conidial stage season ends, the downy mildew produces spherical fruiting bodies (multicellular structure) in the form of small black or dark brown specks called cleistothecia, the overwintering stage of the pathogen that accumulates on infected plant parts or plant debris under the bush (tree). In May-June, under favourable weather conditions, sexual spores - ascospores of fruiting bodies – cause new infections and are the next cycle of the disease.

T. Moskalets *et al.* (2023) reported that if in autumn powdery mildew spores get on generative buds, new inflorescences form late and are often distorted, which further determines the decorative effect or productivity of viburnum plants, Since the development of powdery mildew has significant fluctuations, which is expressed in changes in the coverage of the pathogen's habitats and in the intensity of plant damage, which affects the condition of plants, it is appropriate to have information about the pathological process, which includes five phases: 1 – the phase of appearance on the plant, pathogen transmission, germination and growth of the infectious agent; 2 – the phase of rooting in plant tissue under certain environmental conditions; 3 – the phase of pathogen incubation, growth, and reproduction; 4 – the beginning of the disease development, accompanied by morphophysiological changes, symptoms, and sporulation; 5 – the phase of separation from the host plant and spread of the infectious agent in the area of diseased and still healthy plants.

Therefore, understanding the disease life cycle is vital for the care and protection of cultivated plants, with conidial sporulation forming in spring on shoots affected from the previous year being the primary infection, and conidia forming on primary affected plant organs spreading throughout the garden, getting on young leaves and causing a secondary infection, the manifestation of which was noted after flowering (June) more than once during the growing season, which ends with the formation of bags and bags of spores as a baggy stage of the fungus to mature fruiting bodies – cleistothecia, which overwinter in a closed form on the shoots.

M. Bradshaw *et al.* (2021) believe that an improved understanding of the phylogeny and taxonomy of the powdery mildew pathogen is also of great ecological and applied importance. Identification of the powdery mildew pathogen allows for the analysis of the fungus morphology and also reveals the co-evolutionary relationship between powdery mildew species and host plants. M. Bradshaw *et al.* (2020), after studying the phylogeny and systematics of powdery mildew of viburnum species, noted that the fungus *Microsphaera hedwigii* or *Microsphaera viburni*, which affects common viburnum, should be reduced to synonyms, two new species, *Erysiphe viburniphila* and *Erysiphe pseudoviburni*, previously identified as *Erysiphe viburni* (including *Erysiphe hedwigii*), infect plants of *Viburnum edule*, *V. tinus*, *V. odoratissimum* var. *awabuki*, and *V. sieboldii* cultivated in North American, East Asian and European, areas.

T. Shirouzu*et al.* (2022) note that another species of powdery mildew *Erysiphe viburni-plicati Meeboon*& Takam affects plants of *V. plicatum* Thumb. in particular plants of *V. plicatum* Thumb. var. *plicatum* f. *glabrum* (Koidz. ex Nakai) Rehder and, according to molecular studies, significantly differs from other powdery mildew pathogens – *Erysiphe miranda*, *E. shinanoensis*, *E. hedwigii* and *E. viburni* – in the presence of one ascus per chasmothecia and fewer chasmothecial appendages (up to 5 per chasmothecia). The fungus *Erysiphe hedwigii* affects plants of *V. arrogantum*. The pathogen *Erysiphe pseudoviburni* affects plants of the *V. sieboldii* species, *Erysiphe viburni – V. edule*, *Erysiphe viburni* affects *V. opulus*. And the species of powdery mildew fungi *Erysiphe hedwigii* and *Erysiphe viburni*, infect the same host plant (Heiskanen & Valkonen, 2021).

However, as noted by M. Liu *et al.* (2021), genetic analysis is required to confirm the morphometry of powdery mildew. Since powdery mildew is difficult to detect at an early stage, as its signs and symptoms are often invisible. At the initial stages, the powdery mildew pathogen affects only a small percentage of the total leaf area of viburnum plants and creates a slight stress that does not affect the normal growth and development of the plants under study. In particular, as noted by R. Sanchez-Lucas *et al.* (2023), powdery mildew-affected plants have low photosynthetic productivity.

Laurel viburnum (*V. tinus* L.) plants are severely affected by powdery mildew (George, 2022). Canadian viburnum (*V. lentago*) is also susceptible to powdery

mildew, particularly when submerged, without pruning measures and in partial shade. *V. buldeneum* plants are also susceptible to powdery mildew (Backyard Garden Information Source, 2023). *V. farreri*, unlike plum viburnum and others, is known for its resistance to diseases, including powdery mildew (Sanchez, 2018).

On ornamental crops, powdery mildew spoils their appearance and destroys the marketability of flowers (VseRoste, 2023). Natural hybridisation, heterokaryosis and mutations lead to the emergence of new races of pathogens over time, which overcomes plant resistance and leads to epiphytoties. The large areas occupied by a particular variety contribute to the emergence of aggressive races, their infectious onset and spread increase rapidly, and there is a need to replace the variety with a more resistant one. Plant resistance is one of the best ways to combat plant diseases (Plant Disease Resistance, 2022). K. Wang *et al.* (2023) argue that the implementation of scientific programmes on the implementation of classical, marker-assisted breeding, biotechnology, and genetic engineering methodologies remains an alternative in the fight against diseases.

Therefore, as noted by Q. Li *et al.* (2020), the search for source material and the creation of new genotypes in the development of long-term resistance with a broad spectrum of action is an economical and environmentally friendly approach to the control of crop diseases for sustainable agricultural production. Thus, studying the signs of disease manifestation and implementing a strategy for the selection, creation, and introduction of new varieties (forms, cultivars) of viburnum will reduce the manifestation of phytopathogens in the orchards of the crop under study.

CONCLUSIONS

As a result of phytopathological studies of plants of the genus *Viburnum* L. conducted during 2018-2021 in the collection nursery of the Institute of Horticulture of the National Academy of Agrarian Sciences of Ukraine (northern part of the Forest-Steppe of Ukraine) for the manifestation of fungal pathogens, it was found that the powdery mildew pathogen with the highest degree of damage of 3 points was detected on plants of certain varieties of common viburnum (Plododekorna, Yaroslavna, Kralechka, Eskimo, etc.) only in 2018-2019, with the coefficient of powdery mildew damage ranging from 1.1 to 2.5. Viburnum variants *Viburnum rhytidophyllum* Hemsl., *Viburnum* × *carlcephalum* Cayuga variety), *Viburnum lantana var. Aureum*, *Viburnum lantana* var. *Variegatum*, *Viburnum* × *rhytidophylloides*, *Viburnum* × *burkwoodii* (Mohawk variety) × *Viburnum sargentii* Koehne (Onondaga variety) were not affected by powdery mildew.

By creating a stimulating infectious background, it was possible to distinguish varieties (forms) of Viburnum vulgare by the degree of damage and resistance and to formulate recommendations for production. According to the results of the evaluation, the following varieties (forms) of common viburnum were classified as highly resistant: Anya, Elina, Sonetta, Horikhova, Autumn and Plododekorna, resistant: Yaroslavna, Omriana and Eskimo, and medium resistant: *Viburnum opulus* Roseum, *Viburnum opulus* L., form Kralechka. It was found that under artificial inoculation with spores of the common viburnum powdery mildew fungus (*Microsphaera viburni* (Duby) S. Blumer), no damage to plants of other species of the genus *Viburnum* L. was observed, which confirms the data of other scientists on the species specificity of powdery mildew pathogens.

A promising area for further research is the involvement of non-susceptible or low-susceptible species and varieties of the genus *Viburnum* L. to powdery mildew in the breeding and production processes in the system of ornamental and fruit horticulture, which will prevent the occurrence of this disease.

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CONFLICT OF INTEREST

None.

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Microsphaera viburni (Duby) S. Blumer: еколого-біологічні особливості, способи контролю в системі декоративного та плодового садівництва

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Анотація. Актуальність даної теми полягає в необхідності порівняльного оцінювання різних видів калини в стійкості проти борошнистої роси, хвороби, яка гальмує фізіологічні процеси в рослин, негативно впливаючи на ріст, розвиток і врожайність та декоративність. Мета досліджень – вивчення біоекологічних особливостей прояву *Microsphaera viburni* (Duby) S. Blumer і розроблення заходів щодо контролю борошнистої роси у садах калини. Під час дослідження були використані методи та методики проведення фенології, створення провокаційних фонів, оцінювання рівня ураження наземної частини, встановлення ступеня ураження і стійкості рослин калини. Надано рекомендації щодо уникнення або зменшення ризиків появу борошнистої роси в садах калини, які передбачають. З'ясовано, що азотні добрива доречно вносити рано навесні і уникаючи їх внесенню наприкінці літа, з метою обмеженняросту і розвитку однорічних пагонів, тканина яких є більш чутливою до збудника борошнистої роси. Досліджено, що проведення формуючої, регулюючої і санітарної обрізки рано навесні дозволяє покращити освітлення і циркуляцію повітря в базальній частині рослин калини, інтенсифікувати ріст постійних пагонів та сформувати бажаний тип куща (деревця) в системі плодового чи декоративного садівництва. Доведено, що в умовах Північного Лісостепу України в системі плодового садівництва доцільно вирощувати високостійкі (Аня, Осіння, Еліна, Омріяна) і стійкі (Кралечка, Плододекорна, Сонетта, Горіхова, Ярославна) проти борошнистої росисорти (форми) калини звичайної Інституту садівництва Національної академії аграрних наук України. Рекомендовано для декоративного садівництва використовувати стійкі і середньостійкі сорти калини звичайної карликової (*Viburnum opulus* L.) Ескімо і калини звичайної Розеум (*Viburnum opulus* Roseum). Практична цінність полягала в доведенні, що борошниста роса калини звичайної при штучній інокуляції не уражує інші види роду *Viburnum* L.; підтверджено, що сприйнятливість рослин калини до *Microsphaera viburni* (Duby) S. Blumer можна істотно знижувати за рахунок малосприйнятливих і резистентних видів і сортів роду *Viburnum* L. та своєчасних *агротехнічних заходів*

Ключові слова: види (сорти, форми) роду *Viburnum* L.; борошниста роса; грибна хвороба; оцінка видів; заходи контролю

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Fertilisation system influence on the main agrochemical indicators of soil and productivity of white cabbage

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Abstract. The research relevance is determined by the need to study the long-term use of various fertilisers and their effect on the soil nutrient regime, yield, and quality of white cabbage. The research aims to determine the effect of different nutrition optimisation systems on the yield and quality of late-ripening white cabbage in irrigated vegetable-fodder crop rotation. Field, statistical, calculation-analytical and laboratory methods were used to conduct the research. It was established that the use of a mineral fertilizer system ($N_{550}P_{260}K_{370}$ + "NutriVant Plus Universal") led to an

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increase in the level of supply of the topsoil with mobile nitrogen, phosphorus, and potassium compounds, and had a positive effect on the biometric parameters and productivity of white cabbage plants. All fertilisation systems, except for the application of microbial preparations only provided a significant increase in yields in the range of 21.6-71.8%. However, a significant increase in the content of vitamin C in cabbage heads was observed for all fertilisation systems studied, except for the use of 40-60 t/ha of manure + $N_{60}P_{60}K_{45}$ and $N_{550}P_{260}K_{370}$ + "NutriVant Plus Universal". The nitrate content in the heads did not increase significantly after fertilisation. The ineffectiveness of using the system of microbial preparations, including seed treatment with *Azotobacter chroococcum*, and soil treatment before pre-sowing cultivation with Roundfix, to optimise the nutrition of white cabbage plants was noted. (*Paenibacillus polymyxa, Bacillus megaterium var. phosphaticum, Enterobacter, Azotobacter chroococcum, Bacillus subtilis*) and five foliar fertilisers Organic Balance (*Bacillus subtilis, Azotobacter chroococcum, Paenibacillus polymyxa*). The practical value is determined by obtaining results for adjusting fertiliser doses when planning their application in crop rotations of farms of different forms of ownership

Keywords: *Brassica oleracea* var. *capitata* L.; fertilisation systems; soil; crop rotation; irrigation; cultivation

INTRODUCTION

Ukraine, possessing fertile soils and a favourable climate, could become one of the world's future food suppliers, according to the Food and Agriculture Organisation (n.d.). However, it is worth noting that the use of soil resources in Ukraine is not always rational, which causes various degradation processes. This includes a decrease in the level of organic matter (humus), an increase in erosion processes, deterioration of soil agrophysical properties (increased dispersion, density, deterioration of structure and filtration capacity), changes in the acid-base state of the soil, signs of salinity, toxicity, and allopathy. All of this leads to a decrease in yields, deterioration in the quality of agricultural products, indicators of natural and effective soil fertility, and deterioration of the ecological state of the environment (Lykhovyd *et al*., 2022).

Degradation processes are particularly intense in vegetable production due to the specifics of vegetable growing technologies. Thus, an urgent need arises to develop and implement vegetable-growing technologies that, in addition to increasing yields, also help to preserve or restore soil fertility. The key aspects of this approach include choosing the right crop rotation, optimising tillage, and improving plant nutrition. According to L. Zhang *et al*. (2022), the introduction of even short-term crop rotations (e.g., beans – mustard – rice) in combination with the use of calculated fertiliser rates contributes to a significant increase in yields, maintaining yield stability and sustainability of the crop production system.

Sustainable agricultural biocenosis relies on a sufficient amount of soil organic matter, the main sources of which are organic and green manure fertilisers. The use of organic fertilisers not only increases the humus content in the soil but also contributes to the stability of soil aggregates due to the binding effect of humic substances and microbial waste products (Reichert *et al*., 2018). The combination of organic and mineral fertilisers leads to an increase in carbon sequestration, which is explained by the increase in the amount of plant residues due to the increase in plant productivity. However, without organic fertilisers, even high rates of mineral fertilisers cannot change the humus content. In their research, G. Xiapu *et al*. (2018) noted that the use of organic-mineral fertilisation systems provide the maximum impact on crop yields and soil C and N reserves, but the use of high manure rates can lead to an increased risk of nitrogen losses in the environment.

The introduction of a scientifically based system for optimising the nutrition of vegetable plants should ensure not only a sustainable increase in yields but also an increase in fertility by improving its parameters (agrochemical, microbiological, water and physical) (Stoessel *et al.,* 2018). This has become especially relevant in the context of martial law and the energy crisis. O. Zhernova *et al*. (2022) believe that under such conditions in Ukraine, the volume of fertiliser application has decreased sharply and, as a result, the yield of crops, including white cabbage, has decreased.

X.W. Cui *et al*. (2022) determined that the combined application of mineral and organic fertilisers increased the marketable yield and quality of white cabbage. The most effective was the replacement of 30% of organic fertilisers with mineral fertilisers, which increased the yield by 32.2%, the vitamin C content by 14.9%, the soluble sugar content by 5.5%, the efficiency of nitrogen absorption from fertilisers by 97% and the overall agronomic efficiency of fertilisers by 55.6%. According to L. Jin *et al*. (2022), a 30% reduction in the rate of mineral fertilisers when used in combination with organic fertilisers not only increases yields but also improves the physical and chemical composition of the soil, the number and diversity of beneficial bacteria and fungi in it.

It is worth noting that significant reductions in mineral fertiliser rates also have negative consequences for cabbage yields. Nitrogen fertiliser rates are particularly carefully controlled (Gonzaga *et al*., 2021). A combination of organic and mineral fertilisers with green manure is also effective. For example, in studies on chernozem soils in Kazakhstan, the maximum level of

cabbage yield and vitamin C content in heads is ensured by the application of 60 t/ha of manure + 3 t/ha of straw and N_{30} (Boteva *et al.,* 2019).

Therefore, it is necessary to study the long-term use of fertilisers in crop rotations and their aftereffects on soil nutrient regime, the productivity of vegetable plants (especially white cabbage), and soil fertility, which will allow adjusting fertiliser doses when planning their application in farm crop rotations. The research aims to determine the effect of different nutrition optimisation systems on soil nutrition, biometric parameters of plants, yield, and quality of late-ripening white cabbage in irrigated vegetable-fodder crop rotation.

MATERIALS AND METHODS

The research was carried out in 2020-2022 in a stationary long-term experiment of the Institute of Vegetable and Melon Growing of the National Academy of Agrarian Sciences of Ukraine. The experimental plots are located in the southeastern part of the Left-Bank Forest-Steppe of Ukraine, which is characterised by unstable moisture. During the years of research, the average amount of precipitation was 471 mm, with the highest amount of precipitation (57-73 mm) observed in June and July. The spring and autumn months were dry, with productive moisture reserves in the soil layer up to one metre ranging from 116 to 138 mm in April, and from 39 to 77 mm in July (Archive of meteorological data, n.d.).

The experiment site is located on land with typical chernozem, which is low-humus, heavy and loamy, with signs of forest loam. The agrochemical state of the topsoil has the following indicators: the sum of absorbed bases – 26.0 mg-eq per 100 g of soil; pH of the salt extract – 5.7; hydrolytic acidity – 2.8 mg-eq per 100 g of soil; humus content – 4.3%; hydrolysable nitrogen – 139 to 144 mg/kg; exchangeable potassium – 91 to 266 mg/kg; mobile phosphorus – 140 to 430 mg/kg of soil. The experiments were conducted on long-term stationary plots as part of a 9-year cycle of vegetable and fodder crops, including the following successive crops: barley with grass – alfalfa (first and second year of use) – cucumber – winter wheat – onion – tomato – white cabbage – table beetroot. Stationary trials were started in 1968. The experimental design included 12 different variants of fertiliser application systems: mineral, organic, organo-mineral, resource-saving (with local use of mineral fertilisers), and complex using a calculated dose of mineral fertilisers and microelements (Table 1).

***Table 1**. Fertilisation systems for white cabbage in crop rotation*

Fertilisation system in crop rotation	Fertilisation system for white cabbage
1. Without fertilizer	Without fertilizer
2. Green manure with a complex of microbial chemicals	Complex microbial chemicals
3. Manure 14 t/ha + NPK	Manure 60 t/ha + $N_{120}P_{120}K_{90}$
4. Manure 21 t/ha	Manure 90 t/ha
5. NPK	$N_{120}P_{120}K_{90}$
6. Manure 14 t/ha	Manure 40 t/ha
7. Manure 14 t/ha + ½ NPK	Manure 40 t/ha + $N_{60}P_{60}K_{45}$
8. Manure 21 t/ha + ½ NPK	Manure 60 t/ha + $N_{60}P_{60}K_{45}$
9. NPK (calculated) + microfertilisers	$N_{550}P_{260}K_{370}$ + foliar dressing "NutriVant Plus universal" at 2 kg/ha in 3 terms
10. Manure 14 t/ha + ½ NPK (locally)	Manure 40 t/ha + $N_{60}P_{60}K_{45}$ (locally)
11. Manure 21 t/ha + 1/4 NPK (locally)	Manure 60 t/ha + $N_{30}P_{30}K_{22,5}$ (locally)
12. Biological (organic fertilisers + green manure + microbial preparations)	Manure 40 t/ha + complex of microbial preparations

***Source:** compiled by the authors*

In the experiments, organic fertilisers were applied in the form of cattle manure, and mineral fertilisers (in all experimental variants, except for variants 10 and 11, where fertilisers were applied locally) – in the form of nitroammophoska, ammonium nitrate and potassium chloride. The microbial application system included seed treatment with Azotophyte (1 l/t), soil treatment with pre-sowing cultivation with Groundfix (5 l/ha), foliar feeding with Organic Balance (2 l/ha) five times (3-4 true leaves, 6-7 true leaves, rosette formation, beginning of head formation, 25-30 days after the previous application).

NutriVant Plus Universal is a fertiliser designed for foliar application to crops outside the root zone. Its composition includes the following components: nitrogen (N) – 19%, phosphorus (P2O5) – 19%, potassium (K_2O) – 9%, magnesium (MgO) – 2%, manganese (Mn) – 0.04%, zinc (Zn) – 0.02%, copper (Cu) – 0.005%, iron (Fe) – 0.08%, molybdenum (Mo) – 0.005% (ICL Specialty Fertilizers Logo Vector, n.d.). This fertiliser is used for foliar feeding of plants at three stages: at the stage of 3-4 true leaves, during rosette formation and at the initial stage of head formation.

Azotophyt-p is a formula containing live cells of the rhizosphere bacterium Azotobacter chroococcum, which is capable of fixing nitrogen from the environment and transferring it to plants. This bacterium also

synthesises vitamins, amino acids, and phytohormones and produces antifungal substances. The number of live microorganisms of the bacterium Azotobacter chroococcum is at least 1x109 CFU/g (Brochure about AZOTOPHYT, n.d.).

Organic-Balance-P is a biological product designed to stimulate the growth and development of plants of various crops and increase resistance to diseases, pests, and stress. The composition of the product includes live bacteria that perform the following functions: fix nitrogen, mobilise phosphorus and potassium, have an antagonistic effect on fungi, produce biologically active substances such as vitamins, phytohormones, fungicides, antibiotics, amino acids, enzymes, and contain organic food sources and macro- and microelements. The product is used for foliar feeding and seed treatment (Brochure about ORGANIC-BALANCE (vegetation), n.d.).

Groundfix is a biofertilizer containing cells of the bacteria Paenibacillus polymyxa, Bacillus megaterium var. phosphaticum, Enterobacter, Azotobacter chroococcum, and Bacillus subtilis. The total number of live cells ranges from 0.5 to 1.5 × 109 CFU/cm3. This product increases phosphorus mobility and potassium availability from soil and mineral fertilisers, prolongs the availability of nutrients, improves soil biological activity, and limits the development of phytopathogens (Brochure about GROUNDFIX, n.d.).

The experimental plot area was 58.3 m^2 (8.33 m × 7.0 m), with a recording area of 36.4 m^2 (5.6 m × 6.5 m). The experiment was conducted four times, placing the plots in a systematic arrangement on two levels. The technology of growing white cabbage corresponded to the conditions of the forest-steppe of Ukraine and included the use of drip irrigation. The methodology of the experiment and observation was developed following the "Methodology of experimental work in vegetable and melon growing" (Bondarenko & Yakovenko, 2001).

The following methods were used to determine the content of nutrients in the soil from the topsoil: nitrate determination according to State Standards of Ukraine (hereinafter DSTU) 4729:2007 (2008), determination of mobile phosphorus and potassium compounds in the modification of CINAO by Chirikov, and phosphorus was analysed by colorimetric method, and potassium – by photometer (DSTU 4115:2002, 2003). Biometric measurements at the stage of technical ripeness, harvest accounting and determination of the chemical composition of cabbage heads, including dry matter content according to DSTU 7804:2015 (2016), vitamin C content according to DSTU 7803:2015 (2016), total sugar according to DSTU 4954:2008 (2009), and nitrates according to DSTU 4948:2008 (2009) were carried out. During the research, 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

Analysing the changes in the nitrate nitrogen content in the upper soil layer at a depth of 0-30 cm, it was observed that in the initial period of growth of white cabbage, an increase in this indicator was observed when using mineral fertilisers or combined application of organic and mineral fertilisers (in the range from 66 to 127 mg/kg dry soil). At the time when a complex of microbial preparations was used, or after the application of organic fertilisers alone, the nitrate nitrogen content ranged from 29 to 49 mg/kg dry soil (Fig. 1).

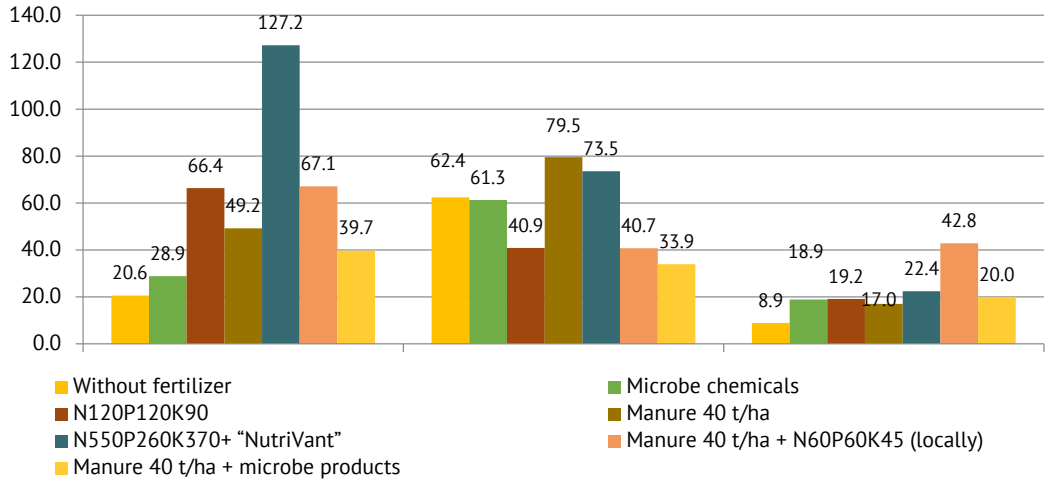

Figure 1. *Dynamics of nitrate nitrogen content in the soil layer 0-30 cm depending on the fertilisation system of white cabbage (average for 2020-2022)*

Source: *compiled by the authors*

The content of nitrate nitrogen in the soil decreased regardless of the fertilisation system, which indicates its active use by cabbage plants and migration in the soil profile. It is also worth noting that the highest level of nitrate nitrogen in the soil was recorded at the beginning of the growing season, at the stage

of 3-4 true leaves – the beginning of the formation of the leaf rosette, when the use of mineral fertilisers was most effective. Instead, at the end of the growing season, a high value of this indicator was observed in the system of resource-saving fertilisation, where mineral fertilisers were applied locally.

A high level of mobile phosphorus in the upper soil layer at a depth of 0-30 cm was observed when both mineral and organic fertilisers were applied, both separately and together (in the range of 324 to 435 mg/kg dry soil, see Fig. 2). The level of mobile phosphorus remained stable throughout the entire growing season of white cabbage. However, it is worth noting a significant increase in mobile phosphorus in the soil when applying microbial preparations, where the content was 290 mg/kg of dry soil. Similar results were obtained in studies conducted by D. Sarkar *et al.* (2021), where the use of beneficial microorganisms (*Trichoderma harzianum, Pseudomonas fluorescens and Bacillus subtilis*) contributed to the activation of phosphorus and potassium in the soil and the uptake of these macronutrients by cabbage plants.

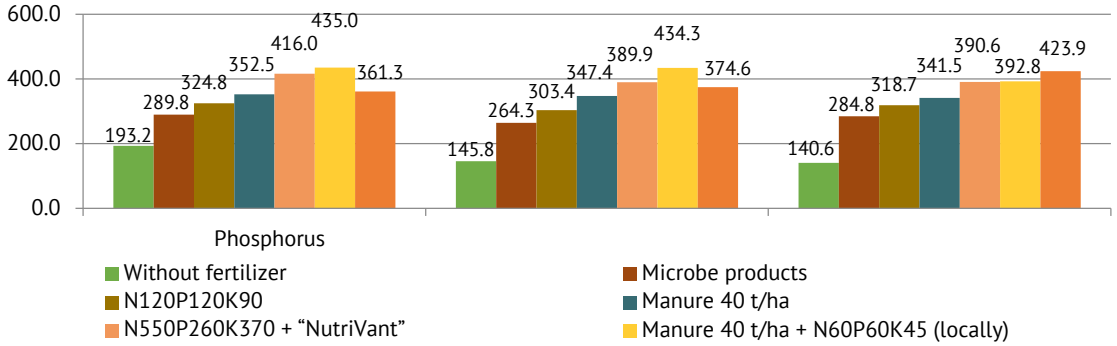

Figure 2. *Dynamics of mobile phosphorus content in the soil layer 0-30 cm depending on the fertilisation system of white cabbage (average for 2020-2022)*

Source: *compiled by the authors*

A significant content of mobile phosphorus forms in the soil at the beginning of the growing season was ensured by the use of an organic-mineral fertilisation system and mineral fertilisers locally (435 mg/kg of dry soil). The effectiveness of localised fertilisation in terms of increasing the content of mobile phosphorus in the topsoil was confirmed in the research of L.O. Duarte *et al.* (2019), where the introduction of this technological measure led to an increase in the phosphorus uptake coefficient from fertilisers from 30.0% to 60.4%. All fertilisation systems led to an increase in the content of exchangeable potassium in the 0-30 cm soil layer. The use of the calculated dose of mineral fertilisers ($N_{550}P_{260}K_{370}$) provided the maximum values of the indicator during the entire vegetation period of white cabbage (213-266 mg/kg). Thus, during the phase of 3-4 true leaves – the beginning of the formation of a rosette of leaves, a high level of exchangeable potassium content was provided by the resource-saving fertilizer system (213-215 mg/kg), and at the end of the growing season – with the application of 40 t/ha of manure (233 mg/kg) (Fig. 3).

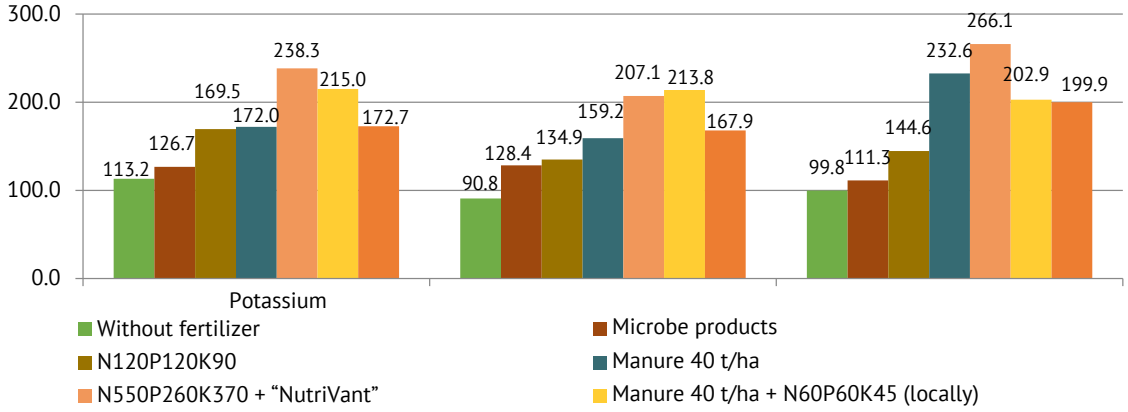

Figure 3. *Dynamics of exchangeable potassium content in the soil layer 0-30 cm depending on the fertilisation system of white cabbage (average for 2020-2022)*

Source: *compiled by the authors*

The use of a complex of microbial products proved to be effective, which ensured an increase in the content of exchangeable potassium in the soil by 11.5-40.6% compared to the control. That is, microbial preparations with phosphorus and potassium mobilising agents have the prospect of being used in technological schemes for growing vegetable plants, which is confirmed by the research of S. Shanmugam *et al.* (2022). The use of fertilisers improved the development of white cabbage plants, especially under organic-mineral fertilisation systems (Table 2). It was noted that under organic-mineral fertilisation systems, the height of plants ranged from 43-46 cm, under mineral fertilisation – 42.6-46.0 cm, under a combination of organic fertilisers and microbial preparations – 43 cm, while the value of this indicator in the control was 35 cm. Separate application of only organic fertilizers, as well as the use of a complex of microbial preparations caused only a positive trend in the growth of the height of white cabbage plants (increase in the value of the indicator relative to the control by 7.4-17.7%).

Table 2. *Biometric parameters of white cabbage plants under different fertilisation systems (average for 2020-2022)*

No.	Fertilisation system	Biometric parameters			
		Plant height, cm	Diameter of the leaf rosette, cm	Diameter of the leaf rosette, cm	Average head weight, kg
1	No fertilisers (control)	35.1	32.1	17.8	1.43
2	Microbial products	37.7	35.8	17.6	1.88
3	Manure 60 t/ha + $N_{120}P_{120}K_{90}$	43.1	32.7	16.9	1.83
4	Manure 90 t/ha	41.3	34.8	21.0	1.80
5	$N_{120}P_{120}K_{90}$	42.6	36.2	17.6	1.88
6	Manure 40 t/ha	41.3	38.3	17.9	1.75
7	Manure 40 t/ha + $N_{60}P_{60}K_{45}$	44.3	41.6	19.7	1.96
8	Manure 60 t/ha + $N_{60}P_{60}K_{45}$	45.8	42.8	20.2	2.03
9	$N_{550}P_{260}K_{370}$ + foliar dressing "NutriVant Plus universal"	46.0	37.8	17.9	2.25
10	Manure 40 t/ha + $N_{60}P_{60}K_{45}$ (locally)	39.7	35.4	18.1	1.90
11	Manure 60 t/ha + $N_{30}P_{30}K_{22,5}$ (locally)	45.8	39.1	19.1	1.92
12	Biological (organic fertilisers + microbial preparations)	43.0	41.1	20.2	2.06
	$HIP_{0.95}$	7.5	5.6	2.1	0.38

Source: *compiled by the authors*

The influence of fertilisers on the diameter of the rosette of leaves of white cabbage had the same tendencies as on the height of plants. There was a significant increase in the diameter of the cabbage head when using organo-mineral fertilisation systems, $N_{550}P_{260}K_{370}$ + foliar feeding with NutriVant plus universal, a combination of organic fertilisers and microbial preparations by 17.8-33.3%. A significant increase in the head diameter was typical for the application of 90 t/ha of manure, 60 t/ha of manure + $N_{60}P_{60}K_{45}$ and a combination of organic fertilisers and microbial preparations (20.2-21.0 cm). Thus, the use of fertilisers contributed to an increase in the average weight of the head of white cabbage by 22.4-57.3%. This growth was not significant in the variants of 90 and 40 t/ha of manure. Improving the soil nutritional regime and biometric parameters contributed to the growth of the yield of white cabbage. On average, over three years in irrigated vegetable-fodder crop rotation, the use of different fertilisation systems provides an increase in the yield of white cabbage by 9.9-33 t/ha or 21.6-71.8% compared to the control with a yield of 45.9 t/ha (Table 3).

Table 3. *Effect of different fertilisation systems on the yield of white cabbage in irrigated vegetable-fodder crop rotation (2020-2022)*

	Crop rotation fertilisation system	Cabbage fertilisation system	Overall yield, t/ha				Increase in comparison to control		Marketability, %
			2020	2021	2022	average	t/ha	%	
1	No fertilisers (control)	Without fertilizer	36.5	31.3	70.0	45.9	-	-	87.7
2	Green manure with a complex of microbial chemicals	Microbial products	38.2	33.4	71.5	47.7	1.7	3.8	89.5

Table 3, Continued

	Crop rotation fertilisation system	Cabbage fertilisation system	Overall yield, t/ha				Increase in comparison to control		Marketability, %
			2020	2021	2022	average	t/ha	%	
3	Manure 14 t/ha + NPK	Manure 60 t/ha + $N_{120}P_{120}K_{90}$	40.2	40.5	88.9	56.5	10.6	23.0	88.7
4	Manure 21 t/ha	Manure 90 t/ha	44.8	41.0	85.4	57.1	11.1	24.2	89.3
5	NPK	$N_{120}P_{120}K_{90}$	39.4	43.3	87.1	56.6	10.7	23.2	91.5
6	Manure 14 t/ha	Manure 40 t/ha	40.8	45.7	81.1	55.9	9.9	21.6	91.0
7	Manure 14 t/ha + ½ NPK	Manure 40 t/ha + $N_{60}P_{60}K_{45}$	42.1	46.3	98.0	62.1	16.2	35.3	89.5
8	Manure 21 t/ha + ½ NPK	Manure 60 t/ha + $N_{60}P_{60}K_{45}$	45.2	46.0	103.9	65.0	19.1	41.6	91.3
9	NPK (calculated) + fertilisation with complex fertilisers	$N_{550}P_{260}K_{370}$ + "NutriVant Plus universal"	41.0	50.7	105.2	78.9	33.0	71.8	91.9
10	Manure 14 t/ha + ½ NPK (locally)	Manure 40 t/ha + $N_{60}P_{60}K_{45}$ (locally)	44.4	49.1	98.7	64.1	18.2	39.5	89.8
11	Manure 21 t/ha + 1/4 NPK (locally)	Manure 60 t/ha + $N_{30}P_{30}K_{22,5}$ (locally)	39.0	51.7	101.7	64.1	18.2	39.6	94.2
12	Biological (organic fertilisers + green manure + microbial preparations)	Manure 40 t/ha + microbial chemicals	44.6	46.1	93.4	61.4	15.4	33.6	88.6
	$HIP_{0.95}$		4.96	5.65	10.85				

Source: *compiled by the authors*

Favourable weather conditions for the growth and development of cabbage plants were formed in 2022, which allowed for a yield higher than in previous years by 107-154%. The most noticeable difference was for organic-mineral fertilisation systems (130-150%). The most efficient is the use of an organic-mineral fertiliser system (60 t/ha of manure + $N_{120}P_{120}K_{90}$, 30 t/ha of manure + $N_{60}P_{60}K_{45}$ and 40 t of manure + locally $N_{60}P_{60}K_{45}$) and mineral ($N_{120}P_{120}K_{90}$ and $N_{550}P_{260}K_{370}$ + "NutriVant Plus universal"), which provided yields of 56.5-78.9 t/ha. A similar pattern is noted in the studies of other scientists. According to O. Ponjičan *et al.* (2021), the use of organic and mineral fertilisers in a complex ensures an increase in cabbage yield by 73.3%, while the yield of barley increased by 21.2-60.6% when applied separately.

The calculated dose of mineral fertilisers ($N_{550}P_{260}K_{370}$ + NutriVant Plus universal), which was planned to obtain a cabbage yield of 100 t/ha, provided an average of 78.9 t/ha over the years of research, although in 2022, with this fertilisation system, the yield level was 105.2 t/ha. The use of a complex of microbial preparations to optimise the nutrition of cabbage plants did not provide a significant increase in yield. It can be assumed that the system of their application selected for the research (Azotophyte for seed treatment, Groundfix for pre-sowing cultivation and Organic Balance for foliar feeding) did not ensure optimal saturation of the root rhizosphere with beneficial microorganisms and a low stimulating effect, since the effectiveness of using microbial preparations for growing cabbage has been proven in various studies. For example, in Kazakhstan, the use of organic fertilisers and a complex of biological products increases crop yields by 15.2-47.2% (Aitbayev *et al.*, 2018).

The marketability of products increases with the use of organic and mineral fertilisers; without fertilisation, this figure was 87.7%, and with different fertilisation systems – 88.6-94.2%. The use of fertilisers has a different effect on the change in the quality indicators of white cabbage products. On average, over the years of research, the content of total sugar and mono sugars in the heads of white cabbage did not change significantly. When applying 60 t/ha of manure + $N_{60}P_{60}K_{45}$, a decrease in these indicators was observed compared to the control to the level of 3.54 and 3.25%, respectively (Table 4).

Table 4. *Effect of fertilisers on the biochemical composition of white cabbage products (average for 2020-2022)*

No.	Fertilisation system	Mass fraction			
		of overall sugar, %	mono sugars, %	vitamin C, mg/100g	nitrates, mg/kg
1	No fertilisers (control)	4.23	4.02	10.4	85.5
2	Microbial products	4.33	4.14	12.6	79.6

Table 4, Continued

No.	Fertilisation system	Mass fraction			
		of overall sugar, %	mono sugars, %	vitamin C, mg/100g	nitrates, mg/kg
3	Manure 60 t/ha + $N_{120}P_{120}K_{90}$	4.05	3.89	13.6	75.2
4	Manure 90 t/ha	4.12	3.96	18.2	54.3
5	$N_{120}P_{120}K_{90}$	4.00	3.71	19.2	41.8
6	Manure 40 t/ha	4.09	3.70	16.2	40.9
7	Manure 40 t/ha + $N_{60}P_{60}K_{45}$	3.89	3.59	9.43	57.1
8	Manure 60 t/ha + $N_{60}P_{60}K_{45}$	3.54	3.25	10.8	80.6
9	$N_{550}P_{260}K_{370}$ + foliar fertilisation "NutriVant Plus universal" 2 kg/ha (100 t/ha)	3.75	3.33	11.9	83.1
10	Manure 40 t/ha + $N_{60}P_{60}K_{45}$ (locally)	4.20	3.94	18.6	93.1
11	Manure 60 t/ha + $N_{30}P_{30}K_{22,5}$ (locally)	4.09	3.88	17.0	104.7
12	Biological (organic fertilisers + green manure + microbial preparations)	3.82	3.68	16.8	71.4
	$HIP_{0.95}$	0.52	0.56	2.9	10.8

Source: *compiled by the authors*

All fertilisation systems studied, except for 40-60 t/ha of manure + $N_{60}P_{60}K_{45}$ and the use of $N_{550}P_{260}K_{370}$ with foliar fertilisation "NutriVant plus universal", showed a significant increase in the content of vitamin C in cabbage heads to the level of 13.6-19.2 mg/100 g, while the value of this indicator in the control was 10.4 mg/100 g. The research of L. Rempelos *et al.* (2023) noted a positive effect on the content of sugars, vitamins C, B_9 and carotene in cabbage heads only in cases where organic fertilisers were used. The biochemical composition of cabbage products did not change significantly when mineral fertilisers were used. The nitrate content in the heads of cabbage did not increase significantly, except for the variant of 60 t/ha of manure + locally applied $N_{30}P_{30}K_{22.5}$ (104.7 mg/kg). However, this indicator was lower than the maximum permissible level (MPL) for white cabbage production (500 mg/kg of raw weight). This pattern is somewhat inconsistent with the research of other scientists. According to the results of X. Jun *et al.* (2023), the introduction of organo-mineral fertilisation systems does not lead to the accumulation of excess nitrogen in cabbage plants at different stages of growth compared to other fertilisation systems.

Thus, according to our research and the results of other scientists, the use of organic fertilisers has a significant impact on plant biometric parameters, yield, and vitamin C content in products, while the application of mineral fertilisers increases the content of nitrate nitrogen and partially the content of mobile phosphorus and potassium compounds in the topsoil, yield and vitamin C content. The introduction of an organo-mineral fertilisation system using mineral fertilisers locally improves the soil's nutritional regime, increases plant biometric parameters, yields and product quality, and reduces the nitrate content in the heads. The use of a complex of microbial preparations as an alternative to organic fertilisers improves the soil nutritional regime, and increases the content of vitamin C, but does not affect the level of yield, while other studies have shown that this effect is significant, indicating the inefficiency of the developed system of using microbial preparations.

CONCLUSIONS

Conducting research in long-term stationary experiments allows us to thoroughly investigate the impact of different fertilisation systems not only on the yield and quality of products but also on the soil condition and the supply of plants with basic nutrients. It is noted that a high level of soil supply with mobile nitrogen, phosphorus and potassium compounds during the growing season is ensured by the use of mineral ($N_{550}P_{260}K_{370}$ + NutriVant plus universal) and resource-saving fertilisation systems (spreading manure in autumn of 40 t/ha + locally in spring $N_{60}P_{60}K_{45}$). These fertilisation systems resulted in a 152-517% increase in nitrate nitrogen in the 0-30 cm soil layer compared to the control, a 116-197% increase in mobile phosphorus, and a 90-166% increase in exchangeable potassium.

The maximum effect on the biometric parameters of cabbage plants was found to be achieved by using the calculated dose of mineral fertilisers (spread in autumn $N_{550}P_{260}K_{370}$), organo-mineral systems (scattered in autumn 40-60 t/ha of manure + $N_{60}P_{60}K_{45}$), resource-saving (scattered in autumn 60 t/ha of manure + locally in spring $N_{30}P_{30}K_{22.5}$) and biological fertilisation systems (scattered in autumn 40 t/ha of manure + a complex of microbial preparations). There was an increase in plant height by 22.5-31.3%, leaf rosette diameter by 21.8-32.1%, head diameter by 10.7-13.5%, and head weight by 32.9-57.3%. All fertilisation systems, except for the application of microbial preparations only, provide a significant increase in the yield of white cabbage within 21.6-71.8%. The maximum yield level (78.9 t/ha)

was recorded when using a mineral fertiliser system ($N_{550}P_{260}K_{370}$+ "NutriVant plus universal").

The ineffectiveness of using the system of microbial preparations for optimising the nutrition of white cabbage plants, including seed treatment with Azotophyte (*Azotobacter chroococcum*), soil treatment before pre-sowing cultivation with Groundfix (*Paenibacillus polymyxa, Bacillus megaterium var. phosphaticum, Enterobacter, Azotobacter chroococcum, Bacillus subtilis*) and five foliar applications of Organic Balance (*Bacillus subtilis, Azotobacter chroococcum, Paenibacillus polymyxa*). Under all fertilisation systems studied, except for the use of 40-60 t/ha of manure + $N_{60}P_{60}K_{45}$ and $N_{550}P_{260}K_{370}$ with foliar application of NutriVant plus universal, a significant increase in the content of vitamin C in cabbage heads to the level of 13.6-19.2 mg/100 g was observed, while fertilisers had no significant effect on other biochemical parameters of the product (total sugar and mono sugar content, nitrate content).

Determination of the mechanisms of influence on soil fertility and productivity of vegetable crop rotations of alternative nutrition optimisation systems with a complex of green manure, humic fertilisers and microbial preparations remains relevant in further research. At the same time, it is necessary to expand the range of beneficial microorganisms that saturate the soil rhizosphere and plan their additional introduction, for example, with irrigation water.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None.

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Вплив систем удобрення на основні агрохімічні показники ґрунту та продуктивність капусти білоголової

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Анотація. Актуальність проведених досліджень полягає у необхідність вивчення тривалого застосування різних добрив та їх післядію на поживний режим ґрунту, формування урожайності та якості капусти білоголової. Метою роботи було встановлення впливу різних систем оптимізації живлення на урожайність і якісні продукції капусти білоголової пізньостиглої в зрошуваній овоче-кормовій сівозміні. Для проведення досліджень використовувалися польові, статистичні, розрахунково-аналітичні та лабораторні методи. Встановлено, що використання мінеральної системи удобрення ($N_{550}P_{260}K_{370}$ + «Нутрівант плюс універсальний») призвело до підвищення рівня забезпеченості орного шару ґрунту рухомими сполуками азоту, фосфору та калію, забезпечувало позитивний вплив на біометричні показники та продуктивність рослин капусти білоголової. Всі системи удобрення, окрім внесення тільки мікробних препаратів, забезпечує істотне підвищення урожайності в межах 21,6-71,8 %. Однак, істотне зростання вмісту вітаміну С в головках капусти зазначено для всіх досліджуваних систем удобрення, окрім використання 40-60 т/га гною + $N_{60}P_{60}K_{45}$ та $N_{550}P_{260}K_{370}$ + «Нутрівант плюс універсальний». Вміст нітратів в головках від внесення добрив зростав не істотно. Зазначено неефективність використання для оптимізації живлення рослин капусти білоголової системи внесення мікробних препаратів, що включає обробку насіння Азотофіт (*Azotobacter chroococcum*), обробка ґрунту до передпосівної культивації Граундфікс (*Paenibacillus polymyxa, Bacillus megaterium var. phosphaticum, Enterobacter, Azotobacter chroococcum, Bacillus subtilis*) та п'ять позакореневих підживлень Органік баланс (*Bacillus subtilis, Azotobacter chroococcum, Paenibacillus polymyxa*). Практична цінність полягає у отриманні результатів для корегування доз добрив за планування їх внесення в сівозмінах господарств різних форм власності

Ключові слова: *Brassica oleracea* var. *capitata* L.; системи удобрення; ґрунт; сівозміна; зрошення; вирощування

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The evaluation of total weed density and seed bank of agricultural landscapes as an example of the Steppe Zone of Ukraine

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Abstract. A high degree of weed infestation of agricultural ecosystems poses a significant threat to high crop yields, which determines the problem of weed control as one of the most urgent in steppe agriculture. The research aims to assess the level of total weed density and seed bank of various components of agroecosystems in the steppe zone of Ukraine. The methods used to determine the species composition of weeds, their quantitative and weight accounting and harmfulness were statistical and mathematical. It has been established that the main reason for the high negative

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impact of weeds is the weed seed bank of soils, which reaches 452 million seeds per hectare in land being actively used for agriculture and 11 million hectares in natural ecosystems. In agroecosystems, the decisive factor for effective regulation of weed seed banks is the sustainability of crops (as part of an ecosystem dominated by 1 plant species), methods of basic tillage and measures to prevent the generative productivity of weeds. According to the impact on the yield of winter wheat, corn, sunflower and spring barley, different tillage systems (ploughing, disc tillage, no-tillage) in the crop rotation were significant, where the no-tillage system was inferior to disc tillage, depending on the fertilization background, by 0.21-0.22 t/ha and ploughing – by 0.19-0.40 t/ha due to increased weed infestation of crops, as well as the presence of a significant amount of carrion and leaf mass of the predecessor on the field surface. The practical value is determined by an improvement of the system of weed control in crop rotations of adaptive agriculture and environmental safety

Keywords: agroecosystems; weed; crop rotation; soil tillage; yield; productivity

INTRODUCTION

Weeds remain one of the most damaging factors in agriculture, causing significant crop yield losses. An important part of weed control is the existing weed seed bank in the soil, which has a high degree of correlation with the degree of actual weed infestation. The topic of research is becoming extremely relevant due to the intense dynamics of the species and quantitative composition of weeds in agrocenoses and the need to predict the agrotechnological and chemical system of weed control for crops.

Modern herbicides used in grain growing technologies have a sufficiently high level of technical efficiency, however, even in this case, weeds with increased resistance to chemicals are not able to sufficiently prevent grain yield losses and the ecological spread of weeds (Fetyukhin *et al.,* 2021; Tkalich *et al.,* 2023). In this context, important results regarding the ecological and economic assessment of agrotechnologies recommended in agriculture were obtained by M. Spoth *et al.* (2022), who showed that weed control measures in many cases exceed the amount of grain production and the amount of profit received.

K. Alijani *et al.* (2023) determined in a study of crop weed infestation that the weed seed bank in the soil is an important determinant of aboveground floristic composition and weed density in agricultural systems. Quantitative and qualitative indicators of the weed seed bank can help producers predict the extent to which they face weed problems. By comparing different tillage systems in studying the dynamics of the weed seed bank and its species composition with the actual weed infestation of crops, it was also proved that the weed seed bank is more influenced by weather conditions than by different tillage systems.

A. Md-Akhir *et al.* (2022) and R. Idziak *et al.* (2022) considered the problem of weeds spreading in the areas of agricultural use for growing various crops as one that is formed not only directly in crops but also on lands that need restoration and reclamation with an existing seed bank in the soil. Significant transformations of pest ecosystems are observed in the context of climate change, global warming, and water availability, which necessitates adaptive technological measures in the production of field crops, in particular one of the most common crops in the world, winter wheat. This has been reliably confirmed by field experiments by Bajwa *et al.* (2020).

The findings of L. Butkeviciene *et al.* (2021) experimentally confirmed that in the context of climate change and intensive agriculture, long-term crop rotations increase crop productivity, reduce weeds and the weed seed bank in the soil, and thus contribute to maintaining the resilience of the agroecosystem. The initial field studies by S. Ali *et al.* (2022) on the effectiveness of weed control showed that one of the ways to improve the protective functions of grain-growing technology is the double use of herbicides. Thus, the authors believe, on a reliable scientific basis, that double treatment of wheat crops is accompanied by a 73% increase in grain yield, as well as a significant clearing of crops from weed seeds in the soil.

Significant positive results in weed control can be achieved by selecting the methods of basic tillage and addressing the peculiarities of weed seed movement in the soil depending on the depth of tillage and the distribution of weeds in the vertical section, this scientific position was confirmed by the research of Q. Maqsood *et al.* (2018). It has been proven that even when concentrated in the upper soil layer and provoking its germination, agrotechnical control measures provide a high degree of soil purification in crop rotation. Comprehensive studies by Beckie *et al.* (2020) have shown that soil weed seed banks can reflect the impact of long-term cumulative field management and crop sequences on weed communities. In addition, soil seed banks provide accurate estimates of future weed problems, as well as potential arable plant diversity and associated ecological functions. To this end, the authors evaluated the impact of different long-term cropping systems in the same crop rotation sequence on weed seed abundance, diversity, and collection, as well as on functional diversity and composition. An important conclusion based on many years of research was made by O. Kurdyukova and O. Tyshchuk (2019)

that in the conditions of the high weed seed bank in Ukraine, to reduce the species and quantitative composition of weed seeds in the soil, it is necessary to apply a set of long-term agronomic, biological, phytocoenotic, chemical and organizational methods that complement and reinforce each other.

The literature review showed that the chosen topic has been studied insufficiently. Therefore, the research aims to assess the level of the weed seed bank and the actual weed infestation of various components of agroecosystems in the steppe zone of Ukraine.

MATERIALS AND METHODS

The following components of agroecosystems have been selected to study the mechanisms of conservation of weed taxonomic diversity and the spread of weed seeds: intact fallow land; areas under 60-year shelterbelts; and land under long-term cultivation (stationary field experiments). The study was conducted during 2018-2021. Research to determine the weed seed bank and actual weed infestation was conducted in stationary experiments of the Arable Lands State enterprise "Experimental farming Dnipro" Institute of Grain Crops of the National Academy of Agrarian Sciences of Ukraine (SE"EF"Dnipro" IGC NAASU) (Vasylivka village, Solonyansky district, Dnipro region), the scientific research field of the Educational and Scientific Center of Dnipro State Agrarian and Economic University (SRF ESC DSAEU) (Oleksandrivka village, Dniprovsky district, Dnipro region), farming state "Olympus-2012" (Olympiadivka village, Petrivsky district, Kirovohrad region). As well as in shelterbelts near these stationary experiments; fallow lands near the village of Honcharka, Solonyansky district, Dnipro region and Oleksandrivka village, Dniprovsky district, Dnipro region.

The following methods and accounting ways have been used in the research.

1. The weed seed bank has been determined by taking soil samples with a Kalentiev drill along the diagonal of the field in five locations of the experimental plot, field protection forest belt, etc. The depth of sampling was 0-10, 10-20, 20-30, 30-40 cm. The collected soil sample has been washed on a sieve with 0.25 mm holes with a 5 cm high rim above the container. Large seeds with a diameter of more than 0.25 mm have been retained on the sieve. A solution of sodium chloride (NaCl) has been used to separate the small seeds that have been passed through the sieve from the sludge and water. In this case, heavy mineral particles of the soil have been settled to the bottom, while light weed seeds and organic residues have been floated to the surface. The surface of the solution, along with the seeds, has been poured onto filter paper, after which it has been dried. Then the seeds have been counted together with the previously strained seeds on a sieve.

After that, soil contamination with weed seeds has been calculated using the formula:

$$C_{ws} = \frac{10000 \times N_{ws}}{N_s \times A}, \quad (1)$$

where C_{ws} – is weed seed contamination of the soil layer, pcs./m²; 10000 – is the area of 1 m² in cm²; N_{ws} – is the number of weed seeds in the sample, pcs; N_s – is the number of samples from which the sample was formed; A – is the area of the inner surface of the drill, cm².

Dividing the numerical value of C_{ws} by 100, the weed seed contamination of the soil was converted to millions of units/ha.

2. The actual weed infestation of crops has been accounted for by the quantitative weight method (using 1.0 m² plots). The surveys have been carried out during the eating phase of early grain crops, before the first inter-row cultivation in row crops, on natural fallow lands and field protection forest belts with simultaneous weed pulling to determine biological species and their mass in an air-dry state. The survey frames have been placed along the diagonal of the plot in 10 locations.

Crop accounting has been carried out by direct threshing (winter wheat, barley, peas) with a Sampo-500 combined, (sunflower – with a Niva-Effect combined) corn – by hand, considering the moisture content and weed infestation of the product at the stage of full grain ripeness. After determining grain contamination and moisture content, the harvest has been recalculated for 100% purity and 14% moisture content.

The data have been analyzed using Statistica 10.0 software (StatSoft Inc., USA). The data have been tabulated as x±SD (x ± standard deviation). The differences between values in control and experimental variants have been determined using Tukey's test, where differences have been considered significant at $P<0.05$ (with Bonferroni correction).

Experimental studies of plants (both cultivated and wild), including the collection of plant material, are conducted following the principles of bioethics and the Convention on Biological Diversity (1992) and the Convention on Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS AND DISCUSSION

The influence of crop rotations and methods of basic soil cultivation on the peculiarities of migration and dislocation of weed seeds in the soil profile of arable land has been investigated. The methodology of wide involvement of variations in the factors that form weed infestation allows us to establish patterns of transformation of the degree of weed infestation, planning of weed control measures and evaluating the efficiency of agricultural systems.

The analysis of the weed seed bank of the lands of the agroecosystems demonstrates that human intervention in ecological and landscape complexes in the form of agricultural activities is accompanied by a significant increase in weed seed stocks in the soil (Table 1). For example, active soil cultivation in crop

rotation on old arable lands has been accompanied by the accumulation of up to 452 million weed seeds in the 0-30 cm soil layer. The danger of such high degrees of potential weed seed infestation is also exacerbated by the soil profile of arable land containing a significant amount of seeds in each layer, which, when vertically migrating, in any case, creates a risk of high weed damage. For example, in the upper 0-10 cm soil layer with a high coefficient of stimulation of seed germination, the number of seeds was 133 million/ha.

Table 1. *The weed seed bank in the lands of agroecosystem components at different depths, million pcs/ha (average for 2018-2021, x±SD, n=12)*

Soils, the method of their use	Soil layers, cm			
	0-10	0-20	0-30	0-40
Fallow lands	6±1^{a}	7±1^{a}	8±1^{a}	8±1^{a}
Arable lands SE"EF"Dnipro" IGC NAASU	133±3^{c}	306±7^{c}	452±7^{c}	464±8^{c}
Farming state "Olympus-2012"	37±4^{b}	128±5^{b}	205±6^{b}	223±5^{b}
Forest protection strips	7±1^{a}	9±2^{a}	11±2^{a}	11±2^{a}
Scientific stationary experiments IGC NAASU	43±4^{b}	140±5^{b}	217±6^{b}	228±5^{b}
SRF ESC DSAEU	63±5^{bc}	180±6^{bc}	305±7^{bc}	311±5^{bc}

Note: *different letters denote values that significantly differ from each other within a column of Table 1 according to the results of comparison according to the Tukey test (P<0.05) with the Bonferroni correction.*
Source: *compiled by the authors*

The more conservative part of the seeds, which is located in the layer of 10-30 cm, is 306 pcs/ha, and carries a prolonged danger of increasing the degree of weed infestation of crops. The level of technological culture and implementation of a system of weed control measures is an effective means of reducing the weed seed bank, which has been experimentally proven. This is evidenced by the study of the degree of weed seed banks in stationary field experiments in research institutions where a full range of agrotechnical and chemical weed control measures has been carried out.

The problems of protecting field crops from weeds do not disappear if the level of weed seed bank is high, even with the latest effective weed control techniques. Understanding the processes of realization of the seed bank of conditionally natural components of agroecosystems will allow making effective decisions in farming practice.

The research of weed seed reserves of fallow lands and shelterbelts created in the 60s of the 20th century has shown that the processes of activation of seed resources on uncultivated lands are significantly slower. In the soils of fallow lands, where no agrotechnical measures are taken, a relatively stable grass cover has developed. Such an herbaceous cover can be characterized as a perennial type of weed infestation. This type of weed infestation must not be characterized by the supply of seeds of annual species in volumes critical for the natural succession development places. The weed seed bank of fallow soils in the topsoil is 6-7 million seeds/ha. In the deeper layers, only residual signs of weed seeds are observed at the level of 1-2 million seeds/ha. Thus, the degree of weed seed bank of arable land is 20-50 times higher than in natural succession development places.

Thus, in both natural and agricultural environments, the most important factors in transforming the weed seed bank are soil quality, plant species competitiveness, agrotechnological features of vertical seed migration and the effectiveness of weed control products. In the farming system, weed seed bank is the main factor that determines the degree of weed infestation, the level of negative impact of weeds and the amount of crop loss (Kurdyukova & Tyshchuk, 2019). The correlation between weed seed bank and crop yield is one of the highest among other factors, even though the sale of seed stocks largely depends on the occupation of ecological niches in agroecosystems, competitive tension at different stages of plant development, soil moisture, synchronization of agricultural cycles with the phases of biological awakening of weeds, and localization of seeds in the zone of active stimulation or long-term conservation (Nath *et al.,* 2022).

The study of the variability of weed seed bank indicators depending on crop rotation and tillage methods (namely, the establishment of the amplitude of oscillation in the arable layer in a rotary grid) allows us to determine the characteristics of variability and conservatism of the nature of weed seed bank. The research results show that the maximum value of weed seed bank in the arable layer has been observed at the beginning of spring fieldwork in the field of black fallow and barley spring, where its indicators were 449-499 million seeds per hectare. The regularity of such dynamics of weed seed bank is that the fields of black steam and spring barley are placed in crop rotation after row crops of sunflower and corn, which are sown at the end of the growing season and harvesting and contribute to the growth of weed seed bank (Table 2).

Table 2. *Influence of soil cultivation method and crop rotation on the weed seed bank, million pcs/ha (average for 2018-2021, x±SD, n=12)*

Crop rotation	Soil layer, cm	Soil tillage		
		moldboard plowing	disc tillage	no-tillage
Black fallow/fallow	0-10	60±5^{a}	187±8^{b}	231±9^{bc}
	0-30	320±9^{a}	388±9^{b}	449±10^{bc}
Wheat winter	0-10	42±3^{a}	85±6^{b}	98±8^{bc}
	0-30	180±9^{a}	242±8^{b}	248±9^{bc}
Sunflower	0-10	45±3^{a}	98±5^{b}	159±8^{c}
	0-30	301±9^{a}	335±9^{b}	391±9^{c}
Barley spring	0-10	72±5^{a}	210±8^{b}	245±8^{bc}
	0-30	368±9^{a}	399±9^{b}	499±10^{c}
Corn for grain	0-10	79±5^{a}	112±4^{b}	148±8^{c}
	0-30	299±9^{a}	354±6^{b}	385±9^{c}

Note: *different letters indicate the values significantly differing one from another within a line of Table 1 on the results of comparison using the Tukey test (P<0.05) with Bonferroni correction*
Source: *compiled by the authors*

The black fallow in the crop rotation has been characterized by a decrease in the degree of the weed seed bank in the winter wheat field by 202-253 million units/ha compared to no-till technology, where the weed seed bank in the crop rotation was maximum. The level of forecasting the degree of negative impact of weeds was the highest in row crops of corn and sunflower, which has been characterized by a high coefficient of realization of weed seed bank in the vegetative phase of weeds (the indicator of weed seed bank is 380-388 million units/ha). The study determined that the highest risk group included fields of black fallow and spring barley – 231-245 million units/ha in the 0-10 cm soil layer, while the lowest risk group included winter wheat crops – 98 million units/ha, and the middle position was occupied by corn and sunflower – 148-159 million units/ha.

An important element of the weed control system is the methods of basic tillage, along with effective regulation of weed infestation through crop rotation. The mechanisms of their influence on weed seed banks are based on the possibility of moving seeds between active and conservative soil layers and ensuring the quality of soil herbicide application. Moldboard ploughing is the most radical way to reduce weed infestation of crops in crop rotation by discharging weed seeds, primarily those that have fallen into the lower dead zone of arable land (Md-Akhir *et al.,* 2022).

As a result of such a migration algorithm of weed seeds in the upper soil layer under all crops, a minimum weed seed bank (41-80 million seeds/ha) has been formed against the background of moldboard ploughing. An increase in weed seed bank by 1.4-3.8 times has been recorded in the topsoil under disk tillage and no-till systems as a result of the concentration of weed seeds of the previous generation. Given that the circulation of weed seeds when implementing no-till methods of basic tillage occurs in a limited volume (0-10 cm), the dominant factor is not this circumstance, but the concentration of the reproductive resource of weeds in the upper layer of arable land. As a rule, this spatial distribution of weed seeds in the soil leads to an increase in active weed infestation against the background of minimized tillage by 1.7-2.3 times.

The regulatory ability of crop rotations and tillage to form weed seed banks is quite significant. For example, while the structure of winter wheat sowing on the background of moldboard ploughing contained 117 million seeds per hectare in the 0-30 cm layer, in the variant of spring barley with direct sowing (no-till), the weed seed bank has been increased to 499 million seeds per hectare. Despite the high cleaning efficiency of black fallow and the significant competitiveness of continuous crops, residual potential contamination always requires the use of herbicides to control weeds and prevent weed seeds from being seeded into the soil. The high biological adaptability of weeds to counteract negative factors allows them to continue to spread in the agroecosystem and remain integral components in the structure of crop rotations, despite the significant obstacles created by humans (use of agrotechnical, chemical, biological control measures, etc.).

The main source of the evolutionary aggressiveness of weeds is their extremely high reproductive capacity. There is no current and sufficient information about the diversity of weed seeds, the duration of the dormant period, stimulation of anabiosis, chemical methods of destroying their reserves, reactions to anaerobic conditions, etc. It is a scientifically proven fact that the main reserves of weeds are associated with agricultural lands, where they receive all the necessary environmental conditions for growth and development

(Schnee *et al.,* 2023). The visual stage of development of weed associations (active weed infestation) in different anthropogenic landscapes confirmed this conclusion. As can be seen (Table 3), the highest degree of weed infestation with weed seed forms has been observed on old arable lands, where it reached 85 units/m^2.

Table 3. *Features of the formation of weed phytocenoses on various technobiogenic land use objects, pcs/m^2 (average for 2018-2021, x±SD, n=12)*

Technobiogenic objects	Types of weeds			Total
	monocotyledons	dicotyledons	perennials	
Fallow lands	13±2^{ab}	17±2^{ab}	98±5^{c}	128±6^{d}
Arable lands SE"EF"Dnipro" IGC NAASU	24±3^{b}	62±4^{bc}	7±1^{a}	93±5^{c}
Farming state "Olympus-2012"	18±3^{b}	34±3^{b}	4±1^{a}	56±4^{bc}
Forest protection strips	8±1^{a}	7±1^{a}	15±2^{b}	30±3^{a}
Scientific stationary experiments IGC NAASU	20±3^{b}	37±3^{b}	5±1^{a}	62±4^{bc}
SRF ESC DSAEU	25±3^{b}	55±4^{bc}	5±1^{a}	85±5^{c}

Note: *different letters denote values that significantly differ from each other within a column of Table 1 according to the results of comparison according to the Tukey test (P<0.05) with the Bonferroni correction*
Source: *compiled by the authors*

In weed associations formed on natural pastures and perennial fallow lands and functioning through biological mechanisms without human agrotechnological involvement, the proportion of annual species decreased to 22-31 pcs/m^2. The perennial weeds that dominate the natural environment (98 plants/m^2) do not pose a threat of significant spread in agroecosystems due to their limited ecological diffusion. The dynamics of aboveground weeds in agroecosystems are subject to the laws of competition in the ecosystems of struggle and the level of efficiency of protective complexes. The most indicative relationship between total weed density and weed seed bank has been manifested in the black fallow field. During the growing season, 431 weeds per m^2 have been recorded in the fallow field on the background of ploughing, and under the no-till system, significantly more, up to 708 weeds per m^2, or 1.6 times (Table 4).

Table 4. *Formation of the degree of actual weediness of the crop rotation depending on the primary tillage, pcs/m^2 (average for 2018-2021, x±SD, n=8)*

Crop rotation	Soil tillage		
	moldboard plowing	disc tillage	no-tillage
Black fallow/fallow	431±4^{a}	607±5^{b}	708±6^{c}
Wheat winter	19±2^{a}	27±3^{ab}	43±4^{b}
Sunflower	34±3^{a}	50±4^{b}	78±5^{c}
Barley spring	29±3^{a}	125±5^{b}	292±6^{c}
Corn for grain	44±3^{a}	62±4^{b}	83±5^{c}

Note: *different letters indicate the values significantly differing one from another within a line of Table 1 on the results of comparison using the Tukey test (P<0.05) with Bonferroni correction*
Source: *compiled by the authors*

Soil clearing from weed seeds in the soil by black fallow and high competition in dense winter wheat crops contributed to a decrease in weed infestation in this crop to 18 units/m^2 in ploughing and up to 44 units/m^2 in direct sowing. The restraining nature of black fallow on the spread of weeds was also manifested in the crops of the next winter crop after wheat (sunflower), where the degree of weed infestation was in the range of 37-77 plants/m^2.

The threat of sunflower blight, a crop that can produce 150-220 thousand seedlings per hectare in next year's crops, is becoming more widespread. The effects of sunflower seeding alone are particularly noticeable against the background of moldboardless tillage methods. For example, in spring barley crops, the total number of weeds and sunflower residue on disk tillage and no-till has reached critical levels of 125-292 pcs/m^2. At the end of the crop rotation in the corn field, the weed infestation was high (44-83 plants/m^2) with a significant increase in moldboard tillage. In other words, crop rotation is an agrotechnical method of weed control through crop rotation and various methods of weed control (agrotechnical, chemical, biological).

Along with the quantitative characteristics of weed associations, the line of their evolution also goes through species transformations. As a result of

biological and technological selection, 3-5 species have become the dominant weeds in agroecosystems: *Ambrosia artemisiifolia* L., *Amaranthus retroflexus* L., *Chenopodium album* L., *Echinochloa crus-galli* L, *Setaria glauca* L., *Polygonum convolvulus* L. The share of these species in the crop rotation is 50-60%, and in row crops it reaches 80-85%.

In stationary experiments of scientific institutions, including the stationary experiment of the Institute of Cereals of the National Academy of Agrarian Sciences of Ukraine, a significant impact of total weed density and weed seed bank, methods of basic tillage, fertilizers and precursors on crop yields was determined. Thus, according to the research results, the yield of winter wheat, regardless of the tillage system in the crop rotation, was almost the same: ploughing – 5.88-6.15 t/ha, disc tillage – 5.93-6.28, no-tillage – 5.86-6.23 t/ha on different nutrition backgrounds (Table 5). The use of mineral fertilizers ($N_{24}P_{18}K_{18}$) on average for 4 years in plowing contributed to an additional 0.27, disc tillage – 0.35, no-tillage – 0.37 t/ha of grain. In terms of the impact on the yield of spring barley, the no-tillage system was inferior to disc tillage, depending on the fertilizer background, by 0.21-0.22 t/ha and ploughing by 0.19-0.40 t/ha.

Table 5. *The influence of the primary tillage and fertilization systems on the productivity of the crop rotation, t/ha (average for 2018-2021, x±SD, n=4)*

Crop sequence in the crop rotation	System of tillage and fertilization in the crop rotation					
	ploughing		disc tillage		no-tillage	
	post-harvest remains	post-harvest remains +$N_{24}P_{18}K_{18}$	post-harvest remains	post-harvest remains +$N_{24}P_{18}K_{18}$	post-harvest remains	post-harvest remains +$N_{24}P_{18}K_{18}$
Black fallow	-	-	-	-	-	-
Wheat winter	5.88±0.11^{a}	6.15±0.12^{b}	5.93±0.11^{a}	6.28±0.12^{b}	5.86±0.12^{a}	6.23±0.11^{b}
Sunflower	3.39±0.09^{a}	3.55±0.10^{b}	3.06±0.09^{ab}	3.25±0.10^{b}	2.62±0.09^{ab}	2.89±0.10^{b}
Barley spring	2.82±0.10^{a}	3.16±0.11^{b}	2.64±0.11^{ab}	3.10±0.09^{b}	2.42±0.09^{a}	2.82±0.09^{b}
Corn for grain	6.93±0.12^{a}	7.36±0.12^{b}	6.78±0.09^{a}	7.20±0.11^{b}	6.16±0.12^{a}	6.50±0.10^{b}

Note: *different letters indicate the values significantly differing one from another within a line of Table 1 on the results of comparison using the Tukey test (P<0.05) with Bonferroni correction*
Source: *compiled by the authors*

As for the effectiveness of mineral fertilizers for spring barley, an inverse relationship was observed in the experimental variants. The application of $N_{30}P_{30}K_{30}$ for pre-sowing cultivation with ploughing yielded 0.33, disc tillage – 0.46, and no-tillage – 0.47 t/ha of grain. Corn crops have formed yield indicators after ploughing in the range of 6.93-7.36 t/ha and 6.78-7.20 t/ha – under disc tillage. The use of no-tillage has resulted in a decrease in corn grain yield of 6.16-6.50 t/ha. The application of additional nitrogen on corn provided a slightly higher return on grain yield in the tillage system. This is due to the better moisture supply of plants and the normalization of the processes of mobilization of mobile compounds of macronutrients when a large amount of post-harvest plant residues is involved in the cycle. In sunflower crops, during the four years of research, a significant difference in different methods and systems of soil cultivation was noted (2.62-3.55 t/ha) with a tendency to increase yields from no-tillage to ploughing the soil. The yield of field crops generally determined the productivity of the five-field grain-steam-tilled crop rotation, which depended mainly on the dose of mineral fertilizers and the soil tillage system.

The analysis of the results of research on the study of the weed seed bank in the soil has shown that the parameters of this indicator on different soils are characterized by significant dispersion and therefore the interpretation of the degree of weediness by the number of seeds in the soil requires the most adequate methods. In the experiments of O.O. Ivashchenko and S.O. Remenyuk (2019), the results show a significant increase in the total reserves of weed seeds of various species in the soil layer of 0-10 cm in the Steppe zone and amount to 570 million units/ha. Objective data on weed seed reserves in the soil are given in the presented article, where this number does not exceed 6 million units/ha on fallow lands to 133 million units/ha in different agroecosystems. However, it is undeniable that significant yield losses will always occur, both at 133 million units/ha and 570 million units/ha. Therefore, as can be seen from the analysis, under any circumstances, reducing the cost of weed control systems for crops is possible primarily by reducing the amount of weed seeds in the topsoil.

When assessing the herbological situation of agrophytocenosis under different predecessors in the experiments of L.V. Peleh (2019), the species composition of weeds depended on the predecessor culture and the allopathic profile of crop plants in the crop rotation. In total, 36 species of weeds from 22 genera were identified. However, our results of research on the impact of crop rotation and individual crops on the species

composition of weed agrocenosis show that in this case, it is also important to address the most harmful group of weeds, the presence of which in crops primarily affects the level of lost yield. In this case, the most harmful group includes 3-5 species of weeds such as *Ambrosia artemisiifolia* L., *Amaranthus retroflexus* L., *Chenopodium album* L., *Echinochloa crus-galli* L., *Setaria glauca* L., *Polygonum convolvulus* L. It is also necessary to consider that, along with crops, the degree and type of weediness are actively influenced by the main soil cultivation and the use of organic and mineral fertilizers.

In the field experiments of N.V. Gytsyuk *et al.* (2022), in a long-term stationary experiment, it was found that the species composition of weed synopsis in crops of crop rotation did not show a significant pattern of its formation and did not depend on the fertilizer system. It was determined that the quantitative changes in weed infestation of crops primarily occurred under the influence of crop cultivation and were less dependent on the use of mineral and organic fertilizers. However, the authors unfairly do not consider the influence of fertilizers on the formation of the degree of weed infestation due to the growth of crop competitiveness and energy density of crops.

The fundamental issues of the dynamics of the weed seed bank in the soil, depending on deep ploughing, minimal and zero tillage using a cover mulch layer, are considered by J.G. Lundgren *et al.* (2023), and M. Akhter *et al.* (2023) who remains on the scientific position of the significant role of seed distribution in the vertical soil profile. However, the author does not consider what additional agricultural practices are included in the complex of ploughing and no-till and provide the advantage of the traditional system of soil loosening. According to the results of research by M.-J. Simard *et al.* (2022) and S. Ghosh *et al.* (2023), tillage methods that inhibit the germination of weed seeds and their negative impact on the yield of cereals and legumes play a significant role in the formation of a weed seed bank and increase the yield of cereals and legumes. However, the authors do not fully disclose the mechanisms of weed control, which generally creates a contradiction between the positive assessment of no-till and the conclusions presented in this article that no-till is accompanied by an increase in weeds and a complication of the system of their chemical control.

The discussion on the effectiveness of various weed control systems convincingly confirmed the significant progress of modern technologies and the achievement of high efficiency in reducing crop losses, but at the same time highlighted new problems related to determining the role of such factors in the formation of weed agrocenoses as crop rotation, energy density of individual crops, the dynamics of the location of weed seed reserves in the soil profile, the role of the mulch layer and methods of controlling weed damage.

CONCLUSIONS

The density and species structure of weed associations largely depend on the anthropogenic impact and the nature of land use under which they are formed. It has been established that the main reason for the high negative impact of weeds is the weed seed bank of soils, which reaches 452 million seeds per hectare in land being actively used for agriculture and 11 million hectares in natural ecosystems. The decisive factor for effective regulation of weed seed banks in agriculture ecosystems is the sustainability of crops (as part of an ecosystem dominated by 1 plant species), methods of basic tillage and measures to prevent the generative productivity of weeds.

According to the impact on the yield of winter wheat, corn, sunflower and spring barley, different tillage systems (ploughing, disc tillage, no-tillage) in the crop rotation were significant, where the no-tillage system was inferior to disc tillage, depending on the fertilization background, by 0.21-0.22 t/ha and ploughing – by 0.19-0.40 t/ha due to increased weed infestation of crops, as well as the presence of a significant amount of carrion and leaf mass of the predecessor on the field surface.

Stabilization of farming systems by such characteristics as specialized short-rotation crop rotations, regular differentiation of the ploughing tillage, reduction of risks of fertility loss based on conservation methods and minimization of mechanical impact on the soil will allow for consolidation of a stable agrocoenotic composition of weeds in areas with different specialization of use, to most accurately reflect the relationship between the spectrum of phytotoxic effects of herbicides and weed resistance. The obtained research results open up broad prospects for new scientific developments of crop rotation systems, optimization of the structure of sown areas, resource-saving tillage, environmentally friendly weed control, and effective monitoring and forecasting of agrophytocenoses.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Оцінка загальної щільності забур'яненості та банку насіння бур'янів агроландшафтів на прикладі степової зони України

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Анотація. Високий ступінь забур'яненості агроекосистем становить значну загрозу для отримання високих врожаїв сільськогосподарських культур, тому проблема боротьби з бур'янами є однією з найактуальніших у степовому землеробстві. Метою даного дослідження було оцінити рівень загальної щільності бур'янів та насіннєвого фонду різних компонентів агроекосистем степової зони України. Для визначення видового складу бур'янів, їх кількісно-вагового обліку та шкодочинності використовували статистичні та математичні методи. Встановлено, що основною причиною високого негативного впливу бур'янів є забур'яненість ґрунтів, яка досягає 452 млн. насінин на гектар на землях, що активно використовуються в сільському господарстві, та 11 млн. га в природних екосистемах. В агроекосистемах вирішальним фактором ефективного регулювання насіннєвого банку бур'янів є стійкість посівів (як частини екосистеми з домінуванням 1 виду рослин), способи основного обробітку ґрунту та заходи щодо запобігання генеративної продуктивності бур'янів. За впливом на врожайність пшениці озимої, кукурудзи, соняшнику та ячменю ярого різні системи обробітку ґрунту (оранка, дисковий обробіток, безполицевий) у сівозміні були суттєвими, де система безполицевого обробітку поступалася дисковому, залежно від фону удобрення, на 0,21-0,22 т/га, а оранка – на 0,19-0,40 т/га, що зумовлено підвищеною забур'яненістю посівів, а також наявністю значної кількості падалиці та листкової маси попередника на поверхні поля. Практична цінність полягає в удосконаленні системи контролю бур'янів у сівозмінах адаптивного землеробства та екологічної безпеки

Ключові слова: агроекосистеми; бур'ян; сівозміна; обробіток ґрунту; урожайність; продуктивність

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Biometric parameters and yield of maize hybrids in dependence on agricultural technology elements

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Abstract. Modern innovative corn hybrids of the intensive type have a significant individual response of morphometric and photosynthetic indicators to the density of the coenosis. Establishing correlations of these indicators with the level of grain yield of different genotypes of corn hybrids and determining the optimal parameters for the manifestation of these characteristics allows technological measures to ensure the realization of productive potential. The purpose of the research was to establish the peculiarities of the formation of biometric and photosynthetic indicators of innovative

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corn hybrids depending on the genotype, and the density of the coenosis, and to determine the correlation-regression dependence of these characteristics. Field experiments were conducted during 2019-2021 in the agroecological zone of the Central Forest Steppe. The soil of the experimental site is typical chernozem, the precursor is soybean. With the help of field, morphometric, laboratory, and statistical (dispersion and correlation analysis) it was established that the height of the plant, the height of attachment of the upper (productive) cob, the area of the assimilation surface of one plant, and the photosynthetic potential depended on the studied factors – the genotype of the hybrid and the density of the coenosis. A medium and strong positive correlation was established between productivity and these characteristics, which indicates the need to technologically ensure optimal plant growth and development at various stages of the development of corn plants of all hybrids. The mid-ripe hybrid Zedan 32 (FAO 320) showed maximum productivity at a density of 80,000 plants/ha and sharply reduced productivity at a density of up to 100,000 plants/ha. Mid-early hybrids showed maximum yield at a density of 90,000 plants/ha, while an increase or decrease in plant density from the optimum led to a decrease in grain yield. Therefore, each hybrid has its optimal coenosis density for obtaining the maximum grain yield, and increasing the photosynthetic potential of crops by agrotechnical measures does not always guarantee a parallel increase in the grain yield of corn hybrids

Keywords: corn; plant height; height of the upper (productive) cob; assimilation surface area; photosynthetic potential; grain yield

INTRODUCTION

Experts of the United States Department of Agriculture (USDA, n.d.) significantly increased the projections for global corn production in 2023-2024 to 1224.47 million tonnes, i.e. by 1.7 million tonnes, and in Ukraine - to 25 million tonnes, i.e. by 0.25 million tonnes. Along with the production, the level of its use will also increase by 0.3 million tonnes (to 1206.65 million tonnes), as well as the volume of grain exports and global ending stocks. Experts believe that this trend will be manifested against the background of increased imports caused by the decline in world prices. These data show the importance of corn as an agricultural crop and the expediency of intensifying its production through the introduction of new competitive hybrids and elements of their cultivation technologies.

J. Cairns & B. Prasanna (2018) proved the difficulty of accurate and timely identification of adapted maize forms for different ecogradients of cultivation. At the same time, long-term ecological studies are a proven method of assessing such adaptive forms, because the contrast in environmental conditions over the years is so enormous that in many cases the impact of weather conditions on yield is stronger than the effect of zonal climatic differences. However, long-term studies by J. Zhao *et al.* (2018) show that the way of testing the environmental gradient formed by agrotechnical measures is more reliable. Thus, testing of the material under non-irrigated growing conditions, under different irrigation regimes and types, and in different plant densities provides very diverse environmental backgrounds, which makes it possible to determine the range of possible impact of the agroclimatic conditions of the region on plant growth and development.

N. Shevchenko & L. Yakovets (2021) believe that the correct selection of hybrids, as an effective factor in the use of their genetic potential, plays an important role in increasing the gross grain yield of this crop. The maximum result can be achieved by considering the biological requirements of the hybrid to the proposed cultivation technology, including sowing seeds of high reproductions, placement according to the best predecessors, sowing dates, plant density, plant nutrition system and protection against diseases and pests.

To obtain sustainable and high yields of any crop, according to H. Hussain *et al.* (2019), a detailed study of the agroclimatic conditions of its cultivation in a certain area is required for more rational use and optimal placement of crops, and this issue is of particular importance in connection with global and local climate change. R. Vozhehova *et al.* (2022) demonstrated that the maximum seed yield of early maturing lines was obtained at a density of 90 thousand plants/ha, medium-early inbred lines showed the highest seed yield at a sowing density of 80 thousand plants/ha, and the mid-season group – at a coenosis density of 70 thousand plants/ha. K. Djaman *et al.* (2018) conducted experiments to study the results of the effect of plant density of hybrids on the growth and development of maize of different maturity groups and proved that early maturing hybrids with an increase in the density of coenosis from 60 to 100 thousand plants/ha increased plant height by 11-17 cm. At the same time, the diameter of the stem decreased by 0.20 cm, and the leaf surface area also decreased.

A. Mastrodomenico *et al.* (2018), on the contrary, insist that when coenosis is thickened, especially in favourable years of rainfall, although the productivity of one plant decreases, the number of productive plants per unit area increases significantly, which leads to an increase in yield for hybrids of all FAO groups. In sparse crops, despite the possibility of obtaining the high productivity of one plant, without sufficient coenosis density, there is

no increase in total yield. Analysis of the results obtained by V. Bahatchenko *et al.* (2018) shows a close relationship between the density of coenosis and grain moisture. It was proved that with an increase in plant density, the moisture content of maize grain predictably increases. The driest grain was found at a planting density of 75 thousand plants/ha in simple hybrids, in self-pollinated lines at a density of 85 thousand plants/ha, and the wettest at planting densities of 95 and 105 thousand plants/ha, respectively. Among the lines – parental components, the maximum grain yield per cob was obtained by early maturing lines with a planting density of 85 thousand plants/ha (82.8%). In the medium-early and mid-season lines, the maximum grain yield was obtained with a sowing density of 105 thousand plants/ha, the grain yield was 82.8 and 76.6%, respectively.

According to the yield data obtained by H. Zhemela *et al.* (2021), the optimal plant density of maize hybrids for early maturing hybrids is 75 thousand plants/ha, medium early hybrids – 70 thousand plants/ha, and mid-season hybrids – 65 thousand plants/ha. Research institutions in Canada, Mexico, China, Germany, and other countries recommend sowing corn hybrids with a planting density of 70-100 thousand plants/ha under optimal moisture conditions and increased rates of basic nutrients (NPK), which provides a leaf area index of 5.5 and the highest increase in dry matter (García-Martínez *et al.*, 2020; Li *et al.*, 2022; Veenstra *et al.*, 2023).

Due to climate change and the introduction of new hybrids, it is becoming important to determine the optimal sowing density for a sustainable harvest and increased production profitability. That is why the study aimed to determine the specific characteristics of the formation of biometric and photosynthetic parameters of innovative maize hybrids, depending on their genetic characteristics and sowing density, as well as to establish the relationship between these traits using correlation and regression analysis.

MATERIALS AND METHODS

The field experiments were conducted during 2019-2021 in the agricultural production cooperative "Peremoha" (Klepachi village, Khorol district, Poltava region) in the Central Forest-Steppe climate zone. When planning the experiment scheme, the principle of "single difference" was observed, as well as the range of gradations of the experiment factors, which allows to establish the optimal parameters of the influence of each factor. A two-factor experiment was set up: factor A – Ukrainian hybrids: Zedan 26 (FAO 240), Zedan 28 (FAO 260) and Zedan 32 (FAO 320). Factor B: corn plant density of 70, 80, 90, 100 thousand plants/ha. The experiment was replicated four times with variants placed in space using the randomised block design. The area of the sown plots was 70 m^2, and the accounting area was 50 m^2.

Biometric measurements were carried out during the growing season. The height of hybrid plants, the height of attachment of the upper (productive) cob, the growth of leaf surface area, and the photosynthetic potential of maize hybrids were determined. The plant density in the crop was measured at the 3-5 leaf stage separately in each variant of the experimental plot. After that, the artificial formation of plant density was carried out according to the scheme of the experiment. Before harvesting, plants were counted again in all variants (in 4 replications).

The grain yield was measured at the stage of full grain ripeness (manually from each plot of the experiment). The harvesting moisture content of maize grain, grain yield from the cob harvest and the yield of conditioned grain (at 14% grain) were determined in samples of cobs (30 pieces), which were taken separately at harvesting on each replication of the experiment. The grain yield of maize hybrids was converted to 14% moisture content. The research was conducted on soils typical for the climatic zone (typical chernozem). Agronomic practices for growing maize hybrids in the research were used by the recommendations for the Central Forest-Steppe zone of Ukraine, except for the variants under study. The predecessor under maize was soybean, and ammonium nitrate was applied at 500 kg/ha for spring cultivation. Weather conditions were typical for the Central Forest-Steppe zone of Ukraine. The research was conducted according to the field experiment methodology, and the statistical processing of the research results was carried out based on the results of biometric and weight measurements by the method of analysis of variance and correlation using the Agrostat software (Ushkarenko *et al.*, 2009; Ushkarenko *et al.*, 2014).

The following hybrids of Ukrainian breeding, listed in the State Register of Plant Varieties Suitable for Distribution in Ukraine, were used in the study: Zedan 26, Zedan 28, Zedan 32. (Bulletin, 2022; State register of plant varieties suitable for distribution in Ukraine, 2023).

Table 1. *Hybrids used in the research*

Hybrid	State registration certificate	Holder of property rights
Zedan 26	State Registration Certificate No. 221030, Application No. 21009008 dated 14.01.2021.	Skakun V.M., Skakun O.O., Vozhehova L.S., Vlashchuk O.A.
Zedan 28	State Registration Certificate No. 221029, Application No. 21009007 dated 14.01.2021.	Skakun V.M., Skakun O.O., Vozhehova L.S., Vlashchuk O.A.
Zedan 32	State Registration Certificate No. 221028, Application No. 21009006 dated 14.01.2021.	Skakun V.M., Skakun O.O., Vozhehova L.S., Vlashchuk O.A.

Experimental studies of plants, including the collection of plant material, complied 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

Plant height is one of the most important biometric indicators of maize growth and development. Depending on agronomic practices and weather and climatic conditions, this indicator can vary significantly. In the studies conducted, it largely depended on both the hybrid genotype and the plant density in the crop (Table 2).

Table 2. *Plant height of maize hybrids of different FAO groups in the flowering phase depending on the factors of the experiment, cm (average for 2019-2021)*

Corn hybrid (Factor A)	Plant density of corn hybrids, thousands of plants per hectare (Factor B)				On average by factor A
	70	80	90	100	
Zedan 26 (FAO 240)	245.1	251.8	253.6	254.9	251.4
Zedan 28 (FAO 260)	266.3	267.5	272.7	273.9	270.1
Zedan 32 (FAO 320)	276.9	279.6	287.6	288.4	283.1
On average per factor B	256.1	259.6	264.6	265.7	
Assessing the materiality of partial differences					
HIP_{05}, cm	A = 12.9; B = 8.8				

Source: *compiled by the authors*

The genotype of the hybrid influenced the height of the plants, the highest values of which averaged 283.1 cm in the mid-season hybrid Zedan 32 (FAO 320). The lowest height was in the mid-early hybrid Zedan 26 (FAO 240) and was 245.4 cm. This is due to both the duration of the growing season and the morphological features of the hybrids' habitus. The increase in plant height from thickening the coenosis from 70 to 100 thousand plants/ha was 11.5 cm or 4.2%. The maximum plant height of 288.4 cm was observed in the maize hybrid Zedan 32 (FAO 320) at a density of 100 thousand plants/ha.

The minimum height of cob attachment was characterised by the mid-early maize hybrid Zedan 26 (FAO 240). On average, over three years, the height of earing in the mid-early maize hybrids Zedan 26 and Zedan 28 was 97.6 and 108.8 cm, respectively, and in the mid-season hybrid Zedan 32 – 113.6 cm, i.e., an increase in the length of the growing season is accompanied by a higher level of earing (Table 3).

Table 3*. The height of attachment of the upper (developed) ear of maize hybrids depending on the factors of the experiment, cm (average for 2019-2021)*

Corn hybrid (factor A)	Corn density, thousand plants/ha (factor B)				On average by factor A
	70	80	90	100	
Zedan 26 (FAO 240)	96.1	96.5	98.1	99.6	97.6
Zedan 28 (FAO 260)	107.3	108.6	109.2	110.1	108.8
Zedan 32 (FAO 320)	111.2	113.5	114.7	114.9	113.6
On average per factor B	107.5	108.5	109.7	110.5	
Assessing the materiality of partial differences					
HIP_{05}, cm	A = 4.8; B = 3.5				

Source: *compiled by the authors*

Having analysed the influence of plant density on the height of heading in hybrids, it is necessary to point out the tendency to increase the height during the thickening of the sowing. Thus, the height of the cobs at a density of 70 thousand plants/ha was in the range of 96.1-111.2 cm, at a density of 80 thousand plants/ha – 96.5-113.5 cm, at a density of 90 thousand plants/ha – 98.1-114.7 cm, at a density of 100 thousand plants/ha – 99.6-114.9 cm. The mid-season maize hybrid Zedan 32 showed the highest value of the height of the cobs per plant at a density of 100 thousand plants/ha – 114.9 cm.

When optimising production processes and maximising crop yields, the size of the plant's assimilation apparatus plays a key role, as it accumulates solar radiation during the photosynthetic process and converts it into organic matter. The productivity of photosynthesis is strongly related to the area of plant leaves, which can be regulated by the crop sowing structure, so one of the effective opportunities for more complete use of photosynthetically active solar radiation is to create conditions by agrotechnical measures for accelerated development of the leaf apparatus at the beginning of

the growing season by using factors of photosynthesis intensification, in particular, establishing the optimal density of coenosis (Polyakov & Karpuk, 2020; Asanashvili, 2020).

Based on the modern theoretical vision of the mechanism of functioning and interrelationships of the donor-acceptor system in a plant, it is possible to ensure an enhanced production process by changing the morphological and physiological parameters of the crop, namely by creating a powerful photosynthetic surface of the plant and prolonging the duration of the photosynthetic apparatus. Over the years of research and comparative evaluation of hybrids, it turned out that the hybrid Zedan 32 showed consistently higher performance, with the area of the assimilation surface of one plant ranging on average from 0.461 m^2/plant at a density of 100 thousand plants/ha to 0.498 m^2/plant at a density of 70 thousand plants/ha (Table 4).

Table 4. *Effect of coenosis density on the assimilation area of one maize plant in the flowering phase depending on the factors of the experiment, m^2/plant (average for 2019-2021)*

Corn hybrid (factor A)	Corn density, thousand plants/ha (factor B)				On average by factor A
	70	80	90	100	
Zedan 26 (FAO 240)	0.413	0.402	0.388	0.375	0.3945
Zedan 28 (FAO 260)	0.426	0.421	0.415	0.395	0.4143
Zedan 32 (FAO 320)	0.498	0.481	0.472	0.461	0.4780
On average per factor B	0.446	0.435	0.425	0.410	
Assessing the materiality of partial differences					
HIP_{05}, m^2/plant	A = 0.021; B = 0.018				

Source: *calculated by the authors*

Zedan 28 hybrid had the lowest assimilative surface area – from 0.395 to 0.426 m^2/plant, and with increasing plant density, the assimilative surface area became even lower. The minimum leaf area per plant in the experiment was formed by the hybrid Zedan 26 – from 0.375 (at a density of 100 thousand plants/ha) to 0.413 m^2/plant (at a density of 70 thousand plants/ha). It should also be noted that the maximum area of the assimilation surface of one plant was recorded for all maize hybrids at a plant density of 70 thousand plants. At the same time, researchers H.M. Kaletnyk *et al.* (2021) observed that increasing the leaf surface area of plants is not always beneficial, because, in the case of thickening of the coenosis, the lower tier of plant leaves is shaded by the upper one, which leads to a deterioration in the illumination of the array and a decrease in the intensity of photosynthesis in general.

One of the most pressing issues in agricultural science is to increase the productivity of plant photosynthesis, which is the basis for crop yields. Corn grain yields, like those of other crops, are entirely determined by the active work of the photosynthetic apparatus. Photosynthesis is a source of organic matter formation and accumulation by plants, which indicates the great importance of photosynthesis in the formation of yield and accumulation of dry matter in the plant (Tan *et al.*, 2021). The photosynthetic potential of maize hybrids increased with the lengthening of the growing season and showed the maximum performance in the mid-season hybrid Zedan 32 – an average of 2111.6 thousand m^2*day (Table 5).

Table 5. *The photosynthetic potential of maize hybrids depending on the factors of the experiment, thousand m^2*day (average for 2019-2021)*

Corn hybrid (factor A)	Corn plant density thousand plants/ha (factor B)				On average by factor A
	70	80	90	100	
Zedan 26 (FAO 240)	1589.1	1606.2	1747.2	1873.9	1704.1
Zedan 28 (FAO 260)	1713.4	1682.3	1866.3	1974.7	1809.2
Zedan 32 (FAO 320)	2092.5	1925.4	2123.7	2304.9	2111.6
On average per factor B	1798.3	1738.0	1912.4	2051.2	
Assessing the materiality of partial differences					
HIP_{05}, thousand m^2*days	A = 90.4; B = 122.9				

Source: *compiled by the authors*

The highest photosynthetic potential of maize hybrids of all FAO groups was found at coenosis thickening up to 100 thousand plants/ha – from 1873.9 thousand m^2*day in Zedan 26 hybrid to 2304.9 thousand m^2*day in Zedan 32 hybrid. The analysis of the influence of traits on grain yield of maize hybrids

showed that there is a medium and strong positive correlation between yield and all studied traits (Table 6). This indicates that at different stages of maize plant development of all hybrids, it is necessary to ensure optimal growth and development of plants technologically.

Table 6. *Correlation between traits and yield of maize hybrids of different FAO groups (r)*

Corn hybrid	Characteristics			
	Plant height	Attachment height of the upper (productive) head	Assimilation surface area	Photosynthetic potential
Zedan 26	0.651*	0.460*	0.778*	0.756*
Zedan 28	0.714*	0.531*	0.841*	0.836*
Zedan 32	0.727*	0.645*	0.945*	0.977*

Note. ** - statistical significance at 0.05*
Source: *calculated by the authors*

A positive correlation coefficient indicates the influence of photosynthetic potential on yield, but there was a decrease in yield with an increase in photosynthetic potential from 2100.0 thousand m^2*day, i.e., an increase in the photosynthetic potential of maize crops utilizing agricultural technology does not always lead to a parallel increase in yield in hybrids, so for each maize hybrid, depending on genotypic characteristics, there should be an optimum plant density that ensures maximum efficiency of photosynthetic potential productivity. It has been determined that hybrids of different FAO groups have their optimal plant density to achieve the highest yield of maize grain (Fig. 1).

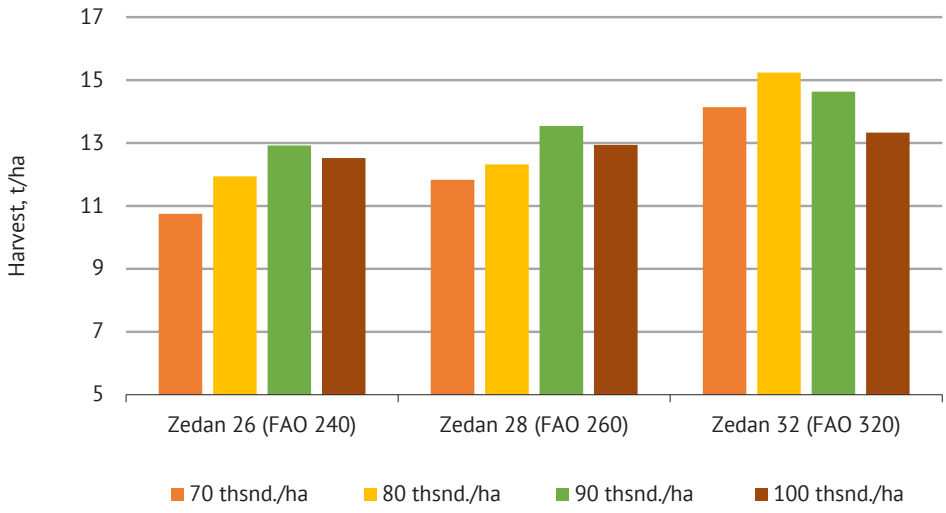

Figure 1. *Dependence of maize grain yield of hybrids of different FAO groups on plant density*
Source: *compiled by the authors*

The mid-early hybrid Zedan 26 (FAO 240) showed a maximum grain yield of 12.92 t/ha at a coenosis density of 90 thousand plants/ha. Reducing the plant density to 80 thousand plants/ha led to a drop in grain yield by 0.98 t/ha, or 7.8%, further thinning of the crop to 70 thousand plants/ha led to a decrease in grain yield by 2.17 t/ha, or 17.1%, Thickening of the crop to 100 thousand plants/ha caused a decrease in yield by 0.40 t/ha or 3.2%. The hybrid of the mid-early group Zedan 28 (FAO 260) showed the highest grain yield of 13.54 t/ha at a plant density of 90 thousand plants/ha. Reducing the density of coenosis to 80 thousand plants/ha led to a decrease in yield by 1.22 t/ha, or 8.9%, and thinning of coenosis to 70 thousand plants/ha caused a drop in grain yield by 1.71 t/ha, or 12.6% while thickening of coenosis to 100 thousand plants/ha led to a decrease in yield by 0.60 t/ha, or 4.5%.

The hybrid of the medium-ripening group Zedan 32 (FAO 320) showed the maximum grain yield of 15.24 t/ha (the highest indicator in the experiment among other genotypes) at a density of 80 thousand plants/ha. A further decrease in plant density to 70 thousand plants/ha caused a drop in yield by 1.10 t/ha, or 7.3%, and an increase in coenosis density to 90 thousand plants/ha affected the reduction of corn grain yield by 0.61 t/ha or 3.9%, and a thickening of the crop to 100 thousand plants/ha caused a sharp decrease in yield by 1.91 t/ha or 12.5%.

It is worth noting that the established patterns of influence of coenosis density on the yield of new Ukrainian maize hybrids are not sufficient, and this issue requires further scientific research. According to the results of our research, a significant increase in corn grain yield depends on the FAO group and plant density. This is consistent with the findings of other researchers, in particular, S. Kalenska and V. Taran (2018) showed that intensive maize hybrids are capable of producing high grain yields at plant densities of 90 thousand plants/ha by increasing the survival of individuals during the growing season, and moisture supply is the main limiting factor for obtaining high grain yields in the Right-Bank Forest-Steppe of Ukraine.

According to R. Vozhehova *et al.* (2021), dry matter increased with increasing coenosis density from 50 to 80 thousand plants/ha. The scientists concluded that maize hybrids with a longer growing season form more crude aboveground mass and dry matter than early maturing maize hybrids. In the studies of S. Anjum *et al.* (2017), it was also proved that for early maturing hybrids under irrigation, the optimal planting density is 90 thousand plants/ha, and it is recommended to reduce the density to 70 thousand plants/ha for mid-season maize hybrids, i.e., to apply a differentiated approach to the seeding rate of different genotypes. Z. Glupak and A. Butenko (2022) also concluded that in northern Ukraine (Chernihiv region), corn yields depended on the maturity group of the hybrid and plant density. For earlier maturing FAO 300-320 hybrids, the best density was 90-80 thousand plants/ha, with a yield of 10.7-10.4 t/ha. For hybrids FAO 360-380, the best density was 80 thousand plants/ha, which yielded a yield of 10.9-11.1 t/ha.

S. Kalenska and V. Taran (2018) noted that Ukrainian breeders have created and offered producers several new maize hybrids, but all of them have different morphological-biological features and characteristics, tolerance to favourable and unfavourable environmental factors, which requires differentiated selection of hybrids with increased yield and grain quality. current research has confirmed the multidirectional response of innovative Ukrainian hybrids to technology elements, which makes the development of varietal technologies for each genotype relevant.

V. Petrychenko *et al.* (2018) emphasise the relevance of the issue of increasing the adaptive potential of new maize hybrids, as the priorities of the morphological-biological type models themselves change, depending on the FAO group. These issues are becoming increasingly important in the context of insufficient technological support for the process of growing and harvesting corn, which is a consequence of the steady rise in energy prices, and the lack of parity in prices for agricultural products and fossil fuels. Given the above, it is difficult to overestimate the role of high-yielding corn hybrids with a wide adaptive potential to growing conditions and increasing the profitability of agricultural production. The results of these studies coincide with the conclusions of the above-mentioned scientists that the FAO maize hybrid group and its adaptive potential are important for providing effective recommendations for production when introducing innovative varietal technologies. This area of research should be implemented in each agricultural-ecological zone, which will increase the economic performance of production.

S. Meseka *et al.* (2018) show that to obtain consistently high yields of maize grain, it is necessary to grow hybrids with different types of response to changing environmental conditions, in particular, intensive type hybrids with optimised growing technologies – to obtain high yields in unlimited conditions, homeostatic – to ensure the predicted grain yield on stressful backgrounds, and finally, medium-plastic – to obtain stable yields of maize grain in fields with unstable agrophysical conditions. In the current research, maize hybrids with different rates of response to technology elements were used, which coincides with the results and conclusions of S. Meseka *et al.* (2018) regarding the need to use varieties with different responses to ecogradients in agricultural production.

Thus, according to the results of the conducted research, a significant increase in maize grain yield depends on the FAO group and elements of plant density technology, which is consistent with the data of other researchers. However, it is worth noting that the established patterns of influence of coenosis density on the yield of new Ukrainian maize hybrids are not sufficient, and this issue requires further research.

CONCLUSIONS

Phenotypic realisation of the genotypic potential of modern innovative maize hybrids of Ukrainian selection depends on the optimisation of technological measures of cultivation. The correlation of quantitative biometric traits in maize hybrids of different FAO groups with grain yield was established. A high dependence of plant height (r=0.651-0.727), height of productive cob attachment (r=0.460-0.645), area of plant assimilation surface (r=0.778-0.945), photosynthetic potential (r=0.756-0.977) with grain yield of maize hybrids of different maturity groups was established. The greatest dependence of grain yield of hybrids was recorded with the area of the assimilation surface of plants and photosynthetic potential. The coenosis density of the hybrid can regulate biometric parameters and influence the level of grain yield. The optimal plant density in corn hybrids depends on the intensity level of the hybrid and the FAO group. The intensive type of hybrid Zedan 32 sharply loses grain yields when thickened from 15 to 13 t/ha. The moderately intensive maize hybrid Zedan 28 reduces grain yields during thinning from 90,000 plants/ha to 70,000 plants/ha by 1-1.3 t/ha. The corn hybrid with the lowest yield potential, Zedan 26, reduces

grain yields when thinned from 90,000 plants/ha to 70,000 plants/ha from 13 to 10.8 t/ha.

It has been established that modern innovative hybrids of maize of Ukrainian selection in the conditions of the Central Forest-Steppe agroecological zone can form grain yields in the range of 13-15 t/ha. The realisation of the genetic potential of hybrids depends on the improvement of technological measures during cultivation. The optimal coenosis density of corn depends on the intensity level and FAO group. To increase the yield level of the hybrid, the priority indicators should be the area of the assimilation surface of plants and photosynthetic potential, which are adjusted at a high level by the density of crop coenosis, but increasing the photosynthetic potential of maize hybrids by increasing plant density has certain limitations, which may not always lead to a parallel increase in grain yield in hybrids of different FAO groups.

The development of varietal technologies for growing modern maize hybrids should be a necessary component of the introduction of breeding developments into production. A promising area for further research may be to determine the response of maize hybrids of different intensity levels and FAO groups to the level of macro- and microelements and growth-regulating elements. Given the trend towards climate change, it is necessary to consider the response of maize hybrids to early sowing to ensure fuller use of the bioclimatic potential and disclosure of the phenotypic realisation of the genotypic potential.

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CONFLICT OF INTEREST

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Біометричні показники та урожайність гібридів кукурудзи залежно від елементів агротехнології

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Анотація. Сучасні інноваційні гібриди кукурудзи інтенсивного типу мають істотну індивідуальну реакцію морфометричних та фотосинтетичних показників на щільність ценозу. Встановлення кореляцій цих показників з рівнем урожайності зерна різних генотипів гібридів кукурудзи та визначення оптимальних параметрів прояву цих ознак дозволяє технологічними заходами забезпечити реалізацію продуктивного потенціалу. Метою досліджень було встановити особливості формування біометричних та фотосинтетичних показників інноваційних гібридів кукурудзи залежно від генотипу, щільності ценозу та визначити кореляційно-регресійні залежності даних ознак. Польові експерименти проводили протягом 2019-2021 років в агроекологічній зоні Центральний Лісостеп. Ґрунт дослідної ділянки – чорнозем типовий, попередник – соя. За допомогою польових, морфометричних, лабораторних, статистичних (дисперсійний та кореляційний аналіз) встановлено, що висота рослини, висота прикріплення верхнього (продуктивного) качану, площа асиміляційної поверхні однієї рослини, фотосинтетичний потенціал залежать від досліджуваних факторів – генотипу гібриду та щільності ценозу. Встановлено середню та сильну позитивну кореляцію між урожайністю та даними ознаками, що свідчить про необхідність на різних етапах розвитку рослин кукурудзи усіх гібридів технологічно забезпечувати оптимальний ріст і розвиток рослин. Середньостиглий гібрид Зедан 32 (ФАО 320) показав максимальну урожайність при густоти 80 тис. рослин на гектарі та різко знижував врожайність при загущеності посівів до 100 тис. рослин/га. Середньоранні гібриди найбільшу врожайності показали за густоти стояння 90 тисяч рослин/га, збільшення ж або зменшення густоти рослин від оптимальної призводили до зменшення врожаю зерна. Встановлена індивідуальна фенотипова реакція новостворених гібридів на щільність ценозу, що дозволило розкрити генотиповий потенціал та надати рекомендації практичному агровиробництву для підвищення урожайності кукурудзи. Встановлена оптимальна щільність ценозу, що дозволяє отримувати урожайність зерна гібридів кукурудзи ФАО 240-320 в умовах Центрального Лісостепу в межах 13-15 т/га. Гібриди впроваджуються в господарствах різних форм власності Полтавської області

Ключові слова: висота рослини; висота верхнього (продуктивного) качана; площа асиміляційної поверхні; фотосинтетичний потенціал; урожайність зерна

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Productivity of soybean varieties of different maturity groups depending on plant density under drip irrigation in the South of Ukraine

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Abstract. Soybeans are a leading leguminous crop for universal use, therefore, measures aimed at increasing their productivity, including the reasonable selection of varietal resources and optimisation of planting density, will make a significant contribution to the creation of sustainable food production systems. The research aims to determine the effect of plant density on the productivity of soybean varieties of different maturity groups. Field laboratory and statistical (correlation and regression analysis) methods were used in the study. The field experiments were conducted during 2018-2020 on dark chestnut soil of a private agricultural enterprise of the agricultural company "Syvash" in Novotroitsk district of Kherson region. Its maximum values for the cultivation of early ripening varieties were ensured by a plant density of 700 thousand/ha, medium early varieties – 500-700 thousand/ha, and medium ripening varieties – 500 thousand/ha. A strong and very strong correlation between yield and soybean yield index was established. Increasing the length of the growing season contributed to the growth of yields. In the group of early maturing soybean varieties, the Monarch variety was determined to be the most productive. There was no significant difference in the level of yield of varieties within other maturity groups. For each variety, the optimum planting density was determined, at which the maximum grain yield was formed. Longer vegetation contributed to a greater accumulation of protein and fat in the grain. In terms of protein content, the difference between varieties of the same maturity group did not exceed 0.2%, but varieties differed in terms of conditional protein yield per hectare of crops. There was no difference in the fat content of mid-season soybean varieties. Among the early-ripening varieties, the Monarch variety was distinguished by higher oil content, and among the medium-early varieties – by Aratta. The maximum conditional fat yield per hectare of crops was

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also determined for these varieties. A very strong and strong correlation was found between soybean grain yield and protein and fat content, respectively. A very strong correlation was also found between the protein and fat content of the grain. To ensure sustainable production and efficient use of soybeans and soybean by-products, it is advisable to take the results of the study into account in production conditions

Keywords: crop density; yield; grain quality; protein; fat

INTRODUCTION

A well-grounded selection of varietal resources and the establishment of optimal plant density are important measures to increase yields and improve the quality of crop production. Variety is one of the resource-saving elements of cultivation technology. It accounts for up to 30% of the yield increase, and in extreme weather years, it is the variety that plays a crucial role in shaping the productivity of the crop, which must be justified from an economic and energy point of view (FAO, n.d.). Varieties of different genotypic origins do not realise their potential productivity in the same way. Some varieties, in the absence of an optimal background of nutrition and plant protection products, sharply reduce productivity, while other varieties can produce high productivity under any, even unfavourable, growing conditions. That is why production conditions require the introduction of high-yielding varieties with high quality, well adapted to specific soil and climatic conditions. R. Krisdiana *et al.* (2021) argue that variety is the most effective element of the technological process and plays an important role in improving productivity and increasing soybean production. L.G. Biliavs'ka & A.M. Rybal'chenko (2018) report that the realisation of the productivity potential of a soybean variety is determined by its adaptive properties – plasticity and stability. For the arid conditions of Ukraine, the authors propose to use high and medium plastic soybean varieties with high stability of the main quantitative traits.

S. Liu *et al.* (2020) note that soybean yields largely depend on planting density, which is influenced by several different factors, including plant height, number of branches and beans per plant, number of seeds per bean, and seed size. Soybean plants with a significant number of long branches can shade each other, resulting in a lower yield. Soybean varieties with fewer shorter branches or less branched branches should be sown with a higher density of coenosis. P. Ranđelović *et al.* (2020) describe that stem density can affect the branching of soybean plants: at high planting densities, plants will form fewer branches and vice versa. V.A. Furman *et al.* (2022) found that in sparse soybean crops, intensive plant branching occurs, the excessive leaf surface is formed, and a significant amount of beans and seeds are formed, under the weight of which branches can break off in windy conditions. In sparse crops, the lower tier of beans is located close to the soil surface, and uneven maturation of the beans occurs, which leads to a shortfall in yield, while at the same time high individual plant productivity.

Y. Shashkov & S. Tanchyk (2018) note that at the optimal density of coenosis, the leaf surface of soybean plants is evenly illuminated, photosynthetic activity improves, and photosynthetic processes are activated, which has a positive effect on the level of yield. M. Jańczak-Pieniążek *et al.* (2021) point out that optimal plant density is crucial in terms of reducing competition between plants for water, nutrients, light, and other environmental factors. According to the results of field studies conducted in 2017-2019 in Przeclaw (Poland), it was found that at lower planting densities, soybean plants form a larger number of beans and seeds per bean. Seeds are formed in larger sizes and weights. In addition, photosynthesis processes are more efficient in less dense crops due to better illumination. Such crops are more stress-resistant and require less seed material, which has a positive impact on the economic efficiency of production. Based on the results of experimental trials in the southern, central, and northern regions of the United States, J.F. Andrade *et al.* (2019) concluded that soybean crops with narrow row spacing produce higher yields due to earlier row closure and better absorption of photosynthetic active radiation by the crops.

Z. Liao *et al.* (2022) studied the effect of planting density on the growth and development of soybean plants and their yield formation in non-irrigated conditions in China in 2019-2020. Two planting densities were set for the study – 160 and 320 thousand/ha. The results of the field experiment showed that the thickening of soybean crops to 320 thousand plants/ha increased leaf area index by 31.9%, aboveground biomass by 59.4%, and water use efficiency per unit yield by 27.9%. At the same time, grain yield increased by 27.4%. Z.I. Hlupak (2020) notes that crop compaction to certain parameters contributes to the growth of soybean yields, but excessive compaction beyond the optimal parameters negatively affects yields due to the intershading of plants.

Analysis of research results shows that varietal characteristics and plant density play a crucial role in shaping soybean productivity. Varietal characteristics are determined by the genetic characteristics of plants. Each variety has its properties, including drought resistance, disease resistance, maturity, etc. By selecting the right variety, we can significantly increase plant productivity. In this case, the crop density should be optimal. Insufficient plant density can lead to low yields, and too high a density can cause competition between plants for water, nutrients, and light. A reasonable

choice of variety and optimal plant density is the key to sustainable production of such a valuable legume crop as soybeans. Therefore, the research aims to determine the effect of plant density on the productivity of soybean varieties of different maturity groups and to establish the relationship between yield and yield index, yield and protein and fat content in grain.

MATERIALS AND METHODS

The research was carried out following the thematic research plan of Kherson State Agrarian and Economic University under the task "Strategic directions of development of adaptive technologies for growing crops under conditions of limited natural and material resources" (state registration number 0117U006764). The field experiments were conducted during 2018-2020 at the university's research site based on a private agricultural enterprise of the agricultural company "Syvash" in the Novotroitsk district of the Kherson region within the Kakhovka irrigation system.

The weather conditions in 2018 and 2019 were dry with very high air and soil temperatures. Hot weather with little precipitation was also observed in the autumn. In 2020, the elevated temperature regime was accompanied by sufficient rainfall, which contributed to the intensive growth and development of soybean crops and the formation of higher grain yields compared to previous years of research, even though soybeans in the experiment were grown under drip irrigation.

The soil of the experimental plot is dark chestnut heavy loamy, residually slightly saline. Agricultural technology of soybean cultivation in the experiment was generally accepted for the conditions of drip surface irrigation in southern Ukraine, except for the factors studied. The soybean predecessor in the experiment was corn. The main soil tillage consisted of two peeling and ploughing, spring tillage – two-track harrowing and pre-sowing cultivation. For pre-sowing cultivation, mineral fertilisers were applied at the rate of $N_{30}P_{60}$, using ammonium nitrate and granulated superphosphate. On the day of sowing, soybean seeds were treated with a strain of nodule bacteria *Bradyrhizobium japonicum* 634b and Maxim XL seed treatment. Sowing was carried out in a wide-row method with row spacing of 45 cm. The pre-irrigation moisture content in the 0-50 cm soil layer was maintained at 80% HB. The crop was harvested in sections when the seeds were fully ripe.

The research was conducted using the "Methodology of field and laboratory research on irrigated lands" (Vozhehova *et al.,* 2014). The experiment is two-factor. Factor A – soybean varieties of different maturity groups selected by the Institute of Irrigated Agriculture of the National Academy of Agrarian Sciences of Ukraine: early maturing Diona, Monarch; medium early Aratta, Sofia; medium early Danaya, Svyatogor. Factor B – plant density: 300, 500, 700, 900, and 1100 thousand plants per hectare. Replication – four times, sown area of the third order plot – 75 m^2, accounting area – 50 m^2.

In the studies conducted, the "yield index" was calculated as the ratio of grain weight to the total aboveground mass of plants. The content of total nitrogen in the grain was determined by the Kjeldahl method (State Standards of Ukraine (hereinafter DSTU) ISO 5983:2003) with subsequent conversion to protein content. The mass fraction of fat was determined by the dehydrated residue using a Soxhlet extraction apparatus (DSTU 7491:2013). The construction of polynomial trend lines, calculation of correlation coefficients R^2 and statistical analysis of experimental data were performed using the Agrostat computer program (Ushkarenko *et al.*, 2009). The degree of correlation was determined by the Cheddock scale (Karaeva & Varava, 2016).

Experimental studies of plants (both cultivated and wild), including the collection of plant material, complied 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 yield index characterises the orientation of the processes of using assimilation products to form the grain part of the crop. It was found that this calculated index depended largely on the factors studied. It increased with the increase in the length of the growing season. Thus, according to the averaged data, the yield index of early maturing soybean varieties in the experiment was 0.40, medium early – 0.43, and medium ripe – 0.47 (Table 1).

In the cultivation of early maturing soybean varieties, the lowest yield index was found in the experimental variants with a plant density of 300 thousand plants/ha, and the highest – at a sowing density of 700 thousand plants/ha. The coenosis compaction of up to 700 thousand plants/ha led to an increase in the yield index, further thickening of the plant density already reduced this indicator. The Monarch variety provided a slightly higher yield index in the group of early maturing varieties.

Table 1. *Yield index of soybean varieties of different maturity groups depending on plant density (average for 2018-2020)*

Soybean variety (factor A)	Plant density, thousand units/ha (factor B)					Average by factor A
	300	500	700	900	1100	
Early ripening varieties						
Diona	0.36	0.40	0.43	0.38	0.36	0.39
Monarch	0.37	0.42	0.42	0.43	0.39	0.41

Table 1, Continued

Soybean variety (factor A)	Plant density, thousand units/ha (factor B)					Average by factor A
	300	500	700	900	1100	
On average per factor B	0.37	0.41	0.43	0.41	0.38	0.40
Medium early varieties						
Aratta	0.43	0.43	0.45	0.44	0.42	0.43
Sofia	0.39	0.47	0.44	0.42	0.38	0.42
On average per factor B	0.41	0.45	0.45	0.43	0.40	0.43
Mid-season varieties						
Danaya	0.45	0.48	0.45	0.45	0.41	0.45
Svyatogor	0.53	0.53	0.52	0.47	0.40	0.49
On average per factor B	0.49	0.51	0.49	0.46	0.41	0.47

Source: *compiled by the author*

In the group of mid-early varieties, Aratta had an advantage over Sofia in terms of the yield index, except for the variant with a plant density of 500 thousand plants/ha. The maximum values of the yield index for the cultivation of the Aratta variety were provided by the density of 700 thousand plants/ha, and the Sofia variety – of 500 thousand plants/ha. In the group of medium-ripening soybean varieties, a higher yield index was determined for the cultivation of Svyatogor, only at a plant density of 1100 thousand plants/ha, which was slightly inferior to Danaya. Both varieties provided maximum yield index values at a planting density of 500 thousand plants/ha. Further compaction of the coenosis led to a decrease in this indicator.

In general, the yield index in the experiment ranged from 0.36 to 0.53, which indicates the ability of soybean plants to effectively use dry matter to form grain productivity. A strong and very strong relationship was established between the yield index and grain yield of the studied soybean varieties, which is demonstrated by the constructed polynomial trend lines of dependence and the calculated values of the correlation coefficient R^2 (Fig. 1).

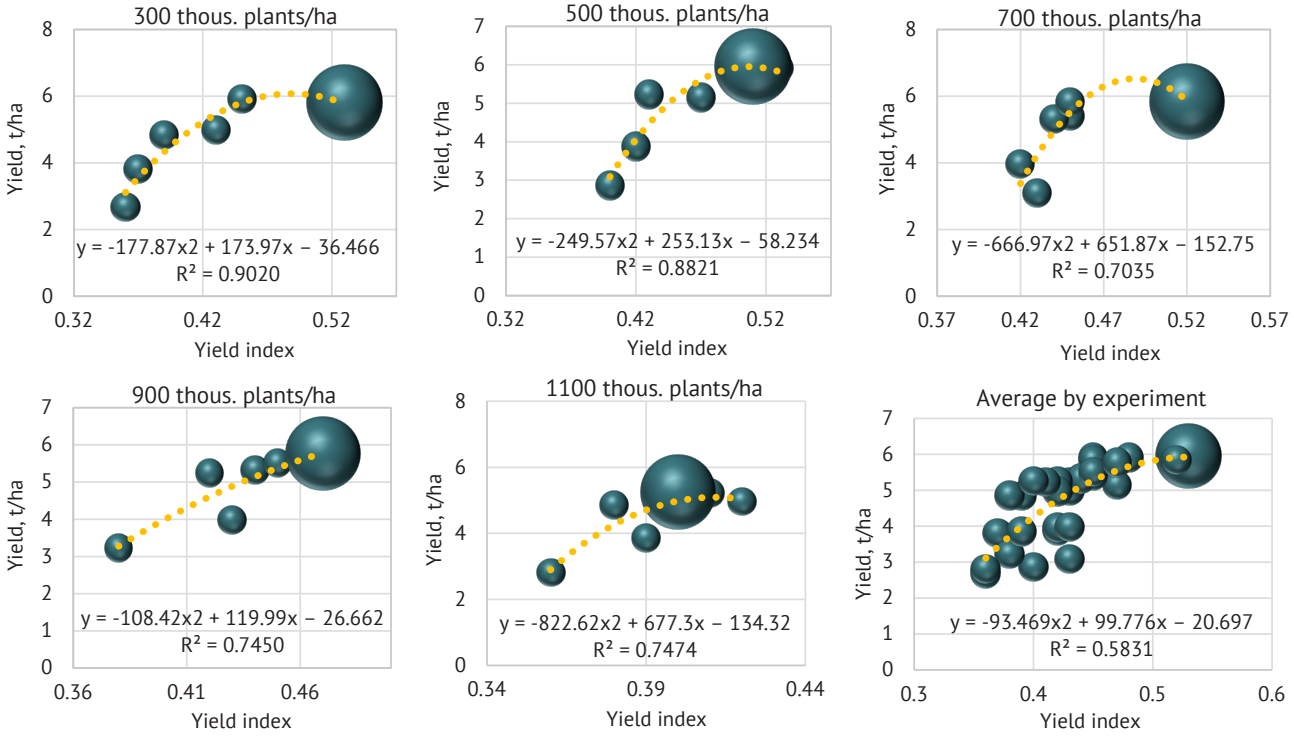

Figure 1. *Polynomial trend lines of the relationship between the yield index and grain yield of soybean varieties (average for 2018-2020)*

Source: *compiled by the author*

The research results show that the yield of soybean grain depended on the studied factors – variety and plant density. With the increase in the duration of the growing season, it increased: on average, the yield of early maturing varieties was 3.42 t/ha, medium early – 5.13 t/ha, medium ripe – 5.71 t/ha (Table 2).

Table 2. *Yield of soybean varieties of different maturity groups depending on plant density (average for 2018-2020)*

Soybean variety (factor A)	Plant density, thousand units/ha (factor B)					Average by factor A
	300	500	700	900	1100	
Early ripening varieties						
Diona	2.68	2.86	3.09	3.23	2.81	2.93
Monarch	3.81	3.88	3.96	3.98	3.85	3.90
On average per factor B	3.25	3.37	3.53	3.61	3.33	3.42
Medium early varieties						
Aratta	4.98	5.23	5.41	5.33	4.96	5.18
Sofia	4.84	5.15	5.33	5.25	4.86	5.09
On average per factor B	4.91	5.19	5.37	5.29	4.91	5.13
Mid-season varieties						
Danaya	5.91	5.91	5.84	5.51	5.23	5.68
Svyatogor	5.81	5.96	5.85	5.77	5.26	5.73
On average per factor B	5.86	5.94	5.85	5.64	5.25	5.71
HIP_{05}, t/ha	by factor A – 0.12-0.15, by factor B – 0.11-0.15					

Source: *compiled by the author*

The Monarch variety had a significant advantage in grain yield in the group of early maturing soybean varieties.

The yield increase concerning the variety Diona, depending on the plant density, ranged from 0.75-1.13 t/ha or 23.2-42.2% (Fig. 2).

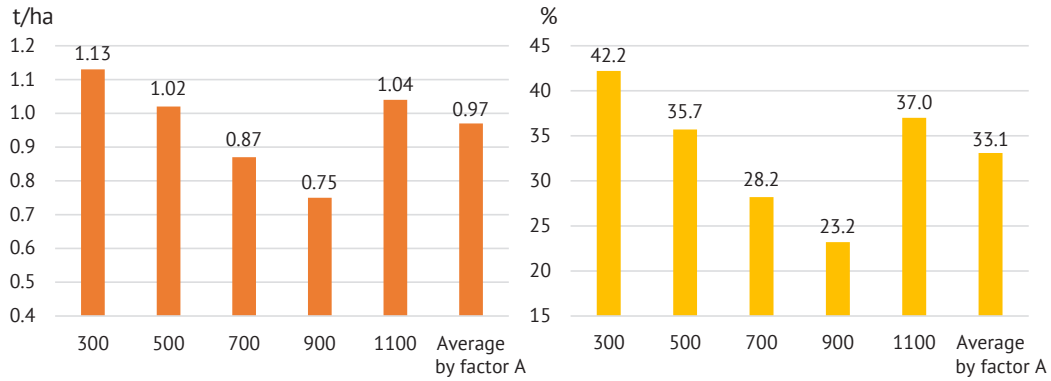

Figure 2. *Increase in grain yield of the Monarch variety compared to the Diona variety (average for 2018-2020)*
Source: *compiled by the author*

In the group of medium early varieties, Aratta was characterised by a slightly higher grain yield. Its increase concerning the variety Sofia was 0.08-0.14 t/ha or 1.5-2.9% (Fig. 3), i.e., it was insignificant and within the error of the experiment (the smallest significant difference NIR_{05} = 0.12-0.15 t/ha).

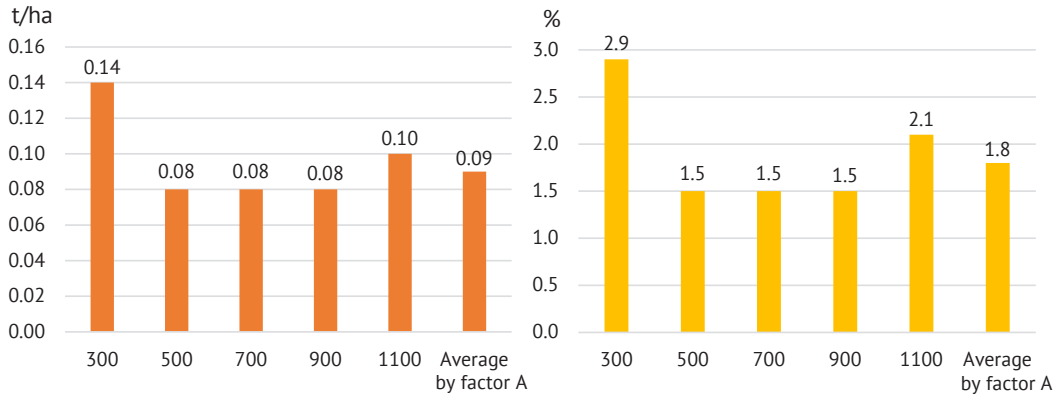

Figure 3. *Increase in grain yield of Aratta variety compared to Sofia variety (average for 2018-2020)*
Source: *compiled by the author*

The difference between the yield data of mid-season varieties Danaya and Svyatogor was also within the error of the experiment, except for the variant with a plant density of 900 thousand/ha, where Svyatogor had a significant advantage over Danaya (Fig. 4).

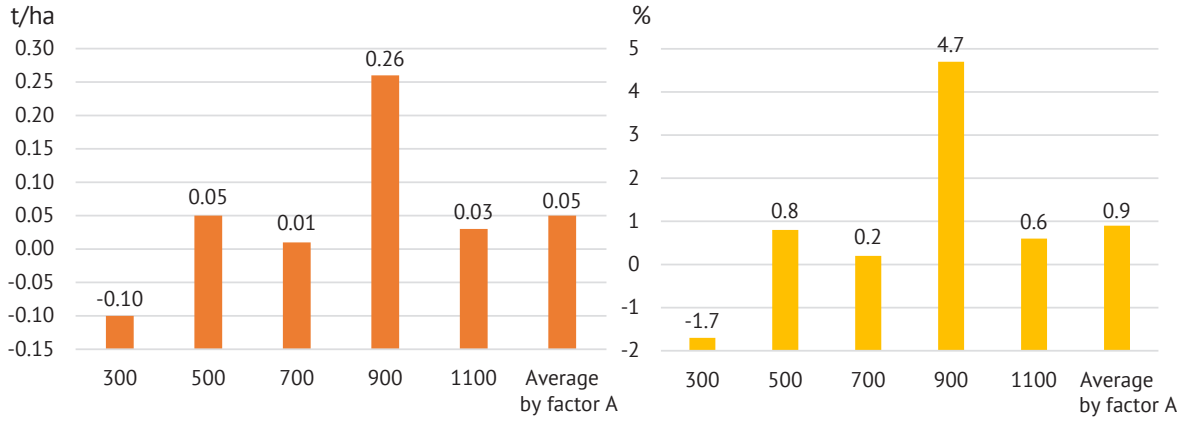

Figure 4. *Increase (decrease) in grain yield of the Svyatogor variety compared to the Danaya variety (average for 2018-2020)*

Source: *compiled by the author*

For varieties of each maturity group, the optimum sowing density was established. The early ripening varieties Diona and Monarch formed the maximum level of grain yield at a plant density of 900 thousand/ha. At the same time, the Monarch variety provided the same level of yield at a plant density of 700 thousand/ha, i.e., this soybean variety is highly plastic in terms of coenosis density. Increasing the stem density to 1100 thousand plants/ha had a negative impact on the productivity of both early maturing soybean varieties under study. The mid-early varieties Aratta and Sofia formed the highest yield level at a plant density of 700 thousand plants/ha (5.41 and 5.33 t/ha), and the mid-season varieties Danaya and Svyatogor – at a plant density of 500 thousand plants/ha (5.91 and 5.96 t/ha).

Not only the level of yields achieved but also the quality of the crops grown is important in implementing modern agricultural technologies. Soybeans are valued primarily for their protein and fat content. These indicators in the experiment largely depended on the genotypic characteristics of the variety. With the increase in the length of the growing season, the protein and fat content in the grain of the soybean varieties under study increased. When growing early ripening varieties, the protein content in the grain averaged 40.2% by a factor, when growing medium early varieties – 40.7%, and medium ripening varieties – 41.2% (Table 3).

Table 3. *Protein and fat content in grain and their conditional yield per hectare of soybean varieties, on average, according to factor B (average for 2018-2020)*

Soybean variety (factor A)	Content in grain, %		Conditional yield per hectare of crops, kg/ha	
	of protein	fat	of protein	fat
Early ripening varieties				
Diona	40.1	18.1	1175	530
Monarch	40.2	18.4	1568	718
Average on early ripening varieties	40.2	18.3	1372	624
Medium early varieties				
Aratta	40.6	18.8	2103	974
Sofia	40.8	18.2	2077	926
Average for mid-early varieties	40.7	18.5	2090	950
Mid-season varieties				
Danaya	41.1	19.1	2334	1085
Svyatogor	41.2	19.1	2361	1094
Average for mid-season varieties	41.2	19.1	2348	1090
HIP_{05} by factor A, %	0.07-0.09	0.05-0.08		

Source: *compiled by the author*

The difference in this indicator between varieties of the same maturity group did not exceed 0.2%. The early-ripening variety Monarch, the medium-early variety Sofia, and the medium-ripening variety Svyatogor had a slight advantage in protein content in the grain. A much larger difference between varieties of the same maturity group was found in terms of conditional protein yield per hectare of soybean crops. In this case, the Monarch variety exceeded the Diona variety by 393 kg/ha or 33.4%. Despite a slightly lower protein content in the grain, Aratta exceeded Sofia by 26 kg/ha or 1.3% in terms of its conditional yield due to higher yields. In the mid-season group of varieties, Svyatogor was superior in terms of both protein content and conditional protein yield per hectare of crops. A very strong correlation was found between grain yield and protein content according to the Chaddock scale, as evidenced by the calculated correlation coefficient R^2=0.9647 (Fig. 5).

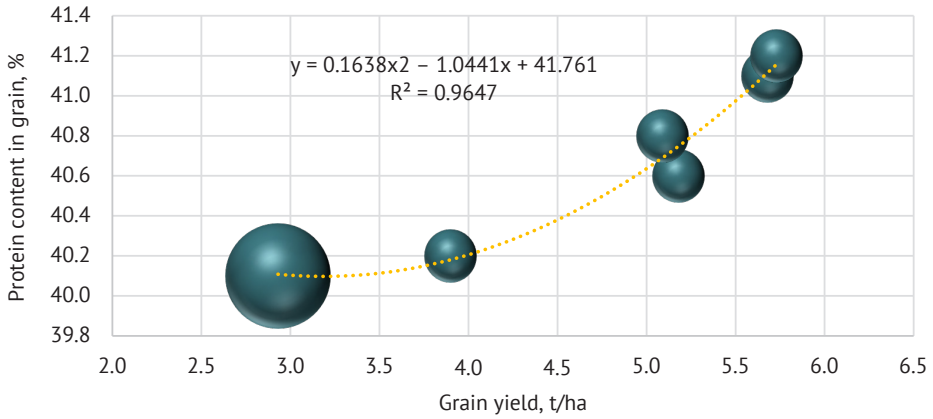

Figure 5. *Correlation and regression model of the relationship between soybean grain yield and protein content*
Source: *compiled by the author*

The fat content in soybean grain also increased with the increase in the duration of the growing season of the studied varieties. When growing an early maturing group of varieties, it was 18.3%, medium early – 18.5%, and medium maturing – 19.1% on average by factor (Table 3). The early maturing variety Monarch surpassed the variety Dion by 0.3% in this indicator of grain quality. An even greater difference was found when growing medium-early varieties. The fat content of Aratta grain was 0.6% higher than that of Sofia. No differences in the fat content of mid-season varieties Danaya and Svyatogor were found. In general, all soybean varieties grown in the experiment met the requirements of DSTU 4964:2008 (2009), according to which the fat content in soybean grain should not be lower than 12%. The Monarch variety had a significant advantage in terms of conditional fat yield per hectare of early maturing varieties. The increase in this indicator compared to the Diona variety was 188 kg/ha or 35.5%. In terms of conditional fat yield per hectare of crops, the mid-early variety Aratta outperformed the variety Sofia by 48 kg/ha or 5.2%. This difference was almost not observed in the cultivation of mid-season soybean varieties – it was minimal in the experiment with a slight advantage of the Svyatogor variety.

The constructed correlation-regression model of the relationship between soybean grain yield and fat content shows a strong degree of correlation, with a correlation coefficient of R^2=0.7412 (Fig. 6).

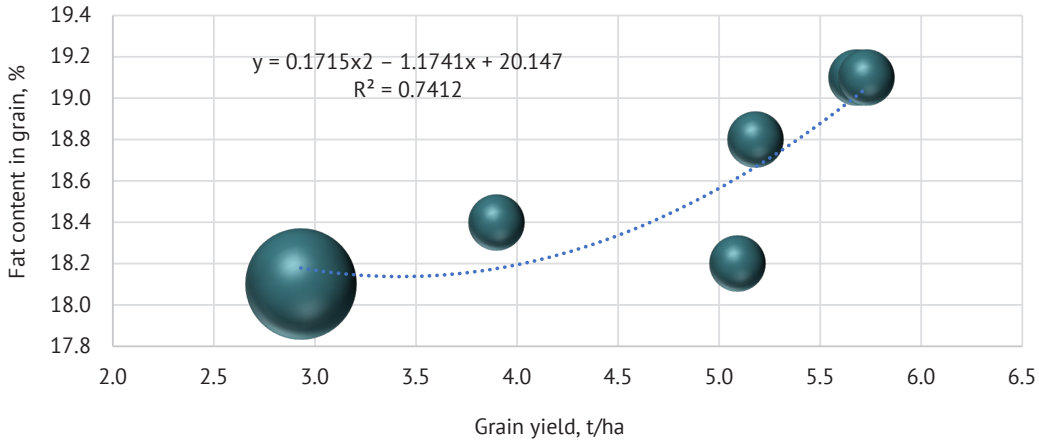

Figure 6. *Correlation-regression model of the relationship between soybean grain yield and fat content*
Source: *compiled by the author*

The relationship between protein and fat content in grain is described by the equation $y=-5.62x^2+454.91x-9187.1$, where y is the fat content in grain and x is the protein content in grain (Fig. 7). A strong correlation was found between these quality indicators: $R^2=0.9342$.

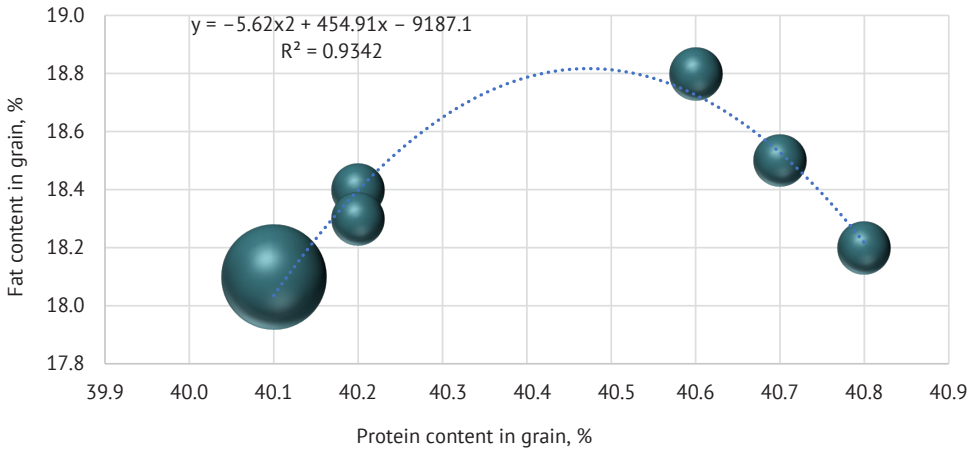

Figure 7. *Correlation-regression model of the relationship between protein and fat content in soybean grain*
Source: *compiled by the author*

The obtained results of the study and the built correlation and regression models of the relationship between grain yield and protein and fat content can be used for programming productivity, sustainable production and efficient use of soybeans and its products.

It is worth noting that other researchers have also noted the dependence of yield, biochemical composition of soybean grain and conditional protein and fat yield on genotypic characteristics of the variety. Thus, according to the results of two years of research (2019-2020), V.V. Liubych *et al.* (2020) found that the protein content in soybean grain can vary from 36.1 to 44.4% depending on the variety. At the same time, only 8 varieties out of 14 had a protein content of ⩾40%. The authors also found a significant impact on this indicator of the quality of weather conditions during the years of research. In the vast majority of the varieties studied, moisture deficit and high air temperatures contributed to the formation of a higher protein content in the grain. Only some varieties showed a 4-10% decrease in protein content. These less drought-tolerant varieties were characterised by premature vegetation termination and reduced accumulation of organic matter. The fat content in the grain of the studied varieties ranged from 18.9 to 21.7% and significantly depended on the varietal characteristics and weather conditions of the growing season. As in the current research, a high correlation was found between protein and fat content in soybean grain.

M. Grabovskyi *et al.* (2023) during 2021-2022 studied the quality indicators of soybean grain of Amadea and Aurelina varieties under different variants of fungicidal plant protection. According to the results of the research, it was found that the yield of the Amadea variety on average over two years of research was 2.7-7.7% higher than the yield of the Aurelina variety. At the same time, the yield of both varieties largely depended on the hydrothermal conditions of the year of cultivation. Despite the level of fungicide plant protection, the protein and fat content in the grain of the Aurelina variety was significantly higher compared to the more productive Amadea variety. There was no effect of fungicides on the oil content of the grain, but an increase in protein content was observed.

The effect of plant density on soybean grain yield was studied by W.D. Carciochi *et al.* (2019). To summarise the research results, they used a database based on 78 experiments conducted over two years in different soil and climatic conditions in the USA and Canada. The plant density was studied from 170 to 670 thousand/ha. The obtained yield data were classified into 3 groups: low (LYE), medium (MYE) and high (HYE) yields. According to the results of the research, it was found that soybean grain yield increased with a decrease in the density of coenosis.

The opposite results were obtained in studies conducted in South Dakota (USA). M. Schutte and T. Nleya (2018) studied the effect of row spacing and seeding rates on the grain yield of soybean varieties. In dense crops with a row spacing of 19 cm, the yield was 8-10% higher compared to a row spacing of 76 cm. Increasing the seeding rate contributed to a 3-7% increase in yield. Also, the yield in the experiment largely depended on the length of the growing season of the varieties grown. Similar to the results of our research, varieties with a longer growing season produced higher yields. However, according to the results of studies conducted in non-irrigated conditions in Bulgaria. G. Naydenova and N. Georgieva (2019) observed a decrease in soybean yields with an increase in the length of the growing season, which is associated with better grain filling of genotypes with a shorter growing season. The importance of the length of the growing season in

shaping soybean productivity has been reported by other researchers, including M.A. Alam *et al.* (2023).

According to the results of research by F. Cheţan *et al.* (2021), conducted during 2017-2019 in the arid conditions of Romania, a significant effect of plant density and weather conditions during the year of cultivation on the yield and quality of soybean grain was found. With an increase in seeding rates, yields increased. The highest level of yield was provided by the seeding rate of 55-65 g/m^2. The compacted crops with two fertilisations with nitrogen and phosphorus fertilisers ensured the formation of grain with high protein and fat content.

R. Vozhehova *et al.* (2020), at the Institute of Irrigated Agriculture of the National Academy of Agrarian Sciences of Ukraine, studied the effect of plant density on grain yield of the mid-season soybean variety Svyatogor during 2016-2018. The highest yield level was provided by a sowing density of 600 thousand plants/ha – 4.32-4.47 t/ha in variants with fertilisation. The maximum yield on the unfertilised plots of the experiment was provided by a plant density of 500 thousand plants/ha – 2.91 t/ha. On more compacted crops, a sharp decrease in grain yield was observed, which coincides with the results of research on the cultivation of the Svyatogor variety.

An analytical review of the results of research conducted in different regions of the world suggests that there is currently no consensus among scientists on the impact of plant density on soybean productivity. Each variety has its optimal parameters of productive stem density. Therefore, research on modern soybean varieties of Ukrainian breeding in the soil and climatic conditions of southern Ukraine is relevant, and their results can be used in production conditions.

CONCLUSIONS

According to the results of research on the influence of plant density on the productivity of modern soybean varieties of Ukrainian selection, it was found that each maturity group has its optimal parameters of crop density to form the maximum yield and high grain quality. It was found that with the increase in the length of the growing season, the yield index increased. When growing early maturing soybean varieties, it was 0.40, medium early – 0.43, and medium mature – 0.47. The maximum values of the yield index for the cultivation of early maturing varieties were ensured by a plant density of 700 thousand/ha, medium early varieties – 500 thousand/ha (Sofia) and 700 thousand/ha (Aratta), and medium ripe varieties – 500 thousand/ha. Higher yield indexes within the ripeness group were provided by the early-ripening Monarch variety, the mid-early Aratta variety and the mid-ripening Svyatogor variety. A strong and very strong relationship between the yield index and soybean grain yield was established.

Varietal characteristics and crop density significantly affected the yield of soybean grain. When growing early ripening varieties, it was 3.42 t/ha, medium-early varieties – 5.13 t/ha, and medium-ripening varieties – 5.71 t/ha, i.e. with an increase in the length of the growing season, the yield increased. The Monarch variety had a significant yield advantage in the group of early maturing varieties. There was no difference in yield data between varieties within the mid-early and mid-season groups, it was insignificant. As an exception, it should be noted the cultivation of the mid-season variety Svyatogor at a plant density of 900 thousand/ha, when it had a significant advantage over the variety Danaya. The optimal plant density for soybean varieties of each maturity group was determined: 900 thousand/ha for early maturing, 700 thousand/ha for medium early and 500 thousand/ha for medium maturing varieties.

Soybean varieties with a longer vegetation period formed grain with a higher protein content: early maturing varieties – 40.2%, medium early varieties – 40.7%, medium maturing varieties – 41.2%. No significant difference was found between varieties within the same maturity group for this quality indicator. However, it was determined by the conditional protein yield per hectare of crops. In the group of early ripening varieties, the Monarch variety provided a higher conditional protein yield, in the group of medium early varieties – Aratta, and in the group of medium ripening varieties – Svyatogor. A very strong correlation was found between grain yield and protein content. With the increase in the length of the growing season, the fat content in soybean grain increased: early maturing varieties – 18.3%, medium early varieties – 18.5%, and mid-season varieties – 19.1%. A higher percentage of oil content and conditional fat yield per hectare of crops was found when growing the early-ripening variety Monarch and the medium-early variety Aratta. No difference in these indicators was found in the varieties of the mid-season group. A strong correlation was found between soybean grain yield and fat content, and a very strong correlation between protein and fat content in the grain. A promising area of research is to determine the influence of plant variety and plant density on a wider range of soybean grain quality indicators, considering the versatility of this crop.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None.

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Продуктивність сортів сої різних груп стиглості залежно від густоти стояння рослин в умовах краплинного зрошення півдня України

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Анотація. Соя є провідною зернобобовою культурою універсального призначення, тому заходи, спрямовані на підвищення її продуктивності, зокрема обґрунтований добір сортових ресурсів та оптимізація щільності посівів, дозволять зробити значний внесок у створення стійких систем виробництва продуктів харчування. Метою дослідження було встановити вплив густоти стояння рослин на продуктивність сортів сої різних груп стиглості. У ході роботи використано польові лабораторні та статистичні (кореляційно-регресійний аналіз) методи. Польові досліди проводили впродовж 2018-2020 рр. на темно-каштановому ґрунті приватного сільськогосподарського підприємства агрофірми «Сиваш» Новотроїцького району Херсонської області. Максимальні його значення за вирощування скоростиглих сортів забезпечила густота стояння рослин 700 тис./га, середньоранніх – 500-700 тис./га, середньостиглих – 500 тис./га. Встановлено сильний і дуже сильний кореляційні зв'язки між урожайністю та індексом урожайності сої. Збільшення тривалості вегетаційного періоду сприяло зростанню врожайності. У групі скоростиглих сортів сої більш урожайним визначено сорт Монарх. Суттєвої різниці за рівнем урожайності сортів в межах інших груп стиглості не визначено. Для кожного сорту встановлено оптимальну щільність посівів, за якої формується максимальний рівень урожайності зерна. Триваліша вегетація сприяла більшому накопиченню протеїну та жиру в зерні. За вмістом протеїну різниця між сортами однієї групи стиглості не перевищувала 0,2 %, проте сорти різнились за умовним виходом протеїну з гектару посівів. Різниці за вмістом жиру в зерні середньостиглих сортів сої не встановлено. Із скоростиглих сортів вищою олійністю вирізнявся сорт Монарх, із середньоранніх – сорт Аратта. За вирощування цих сортів визначено і максимальний умовний вихід жиру з гектару посівів. Між урожайністю зерна сої та вмістом у ньому протеїну і жиру встановлено відповідно дуже сильний і сильний кореляційний зв'язок. Дуже сильну кореляцію визначено також між вмістом у зерні протеїну та жиру. Для забезпечення сталого виробництва та ефективного використання сої та продуктів її переробки доцільно одержані результати дослідження враховувати у виробничих умовах

Ключові слова: щільність посівів; урожайність; якість зерна; протеїн; жир

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Evaluation of sunflower breeding material for resistance to broomrape (*Orobanche cumana Wallr.*) and herbicides under artificial climate conditions to accelerate the breeding process

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Abstract. Sunflower is an important oilseed crop, so increasing its yield and resistance to diseases and pests can lead to significant economic improvements for agricultural businesses and the country as a whole. Climate change and the spread of new races of broomrape (*Orobanche cumana Wallr.*) pose serious threats to sunflower production, and research in this area is helping to develop varieties that can adapt to changing conditions. The purpose of the study is a comprehensive assessment of breeding

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material to identify the most resistant forms and hybrids of sunflower. To achieve the goal, an experiment was conducted in the period 2015-2023 in the LLP "Experimental Farm of Oilseed Crops", in which the assessment of sunflower breeding material for resistance to broomrape and herbicides was studied. As a result of the experiment, sunflower lines were successfully created that are resistant to broomrape and herbicides, which helps to increase productivity and reduce crop losses. The created sunflower lines were introduced into the breeding process in order to develop highly productive interline sunflower hybrids, which became an important step in improving the agriculture of Kazakhstan. These innovative hybrids, such as "Agribusiness 2050" and "Batyr", have shown high resistance to broomrape of races E-F, which significantly reduces crop losses and ensures reliable products. In addition, herbicide-resistant hybrids have been developed, such as Baiterek S and Baikonur, which can effectively control weeds and maintain crop cleanliness, which is important for increasing yields and reducing tillage costs. These hybrids have been recommended for use in agriculture in Kazakhstan and can help improve sunflower productivity. This study contributes to the expansion of scientific knowledge in the field of sunflower breeding and pest control, which is a relevant area for improving agricultural practices and ensuring food security

Keywords: variety; hybrid; agriculture; experimental conditions; genetic markers

INTRODUCTION

Agriculture plays an important role in ensuring food security and meeting the needs of the population for raw materials for industry. However, various factors stand in the way of increasing yields and quality of agricultural products, among which plant diseases and weeds occupy a special place. One of the major challenges for agriculture is the problem of sunflower blight (*Orobanche cumana Wallr.*). This parasitic organism can cause significant yield losses in sunflowers and can be a serious limiting factor for sunflower production.

Prevention and control of sunflower blight are of great importance for sustainable agricultural development (Tajibayev *et al.,* 2023). On the other hand, one of the most urgent problems of agriculture is weed infestation of cultivated crops. Yield losses caused by weeds can reach 30% or even more, especially in some crops. Herbicides are often used to combat this problem. However, previously used herbicides had environmental risks, a wide range of effects and could be toxic to mammals. In addition, they remained in the environment for a long time. Plant breeding for herbicide resistance is becoming an integral part of modern agriculture (Trotsenko *et al.,* 2020). A. Zatybekov *et al.* (2020) focused on genetic studies aimed at identifying specific genes and molecular mechanisms responsible for resistance to broomrape and herbicides. This helps to understand in more detail the mechanisms of resistance and the possibilities of editing them through genetic engineering. In turn, S. Liu *et al.* (2020) studied the ecological context of the interaction between sunflower, broomrape and herbicides. They studied which environmental factors facilitate or limit the spread of broomrape and how these factors can be used to control it without the use of herbicides.

In recent years, the demand among agricultural producers for sunflower hybrids resistant to sulfonylurea and imidazoline group herbicides has increased. These herbicides have a broader spectrum of action, covering perennial, single and dicotyledonous weeds as well as cereals. This is due to market needs, where high cultivation intensity of sunflower hybrids and reduced crop care costs play an important role in reducing the cost of final production (Pinar *et al.,* 2021). Researchers A. Babkenov *et al.* (2020) have also studied phytosanitary methods of controlling broomrape, such as biological control by using natural enemies of broomrape or the use of biological products that may be less harmful to the environment.

To accelerate the breeding process, it is necessary to conduct research under artificial climate conditions, which allow a more accurate and rapid assessment of the genetic characteristics of plants and their response to various stresses. With this in mind, researchers D. Kurylych and K. Makliak (2022) have begun work on creating herbicide-resistant linear breeding material. One such production system is the SUMO or Express Sun system, which is a combination of a herbicide-resistant sunflower hybrid and a herbicide with the active ingredient tribenuron-methyl. The introduction of the tribenuron-methyl resistance gene into the gene pool of cultivated sunflower has led to the establishment of two publicly available sources of this trait, known as SURES-1 and SURES-2. Other researchers, A. Ryzhenko *et al.* (2020), are exploring the possibility of using modern technologies, such as CRISPR-Cas9, to create genetically modified sunflower varieties that are resistant to broomrape and herbicides.

It should be noted that despite considerable research in plant breeding and pest management, many aspects remain completely unexplored. In particular, the genetic basis of resistance, as the mechanisms of plant resistance to Broomrape and herbicides are still not fully understood. A detailed study of the genetic basis of resistance and molecular mechanisms of plant response to stresses may lead to more effective breeding methods, hence the relevance of the study. The aim of the study is to comprehensively evaluate the breeding material that has been generated over the years in order to identify the most resistant forms and, using them

as a starting point, to establish a new plant collection that will serve as a base for the development of resistant sunflower hybrids.

MATERIALS AND METHODS

To study the evaluation of sunflower breeding material for resistance to Broomrape (*Orobanche cumana Wallr.*) and herbicides in the period 2015-2023, an experiment was conducted in the limited liability partnership (LLP) "Experimental Farm of Oilseeds". The experiment was carried out under artificial climate conditions, using the following steps:

1. Collection and preparation of breeding material. Sunflower breeding material was collected, including different varieties and lines that had been grown for several years.

2. Evaluation of resistance to Broomrape. Two methods were used to evaluate the resistance of sunflower seeds to Broomrape. The first method involved visual assessment of the root system of sunflower plants and counting the number of Broomrape haustoria (nodules) on affected plants (Fig. 1). The second method was based on a more detailed evaluation of uninfected sunflower seedlings under a binocular lens. These seedlings were examined for the presence of brown necrotic spots at the sites of dead Broomrape haustoria, and the elongation of Broomrape seedlings was measured, as this contributed to the depletion of nutrient reserves in the seeds of the parasite and its subsequent die-off (Fig. 2). Race-differentiator samples were used as controls to assess the racial composition of the parasite: variety Kruglik (race A) and line LC-1093 (race F-Or_6). The degree of infestation was determined by multiplying the percentage of susceptible plants by the average number of nodules of the parasitic plant and dividing this value by 100.

Figure 1. *Visual assessment and counting of nodules of Broomrape*
Source: *composed by authors*

3. Development of resistant lines and hybrids. To create sunflower lines resistant to Broomrape, self-pollinated lines were used, which were isolated from interspecific varieties-populations, such as R-Y-60, as well as hybrids of foreign selection, such as 11 – Berk, 9 – Nika, and others. These lines provided donors of resistance to Broomrape, which were further used for crosses and creation of new resistant forms. When working on the development of lines resistant to herbicides of the sulfonylurea and imidazoline groups, donors (testers) with genetic resistance such as CB-c, CB-i, SUR 3, K 259 were also used. These testers served as a starting point for crosses and creation of new plants with resistance to these herbicides.

Figure 2. *Estimation of stable numbers under binoculars*
Source: *composed by authors*

4. Sowing and cultivation under artificial conditions. Every year, between November and April, sowing was carried out in a room with an artificially created climate. A mixture of soil and sand in the proportion of 2:1 was used as substrate. A certain amount of seeds of Broomrape was applied to the growing vessels, based on the calculation of 200 mg for each kilogram of soil mixture. A labelled sowing scheme was also created, and the tested samples were sown together with control samples, which were susceptible to Broomrape (Fig. 3).

Figure 3. *The growing box used to conduct the assessment of sunflower resistance to Broomrape*
Source: *composed by authors*

5. Herbicide treatment. Treatment was carried out on plants in the development phase with 2-3 pairs of true leaves. The recommended doses of herbicides were used: 30 g/ha for herbicide from sulfonylurea group (Express) and 1 litre/ha for herbicide from imidazolines group (Eurolightning) (Fig. 4).

Figure 4. *Sunflower plants before herbicide treatment*
Source: *composed by authors*

6. Selection of new parental forms. Based on the results of resistance assessment and herbicide treatment, the best plant samples were selected to create new parental forms with the desired resistance characteristics (Fig. 5).

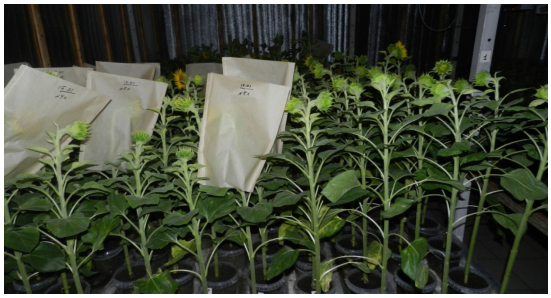

Figure 5. *Isolation of plants in cross-breeding and self-pollination operations*
Source: *composed by authors*

All these steps were improved and optimized in accordance with the sunflower breeding methodology, which allowed successfully achieving the objectives and obtaining stable sunflower hybrids and lines that contribute to improved agricultural productivity and sustainability. The authors followed the standards of the Convention on Biological Diversity (1992) and the Convention on Trade in Endangered Species of Wild Fauna and Flora (1979).

This research was carried out within the framework of programme-targeted financing of the Ministry of Agriculture of RK 2021-2023 (BR10765017 "Study and provision of storage, replenishment, reproduction and effective use of genetic resources of agricultural plants to ensure breeding process").

RESULTS

The material, including self-pollinated Broomrape lines and self-pollinated (F1) progeny, was studied with seeds from populations of the parasitic plant collected from different growing regions such as Ukraine and Kazakhstan. To improve the selection of forms of sunflower being resistant to Broomrape, a comparative evaluation of Broomrape populations represented by samples from the above-mentioned countries was carried out. The response of self-pollinated sunflower lines to infection by the parasitic plant strongly depended on the seed origin. For example, the sample of the variety 'Kruglik' (race A – Or1) was 100% affected by all types of Broomrape populations, while the line LC-1093, known to be resistant to Or6 (race F), showed the lowest degree of infestation when using seeds from the Krasnodar population – only 13.5% (Table 1).

Table 1. *Response of sunflower lines to infection by different populations of Broomrape*

Line, control	Kazakhstan (East Kazakhstan region)			Ukraine (Zaporizhzhia)		
	Tested plants, pcs.	Reproduced plants, %	Degree of infestation, %	Tested plants, pcs.	Reproduced plants, %	Degree of infestation, %
BKU101 A	14	29.3	2.3	15	62.3	4.9
BKU101 A	27	26.0	2.1	22	58.7	4.7
LC-1093	15	25.8	1.2	14	26.3	2.1
Kruglik	21	100	42.3	19	100	44.6

Source: *composed by authors*

All subsequent experiments on the resistance of breeding material to Broomrape were conducted on populations of Broomrape collected from commercial sunflower crops in Kharkiv, Zaporizhzhya and Donetsk regions of Ukraine, provided by Ukrainian specialists. Between November 2015 and April 2016, 427 sunflower breeding numbers including maternal lines and paternal forms (Rf) of different levels of backcrossing and incucht were analysed for resistance to Broomrape. As a result of screening, 20 accessions with 100% resistance were identified among the tested accessions (Table 2).

Table 2. *Results of analyses of sunflower breeding numbers (2015-2016)*

Number of lines, pcs.	Plants tested, pcs.	% of susceptible plants	% of resistant plants	Infestation degree, %
Control	1197	100	0	21.1
248	1806	61-78	28-42	23.2
112	896	39-45	11-19	14.3

Table 2, Continued

Number of lines, pcs.	Plants tested, pcs.	% of susceptible plants	% of resistant plants	Infestation degree, %
47	423	11-21	5-8	16.9
20	170	-	100	-
In total: 427	4492	-	-	-

Source: *composed by authors*

During the experiment, certain numbers of plants from backcross progenies BC_4-BC_6 and self-pollination $I_2 – I_3 – I_4$ that showed particular resistance were identified. These numbers include 3626 (BC_4), 3638 (BC_4), 3641 (BC_5), 4910, 4959, 4960, 4965, 4969 (I_2), 3323 (I^3), 4656, 4963 (I^2), 4614, 3889, 4043, 3473, 3504, 3936 (I^4), 6727 (BC^4), 8061 (BC_6) and 8652 (I_4). Resistant moulds that reached 100% resistance level were transplanted into special growing vessels for further cultivation and seed production (Fig. 6).

Figure 6*. Sunflower plants after transplanting for resistance to Broomrape*
Source: *composed by authors*

During the flowering of fertile plants from backcross progenies, pollen was transferred to their sterile counterparts to produce new progeny. As for all plants of the fourth generation of Incucht (I_4), forced self-pollination was carried out on them. For 2016-2017, 331 self-pollinated sunflower lines that were grown in breeding nurseries in the experimental field under natural conditions in 2016 were also evaluated (Table 3). The aim of this evaluation was to confirm the presence of the trait of absolute resistance to the plant-parasite Broomrape (*Orobanche cumana Wallr.),* in the progenies obtained from backcrossing (BC) and self-pollination (I). Nineteen accessions were selected that showed complete resistance to Broomrape. Among them were 2 accessions from progeny of BC_6 (8757, 8794) and 17 accessions from progeny obtained from self-pollination $I_3 – I_4 – I_5$. These samples were selected based on evaluations conducted during the autumn-spring period of 2015-2016: I_3 – 8141, 8142, I_4 – 8019, 8033, 8051, 8065, 8089, 8097, I_5 – 6259, 6747, 8379, 8434, 8533, 8545, 8606, 8641. Then transplanting of plants resistant (100%) to Broomrape was carried out in order to further work on crossing and obtaining progeny under artificial climate conditions.

Table 3. *Results of analyses of sunflower breeding numbers (2016-2017)*

Number of lines, pcs.	Plants tested, pcs.	% of susceptible plants	% of resistant plants	Infestation degree, %
Control	960	100	0	11.4
214	1926	69-82	58-92	13.3
65	520	52-61	42-52	8.5
33	297	31-42	27-31	11.5
19	161	-	100	-
In total: 331	3864	-	-	-

Source: *composed by authors*

Evaluation of 208 sunflower accessions that were selected from self-pollinated progenies during summer 2017 was also carried out in 2017-2018 (Table 4). These accessions were evaluated under artificial climatic conditions and also included new promising numbers from breeding nurseries. From the whole set, 8 resistant accessions were identified and will be used for further breeding work.

Table 4. *Results of analyses of sunflower breeding numbers (2017-2018)*

Number of lines, pcs.	Plants tested, pcs.	% of susceptible plants	% of resistant plants	Infestation degree, %
Control	280	100	0	9.9
114	832	64-73	39-42	9.6
63	475	59-61	16-20	16.1
23	184	32-46	9-12	11.3
8	59	-	100	-
In total: 208	1830	-	-	-

Source: *composed by authors*

The studied sunflower accessions, totalling 187 numbers, were selected from different sources including backcross progeny nurseries, pollen fertility restorer lines, and initial breeding material (Table 5). These accessions were subjected to evaluation for resistance to Broomrape, and 6 resistant forms were selected based on the results. These selection samples, belonging to generations BC_6 and I_6, represent new maternal and paternal forms that will be used in the development of experimental sunflower hybrids.

Table 5. *Results of analyses of sunflower breeding numbers (2018-2019)*

Number of lines, pcs.	Plants tested, pcs.	% of susceptible plants	% of resistant plants	Infestation degree, %
Control	77	100	0	8.3
96	653	60-71	30-59	4.9
61	488	51-55		11.3
24	201	34-41		16.8
6	59	-	100	-
In total: 187	1401	-	-	-

Source: *composed by authors*

During the autumn-winter-spring period of 2019-2020, 352 breeding numbers were evaluated (Table 6). This work resulted in the isolation of 14 accessions that showed resistance to Broomrape. These accessions were transplanted to carry out crosses for subsequent backcrossing and self-pollination. The use of vegetative vessels over several years has improved the evaluation of the breeding material under study under practical conditions. This method eliminated the possibility of mixing sunflower root shoots with nodules of Broomrape, which increased the accuracy of the evaluations. As a result, 14 accessions were isolated that proved to be resistant to Broomrape and will be used in further breeding work.

Table 6. *Results of analyses of sunflower breeding numbers (2019-2020)*

Number of lines, pcs.	Plants tested, pcs.	% of susceptible plants	% of resistant plants	Infestation degree, %
Control	125	100	0	16.4
211	1582	53-67	29-32	18.3
78	656	40-42	17-22	16.8
49	460	11-26	9-11	11.7
14	119	-	100	-
In total: 352	2942	-	-	-

Source: *composed by authors*

In 2020-2021, 443 breeding numbers including 68 hybrid combinations were evaluated in the artificial climate room (Table 7). As a result of this evaluation, both maternal and paternal forms with 100% resistance to Broomrape were isolated. Based on the evaluation results, the following hybrid combinations were included in the breeding process: (R-Spase × CB 65), (R-Spase × CB 31 Rf), (R-Spase × CB 268), (CB 8 × R-Berk), (CB 55 × R-Nica), (R-Spase-90 × R-Berk), and the lines R-Berk, R-Nica, SRS-82, SiR-99, CB-R, CB 8 and CB 55.

Table 7. *Results of analyses of sunflower breeding numbers (2020-2021)*

Number of lines, pcs.	Plants tested, pcs.	% of susceptible plants	% of resistant plants	Infestation degree, %
Control	470	100	0	14.2
249	2116	73-81	32-68	8.9

Table 7, Continued

Number of lines, pcs.	Plants tested, pcs.	% of susceptible plants	% of resistant plants	Infestation degree, %
103	814	52-61	14-41	11.3
78	647	40-46	16-21	10.8
13	86	-	100	-
In total: 443	4133	-	-	-

Source: *composed by authors*

During the autumn-winter-spring months of 2021-2022, 350 breeding numbers were evaluated. This set included 29 accessions that were pre-tested for seed production under artificial climates, 62 sterility fixing lines, 114 pollen fertility restoring lines and 145 new progenies obtained from breeding nurseries (Table 8).

Table 8. *Results of analyses of sunflower breeding numbers (2021-2022)*

Number of lines, pcs.	Plants tested, pcs.	% of susceptible plants	% of resistant plants	Infestation degree, %
Control	360	100	0	11.3
91	719	68-71	32-50	8.7
58	464	52-63	29-42	10.3
33	264	21-29	17-19	11.8
168	1310	-	100	-
In total: 350	3117	-	-	-

Source: *composed by authors*

To accelerate the breeding process in the creation of maternal lines and their fertile analogues of male sterility fixing lines, the method of sowing immature seeds was applied to obtain two generations under artificial climatic conditions and the third generation under field conditions. This approach made it possible to create new homozygous lines that proved to be resistant to Broomrape within 2-3 years. A total of 33 breeding numbers were obtained. In the winter of 2022-2023, 284 progenies of self-pollinated lines were tested (Table 9).

Table 9*. Results of analyses of sunflower breeding numbers (2022-2023)*

Number of lines, pcs.	Plants tested, pcs.	% of susceptible plants	% of resistant plants	Infestation degree, %
Control	336	100	0	11.2
64	512	63-69	32-41	8.3
41	324	49-51	29-34	6.7
29	242	28-33	23-28	14.8
150	1170	-	100	-
In total: 284	2584	-	-	-

Source: *composed by authors*

The main focus of the experiment was the evaluation and multiplication of promising breeding material. 150 selection numbers were identified, and two generations were obtained, each including 42 accessions. These accessions carry pollen fertility restoration (Rf) genes and 2 maternal forms (CMS) in combination with sterility fixers. To further study the Rf lines of the sixth and seventh generation of the insecta (I6-I7) under natural field conditions, 137 sunflower accessions were sown in the infected stationary experimental plot in 2023 (Table 10).

Table 10*. Evaluation of sunflower breeding material for herbicide resistance under artificial climate conditions*

Years of experiments	Resistant to Express			Resistant to Eurolightning		
	Estimated	Selected	Prospective numbers	Estimated	Selected	Prospective numbers
2016-2017	112	24	(93 × R 15) (92 × R 10) (45 × R 10) (123 × 1410) (123 × R 15) (19 × 10) and other	64	5	689/1, 723/1, 725/3, 725/4, 765/5
2017-2018	319	40	609/2, 612/2, 633/2, 650/1, SP 215, SP 222, SP 228 and other	58	4	685/10, 582/9, 683/2, 580/10
2018-2019	354	25	38/11, 33/9, 29/3, 34/5, 38/2, 34/13 and other	272	22	183/2, 183/3, 184/6, 185/5, 185/8, 192/3 CB215, CB219 and other

Table 10, Continued

Years of experiments	Resistant to Express			Resistant to Eurolightning		
	Estimated	Selected	Prospective numbers	Estimated	Selected	Prospective numbers
2019-2020	234	12	SP 329, SP 287, SP 341, SP 368, 6423/3, 6428/1, 6472/4 and other	136	4	CBK 629, CBK 712, CBK 763, CBK 766
2020-2021	184	115	SS 252, SS 262, SS 340, SS 268L, SS 269L, SS 332, SiS 45/4, SiS 43 (258 × Am 4), SiS 46/2 and other	92	6	CB 211/1, CB 214/3, CBK 811, CBK 842, CBK 798, CBK 781
2021-2022	347	224	6239/1, 6239/5, 6301/3, 6307/5, 6401/1, 6415/3, SP 347, SP 362, SP 388, SP 403 SP1459 and other	72	19	CBK 618, CBK 672, CBK 729, CBK 741, CBK 747, 6902/3, 6907/1, 6913/5 and other
2022-2023	400	208	249/3, 250/1, 256/3, 273/5, 286/3, 347/2, [BKU 140 × (258 × Am 4)-2], BKU 140 × Am1 SiS 44, SiS 45, SiS 44-1 and other	108	49	BKU 140 x (10 × Patra), BKU 140 x (10 × Patra)/2 5427, 5432, 5466, K 5, (80 × K5), K8 (80 × K 8), CBK 729 B, CBK 731 B, CBK 739 B and other

Source: *composed by authors*

Thus, as a result of experiments aimed at evaluating breeding material for resistance to herbicides of the sulfonylurea and imidazoline groups under artificial climate conditions, maternal and paternal forms were isolated. These forms became the basis for the creation of herbicide-resistant sunflower hybrids, such as Baiterek S and Baikonur, as well as interlinear sunflower hybrids Agrobusiness 2050 and Batyr, resistant to Broomrape of races E, F, which were entered in the Register of Breeding Achievements of the Republic of Kazakhstan in 2023.

DISCUSSION

Sunflower is a strategically important oilseed crop, and the area under sunflower cultivation continues to expand every year. However, this also provokes the emergence of new and more aggressive races of *Orobanche cumana Wallr.*, which is a parasite that is detrimental to the normal growth and development of sunflowers and can cause significant yield losses. The creation of sunflower hybrids (F1) involves crossing parental components that share several important characteristics, including herbicide and Broomrape resistance. Given that the creation of each of these components requires long and careful work in the breeding process, modern techniques and approaches are being used to accelerate the creation of new breeding material.

In vitro culture technology reduces the time required to develop herbicide resistant lines, for example. Pathogen resistance breeding usually involves testing on artificial infection media, both in the field and in the laboratory, to identify and isolate material with the desired resistant characteristics. This allows for more efficient selection and development of sunflower varieties and hybrids that will be resistant to both diseases and pests, as well as chemical defences (Kocira *et al.,* 2020). Thus, modern sunflower breeding aims to develop high-yielding varieties and hybrids that have not only high yields but also improved seed characteristics such as oil content, 1000-seed weight, huskiness. In addition, resistance to diseases and pests as well as adaptation to various abiotic factors are important criteria (Anastasi *et al.,* 2002).

In this regard, in order to establish the main components for hybrid combinations of sunflower D. Škorić *et al.* (2021) and E.O. Domaratskiy *et al.* (2018) paid attention not only to the quality of the source material, but also to its resistance to major diseases and pests. One of the main parasitic plants affecting sunflower is Broomrape (*Orobanche cumana Wallr.),* which is an obligate parasite and affects the root system of the host plant. Studies by scientists such as W. Adugna and M.T. Labushange (2002) and also D. Sisou *et al.* (2021) highlight the constant dynamics in the formation of new physiological races of the Broomrape, which represents a constant threat to sunflower. This evolution of the parasite emphasizes the need for continuous monitoring of Broomrape populations and ongoing research in this area, which also confirms the study carried out. At the same time, I. Sperdouli *et al.* (2022) notes that the specificity of resistance control to new, highly virulent races of Broomrape is determined by genetic factors. Genetic methods are becoming the best tools for Broomrape control. These methods allow identification and labelling of genes responsible for resistance, which contributes to more efficient breeding and development of varieties and hybrids resistant to the parasite, which is also confirmed by the study conducted.

A number of scientists, such as O. Kovalenko *et al.* (2021) and Z. Flagella *et al.* (2002) have identified and studied several key genes that are responsible for sunflower resistance to Broomrape. These genes were successfully labelled, representing a significant scientific breakthrough. This important step in breeding allows for more accurate detection of the presence of resistance in sunflower varieties and hybrids. Such markers allow breeders to more effectively select and develop varieties that are resistant to Broomrape. Thanks to the

developed gene labelling methods, breeding for resistance to Broomrape has become more accurate and accelerated. This opens up new perspectives for improving existing breeding methods and creating new, more progressive approaches to the development of sunflower varieties that are highly resistant to this pest.

An equally significant aspect is the study of the relationship between resistance to new virulent races of the Broomrape and the valuable economic characteristics of F1 hybrids, allowing the development of hybrids that combine two important aspects: resistance to the parasite and high yield. Understanding which hybrids have not only resistance to the Broomrape, but also the ability to achieve high yields, is key to developing efficient sunflower varieties. These hybrids not only help to reduce yield losses caused by Broomrape, but also increase overall productivity, which is an important factor for the agricultural industry and food security. Research in this area helps in identifying the optimum combinations of genetic traits to develop resistant and high yielding sunflower varieties and hybrids (Casali *et al.,* 2022).

In addition, the study conducted by P. Deepika and D.M. Ali (2020) revealed that the application of biological defence methods such as the use of bacterial inoculants has the potential to reduce sunflower infestation by Broomrape and increase yield. This study emphasizes the importance of developing and implementing biological pest and pathogen control methods in agriculture. Bacterial inoculants can help improve plant health and reduce infection levels, which in turn can lead to higher sunflower yields and provide more sustainable agricultural outcomes. These results also emphasize the importance of integrating biological defence methods into agricultural practices to improve crop sustainability and productivity.

V. Giannini *et al.* (2022) state that with climate change, including increasing temperatures, it is clear that the intensity of sunflower infestation by Broomrape may increase. This encourages breeders to develop varieties that are not only resistant to the parasite, but also adapted to abiotic stresses caused by climatic changes. J. Louarn *et al.* (2016) note that the use of artificial climatic conditions allows for faster breeding cycles. This means that breeders can more quickly select and develop varieties that exhibit desired resistance and other characteristics. This process also allows evaluation of which herbicides are effective in controlling the Broomrape and which sunflower varieties are most responsive to certain chemical defences. This is important for the development of recommendations on the use of herbicides in agriculture, which is also reflected in the study.

The results of the study are echoed in the scientific works of S. Cvejić *et al.* (2020), who state that the development of varieties with herbicide resistance allows agricultural producers to manage weeds more effectively and reduce weed control costs. In addition, sunflower varieties that are resistant to Broomrape and herbicides can provide higher quality seeds and oil, which is important for the food and oil and fats industry. Similar results were also obtained in a study by T.A. Howell *et al.* (2015), in which the authors state that evaluation of sunflower breeding material for resistance to Broomrape and herbicides has high practical importance for agriculture. The results of the study confirm the importance of breeding in creating sunflower varieties that can effectively cope with these damage factors and provide a stable level of yield.

Thus, the results of this study confirm the importance of evaluating sunflower breeding material for resistance to Broomrape and herbicides under artificial climate conditions. This study has significant implications for agriculture and breeding as it contributes to the development of new sunflower hybrids that have high yields, resistance to diseases and pests, and can reduce weed control costs. This is an important contribution to food security and sustainable agricultural development.

CONCLUSIONS

Sunflower breeding is an important tool for the modern agricultural sector. It enables the development of varieties that meet the diverse needs of the agricultural industry, providing higher yields, resistance to diseases and pests, adaptation to changing climatic conditions and improved product quality. From 2015 to 2023, Oilseeds Experimental Farm LLP carried out successful work to develop resistant sunflower lines with resistance to the parasitic plant *Orobanche cumana Wallr.* and herbicides of the sulfonylurea and imidazoline groups. These lines represent valuable breeding material and have potential for further use in sunflower breeding. The created lines were integrated into the breeding process in order to develop high-yielding interlinear sunflower hybrids. This allowed the development of new hybrids such as Agrobiznes 2050 and Batyr, which are resistant to Broomrape races E and F, as well as herbicide-resistant sunflower hybrids such as Baiterek S and Baikonur. It is important to emphasize that these outstanding hybrids have been included in the State Register of Breeding Achievements and recommended for use in agriculture in the Republic of Kazakhstan. This is an important step in ensuring the sustainability and increasing the productivity of sunflower.

The results of the experiment show that the study of resistance of sunflower varieties to Broomrape and herbicides is an effective way to control pests and weeds. It can help to increase yields and reduce yield losses. The results of the experiment not only contribute to the development of agriculture, but also have the potential for export and exchange of agricultural resources with other countries, which contributes to the development of the agricultural sector and strengthening

the position of the Republic of Kazakhstan in the world agri-food market. The practical significance of the study is the possibility of identifying genotypes and varieties of sunflower, which have increased resistance to harmful factors such as Broomrape and herbicides, which contributes to increased yields, and is of great importance for agricultural enterprises and food security. Molecular studies, identification of specific genes and genetic markers responsible for these traits may be a prospect for further research in sunflower breeding for resistance to Broomrape and herbicides, allowing more accurate and rapid selection.

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CONFLICT OF INTEREST

None.

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Оцінка селекційного матеріалу соняшнику на стійкість до вовчка (*Orobanche cumana Wallr.*) та гербіцидів в умовах штучного клімату задля прискорення селекційного процесу

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Анотація. Соняшник є важливою олійною культурою, тому збільшення його врожайності та стійкості до хвороб і шкідників може призвести до значного економічного покращення для сільськогосподарських підприємств і країни в цілому. Зміни клімату та поширення нових рас вовчка (*Orobanche cumana Wallr.*) створюють серйозні загрози для виробництва соняшнику, а дослідження в цій галузі допомагають розробити сорти, здатні адаптуватися до мінливих умов. Мета дослідження – комплексна оцінка селекційного матеріалу для виявлення найбільш стійких форм і гібридів соняшнику. Для досягнення мети проведено експеримент у період 2015-2023 років у ТОВ «Дослідне господарство олійних культур», у якому вивчали оцінку селекційного матеріалу соняшнику на стійкість до вовчка та гербіцидів. У результаті експерименту успішно створено лінії соняшнику, які мають стійкість до вовчка та гербіцидів, що сприяє підвищенню продуктивності та зниженню втрат урожаю. Створені лінії соняшнику були впроваджені в селекційний процес з метою розробки високопродуктивних міжлінійних гібридів соняшнику, що стало важливим етапом у поліпшенні сільського господарства Казахстану. Ці інноваційні гібриди, такі як «Agribusiness 2050» і «Batyr», проявили високу стійкість до вовчка рас E-F, що істотно знижує втрати врожаю і забезпечує надійну продукцію. Крім того, розроблено гербіцидостійкі гібриди, як-от Baiterek S і Baikonur, які дають змогу ефективно боротися з бур'янами та зберігати чистоту посівів, що важливо для збільшення врожайності та зниження витрат на обробіток ґрунту. Ці гібриди були рекомендовані для використання в сільському господарстві Казахстану і можуть сприяти підвищенню рівня продуктивності соняшнику. Дане дослідження сприяє розширенню наукових знань у галузі селекції та боротьби зі шкідниками соняшнику, що є актуальним напрямком для поліпшення сільськогосподарської практики та забезпечення продовольчої безпеки

Ключові слова: сорт; сільське господарство; експериментальні умови; генетичні маркери

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Biodiversity and functional roles of soil organisms: An analysis of millipede populations in Southern Albania

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Abstract. Soil organisms are an important component of the biodiversity of terrestrial biogeocenoses. Their considerable taxonomic and ecological variability determines a significant functional role in soil formation processes, mechanisms of sustainable development and productivity of natural ecosystems. The aim of the study is to develop a practical approach to the ecological assessment of soil organisms populations using the example of *Diplopoda* in the southern region of Albania. The study was carried out using general scientific methods of cognition: system and cluster analysis, synthesis, specification, abstraction, formalization, deduction, generalization, and the statistical method. The article systematizes and analyses statistical data on the assessment of populations of millipede species found in the study area. It considers the influence of environmental factors on the distribution of representatives of the class *Diplopoda*. It calculated the frequency of species according to the collection areas, constant values for the species of the three represented orders. Based on the data variety, composition of each zone is carried out with cluster analysis using Average Linkage. The similarity between zones is studied. The dendrogram obtained indicates the proximity of zones according to their diversity composition. Based on the results of the study, a system of tools was proposed as part of the ecological assessment of soil organisms populations, and the main approaches to its implementation were developed. The practical significance of the obtained results lies in the possibility of using them to study the dynamics of soil organism populations, including in the period of global climate change, to develop a dynamic approach to the ecological assessment of soil ecosystems and to implement an appropriate adaptation and regeneration strategy

Keywords: terrestrial ecosystem; *Diplopoda*; statistical data; geographical distribution; resistance; monitoring

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INTRODUCTION

Millipedes are a group of soil invertebrates characterized by significant species diversity in terrestrial ecosystems. As saprotrophs, millipedes perform a number of important functions, including fragmentation, transformation, and decomposition of litter in ecological systems, ensuring the recycling of carbon and nutrients, and regulating their cycle. In addition, the life cycle of millipedes affects the content of available phosphorus in the soil (Gestel *et al.*, 2021). These organisms interact with other soil organisms and can have a significant impact on the number of soil microorganisms.

Given the priority of the ecosystem approach to managing biogeocenoses, as well as the challenges of our time caused by global adverse climate change, there is a need to develop research on this topic to better understand the role of millipedes in ecosystem functioning and to develop an optimal approach to the ecological assessment of populations of these organisms. The latter can serve as a representative approach for effective ecological assessment of other soil organisms. An effective ecological assessment of soil organisms, subject to the requirements for the reliability of monitoring data, the organization of a system of practical ecological and biological research and the use of innovative scientific and technological capabilities, can solve a number of problems in the ecosystem management system.

The results of research by modern scientists led by G. Deckmyn *et al.* (2020), as well as M. Delgado-Baquerizo *et al.* (2020) and N. Eisenhauer *et al.* (2021) indicate that ecological indicators such as frequency, constant, and processing statistics show how ecological factors influence the spread of *Diplopoda*. At the same time, V. Langraf *et al.* (2021) and X. Zeng *et al.* (2023) emphasize in their works the fact that a sharp increase in the frequency of occurrence and the strength of the impact of anthropogenic factors threatens the sustainable functioning of soil ecosystems in the future. Researchers A. Potapov *et al.* (2022) in a recent publication highlighted the peculiarities of modern approaches to the ecological assessment of the population of living organisms, as well as the strategy of adaptation to climate change. Researchers C. Guerra *et al.* (2021) substantiate the expediency of using modern predictive modelling capabilities and innovative monitoring capabilities to identify significant factors of impact on ecosystems and populations of organisms, in particular.

The scientific community studies millipede populations mainly from the classification and description approach. Information about the representatives of *Diplopoda* in Albania is based on the results of scientific works of local and foreign researchers, in particular H. Kicaj and M. Oirjo (2023). Scientists are studying the peculiarities of the spatial distribution of millipedes, depending on the intensity of the impact of climatic factors on the population. It should be noted that current research on the ecological functions of millipedes is very narrow and limited. Given the limited functionality of scientific research on the issues considered in this study, it is necessary to expand the parameters for assessing the ecological status of populations of soil organisms, to deepen the study of their adaptive capabilities, and to carefully analyse the set of interrelations and interdependencies between elements of soil biogeocenosis. It is also advisable to implement the basic principles of sustainable development of ecosystems into the methodology of ecological assessment of soil organisms.

Currently, many issues related to the ecology of the class *Diplopoda*, especially in Albania, remain unresolved. The aim of the study was to investigate the peculiarities of the functioning of soil organism populations using the example of *Diplopoda* representatives in the southern region of Albania, as well as to develop an effective approach to the ecological assessment of such populations as representative ones.

MATERIALS AND METHODS

In the course of the research, general methods of scientific knowledge were applied. General scientific methods of cognition were used in the course of the work: system and cluster analysis, synthesis, specification, abstraction, formalization, deduction, generalization, and the statistical method. The formation of a system of regularities and features of the object of study of the influence of a set of factors on the processes occurring in populations of soil organisms was implemented using the method of generalization. The method of ascending from the abstract to the concrete was applied in the context of the transition from general knowledge about the vectors of climate change on populations of living organisms to the essence of the consequences of such impact on populations of soil organisms, in particular, specific species of *Diplopoda*. Using system analysis, the structural links between the elements of the phenomenon under study were established, and existing approaches to the ecological assessment of populations of living organisms were studied. The method of deduction was used to highlight the essence of the negative impact of anthropogenic pressure on the development and functioning of soil organisms. Also, some ecological and statistical indicators are used to assess *Diplopoda* populations.

Constant (c) expresses the ratio between the number of samples where the species are found and the total number of samples taken. It is used to determine the constant groups of soil fauna on which the study was conducted. This classification is made: for values of constant from 50-100, the group is considered "constant"; for values of constant from 25-50, the group is considered a "companion"; for values of constant from 0-25, the group is considered "casual" (Mauries *et al.*, 1997).

Frequency (f): report of the individuals expressing a kind on the total number of individuals collected. Determination of this indicator is intended to give its performance for any stage within each and between different stations. For the studying of the variety, the Sorenson indicator is used (1):

$$d = \frac{S-1}{\log N}. \quad (1)$$

This indicator helps to assess the degree of variety of species between stations or different areas defined previously. The size of samples that have been calculated is different and also the relative density of each type (2):

$$d = \frac{H}{\log 2\ N}, \quad (2)$$

where H is the Shannon index as an indicator of overall variety (3, 4):

$$H = -\Sigma\pi \log \pi, \quad (3)$$

$$\pi = \frac{Ni}{N}, \quad (4)$$

where "Ni" – the number of individuals of type "I", "N" – the total number of individuals.

The relative density of any kind of theory differs from "0" to "1". He tends to move toward "0", when almost all the effective belongs to a type, while tends to "1" when each type is represented by the same number of individuals. Based on data, variety composition of each zone is carried out with cluster analysis using the Average Linkage method. The similarity between zones is studied. The dendrogram obtained indicates the proximity of zones according to their variety composition.

RESULTS

The essence of the ecological assessment of populations of living organisms is mainly to study the development processes, viability of individuals, resilience and adaptability, and the nature of their environment (Creamer *et al.*, 2022). Strategic assessment is also seen as a necessary component, which includes elements of forecasting and the development of appropriate measures for the purpose of preventive protection, rational exploitation and regeneration of ecosystems. It is worth noting that, in general, the main ecological characteristics of a population are its range, density, number, population dynamics, as well as age, spatial and sex structures (Le Provost *et al.*, 2021).

An effective environmental assessment is impossible without the use of monitoring tools that provide a complete information base on changes in the main parameters of the population, the nature, and intensity of the impact of external factors and anthropogenic pressure. The main parameters for effective monitoring of populations are the number of individuals, the population area, reproduction and population structure parameters, and the level of anthropogenic pressure (Burton *et al.*, 2022). Population studies should be aimed at recording the total number of individuals and the dynamics of the indicator in the time aspect. Studying changes in the population's range allows the identification of fragmentation features. In general, the main task of a population monitoring system is to record the result of the interaction between the natural environment and anthropogenic load in terms of the impact on the population of specific organisms, taking into account the factors of dynamics and natural regeneration (Potapov *et al.*, 2022). At the same time, the range of monitoring parameters can be significantly expanded and adapted to the population under study, in this case, to the characteristics of millipedes as representative organisms of the soil environment.

One of the important structural elements of the ecological assessment of populations of soil organisms is the formation of prognostic parameters of population functioning (Guerra *et al.*, 2021). In this case, the forecasting should be based on the results of analytical processing of observations of long-term dynamics of the structure and characteristics of the population. Thus, it can be argued that an effective ecological assessment of soil organism populations should be based on arrays of monitoring information on the structural and functional organization of the population, the peculiarities of relationships within the ecosystem, and trends in the dynamics of environmental parameters. Particular attention should be paid to the study of microevolutionary processes occurring in populations under conditions of anthropogenic pressure on the environment and global climate change.

The class *Diplopoda* includes terrestrial organisms, phytophages. Their distribution is influenced by numerous factors, among which the most decisive are temperature, humidity, altitude, soil type, phytocoenosis and the size of decomposing plants. The study compared territories according to various parameters as part of an ecological assessment of the population of soil organisms, using the example of *Diplopoda* in the southern region of Albania. The statistical data were collected over several years in the basic areas of the study. In addition, in order to expand the information base of the current work, the results of researches by H. Kicaj (2023) and H. Kicaj & M. Qirjo (2014) were used, which provided a detailed analysis of the effect of temperature and humidity on the distribution of representatives of the family Glomeridae belonging to the class *Diplopoda*. The researcher notes that the smallest number of *Diplopoda* was isolated from the natural environment in July and August, as this period of the year is the driest in Albania. In addition, the researchers analysed the distribution of *Diplopoda* populations in the soil profile. Most of them lived in the litter and at a depth of up to 10 cm, and only 18% of millipedes migrated to a depth of 10-20 cm.

This study presented the data for the number of individuals for any of the species collected. The analysis of these data constitutes the basis of calculating the ecological indicators: constant, frequency, Shanon indicators (H), and relative density of any kind (ē). In the Table 1 are given the defined types of the *Diplopoda* class, the value of the constant, and the group to which these types belong.

Table 1. *The constant value for three represented orders*

No.	Species	Constant, %	The relevant group
	Order *Julida*		
1	*Anoploiulus pusillus* (Leach 1814)	100.00	Constant
2	*Megaphyllum karschi* (Verhoeff 1901)	62.50	Constant
3	*Pachyiulus cattarensis* (Latz 1884)	50.00	Constant
4	*Pachyiulus dentiger* (Verhoeff 1901*)*	37.50	Companion
5	*Pachyiulus varius* (Fabricius 1781)	37.50	Companion
6	*Ommatoiulus sabulosus* (Line 1758)	37.50	Companion
7	*Cylindroiulus boleti* (C.L. Koch,1847)	37.50	Companion
8	*Leptoiulus trilineatus* (C.L. Koch,1847)	25.00	Companion
9	*Pachyiulus hungaricus* (Karsch,1881)	25.00	Companion
10	*Pachyiulus valonensis* (Verhoeff 1901)	25.00	Companion
11	*Anoploiulus apfelbecki* (Verhoeff 1898)	12.50	Casual
12	*Leptoiulus macedonicus* (Atems,1927)	12.50	Casual
13	*Typhloiulus albanichus* (Atems 1929)	12.50	Casual
14	*Nopoiulus kochii* (Gervais 1847)	12.50	Casual
	Order *Polydesmida*		
15	*Polydesmus complanatus* (Verhoeff 1901)	12.50	Casual
16	*S. stigmatosum balcanicum* (Schubart, 1937)	25.00	Casual
	Order *Glomerida*		
17	*Glomeris pulchra* (C.L.Koch. 1847)	87.50	Constant
18	*Glomeris bureschi* (Verhoeff 1926)	33.15	Companion
19	*Glomeris hexastica* (Brandt,1833)	12.50	Casual
20	*Glomeris balcanica* (Verhoeff, 1906)	12.50	Casual
21	*Glomeris pustullata* (Latrielle 1804)	12.50	Casual
22	*Glomeris latermarginata* (Villers 1789)	12.50	Casual

Source: *compiled by the authors*

Based on the method of material collection and the representation of the stations within each area, can see that the constant value according to the area is more representative. According to the represented orders, the following results are noticed: *Anoploiulus pusillus*, *Megaphyllum karschi*, *Glomeris pulchra*, which result in widespread in the study area. The species encountered for the first time in Albania have been noticed to have a constant value: *Polydesmus complanatus*, *Strongylosoma stigmatosum balcanicum*, *Glomeris latermarginata*, and consequently considered casual. The represented individuals of the order *Polydesmida* are considered random species. The number of species is the least represented in the area of study. Species with a constant value over 50% are evaluated as constant species*: Pachyiulus cattarensis*. Frequency per zones. The frequency of species for each collection station was calculated (Table 2).

Table 2. *Frequency of species according to the collection areas*

Species/Zone	Vlora	Shashica	Llogara	Shushica	Borsh	Delvina	Butrint	Kardhiq
			Order: *Julidae*					
Pachyiulus cattarensis (Latz, 1884)	0.49			0.08		0.36	0.08	
Pachyiulus dentiger (Verhoeff, 1901)	0.04	0.04	0.02	0.09				
Pachyiulus varius (Fabricius, 1781)	0.04			0.21	0.46			
Pachyiulus valonensis (Verhoeff, 1901)	0.07				0.04		0.36	

Table 2, Continued

Species/Zone	Vlora	Shashica	Llogara	Shushica	Borsh	Delvina	Butrint	Kardhiq
Pachyiulus hungaricus (Karsch, 1881)			0.01					0.02
Anoploiulus apfelbecki (Verhoeff, 1898)	0.02							
Anoploiulus pusillus (Leach, 1814)	0.13	0.21	0.16	0.09	0.18	0.17	0.28	0.89
Megaphyllum karschi (Verhoeff, 1901)	0.06	0.22	0.28	0.14		0.14		
Ommatoiulus sabulosus (Line, 1758)		0.09	0.08				0.06	
Cylindroiulus boleti (Koch, 1847)		0.09		0.05				0.06
Leptoiulus trilineatus (Koch, 1847)			0.02		0.02			
Leptoiulus macedonicus (Atems, 1927*)*						0.02		
Typhloiulus albanichus (Atems, 1929)			0.03					
Nopoiulus kochii (Gervais, 1847)			0.02	0.02				
Rendi: *Polydesmida*								
Polydesmus complanatus (Verhoeff, 1901)			0.01					
S. stigmatosum balcanicum (Schubart, 1937)		0.09		0.11				
Rendi *Glomerida*								
Glomeris hexastica (Brandt, 1833)						0.13		
Glomeris pulchra (Koch, 1847)	0.15	0.08	0.26	0.06	0.12	0.17	0.22	0.03
Glomeris bureschi (Verhoeff, 1926)		0.05	0.06	0.16	0.18			
Glomeris balcanica (Verhoeff, 1906)			0.04					
Glomeris pustullata (Latrielle, 1804)		0.11						
Glomeris latermarginata (Villers, 1789)			0.01					
	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Source: *compiled by the authors*

It is referred from the data that the frequency of species is very variable according to the area. Thus, *Anoploiulus pusillus* has a high frequency in Kardhiq (89%); *Pachyiulus cattarensis* in the Bay of Vlora (49%) and Delvina's hollow 36%; *Pachyiulius varius* with high frequency in Borsh 46%; *Pachyiulus valonensis* with high frequency 28% in Butrint (Table 3, 4). It is also observed from the table is observed that the frequency of types of Order Julida is significantly higher than that of the two others. Since the size of the samples has been different, authors have also calculated the relative density of each kind.

Table 3. *Index of relative density of any kind*

Species/Zone	Vlora	Shashika	Llogara	Shushika	Borsh	Delvina	Butrint	Kardhiq
Order *Julidae*								
Pachyiulus cattarensis (Latz, 1884)	0.09			0.23		0.12	0.14	
Pachyiulus dentiger (Verhoeff, 1901)	0.18	0.30	0.43	0.22				
Pachyiulus varius (Fabricius, 1781)	0.17			0.17	0.10			
Pachyiulus valonensis (Verhoeff, 1901)	0.15				0.22		0.09	
Pachyiulus hungaricus (Karsch, 1881)			0.55					0.21

Table 3, Continued

Species/Zone	Vlora	Shashika	Llogara	Shushika	Borsh	Delvina	Butrint	Kardhiq
Anoploiulus apfelbecki (Verhoeff, 1898)	0.24							
Anoploiulus pusillus (Leach, 1814)	0.12	0.17	0.17	0.22	0.13	0.15	0.09	0.03
Megaphyllum karschi (Verhoeff, 1901)	0.15	0.16	0.14	0.19		0.16		
Ommatoiulus sabulosus (Line, 1758)		0.21	0.21				0.16	
Cylindroiulus boleti (Koch, 1847)		0.21		0.26				0.09
Leptoiulus trilineatus (Koch, 1847)			0.37		0.40			
Leptoiulus macedonicus (Atems, 1927)						0.44		
Typhloiulus albanichus (Atems, 1929)			0.31					
Nopoiulus kochii (Gervais, 1847)			0.43	0.47				
Order *Polydesmida*								
Polydesmus complanatus (Verhoeff, 1901)			0.55					
S. stigmatosum balcanicum (Schubart, 1937)		0.21		0.20				
Order *Glomerida*								
Glomeris hexastica (Brandt, 1833)						0.17		
Glomeris pulchra (Koch, 1847)	0.12	0.22	0.15	0.25	0.15	0.15	0.10	0.13
Glomeris bureschi (Verhoeff, 1926)		0.26	0.23	0.18	0.13			
Glomeris balcanica (Verhoeff, 1906)			0.26					
Glomeris pustullata (Latrielle, 1804)		0.20						
Glomeris latermarginata (Villers, 1789)			0.55					

Source: *compiled by the authors*

Table 4. *Shannon Index according to zones*

Zone	Vlora	Shashica	Llogara	Shushice	Borsh	Delvina	Butrint	Kardhiq
Shannon index (H)	0.69	0.90	0.86	0.94	0.63	0.70	0.46	0.21

Source: *compiled by the authors*

From this table appears that the variety of *Diplopoda* collected in eight areas of study varies significantly. Higher values in Llogara, Shushica, Shashica, authors think are related to vegetation, and to the amount of material in decomposition, and the microclimate created in these environments. While lower values are associated with the collection of material in open environments, in the absence of vegetation and infields. Authors have compared the species according to the areas where they are found. The data is presented in the Figure 1.

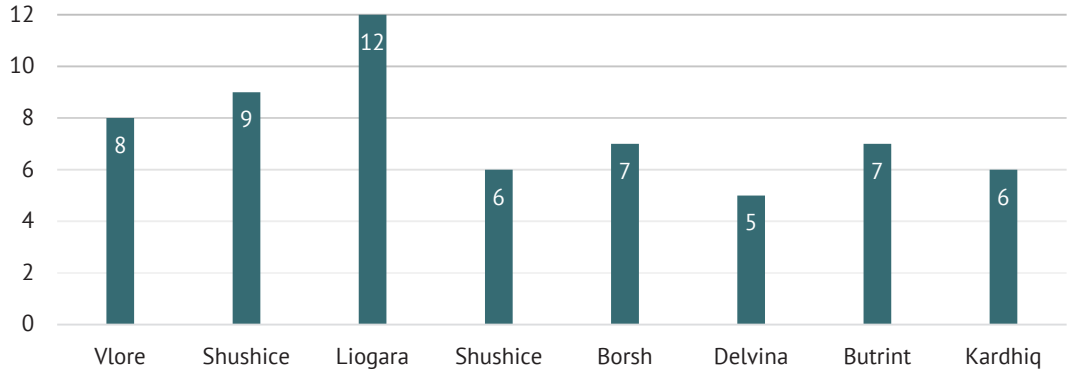

Figure 1. *The number of species in areas collected*

Among the areas taken in the study, the following areas result with greater variety: Llogara-Karaburun (12 species), Vlora city (eight species), and Shashica-Tragjas (nine species). These areas have a high percentage of humus, decomposed leaves, and good decomposition. Lands are classified according to constituent elements, an earth category V, VI, VII. Result with fewer species Delvina's station, Butrint-Stillo, Kardhiq, and Shushica's

Valley respectively with 5, 7, and 6 species defined. Collection stations in these areas are presented with low biodiversity and poor land with alimentary elements. Variety differs even within the same area, at various collection stations. These changes are evident in the values of frequencies according to zones and stations. The areas' similarity according to species. Based on the variety of species of each zone, cluster analysis is carried out using Average Linkage. The zone of Llogara is separated from other areas. The high biodiversity in this area, the height of the collection areas, and the high content of decomposed material affect the variety of this zone. In the context of this study, eight species are referred to for the first time in this area. In similarity between areas Tragjas-Shashicë and Kardhiq factor that could affect is the type of land. The data according to pedology for these collection stations represent similarities in composition and type of land.

Among other stations, a rough grouping of stations Delvine, Butrint, Vlore, and Borsh can be influenced by climatic factors, the similarity of vegetation, and height above sea level. Areas of Borsh have differences between them. The collecting places for this area have started in the valley Fterra-Borsh with rich vegetation and Mediterranean shrubs, the valley of this area presents high climate change. The functioning of ecosystems is based on the principle of energy binding, thus preserving the internal organization of the structure. If there is a significant gradient between the energy reserves of individual components of the ecosystem, an imbalance occurs, with a significant increase in entropy and a decrease in the level of orderliness (Arnolds *et al.*, 2023). In such conditions, natural ecosystems are no longer able to maintain a state of stability, energy flows are dynamically changing in vertical and horizontal dimensions, and the ecosystem becomes unable to counteract external destructive influences.

Today, it is still possible to prevent the negative effects of climate change on soil ecosystems by applying appropriate technical, economic, and management measures. Modern scientific forecasts require the development of an appropriate plan of preventive and regeneration measures and their consistent implementation. The effectiveness of the soil ecosystem management system in the face of negative climatic trends depends on the adaptive capacity of the system, which, in turn, is determined by genetic variation of traits (De Deyn & Kooistra, 2021). It is worth noting that the basis of soil ecosystems is the biotic component, which ensures adaptation to new environmental conditions and effectively counteracts the impact of destabilizing exogenous factors.

For optimal ecological assessment of populations in the context of ecosystem dynamics, it is necessary to organize monitoring, including observation of soil organisms and their habitats, as well as forecasting changes to ensure a sustainable ecosystem. A prerequisite for effective monitoring is regular comprehensive research using modern scientific achievements and innovative technological capabilities. It is advisable to select a representative network of test sites with different types of zonal features of soil ecosystems. The implementation of systematic ecological and biological research allows for a full ecological assessment of soil organism populations, as they are a sensitive indicator of the state of the environment. In addition, the management of sustainable ecosystems involves the development of an ecological network to preserve the natural environment and individual species in the face of climate change.

DISCUSSION

The results obtained in this study are in line with the findings of many researchers. Firstly, most scientists are unanimous in their belief that climatic factors play a significant role in the geographical distribution of millipedes. At the same time, scientists D. Bachvarova *et al*. (2022) note that with the onset of drought, millipedes burrowed into deeper soil layers. This may indicate a wide range of ecological tolerance of the studied species. The results of the current study are in line with the following conclusions of scientists: the distribution of *Diplopoda* populations indicates a rather high adaptive capacity of organisms. At the same time, climatic factors such as temperature and humidity affect the geographical distribution of soil organisms.

Recent studies by M. de Oliveira (2019), T. de Almeida (2022), and R. Bouzan *et al.* (2022) show that, in addition to climatic factors, the distribution of the organisms under study is influenced by phytocoenosis and soil composition. Scientists argue that soil with a high content of humus and nitrogen is a more favourable habitat for the *Diplopoda* class. Researchers believe that the nature of the phytocoenosis plays a minor role in the spatial distribution of *Diplopoda* populations. At the same time, soil with a high content of humus and nitrogen is a favourable factor for their functioning. However, similar data for Albania is virtually non-existent. The current study analysed the distribution of *Diplopoda* populations related to vegetation, the amount of decomposing material, and the microclimate created in these environments. Obviously, lower population figures are associated with the collection of material in open environments, in the absence of vegetation and fields. Thus, it can be argued that phytocoenosis and soil composition have a significant impact on the ecological parameters of soil organisms.

In addition, an important parameter of the ecological characteristics of millipede populations is their vertical distribution in the soil profile. Most species are able to migrate between different soil layers to adapt to unfavourable environmental factors. Such conclusions of the study coincide with the results of scientific research by Z. Tóth & E. Hornung (2020). The scientists carried out a comparative analysis of the vertical

distribution of millipedes, which is synergistic with the results of research on the southern region of Albania in the current study. The researchers note that *Diplopoda* are saprophages, so they mostly live on the soil surface in the forest floor and in the forest litter. In addition, *Diplopoda* are more tolerant of low humidity. Modern researchers K. Arnolds *et al*. (2023) pay special attention to the role of an effective ecological assessment of soil organisms in the ecosystem management system. At the same time, they emphasize the need to establish effective population monitoring of species to form an information base for further assessment and development of preventive and regeneration measures. It is difficult to disagree with the conclusions of the scientists.

Scientists X. Sun *et al*. (2022) and W. So *et al*. (2022) identify priority areas of practical implementation within the monitoring system, including the allocation of population areas, study of the spatial structure and habitat changes. At the same time, G. Blume-Werry *et al*. (2023) argue that habitat analysis requires an integrated approach, i.e. it is advisable to monitor both the abiotic component of the habitat (in particular, the characteristics of the soil cover) and the biotic component (e.g. species living nearby). According to the scientists, this monitoring parameter is of paramount importance, as it demonstrates the dynamics of habitats and the causes of its occurrence (e.g., drought, anthropogenic factors, floods). The conclusions of the current study are in line with such beliefs. It should be added that habitat monitoring should be carried out both in conditions that are comfortable for populations and in unfavourable conditions. Information on the characteristics of habitats in different conditions, in terms of comparative analysis, may be of scientific and practical value in the reconstruction or reintroduction of populations.

It is worth noting that effective monitoring of soil organism populations can be carried out not only by standard methods, but also by simplified visual assessments of parameters that reflect the basic parameters of the population's state. It is undeniable that individual parameters specific to each species can play the role of markers of population status. However, for certain species, it may be preferable to use reasonable minimized integral indicators that can be used to assess the ecological status of the population (Yarwood *et al.*, 2020; Gunstone *et al.*, 2021; Asato *et al.*, 2023). Based on monitoring data, it is possible to conduct an integrated ecological assessment of population indicators for rapid diagnosis of their condition.

Taking into account the results of the current study and the results of scientific research, it can be argued that the vital activity of most *Diplopoda* species in the southern region of Albania takes place in conditions of ecological compliance with the main limiting factors, including the water regime and soil moisture level, soil salt regime and nutrient content, and temperature fluctuations. The populations of the studied organisms are quite stable and tolerant to minor changes in environmental factors. In general, the problem of studying the ecological characteristics of millipede populations in Albania was complex and multidimensional. The current study creates prerequisites for its further comprehensive study. The main directions of prognostic prospects for further scientific research include improving approaches to the ecological assessment of soil organisms populations based on the principles of individualization and sustainable development of the ecosystem.

CONCLUSIONS

As a result of the study, the peculiarities of the functioning of soil organisms populations were analysed on the example of *Diplopoda* in the southern region of Albania, and an effective approach to the ecological assessment of such populations as representative ones was developed. The paper scientifically substantiates the principles of determining the parameters of the ecological status of populations of certain species of soil organisms at the biogeocenosis level, based on the concept of ecological niche. In addition, the basics of scientific and methodological tools for assessing the spatial variation of the population within the framework of environmental assessment have been developed.

It was found that *Pachyiulus varius*, *Anoploiulus pusillus*, *Pachyiulus cattarensis*, *Glomeris pulchra*. These are species with wide spreading regional but in Albania. The zones that have a bigger number of species are Llogara and Shashica. The presence of forest environments, materials in decomposition, and microclimate elements influence the degree of high variety. Some sampling stations present similarities in terms of the species found. In the proximity between the areas affected: high above the sea level stations and collection materials, similarity in the composition and type of land, climatic factors, vegetation almost similar in most collecting areas, which dominates the growth of vegetation. Among areas of study, those with the greatest similarity of variety are Delvina – Butrinti – Vlora, and Tragjas – Kardhiq. While Llogara is estimated as the most different area. Although studies need more specific comparisons, authors think that this result is a consequence of the similarity of the areas and of other factors such as pedology, climate, and vegetation, predators.

The paper substantiates the need to improve existing approaches to effective and reliable ecological assessment of soil organism populations. In addition, the main prerequisites and factors for the effective implementation of the ecosystem management system under negative weather and climate trends, as well as taking into account the specifics of the soil habitat, are identified.

Based on the results obtained in this work, the author proposes priority vectors for further research on the topic, and substantiates the need to organize the availability and systematization of research and practical information on the methodology of ecological

assessment of populations of living organisms. There is a need for further study of the problem in the regional context, with the use of modern tools for forecasting and adaptation modelling.

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CONFLICT OF INTEREST

None.

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Біорізноманіття та функціональна роль ґрунтових організмів: аналіз популяцій багатоніжок у Південній Албанії

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Анотація. Ґрунтові організми являють собою важливу складову біологічного різноманіття наземних біогеоценозів. Їх значна таксономічна та екологічна варіативність зумовлює вагому функціональну роль в процесах ґрунтоутворення, механізмах сталого розвитку та продуктивності природних екосистем. Метою дослідження було розробка практичного підходу до екологічної оцінки популяцій ґрунтових організмів на прикладі *Diplopoda* у південному регіоні Албанії. Дослідження здійснювалось з використанням загальнонаукових методів пізнання: системного та кластерного аналізу, синтезу, конкретизації, абстрагування, формалізації, дедукції, узагальнення, а також статистичного методу. У статті систематизовано та проаналізовано статистичні дані щодо оцінки популяцій видів багатоніжок, виявлених на досліджуваній території. Розглянуто вплив екологічних факторів на поширення представників класу *Diplopoda*. Розраховано частоту видів відповідно до зон збору, константні значення для видів трьох представлених порядків. На основі отриманих даних проведено кластерний аналіз видового складу кожної зони з використанням методу середніх зв'язків (Average Linkage). Вивчено подібність між зонами. Отримана дендрограма вказує на близькість зон за видовим складом. За результатами дослідження було запропоновано систему інструментів в складі екологічної оцінки популяцій ґрунтових організмів, розроблено основні підходи щодо її реалізації. Практична значимість отриманих результатів полягає в можливості їх використання для дослідження динаміки розвитку популяцій ґрунтових організмів, в тому числі у період глобальних кліматичних змін, розробки динамічного підходу до екологічної оцінки ґрунтових екосистем та реалізації відповідної стратегії адаптації та регенерації

Ключові слова: наземна екосистема; *Diplopoda*; статистичні дані; географічне поширення; резистентність; моніторинг

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The influence of different fertilization regimes on the yield and nutrient content of the sugar beet crop

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Abstract. Sugar beet is one of the crops with high industrial significance, the reduction of the area of its crops in Ukraine in recent years actualizes the development of technologies for increasing yield and technological indicators of the crop. The research aims to study different regimes of applying mineral fertilizers on productivity, and the content of soluble sugars and proteins in sugar beet. The field study was conducted in the period of April-September 2023. The pre-sowing treatment was carried out using a hybrid of the productive and sugary direction Oleksandria employing deep ploughing up to 30 cm deep, the seeding density was 100 thousand/ha. The fertilization scheme provided for the introduction of a combination of complex fertilizers in one of two concentrations: $N_{180}P_{150}K_{200}$ or $N_{250}P_{200}K_{280}$ and a growth stimulator based on amino acids and trace elements Quantum. The application was carried out separately or in combination, the frequency of fertilization was one or two times. It has been demonstrated that the most pronounced positive effect on the increase in biomass

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and sugar content of beets is caused by the combined application of mineral macro fertilizers with the drug Quantum. In the case of the combined application option, the increase in the biomass of the root crop compared to the control was 120.8±8.5%-143.0±14.3%; the increase in the content of soluble sugars – in the range from 4.23±0.6% to 5.3±0.45%. An increase was also observed in comparison with the variants of separate applications of fertilizers. There was no significant difference between the two applied fertilizer concentrations, as well as when individual fertilizers and their combinations were re-applied. The content of proteins in terms of dry weight increased depending on the concentration and frequency of application of complex fertilizers. The obtained data on the increase in biomass of sugar content indicate the expediency of increasing these indicators is the use of a combination of mineral fertilizers containing macro- and microelements, so it is advisable to recommend a similar mode of fertilization. The data can become the basis for the development of recommendations for implementation in the industrial cultivation of sugar beet. Such techniques are economically feasible, as they allow for a reduction in the number of treatments and the consumption of fertilizer to obtain a harvest with high indicators

Keywords: trace elements; macronutrients; growth stimulant; agrotechnical characteristics; sowing treatment

INTRODUCTION

Sugar beet is one of the crops of strategic industrial and national importance. In recent years, Ukraine has seen a significant and progressive reduction in sugar beet acreage: from 318,000 hectares in 2017 to 220,000 hectares in 2023. Irrational use of soils, lack of proper crop rotation planning, reduction of areas under perennial grasses and legumes, as well as climatic factors, lead to a decrease in the fertility of black soil (Gamajunova *et al*., 2021). Another unpredictable factor in soil erosion is the full-scale Russian invasion of Ukraine, which caused a reduction in the area available for agricultural cultivation, with some soil areas experiencing erosion and loss of fertility due to explosions and demining (Drobitko *et al*., 2023). Under the current circumstances, it is particularly important to make the most efficient use of the available areas to obtain the highest possible yield. Although beet cultivation technologies have been known and used for a long time, there is a need to improve them due to the peculiarities of changing climatic conditions, soil composition, and peculiarities of changing plant varieties (Hospodarenko & Martyniuk, 2020). Among the known ways to increase yields are the application of organic and mineral fertilisers, as well as the use of growth stimulants. For most macro- and microelements, the concentrations required to obtain a certain yield weight are set, so their application is the key to obtaining the predicted weight of the beet crop (Tyrus, 2018). The dependence of yield and sugar content is shown in many modern studies, while the selection of the amount of fertiliser, conditions and method of application should be selected considering the specific conditions of cultivation: soil characteristics and climatic conditions in the area of cultivation.

The experience of international authors can be useful in developing beet cultivation schemes, but soil and climatic conditions require adaptation, so it is important to consider the experience of Ukrainian scientists. M. Tyrus (2018) studied the influence of tillage methods and different regimes of nitrogen, potassium and phosphate fertilisation and demonstrated that, regardless of the tillage method, the application of higher fertiliser concentrations led to an increase in root crop weight. O.V. Pismennyi (2012) demonstrated the importance of using micro fertilisers containing phytohormones and trace elements to increase the yield of table beet. S. Shahini *et al*. (2023) in their study of the quality of agricultural soils indicate that there is a reverse problem with the use of mineral fertilisers: the accumulation of some elements and products of their transformation in the soil, and increased eutrophication. M.O. Lukyaniuk *et al*. (2021) describe the problem of the negative effects of excess nitrogen in the soil, especially when it is accompanied by a lack of potassium and phosphorus. The authors draw attention to the need to select fertiliser doses since despite the importance of nitrogen for increasing sugar content, high doses (over 120 kg/ha) have the opposite effect: a decrease in yield and sugar yield. In this regard, the use of fertilisers should be as rational as possible, ensuring maximum absorption by plants, so it is important to monitor soil agrochemical parameters and study the needs of individual crops.

The main industrially valuable component of sugar beet raw materials is soluble sugars, namely sucrose. However, production wastes, in particular sugar pulp, can be a valuable source of other nutrients for feed production (Türk & Arslanoglu, 2023). Therefore, it is also important to determine the protein value of the resulting crop. The research aims to determine the influence of fertilisation regime on the increase of root biomass and soluble sugars and protein content in sugar beet crops.

MATERIALS AND METHODS

The field study was conducted in April-September 2023. Pre-sowing cultivation was carried out by deep ploughing up to 30 cm deep. The soil belongs to the type of ordinary low-humus dusty light clay soil. Before sowing the seeds, the agrochemical characterisation of the soil of the experimental area was carried out, using the following methods: humus content – according to Tyurin; alkaline hydrolysable nitrogen – according

to the Kornfield method; mobile forms of phosphorus and potassium – determination by Chirikov (Ovcharuk *et al.*, 2019). pH was determined ionometrically.

The study of the effect of mineral fertilisers on beet yields was conducted using the yield-sugar beet hybrid Alexandria, which has been included in the State Register of Varieties and Hybrids since 1997. The planting density was 100 thousand/ha. The following concentrations were used as the baseline level of mineral fertilisers in terms of the main elements: $N_{180}P_{150}K_{200}$, with higher concentrations used as a second option: $N_{250}P_{200}K_{280}$. The Quantum growth stimulator, which is a mixture of amino acids and trace elements, was also used separately. According to the manufacturer's instructions: N – 9.5% (95 g/l); CaO – 2.0% (20 g/l); MgO – 1.5% (15 g/l); Fe – 1.2% (12 g/l); Zn – 1.2% (12 g/l); Cu – 0.7% (7 g/l); SO3 – 1.8% (18 g/l); Mn – 0.7% (7 g/l); B – 0.5% (5 g/l); Mo – 0.01% (0.1 g/l); amino acids – 5% (50 g/l). The stimulant was applied at a concentration of 1.5 litres/ha. Each of the mineral fertilisers was applied separately once: during pre-sowing cultivation, or twice: the second fertilisation was applied 30 days after sowing. In variants with combined micro fertiliser application, they were applied simultaneously with mineral fertilisers, 30 days after sowing. In case of repeated application, micro fertilisers were applied 30 days after the first application. All fertiliser application options are presented in Table 1.

Table 1. *Fertiliser options and combinations*

Control	-	No treatment
One-time treatment	1	$N_{180}P_{150}K_{200}$
	2	$N_{250}P_{200}K_{280}$
	3	Quantum
	4	$N_{180}P_{150}K_{200}$+ Quantum
	5	$N_{250}P_{200}K_{280}$+Quantum
Two-time treatment	1	$N_{180}P_{150}K_{200}$
	2	$N_{250}P_{200}K_{280}$
	3	Quantum
	4	$N_{180}P_{150}K_{200}$+Quantum
	5	$N_{250}P_{200}K_{280}$+Quantum

The size of each plot was 35 m_2, and each trial was replicated three times. Thus, a total of 31 experimental plots were laid out. The crop was harvested and weighed separately from each plot, and only the weight of the roots was considered, after separating the green mass of the tops. The weight was recalculated per 1 ha of sown area.

Sugar content was determined individually for each plot and averaged for each experimental variant. The sugar content was determined in the laboratory by the acid inversion method, and the soluble carbohydrate content was measured spectrophotometrically. Protein content was determined by the Lowry method with photocolourimetric measurement of optical density. To make the data on protein and carbohydrate content comparable and to compare their relative increase in total biomass, the resulting amounts of sugars and proteins were converted into percentages of dehydrated biomass. The measurement results were compared using a one-way ANOVA analysis of variance. The statistical significance of the data was assessed using the F-criterion.

The experimental studies of plants (both cultivated and wild), including the collection of plant material, were 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 International Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS

Analysing the agrochemical parameters, the following characteristics were obtained, as shown in Table 2. The methods used to determine the agrochemical characteristics are also shown in Table 2. These indicators are quite typical for typical chernozem soils and are favourable for sugar beet cultivation.

Table 2. *Agrochemical parameters of the soil of the experimental area*

Characteristic	Humus content (by Tyurin)	Alkali-hydrated nitrogen, mg/kg (by Grandval-Lajoux)	Mobile phosphorus forms, mg/kg (by Chirikov)	Mobile potassium forms, mg/kg (by Chirikov)	pH
Indicator	4±0.3%	97±7.5	115±8.7	160±12	6±0.2

The results of the study indicate that the application of mineral fertilisers contributes to a significant increase in the biomass of sugar beet roots. The average biomass of root crops harvested in the control variant without fertilisation was 23.50±1.32 t/ha. In the experiment where fertilisers were applied once, during

sowing, a significant increase in weight was observed. In the variant with the use of average doses of mineral fertilizers $N_{180}P_{150}K_{200}$, the harvested biomass of the root crop was 40±3 t/ha, which is an increase of 70.9±10.54% compared to the control without treatment. In the variant where the pre-sowing treatment with $N_{250}P_{200}K_{280}$ was applied, the yield weight was 45±2.5 t/ha, which is 91.66±5.04% more than in the control. In the sowing treatment with Quantum micro fertiliser, the weight of harvested roots was 34.50±1.50 t/ha, which is 41.94±5.55% higher than without treatment. Thus, these data indicate a significant impact of mineral fertilisers on the increase of sugar beet biomass, which is also well-known from previous experience. At the same time, the combination of microelements is more effective for biomass growth compared to micro fertilisers. The generalised data on biomass growth in all variants of the experiment are presented graphically in Figure 1.

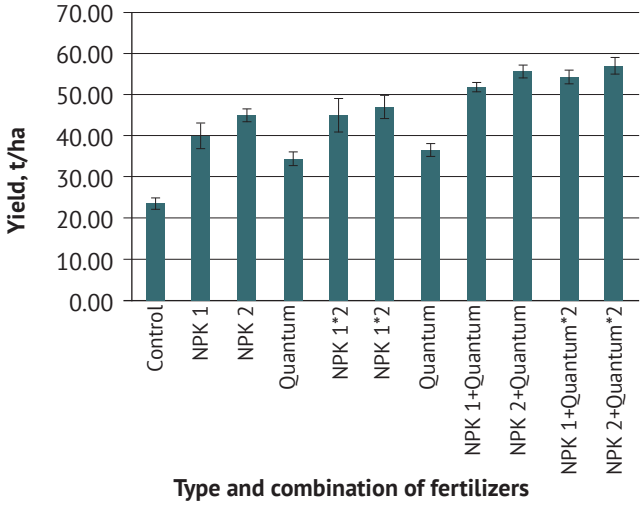

Figure 1. *Yield of sugar beet harvested from plots with different fertilisation regimes, t/ha*
Note: *NPK1 – $N_{180}P_{150}K_{200}$; NPK2 – $N_{250}P_{200}K_{280}$*

The biomass growth compared to the control variant without treatment is shown in Table 3. The second fertilisation, which was carried out 30 days after sowing, coincided with the phase of 4-6 leaf formation. The harvested yield was as follows: with the second application of $N_{180}P_{150}K_{200}$ – 45±4 t/ha (92.35±12.4% higher than in the control). With the application of mineral fertilisers in increased concentrations of $N_{250}P_{200}K_{280}$ – 47±2.65 t/ha (100.2±11% higher than in the control). Re-application of micro fertilisers allowed for a harvest of 36.5±4 t/ha, which is 55.43% higher compared to the untreated control. As you can see, repeated fertilisation did not significantly affect biomass growth compared to a single application, there was some tendency to increase biomass, but it was not significant (Table 3). The data obtained cast doubt on the need for repeated application of mineral fertilisers, it can be assumed that pre-sowing treatment with the applied combinations sufficiently saturates the soil with the necessary elements for the full growth of root crops when sowing beetroot at this density. However, these data may not be relevant for other agrochemical parameters of the soil or an increase in sowing density.

Table 3. *Relative weight gain of sugar beet under different fertilisation schemes*

Fertiliser application rate	Fertiliser type	Mass increase in comparison to control
One-time treatment	$N_{180}P_{150}K_{200}$	70.9±10.54
	$N_{250}P_{200}K_{280}$	91.7±5.0
	Quantum	46.9±5.5
Two-time treatment	$N_{180}P_{150}K_{200}$	92.3±12.4
	$N_{250}P_{200}K_{280}$	100.2+11.3*
	Quantum	55.4±3
One-time treatment	$N_{180}P_{150}K_{200}$+ Quantum	120.8±8.5*
	$N_{250}P_{200}K_{280}$+Quantum	137±14.8*
Two-time treatment	$N_{180}P_{150}K_{200}$+ Quantum	131.8±16.5*
	$N_{250}P_{200}K_{280}$+Quantum	143.0±14.3*

Note: ** – significant compared to the control ($p \leqslant 0.05$)*

At the next stage of the study, the effectiveness of the use of a combination of mineral fertilisers containing trace elements with micro fertilisers was analysed. In the case of pre-sowing one-time treatment with fertilizer containing $N_{180}P_{150}K_{200}$ in combination with Quantum, the harvested weight of root crops was 51.83±1.05 t/ha, which is 120.88±8.48% higher than in the untreated control and more than in each of the variants of individual fertilizer application. The combination of $N_{250}P_{200}K_{280}$ with Quantum allowed to harvest of a root crop weighing 55.67±1.05 t/ha, which is 137.37±14.84% more than in the untreated control and higher than in each of the variants of individual fertilisation. It should be noted that the difference between the two concentrations of mineral fertilisers – standard and increased, in this treatment variant, was 16.49% on average, which is not a statistically significant difference. The second treatment with the fertiliser combination also did not lead to a significant increase in yield compared to the single treatment, similar to the separate application of fertilisers. Repeated treatment with the combination $N_{180}P_{150}K_{200}$ – Quantum allowed to harvest a yield of 54.33±1.53 t/ha (131.77% more compared to the untreated control). Double fertilisation with a higher concentration of macro-mineral fertiliser $N_{250}P_{200}K_{280}$ with Quantum increased the yield to 57±2 t/ha (142.2±14.32% more than the untreated control). As you can see, the double application of an increased dose of complex mineral fertiliser in combination with micro fertiliser allowed us to collect the highest yield, but the difference between a single pre-sowing treatment and a double treatment was on average 22.11%. As can be seen from the data in Table 3, the best effect on the growth of sugar beet biomass is provided by the use of a combination of complex fertilisers and micro fertilisers, which proves the feasibility of using such a combination.

Biomass growth is an important indicator of fertiliser efficiency. However, the crop must not lose its industrial characteristics, the main of which for sugar beet is the sugar content. Therefore, in the second stage of the study, the soluble sugar content of the roots harvested from all plots was compared. The sugar content was converted to a percentage of dry biomass. The content of soluble sugars in the control variant of the experiment was 14.03±0.25%, which is the average for this variety, the maximum sugar content for which is 18-20% (Fig. 2). The sugar content in beetroot harvested from the plot fertilised with $N_{180}P_{150}K_{200}$ was 15.83±0.58%, which is 1.8±0.66% higher than in the control variant. With the application of increased doses of mineral fertiliser $N_{250}P_{200}K_{280}$, the sugar content in the root crop increased to 3.60±0.26%, an increase over the control of 2.23±0.25%. When applying the micro fertiliser Quantum, the sugar content in the biomass was 16.97±0.64%, which is 2.93±0.45% higher compared to the control. This increase in sugar content compared to the control is quite significant and correlates with the effect of macro-mineral fertilisers, which indicates various possible mechanisms for increasing the content of simple carbohydrates in sugar beet.

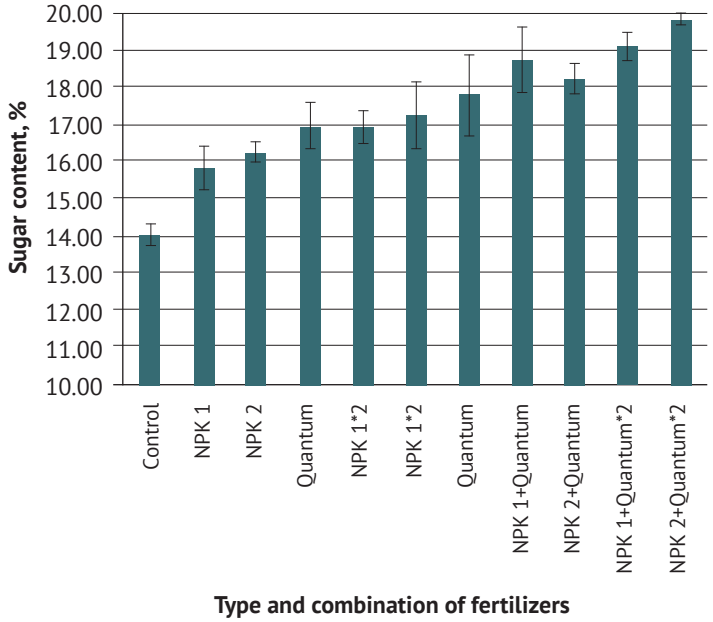

Figure 2. *Sugar content in beetroot harvested from plots with different fertilisation regimes, % of dry weight*
Note: *NPK1 – $N_{180}P_{150}K_{200}$; NPK2 – $N_{250}P_{200}K_{280}$*

Repeated fertilisation affected sugar content as follows. In the variant with the introduction of an average dose of mineral fertiliser $N_{180}P_{150}K_{200}$, this indicator was 16.93±0.4% (2.9±0.66% higher than in the control

variant). With the repeated application of a higher concentration of fertiliser $N_{250}P_{200}K_{280}$, the sugar content was 17.27±0.87% (3.23±0.95% higher than in the control). In the variant with the introduction of micro fertiliser, the sugar content was 17.80±1.08%, which is 3.77±1.25% higher than in the control. Thus, it can be seen that there is some tendency to increase sugar content after the second treatment with individual complex fertilisers, but this difference is not significant compared to a single application of these types of fertilisers. All the data on sugar content in the dry weight of sugar beet in different variants of the experiment are shown graphically in Figure 2, and the increase in the indicator relative to the control is given in Table 4.

Table 4. *Sugar increase relative to the control in sugar beet harvested from plots with different fertilisation regimes, %*

Fertiliser application rate	Fertiliser type	Increase in sugar content relative to control
One-time treatment	$N_{180}P_{150}K_{200}$	1.8±0.65
	$N_{250}P_{200}K_{280}$	2.23±0.25
	Quantum	2.93±0.45
Two-time treatment	$N_{180}P_{150}K_{200}$	2.9±0.66
	$N_{250}P_{200}K_{280}$	3.23±0.95
	Quantum	3.8±1.1
One-time treatment	$N_{180}P_{150}K_{200}$+ Quantum	4.7±0.64*
	$N_{250}P_{200}K_{280}$+Quantum	4.23±0.6
Two-time treatment	$N_{180}P_{150}K_{200}$+ Quantum	5.0±0.2*
	$N_{250}P_{200}K_{280}$+Quantum	5.3±0.45*

Note: ** – significant compared to the control ($p \leqslant 0.05$)*

A comparison of the results of the combined use of fertilizers indicated the presence of a cumulative effect on sugar content. In the variant with sowing treatment with a combination of fertilizers in the usual concentration of $N_{180}P_{150}K_{200}$ and Quantum, the sugar content in root crops was 18.77±0.87% (an increase over the control of 4.7±0.64%). When applying an increased concentration of complex fertiliser $N_{250}P_{200}K_{280}$ with Quantum, the studied indicator was 18.27±0.87% (an increase compared to the control of 4.23±0.6%). The increase in sugar content was even more pronounced when the fertiliser combination was applied again. The treatment with $N_{180}P_{150}K_{200}$ and Quantum led to an increase in the sugar content in root crops to 19.9±0.36% (an increase over the control of 5±0.2%). At the same time, the increased concentration of mineral fertilizers $N_{250}P_{200}K_{280}$ in combination with Quantum increased the sugar content to 19.83±0.45%, which is 5.8±0.4% more than in the control. As can be seen from the above data, the combination of mineral fertilisers containing macronutrients with micronutrient fertilisers leads to a pronounced cumulative effect of application that exceeds the effect of each fertiliser separately. Thus, the use of the combination is advisable, especially given that the combination of fertilisers leads to a more pronounced increase in biomass and sugar content than the repeated application of mineral fertilisers based on nitrogen, potassium, and phosphorus.

The protein content can be an important indicator in terms of the nutritional value of the pulp, which can be used as animal feed – both directly and for the production of mixed fodder. The determination of protein content in the control variant showed its content at the level of 9.40±0.36%, which is a standard average for sugar beet. The application of mineral fertilisers on pine needles increased the protein content to 10.60±0.37% and 11.50±0.5% – when applying standard and increased concentrations, respectively. The application of micro fertiliser did not significantly affect this indicator – 9.73±0.25%.

Two-time treatment with complex fertiliser resulted in a slight increase in protein content both in comparison with the control and in comparison, with a single treatment: 12.3±0.36% and 12.40±0.56% and at medium and high doses, respectively. In the variant with repeated application of micro fertilisers, no significant differences were observed: 9.67±0.29%. The result of combined fertilisation was equivalent to the results of macro fertilisation: 11.73±0.21% and 11.43±0.29 when combining medium and high doses with Quantum. Repeated application of the fertiliser combination slightly increased the protein content: 12.53±0.45% and 12.74±0.15%, respectively. The data on protein content are shown graphically in Figure 3. As can be seen, the greatest impact on the protein content of sugar beet is made by the application of fertilisers containing nitrogen, potassium, and phosphorus, with a certain effect of repeated application. The combination with micro fertilisers in the experimental conditions did not have a significant effect on the protein content of sugar beet. It can be assumed that the increase in biomass observed in the experiment was mainly due to the accumulation of carbohydrates in plants, rather than an increase in the protein part.

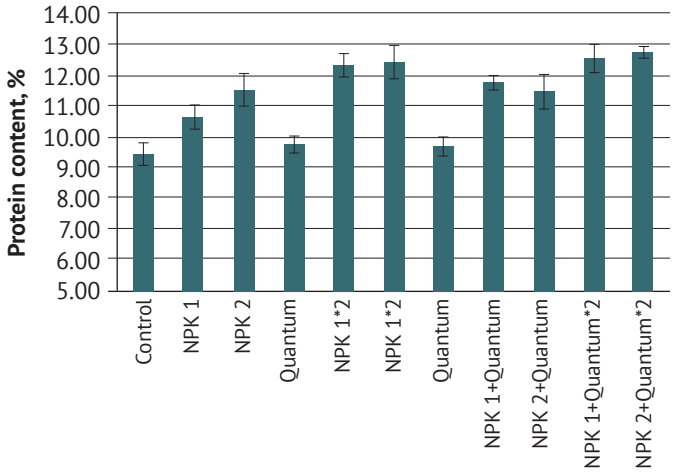

Figure 3. *Protein content in beetroot harvested from plots with different fertilisation regimes, % of dry weight*
Note: *NPK1 – $N_{180}P_{150}K_{200}$; NPK2 – $N_{250}P_{200}K_{280}$*

In general, the aggregate data on biomass growth and sugar content indicate that under the existing growing conditions, the most appropriate way to increase yields is to use a combination of mineral fertilisers containing macro- and microelements. The relative effect of other technological methods, such as increasing the concentration of the main elements per unit area and repeated fertilisation, does not have such a pronounced positive effect. Therefore, it is advisable to recommend such a fertilisation regime, which can reduce the cost of growing and harvesting sugar beet. The results of the study may be useful for the development of large-scale fertilisation technologies for sugar beet cultivation on an industrial scale, but the economic component of the process should be considered.

DISCUSSION

The study shows that the nature of the increase in biomass and soluble sugar content in sugar beet largely depends on the presence of macro- and microelements in the soil. The data are confirmed in numerous studies by colleagues. M. Abbas *et al.* (2018) studied the effect of nitrogen fertiliser deficiency on the sugar content of sugar beet when grown under drought conditions on sandy soils, showing that nitrogen fertiliser deficiency significantly reduces yields, but maintains and increases the sugar content. Y.E. El-Ghobashi and A.E.M. Eata (2020) in their studies emphasise the leading role of nitrogen fertilisers in increasing sugar beet yields when grown on depleted soils. H.A. Aslanov *et al.* (2023) investigated the effect of phosphate and potassium fertilisers in combination with different planting regimes, concluding that additional fertilisation and sparse planting (increased access to nutrients) increased yield quality. J. Chen *et al.* (2023) point out the importance of mineral fertilisation for satisfactory yields even when using organic fertilisers.

A combination of macro fertilisers, including nitrogen, phosphate, and potash, is essential for sugar beet growth. Usually, half of the fertiliser is applied in autumn and the other half during ploughing. In this study, the soil was not fertilised beforehand, so the background average recommended dose of fertiliser was applied during sowing. As a result, yields increased significantly compared to the control, and sugar content approached the maximum values for this variety. The most important mineral element that stimulates biomass growth is nitrogen. It is a component of building proteins, enzymes, vitamins, and chlorophyll, which together are essential for plant growth. K. Steinke & C.A. Bauer (2017) emphasise the leading role of nitrogen in increasing beet biomass and the problems that arise in the natural denitrification of soils. M. Tyrus (2018) cites data according to which about 4-5 kg of nitrogen, 1.5-2 kg of phosphorus, and 5-6 kg of potassium are removed from the soil to produce one tonne of sugar beet, so the introduction of these mineral fertilisers is the key to ensuring proper soil productivity. M. Tyrus demonstrated a dose-dependent increase in root crop weight with increasing fertiliser doses, the author uses 3 fertiliser concentrations: $N_{180}P_{135}K_{210}$, $N_{240}P_{180}K_{280}$, and $N_{300}P_{225}K_{350}$. As a result, it is possible to achieve biomass growth rates of 200 to 300% compared to the unfertilised variant. However, similarly to the results of this study, the amount of growth increases only slightly with increasing fertiliser concentration. Thus, it is necessary to calculate the amount of fertiliser based on the expected yield and the economic feasibility of increasing fertiliser concentrations. X. Xie *et al.* (2022) studied the combination of different fertiliser concentrations under different irrigation regimes. Among the fertilisers, the best growth and sugar content indicators were provided by the fertiliser concentration of $N_{229.5}P_{180}K_{202.5}$ kg/ha.

Both lower and higher concentrations of fertilisers showed worse growth-stimulating performance. At the same time, it was the potassium content that was recognised as a factor limiting the growth of biomass and sugar content. The study also demonstrated that irrigation is important and has a cumulative effect on yields along with fertilisation, which confirms the importance of considering the water regime of a particular growing area to determine optimal fertiliser concentrations.

A.M. Ali *et al*. (2023) demonstrate the limiting role of nitrogen fertiliser deficiency in increasing sugar beet fertility on depleted soils, with the best results obtained when using the maximum nitrogen fertiliser concentration of 215 kg/ha. M. Abbas *et al*. (2018) studied the effect of reducing the dose of nitrogen fertilizers from 288 to 216 kg/ha against the background of water deficit. It was shown that a decrease in soil nitrogen led to a decrease in yield and sugar content, but the relative sucrose content was higher, however, this did not increase the sugar level to control values. Thus, the availability of this element is a basic condition for the realisation of the growth potential of the crop, which is confirmed by the significantly lower yield of the control, unfertilised variant in this study. A. Salarian and A. Salari (2021) in his experiment compares the effect of fertilisation with nitrogen, potassium and phosphorus on such indicators as dry weight, sugars, proteins, and carbohydrates. The variants with background concentrations ($P_{120}K_{90}$) and N_{90} are compared with the unfertilised control. It is demonstrated that each of the application options leads to an increase in all these indicators. Reducing the planting density, i.e., greater availability of substances, leads to a similar effect of increasing the nutrient content of the crop.

The study by A. Panfilova and V. Gamayunova (2019) demonstrated that the second fertilisation did not have a significant effect on the growth of biomass and sugar content compared to the single fertilisation. This can be explained by the low absorption of substances, including microelements, from the soil in the initial phase of growth – up to 40-45 days of growth, before the first 10 leaves appear. However, as L. Kolaric *et al.* (2015) points out, the crop is very sensitive to soil nutrient deficiencies during this period, especially in the period of 4-6 pairs of leaves, during the period of secondary cambium establishment, so fertilisation is mandatory. Since most of the nutrients were not absorbed from the soil, the addition of the second portion of fertiliser did not significantly affect the yield and sugar content. As shown in the study, the weight of beetroot was significantly lower in the control variant, so the lack of mineral fertilisation may have played a limiting role in increasing biomass. K. Bürcky *et al.* (2018) present the results of long-term studies of the extraction of nutrients from the soil by sugar beet, which were conducted over 19 years. These studies demonstrate that the extraction of trace elements such as nitrogen, potassium, and sulphur is gradually decreasing. The authors attribute this phenomenon to the development of more optimised varieties with high productivity and lower absorption of trace elements from the soil. These studies emphasise the importance of reviewing soil cultivation methods and selecting fertilisation methods that are optimal for a given natural zone and period.

One of the most important results of this study is the identification of the cumulative effect of the combination of complex fertiliser and micro fertiliser. Many researchers have reached similar results when cultivating sugar beet in different climatic conditions. A. Salarian and A. Salari (2021) in their study demonstrated that the use of micro fertilisers together with fertilisers containing trace elements significantly increases the sugar content in sugar beet roots, especially when it is accompanied by a decrease in nitrogen in fertilisers. They managed to achieve a sugar content of 19.16-20.01% when combined with micro fertilisers. The main elements that influenced the sugar content were iron, zinc, manganese, and magnesium. These elements are also present in the Quantum preparation used in this study. M.Z. Aghdam and R. Valilue (2023) studied the effect of the interaction of micro fertilisers containing iron, zinc, and boron on the technological parameters of sugar syrup obtained from beetroot. The maximum growth of root crops and the purity of raw syrup were obtained with the combined use of $Zn_{100}B_{20}$. O.V. Pismennyi (2012) studied the effect of micro fertilisers in different concentrations on yield and sugar content and demonstrated an increase in yield by 17 – 94% when applying different types and concentrations of micro fertilisers. It should be noted that in this study, even higher yields were achieved by applying a combination of fertilisers at medium doses of macro fertilisers and the lowest doses of micronutrients recommended by the manufacturer. Thus, numerous studies by Ukrainian and international colleagues point to the need to use mineral fertilisers, with due regard to climatic conditions and soil agrochemical parameters. With a competent and planned approach to cultivation and the use of reasonable combinations of different types of mineral fertilisers, it is possible to achieve a crop with high technological indicators and reduce economic costs. Further research should be aimed at studying the effect of the proposed fertiliser combinations on other technological indicators of sugar beet, such as juice purity, sugar extraction, and concentration of reducing substances. It is also advisable to analyse the effect of different concentrations and combinations of micro fertilisers to increase yield and sugar content.

CONCLUSIONS

The influence of different fertilisation regimes on the yield, and accumulation of sugars and proteins in the roots of sugar beet of the Alexandria hybrid was studied. The data obtained confirm the need for mineral

fertilisers in the cultivation of beet to realise the growth potential of the variety. The most effective for increasing biomass growth was the application of a combination of complex mineral fertiliser containing nitrogen, sodium, and phosphorus in combination with micro fertiliser Quantum: the biomass growth compared to the untreated control was 120.8±8.5-143.0±14.3%, depending on the amount and frequency of fertilisation. The difference between the concentrations of fertilisers $N_{120}P_{90}K_{180}$ and $N_{150}P_{110}K_{300}$ was more pronounced at a single application (about 20%), with repeated application it was reduced to 10%, so the concentration in the soil reached a certain saturation, and further increase in fertilisers did not affect the biomass growth.

The combined fertiliser application also had the best effect on the sugar content of beetroot, the increase in soluble sugars ranged from 4.23±0.6 to 5.3±0.45% under different combined fertiliser application schemes and reached the maximum values for this hybrid, about 20%. Increasing the concentration of fertilisers when used separately, as well as the frequency of their application, did not significantly affect the increase in the sugar content of beet (no significant difference).

The most significant effect on the protein content of biomass was exerted by the concentration of combined fertilisers containing nitrogen, potassium, and phosphorus. The addition of mineral micronutrient fertilisers did not make a significant contribution to the increase in this indicator. Probably, these macronutrients are the main limiting components for protein synthesis. Thus, the increase in biomass observed in the experiment was mainly due to the accumulation of carbohydrates in plants.

Based on the study, it can be concluded that it is advisable to use a combination of fertilisers containing macro- and microelements. From the point of view of improving the commercially valuable qualities of sugar beet, this is more appropriate than repeated processing. Implementation of the proposed measures can reduce fertiliser costs and allow for achieving high yields and sugar content. Further research should be aimed at deepening the influence of micro fertilisers on the yield, sugar content, and other technological parameters of sugar beet.

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CONFLICT OF INTEREST

None.

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Вплив різних режимів удобрення на врожайність і вміст поживних речовин у врожаї цукрового буряка

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Анотація. Цукровий буряк є однією з сільськогосподарських культур з високою промисловою значущістю, скорочення площ його посівів в Україні останніми роками актуалізує розвиток технологій підвищення врожайності та технологічних показників культури. Метою роботи було дослідження різних режимів внесення мінеральних добрив на урожайність, вміст розчинних цукрів та білків у цукровому буряку. Польове дослідження проведене в період квітня-вересня 2023 року. Передпосівна обробка проводилась з використанням гібриду урожайно-цукристого напрямку Олександрія шляхом глибокої оранки глибиною до 30 см, щільність висіву становила 100 тис/га. Схема удобрення передбачала внесення комбінації комплексних добрив у одній з двох концентрацій: $N_{180}P_{150}K_{200}$ або $N_{250}P_{200}K_{280}$ та стимулятору росту на основі амінокислот та мікроелементів Квантум. Внесення відбувалось окремо або в комбінації, кратність удобрення – одно- чи двократна. Продемонстровано, що найбільш виражений позитивний ефект на приріст біомаси та цукристості буряка чинить комбіноване застосування мінеральних комбінованим макродобрив з препаратом Квантум. При комбінованому варіанті внесення приріст біомаси коренеплоду стосовно контролю склав 120.8±8.5 %-143.0±14.3 %; приріст вмісту розчинних цукрів – в межах від 4.23±0.6 % до 5.3±0.45 %. Також спостерігався приріст в порівнянні з варіантами роздільного внесення добрив. Значущої різниці між двома застосованими концентраціями добрив, а також при повторному внесенні окремих добрив та їхньої комбінацій, виявлено не було. Вміст білків у перерахунку на суху масу збільшувався в залежності від концентрації та кратності внесення комплексних добрив. Отримані дані щодо приросту біомаси вмісту цукру, вказують на доцільність підвищення зазначених показників є застосування комбінації мінеральних добрив, що містять макро- та мікроелементи, тож доцільно рекомендувати подібний режим удобрення. Дані можуть стати основою для розробки рекомендацій для впровадження в промисловому вирощуванні цукрового буряку. Подібні прийоми мають економічну доцільність, оскільки дозволяють скоротити кількість обробок та розхід добрива для отримання урожаю з високими показниками

Ключові слова: мікроелементи; макроелементи; стимулятор росту; агротехнічні характеристики; припосівна обробка

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Assessment of the impact of climate change on crop production in Ukraine: Adaptation mechanisms for mitigating the consequences

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Abstract. Climate changes in modern conditions have a significant impact on the development of agriculture, which is associated with changes in natural conditions in various territories, pollution of soils, air, water bodies and other components of the ecosphere. Such conditions make research on finding mechanisms that would allow mitigating the negative consequences on the development of the country's agriculture relevant. Thus, the study aims to investigate the interaction between climate change and the development of crop production in Ukraine. The main research methods used in the study were analysis, abstraction, and forecasting. As part of the work, an analysis of the trend in terms of climate change observed in Ukraine was carried out: the data clearly showed a trend towards warming of average annual air temperatures, and a decrease in average wind speed and precipitation. All this harms the development of agriculture. The study showed what losses businesses can suffer due to the negative impact of climate change, which can be reflected in both reduced fertility and financial losses. Based on all the information, recommendations were formed for both enterprises and representatives of state authorities, which will make it possible to adapt to such climate changes more effectively. This work makes it possible to better understand both the peculiarities of Ukraine's development from an ecological and economic point of view (in particular, its agricultural sector). In addition, it provides recommendations that can be used by enterprises or government officials to reduce the negative impact of environmental factors on agriculture

Keywords: pollution; aquatic resources; policy; macroeconomics; innovations

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INTRODUCTION

In the current environment, climate change, which is a temperature rise, change in climatic zones, melting glaciers and other natural changes, is one of the most important issues facing society. The negative impact of climate change on humanity as a whole is a significant and multifaceted phenomenon, causing serious threats that are already being felt and will increase in the future. They are leading to an increase in average annual temperatures and heat waves, which can lead to an increase in heatstroke and stress, especially in urbanised areas. Increased temperatures also contribute to the spread of diseases such as malaria and heart or lung disease. In addition, climate change is leading to an uneven distribution of precipitation, leaving some regions prone to prolonged droughts that threaten the availability of water for drinking and agriculture. Other regions may experience extensive flooding due to intense rainfall. Similar negative effects arise for other reasons, such as extreme weather events or rising sea levels. All of this leads to problems in economic development and food security, as such changes cause a decrease in crop yields and a change in the distribution of plants. In some regions, this can lead to food shortages, higher food prices, difficulties with food distribution, or even famine. Therefore, new ways of adapting agriculture to such conditions and mitigating such negative impacts on the development of this sector and companies remain relevant.

The assessment in this study was carried out on the example of Ukraine, which has also been studied by a significant number of scholars. Thus, the state of the environment in Ukraine, and in particular its legal regulation, was studied by I.O. Sivak (2022). The scientist described the current difficulties in the country in this area and also noted the role of improving the legal framework to increase the effectiveness of combating problems related to the state of the environment. In the context of war, the state of the environment in Ukraine was assessed by I.G. Patseva *et al.* (2023). They described the difficulty of assessing the impact of hostilities but noted their overall negative effect. Despite this, the scientists did not formulate advice to reduce this environmental impact. V. Skyba & K. Turyak (2023) assessed changes in the agricultural sector of Ukraine in the context of climate change. They noted that the growing areas of some of the country's main crops have been displaced and called for the state and businesses to be able to respond flexibly to climate change. However, the scientists did not specify any concrete steps to do so. Opportunities for the agricultural sector in terms of adaptation to climate change were explored by L.V. Moldavan (2023). The scientist described the role of the country's natural resource potential for agricultural development and outlined methods of supporting it in Ukraine in the face of climate change. However, little attention was paid to the study of the negative impact of hostilities on this sector. O.P. Mysnyk (2022), in turn, assessed the opportunities for the development of the agricultural sector of Ukraine's economy in the period up to 2030, considering the concept of sustainable development. The scientist described the country's significant potential in the agricultural sector and described the opportunities for its development, considering the basis of the concept of sustainable development. However, he paid little attention to the problems associated with the beginning of Russia's full-scale invasion of Ukraine and its impact on the environment and the agricultural sector. An econometric analysis of the impact of climate change was conducted by A. Skrypnyk *et al.* (2021). The study investigated the dynamics of sown areas under export-oriented crops in three agroclimatic zones of Ukraine and analysed their yields depending on the territories and climate change. O.H. Tarariko *et al.* (2017) also assessed the capacity of the Ukrainian agro-industrial complex to adapt to climate change based on climate change projections. The researchers described the need to develop effective methods of combating climate change and provided some of them, which concerned both changes in the context of technological processes of companies (use of the latest technologies) and management decisions. Risk management issues related to global climate change are highlighted in the study by O.M. Nechyporenko (2020). In his work, the researcher reveals the impact of climate change on the development of the agricultural sector and the state of food security in the country. At the same time, he analyses existing climate risk management strategies and proposes an algorithm for adapting to the climate crisis.

Thus, the study aims to assess the current state of the environment in Ukraine and climate change, as well as to investigate the interaction of these phenomena with crop production indicators. This will allow for more effective formulation of state policy in this area, and thus increase the efficiency of agriculture.

MATERIALS AND METHODS

The study analysed statistical data on average air temperature, precipitation, and wind speed in the period from 2010 to 2023. The study aimed to investigate the impact of climate on the development of crop production in Ukraine as a whole. The average monthly data for these indicators were used for the calculation, and subsequently, annual averages were calculated on this basis. This was done using the formula below (1):

$$C = \frac{(c_2+c_3+\cdots c_{12})+(c_1+c_{13})}{12}, \quad (1)$$

where: C – average annual value; c_1, c_2, ... c_{13} – the respective monthly averages for each month.

In Formula 1, given that the period for which the value was formed was even, 13 observations were used,

but the value for months 1 and 13 was calculated as a single value (their half-sum was used). By plotting a series of values using the formula above, it becomes possible to build a trend line for them and draw a conclusion about the decrease or increase in average annual air temperatures over time.

This study used information on the average air temperature (°C), maximum air temperature (in degrees Celsius), minimum air temperature (°C), average wind speed (m/s) and precipitation (mm). The indicators were analysed monthly, which was used to create graphs describing trends in the context of climate change in Ukraine. The period was chosen between 2010 and 2023. All subsequent plots and calculations were made using Microsoft Excel.

The approach used in the study was systematic. It was used to analyse the main factors influencing the development of agriculture in Ukraine (both from the economic and other points of view) by placing them within separate systems where they interact with each other and influence each other. This provided an opportunity to improve the effectiveness of the assessment of factors and their impact on the object of study. The main research method used in this study was analysis. It allowed us to formulate certain conclusions about the mechanisms of adaptation to climate change and mitigation of its effects on Ukrainian agriculture based on quantitative and qualitative data available from free sources of information. The historical method was also used, which allowed us to evaluate the data in terms of their historical change, in retrospect. The method of abstraction was also used, which made it possible to limit the influence of factors on the object of research in case the effect of such a factor was insignificant. This, in particular, made it possible to increase the accuracy of the study. Forecasting was used to assess the prospects for the development of Ukraine and its agriculture in the face of active climate change. In addition, statistical research methods were used to analyse quantitative data.

RESULTS

In general, the following typical signs of climate change can be identified: an increase in the average annual temperature, changes in precipitation patterns (some regions are experiencing decreased precipitation, leading to drought conditions, while other regions may experience more intense rains, leading to floods and flooding), shifts in seasons (summers start relatively later and are prolonged; winters are becoming warmer, with less snowfall) Given this, climate change in Ukraine has become a serious challenge and requires attention and measures to adapt to new conditions. In particular, it leads to environmental pollution, which is a serious problem in Ukraine as a whole, much of which includes air, water, and soil pollution. Air pollution is caused by emissions from industrial plants, vehicles, and other sources, and hurts air quality, public health, agriculture and ecosystems. Water pollution, mainly from wastewater and chemical discharges, also threatens water resources and aquatic ecosystems. Soil pollution, in particular from pesticide residues and chemical fertilisers, can affect soil fertility and the safety of agricultural products. As shown later in the paper, prolonged droughts remain the most pressing of these for Ukraine. To assess climate change trends in Ukraine, it is worth considering the data that characterise it. The trends in average, maximum and minimum air temperatures are analysed in Figures 1-3.

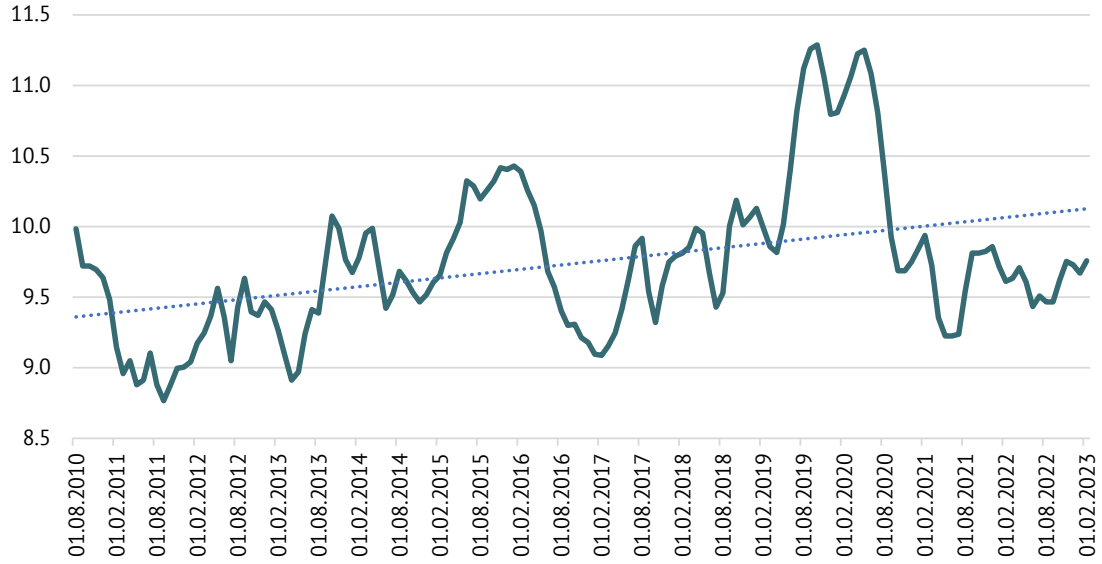

Figure 1. *Data on average annual air temperatures in Ukraine for the period from August 2010 to February 2023, °C*
Note: *here and in all the figures below, the calculation of annual averages for the graphs is based on the data shown in Materials and Methods and the methodology described in the section*
Source: *compiled by the author based on Meteorological station Weather statistics. Climatic data by year and month (2023)*

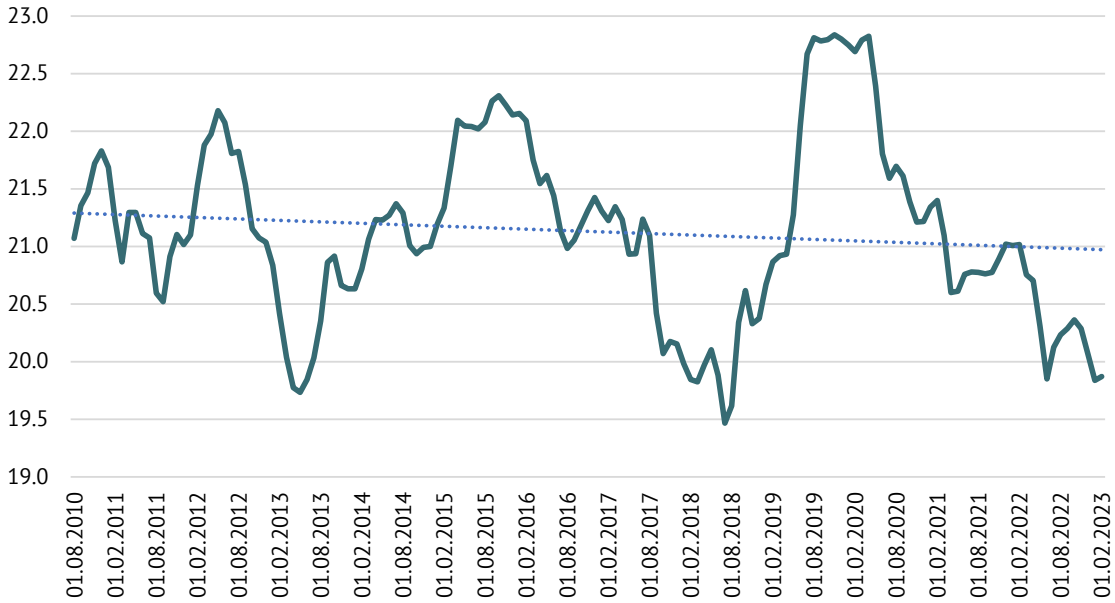

Figure 2. *Data on average annual maximum air temperatures in Ukraine for the period from August 2010 to February 2023, °C*

Source: *compiled by the author based on Meteorological station Weather statistics. Climatic data by year and month (2023)*

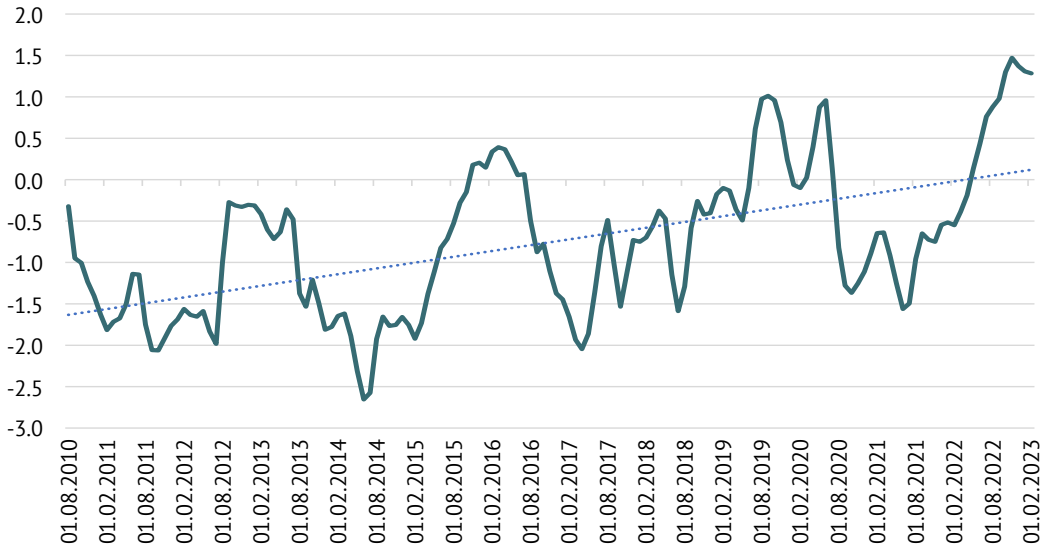

Figure 3. *Data on average annual minimum air temperatures in Ukraine for the period from August 2010 to February 2023, °C*

Source: *compiled by the author based on Meteorological station Weather statistics. Climatic data by year and month (2023)*

As can be seen from Figures 1-3, the average annual air temperature in Ukraine is generally increasing. Although the situation may vary from month to month and year to year (some periods may be colder or warmer), the construction of trend lines allows us to see the warming trend in recent years (in particular in Figures 1 and 3; Figure 2 shows a slight decrease in maximum temperatures, but it does not change the overall upward trend). It is worth noting that such an increase in air temperature, even if it does not seem high, can significantly complicate the process of growing agricultural products. For example, the increase in maximum temperatures means that the country as a whole is experiencing warmer winters, which can be dangerous for plants. For example, between 2019 and 2020, the average annual temperature increased by 0.3°C (3%), and at the same time, there was a decline in gross receipts of agricultural companies by an average of about 10%. In particular, due to the warm, snowless winter of 2020, Ukraine lost 568.2 thousand ha of winter crops (37% less than last year) and millions of dollars in exports (Buono, 2021; Lazareva, 2021; Nalau & Verrall, 2021).

Sunflower yields in the Kherson region dropped from 2 tonnes per hectare to less than one that year, with corn crops also suffering significantly. In the Odesa

region alone, losses of UAH 6.5 billion were recorded. The following year, the situation was different: while the average temperature dropped by 22% (1.8°C), gross harvest volumes increased by 22.6%. In general, due to the very hot year of 2020, which set a significant number of temperature records, 570 thousand ha were lost in Ukraine due to prolonged droughts and unusually severe spring frosts (Ukraine may not..., 2021). Thus, there is a possibility of a situation where, in the face of a cold winter, planted crops will begin to germinate earlier than necessary, which will complicate their development and may lead to a loss of the crop in general. Figures 4 and 5 provide information in terms of average wind speed and precipitation.

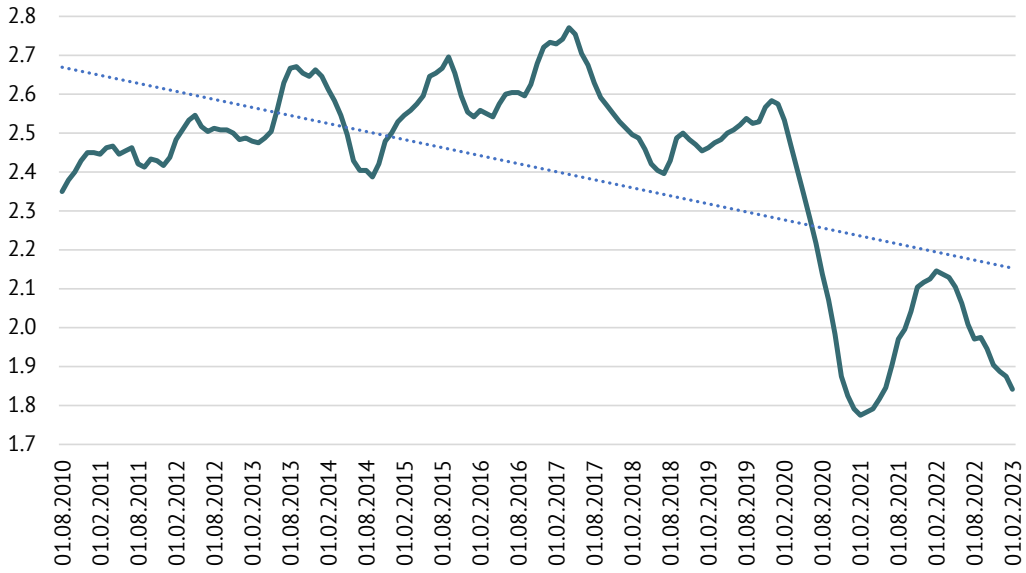

Figure 4. *Data on the average annual wind speed in Ukraine from August 2010 to February 2023, m/s*
Source: *compiled by the author based on Meteorological station Weather statistics. Climatic data by year and month (2023)*

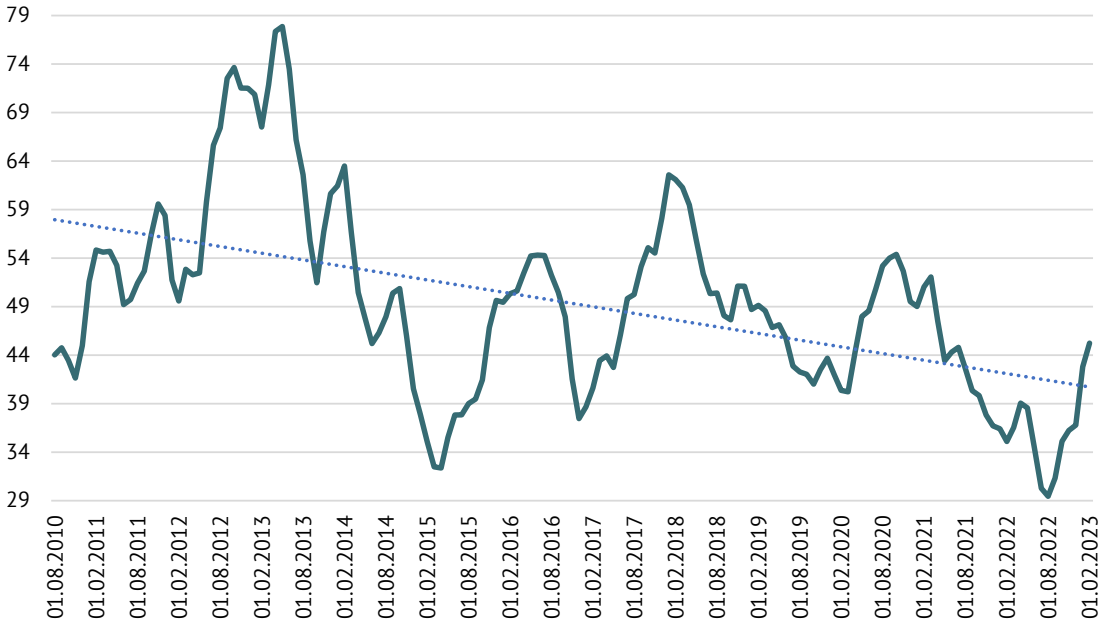

Figure 5. *Data on the average annual precipitation in Ukraine in the period from August 2010 to February 2023, mm*
Source: *compiled by the author based on Meteorological station Weather statistics. Climatic data by year and month (2023)*

As can be seen from Figures 4 and 5, both average annual precipitation and wind speed data in Ukraine have decreased over the selected period. In the context of agricultural development, this also hurts the industry, as it reduces the natural ventilation of fields and affects seed dispersal and pollination; when considering precipitation data, the decline in precipitation indicates a need for increased manual watering of plants, which can also complicate the process of growing them.

Thus, gradual climate change around the world, and in Ukraine in particular, is causing significant problems in terms of doing business in the agricultural sector. For example, over the past 20 years, climate change-related natural disasters have caused more than $2 billion in losses in Ukraine's agricultural sector, which has complicated business operations (Climate Change and..., 2021). As can be seen from the Figures above, there are clear changes in Ukraine, even over short periods, in terms of weather changes over time. However, their interaction with data on company performance is not always obvious. Considering the interaction in terms of collection volumes and precipitation, in 2020, compared to 2019, precipitation increased by 11.8%, while in 2021, compared to the previous year, it decreased by 8%. This is not surprising, as Ukraine is indeed facing an annual rainfall deficit of 578 mm, while sustainable agriculture requires at least 700 mm. Over the past five years, the average annual rainfall has been around 553 mm, and in recent years it has dropped to 557 mm. This lack of precipitation combined with increased evaporation due to rising temperatures requires intensive irrigation. The cost of irrigation for farmers has increased by about 25%, adding to the difficulties of growing crops (Climate and Agriculture..., 2021). The drought in spring and summer resulted in losses that included 200 thousand ha of corn and slightly lower yields of other crops across the country (Ukraine may not..., 2021). Grain harvest volumes in 2021 decreased significantly in Ukraine due to the drought. Nevertheless, due to the increase in prices for this product on the international market, companies in the sector were able to make excessive profits this year. Experts estimate that a continuation of this trend of decreasing precipitation may lead to the need to actively irrigate about 70% of agricultural land in Ukraine, which is 30% more than now (Dankevich 2020). This will lead to a significant increase in the cost of growing crops, and thus negatively affect the country's position in the international arena.

As for the net income of enterprises, in 2020 and 2021, they grew by 2% and 16%, respectively, adjusted for inflation. Thus, despite the weather conditions, agricultural companies were able to increase their profits. This suggests that for agricultural companies in Ukraine, company revenues are much more strongly influenced by factors other than weather conditions, such as the price of inputs, which increased significantly during the COVID-19 crisis, which led to an increase in net income. In turn, in 2022, despite the natural conditions, companies' revenues decreased by 34% in real terms compared to 2021 due to the start of the full-scale invasion. Although there are currently factors in the country that are much more influential on the welfare of agriculture than natural disasters, they must also be considered to reduce their negative impact in the long term. If similar declines in the revenues of agricultural companies continue in the future, it is possible to expect a significant negative social and economic impact on the country. In particular, this will affect the state budget, given that the tax revenues of companies exceed the losses associated with their support. Such a reduction in budget revenues could have a significant negative impact on the budget, especially in the context of a significant budget deficit during the war.

Thus, various methods can be proposed to facilitate the process of adaptation of the agricultural sector to climate change. One of them is investing in and developing new crop varieties that will be able to withstand climate change or be more adapted to it, and not be so negatively affected by it (Reid, 2019; Ovcharenko *et al*., 2022). In addition, the implementation of sustainable land management practices is effective, for example, crop rotation, conservation tillage (Olabi & Abdelkareem, 2022). These methods help to improve soil health, reduce erosion, and thus increase the resilience of agricultural systems to climate change. The transition of farms to renewable energy sources is also effective. This will help reduce greenhouse gas emissions, which will improve natural development in the long term, and the energy generated from wind or solar power can also power irrigation systems and other agricultural machinery. It is also important to invest in efficient water management methods, which may include rainwater harvesting and use technologies, as well as water-efficient irrigation systems. This is especially important for growing crops in the face of rainfall variability, and in particular, the identification of a downward trend in rainfall (Heil & Muni-Morgan, 2021). For all of the above methods to be used, the state should pursue appropriate policies aimed at raising awareness among farmers, businesses, and the public about the challenges posed by climate change and the importance of taking the measures described above. However, at the moment, the introduction of any new technology that can ensure efficient irrigation of land can cost several billion dollars of investment, which is a very large sum for Ukraine, and it seems impossible to attract such funds in the framework of a full-scale invasion.

So far, only methods that can be used by farmers to improve the situation in agricultural development in Ukraine concerning climate change have been considered. However, this problem should also be addressed at the level of advisory services. Thus, the state should implement policies aimed at increasing the resilience of the agricultural sector to climate change. Such actions should be well coordinated at different levels of government, from local to national and international. This requires establishing institutions and financing mechanisms to support agricultural adaptation to climate change, which may not be easy, particularly in the context of Russia's full-scale invasion of Ukraine. It is important not only to engage with government officials at the national and regional levels, but also on the international stage, in particular, to share experiences,

technologies, or theoretical knowledge on how to reduce the negative impact of climate change on the country.

DISCUSSION

Current assessments of the impact of climate and environmental change on various areas have estimated K. Abbass *et al.* (2022). They noted the significant impacts of climate change on socio-agricultural, socio-economic, and physical systems, emphasising the potential for catastrophic consequences. They highlighted issues such as worsening food security, including higher food prices and inadequate food distribution systems, as well as a range of challenges related to forest development. They suggest some policy actions to reduce these impacts, particularly in the agricultural sector. Thus, it would be effective to consider seasonal variations and cultivation methods, develop new crop varieties with desirable properties, introduce changes in management and inputs, and promote technological and socio-economic adaptation. The use of renewable energy sources would also be effective, as well as raising awareness of these issues among businesses and the public. It is worth noting that the paper above also made similar recommendations on how to improve the efficiency of agricultural development in Ukraine.

The importance of confronting climate change was also stated by S. Khalid *et al.* (2017). The scientists wrote that the review of global climate trends conducted in their paper showed significant risks and vulnerabilities associated with climate change to the environment. They drew attention to the indebtedness, urgency and severity of these impacts, as well as the importance of the resources affected, underscoring the importance of ongoing scientific research. The importance of understanding the role of the processes that influence weather and climate change was also explored by J. Ringard *et al.* (2022). They emphasised the importance of understanding the physical processes behind changes in the environment, especially during the summer season, and discussed the relevance of studying them to find more effective methods to counteract them.

A.M. York *et al.* (2021) discussed climate change as a multi-level collective action issue, emphasising the need for a comprehensive understanding of decision-making processes at different levels of society. They noted that an effect such as climate change requires a response at all levels, from individuals to global organisations. Each level can influence climate change actions and policies. In modern conditions, despite the importance of addressing climate change, insufficient measures are often taken, both by businesses or society and the state. D. Alagador & J.O. Cerdeira (2020) examined in their study the problems associated with planning protected areas to optimise species resilience in a dynamic environment, i.e., one in which climate change is occurring and budgetary constraints exist. In particular, the scientists identified the role of technology in this process and noted its importance in creating opportunities for quality development in the country to improve the environmental situation.

The impact of climate change on agriculture and mitigation strategies was studied by G.S. Malhi *et al.* (2021). They noted that the growth of the world's population puts significant pressure on agriculture, which is also constantly growing. Although it is unclear how the climate will change in the future, the current course of climate change is harming agriculture. To overcome these challenges, numerous mitigation and adaptation strategies have been developed, covering various strategies related to the methods of processing agricultural products, the use of certain inputs for their growth. However, it is important to interact to combat climate change not only at the micro but also at the macro level. Thus, government officials should ensure planning and coordination at the regional and local levels to maximise the effectiveness of these strategies. Such measures should increase farmers' incomes and increase (or maintain) the resilience of agriculture to similarly severe disasters, and thus have a positive impact on agricultural development and food security in the long run. S. Skendzic *et al.* (2021) wrote that climate change has a significant impact on agricultural plants. They analysed how changes in the weather affect insect pests (scientists noted that their number has increased significantly due to climate change, which has led to the need to find new opportunities to combat them. They also pointed out that although it is not known for certain how the changes in the situation will develop in terms of the environment, it is clear that farmers need to prepare for them.

J.P. Aryal *et al.* (2020), adaptation to climate change is crucial for agricultural sustainability. Successful adaptation in agriculture requires a combination of strategies, including the adoption of different technologies, sustainable land management practices, and the establishment of enabling policies and institutional frameworks. Therefore, as noted by scientists, institutional development and adequate financing are crucial for agriculture to successfully face climate challenges. A.A. Chandio *et al.* (2020) conducted an empirical study that focused on assessing the impact of agricultural production in China from 1982 to 2014. As China's population is growing, addressing the adverse effects of climate change on agriculture is crucial for food security; and while this is a critical topic for this country, it is also relevant for other countries. The main findings of the study showed that climate change, in particular factors such as CO_2 emissions, cereal area, fertiliser consumption and energy consumption, have a positive impact on agricultural value added. Conversely, rising temperatures or changes in precipitation have a negative long-term impact but a positive short-term impact on agricultural value added. Based on these findings,

the researchers recommend that the Chinese government take specific measures to overcome these challenges. Actions to this end may include the introduction of accurate weather forecasting, improved irrigation systems, and the modernisation of farmland infrastructure to adapt to climate change. A similar study was conducted by N.T.L. Huong *et al.* (2019). The researchers used empirical data from Vietnam to estimate the impact of certain climate changes (including temperature and precipitation) on farmers' net income. The study found that the impact of these climate variables on net income is non-linear; in this case, it is still possible to find a solution that will maximise efficiency. The researchers noted that adaptation measures are important to mitigate the negative effects of climate change on agriculture. Farmers who adopt adaptation strategies will take risks in their agricultural practices and therefore achieve better results in their operations. The study above also concluded that farmers, and agricultural enterprises, can significantly improve their performance in the face of climate change if they use them.

Thus, Ukraine needs to apply methods that would reduce the impact of climate change on the development of agriculture in the country. However, it is worth remembering that such results can only be achieved if there is effective cooperation between the state, businesses, and citizens, especially in wartime. Therefore, first and foremost, the authorities should formulate a policy that would effectively meet the needs of all components of the country's population and achieve significant progress in meeting their needs.

CONCLUSIONS

Climate change has a significant impact on Ukraine, especially in crop production. It is causing changes in temperature, precipitation patterns and wind speed, which affects crop yields. Data shows a clear link between weather changes and the performance of agricultural companies in Ukraine. Climate change-related natural disasters have caused more than $2 billion in losses in the agricultural sector over the past two decades, complicating business processes. Unpredictable weather conditions, such as droughts and temperature fluctuations, can have a significant impact on crop yields and subsequently on farmers' incomes. The study showed that agricultural enterprises lost millions of dollars in profits due to drought due to reduced fertility of crops such as corn, wheat: in 2020 alone, 200 thousand ha and 568.2 ha of these crops were lost, respectively, which is a huge loss.

While the impact of climate change on agriculture is clear, other factors such as resource prices and political instability also affect agricultural revenues. In 2020 and 2021, agricultural companies managed to increase their profits despite the weather conditions, but in 2022, the onset of the full-scale invasion led to a significant decline in company revenues, highlighting the sector's vulnerability to external shocks. In the long term, adaptation to climate change through investment and development of climate-resistant crop varieties, implementation of sustainable land management, water management is crucial for the sustainability of crop production.

Further research is needed to assess the impact of climate change on other sectors of the Ukrainian economy, not just agriculture. In addition, it is important to find ways to combat the negative impact of these changes using all possible methods. In addition, it is important to conduct research in the context of assessing foreign experience in this area and finding opportunities to use it in Ukraine.

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CONFLICT OF INTEREST

None.

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Оцінка впливу змін клімату на рослинництво в Україні: механізми адаптації для пом'якшення наслідків

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Анотація. Зміни клімату в сучасних умовах чинять значний вплив на розвиток сільського господарства, що пов'язано із змінами природніх умов на різних територіях, забрудненням ґрунтів, повітря, водойм та інших складових екосфери. Подібні умови роблять актуальними дослідження з приводу знаходження механізмів, що дозволили б пом'якшити негативні наслідки на розвиток сільського господарства країн. Таким чином, ціллю даного дослідження стало дослідити взаємодію між зміною клімату та розвитком рослинництва в Україні. Основними методами дослідження, що були використані в рамках роботи, стали аналіз, абстрагування та прогнозування. В рамках роботи було проведено аналіз тенденції у розрізі зміни клімату, що спостерігаються в Україні: дані чітко показали тенденцію до потепління середніх річних температур повітря, зниження середньої швидкості вітру та кількості опадів. Усе це спричиняє негативний вплив на розвиток сільського господарство. В дослідженні було показано, яких втрат можуть зазнати підприємства у зв'язку із негативним впливом змін клімату, що можуть відображатися як зі зниженням родючості, так і фінансовими втратами. На основі усієї інформації було сформовано рекомендації, як для підприємств, так і представників державної влади, що дадуть змогу більш ефективно пристосуватися до подібних змін клімату. Дана робота дозволяє краще зрозуміти як особливості розвитку України з екологічної точки зору, так і економічної (зокрема її сектору сільського господарства). Крім того, вона надає рекомендації, що можуть бути використані підприємствами чи представниками влади для зниження негативного впливу на сільське господарство з боку екологічних чинників

Ключові слова: забруднення; водні ресурси; політика; макроекономіка; інновації

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The role of agriculture in shaping the prospects of socio-economic development of Uzbekistan

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Abstract. The role of agriculture in ensuring food security, creating jobs, and generating export earnings makes it particularly relevant to analyse the impact of this sector on the socio-economic development of the country. The research aims to analyse and assess the impact of agriculture on the socio-economic development of Uzbekistan. To achieve the goal, the indicators of the agricultural sector and socio-economic development from 2013 to 2022 were analysed. It is established that the natural resources of Uzbekistan play a crucial role in the development of agriculture. The

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analysis of diversified trends in agriculture emphasises the key role of this sector in the socio-economic progress of the country. Despite the variability, the growth in the share of agricultural land and rural population indicates the still high importance of agriculture. However, the decline in value added in the agricultural, forestry and fisheries sectors, as well as the low growth rate of cereal yields, reflects the current challenges in this area. Rising unemployment rates, as well as changes in exports and inflation rates, point to difficulties in the socio-economic environment. In this light, the prospects for agricultural development as a key agent in improving the socio-economic situation are particularly important. Effective resource management, productivity improvement, job generation, product promotion and expansion of production are all important areas for future development. A strategic approach to agricultural development requires the implementation of complementary measures such as public financial support, mobilisation of investment, use of evaluation ratings and improved public policies. The findings of the study can be used to adapt public policies and programmes in the agricultural sector, as well as to identify priority areas for investment and resources for sustainable economic development

Keywords: natural resources; food security; economic growth; societal progress; sustainability

INTRODUCTION

Agriculture in Uzbekistan remains an important component of the country's socio-economic development, as it provides not only food security but also high levels of employment, especially in rural areas. Improvements in agriculture contribute to infrastructure development, increase rural incomes, reduce poverty, and expand opportunities for agricultural exports, which helps to attract investment and support sustainable economic growth in Uzbekistan. Therefore, the development of this sector remains an urgent task for the country and is of great importance for its future socio-economic development.

According to R. Khakimov *et al.* (2022), sustainable agricultural development has an impact on many areas, including the economy, employment, social equity, and quality of life. The rural population plays an important role in shaping the social structure, and the development of rural areas contributes to the improvement of infrastructure and access to education and health services. From the point of view of D. Niyazmetov *et al.* (2021), agricultural development contributes to the distribution of land resources, labour opportunities and income among different segments of the population. This is particularly important for improving the lives of women and youth, strengthening their participation in the rural economy, and ensuring equal chances for all.

Sh.Y. Salimov (2018) argues that agriculture is one of the main sources of employment in many developing countries. The development of the agricultural sector leads to the creation of jobs in rural areas, which helps to reduce unemployment and provide people with income opportunities. This contributes to a more even economic development of the country. According to K. Ruziev (2021), considering global challenges such as climate change and demographic change, agricultural development becomes an integral part of sustainable development strategies. Agricultural development contributes to the creation of equal opportunities for different segments of the population, ensures food security and forms the basis for stable economic development of the country. In this context, Uzbekistan, with its rich agricultural potential and unique natural resources, is an important object of study. Agriculture, as one of the key sectors of the country's economy, not only provides food security and a raw material base but also has a significant impact on the social well-being of the population.

A. Ilkhamov (2013) believes that agriculture in Uzbekistan plays a critical role in the country's economy, as the majority of the population is engaged in rural labour, and the agricultural sector is one of the main sources of income and exports. The development of this sector is aimed at improving productivity, introducing modern technologies, and improving the quality of agricultural products. J.J. Robalino and J. Bathe (2022) argue that sustainable agricultural development in Uzbekistan also has a direct impact on economic growth and living standards. Infrastructure development, job creation in rural areas and increased incomes complement the country's societal progress.

Agriculture provides food security, creates jobs for many citizens and is a key source of export earnings. With this in mind, it is particularly relevant to analyse the impact of this sector on the socio-economic development of Uzbekistan. A scientific analysis of this relationship will help identify success factors and determine ways to optimise agricultural development, contributing to the formation of a sustainable and prosperous socio-economic outlook for Uzbekistan. In this regard, the study of the relationship between the development of agriculture and the socio-economic perspective of Uzbekistan becomes an object of significant scientific study, revealing new perspectives in understanding the dynamics of economic growth, living standards of the population and social progress. This study on the role of agriculture in shaping the prospects of socio-economic development of Uzbekistan acquires special significance for the formation of strategic decisions and national policies aimed at sustainable development.

Therefore, the research aims to analyse and assess the contribution of agriculture to the overall

socio-economic development of Uzbekistan, as well as to identify its potential and role in creating a sustainable and prosperous country.

MATERIALS AND METHODS

In the course of the study, practical recommendations, and scientific and methodological provisions for determining the real state of agriculture and its impact on the formation of prospects for the socio-economic development of Uzbekistan were used to achieve the set objectives. The informative component of the research was monographic and periodic literature, as well as the Decree of the President of the Republic of Uzbekistan No. P-K-4653 (2020).

The study used the method of comparison to make an analytical comparison of various aspects of agriculture and their impact on the prospects of socio-economic development. In addition, an abstract logical method was applied, aimed at a deep understanding of the role of agriculture in the context of the socio-economic development of Uzbekistan. This method was used to analyse complex interrelationships, identify patterns, and formulate assumptions about the impact of the agricultural sector on the country's development processes. In addition, a set of special and general scientific groups of methods was used, namely:

– induction and deduction (for a more complete analysis and study of agricultural development and its impact on the socio-economic perspective of Uzbekistan);

– analyses (to evaluate the collected information, draw conclusions, provide recommendations, and determine the prospects for further research);

– statistical methods (to quantify the data obtained);

– synthesis (to combine the acquired knowledge into a coherent whole).

As part of the study of Uzbekistan's socio-economic development, gross domestic product (GDP), exports, imports, inflation, unemployment, and GDP per capita were analysed. It also examined the characteristics of the agricultural sector in Uzbekistan, including the share of agricultural area, the share of rural population, value added of agriculture, forestry and fisheries, and grain yields.

The method of conceptual analysis was used to justify the direction of improvement of socio-economic development of Uzbekistan, and the integrative approach identified the main measures to improve the functioning of agriculture. The study also used SWOT-analysis to identify the strengths, weaknesses, opportunities, and threats of the agricultural sector of Uzbekistan. This gave a more complete picture of the current state and prospects of agricultural development. Based on the analysis of statistical data, a correlation and regression analysis were conducted to establish a multifactor regression relationship between the socio-economic development of Uzbekistan and the state of agriculture in general for the period 2013-2022. This analysis aims to characterise and identify the relationship between the socio-economic indicators of the country and the state of the agricultural sector of the economy.

The analysis of regression models will reveal which of the above factors have a significant impact on the socio-economic development of Uzbekistan. The selection of these parameters assumes that they play a key role in shaping and influencing the socio-economic development of Uzbekistan through important aspects of agriculture. Each of the selected parameters is considered as an important factor influencing economic, social and food aspects of the country.

RESULTS

Uzbekistan's agriculture has enormous prospects and potential that should be maximally utilised. To successfully realise this goal, the strategy of long-term development of the national economy should be oriented towards anticipating and adequately responding to the global challenges that the country will undoubtedly face in the future. This will not only ensure food security within the country but will also play an important role in guaranteeing food security in the global arena. Based on the potential of agriculture, Uzbekistan can become a significant participant in the global dynamics of food resource distribution. With the right development strategy, the agricultural sector will become one of the key players in this process, proving itself to be quite competitive.

The analysis of socio-economic indicators in the agricultural sector of Uzbekistan for the period from 2013 to 2022 reveals multidirectional trends. The share of agricultural land varies from 58.1% to 60%, with a slight decrease of 1.4%. The share of the rural population increased from 49.1% to 49.6% with a growth rate of 1.1%. The value added of agriculture, forestry and fisheries first increases to 29.3% in 2015 and then declines to 25% in 2021, with a growth rate of 10.2%. The value of this value also falls from 20.34 billion USD in 2013 to 16.06 billion USD in 2022, with a growth rate of -14.9%. Cereal yields fell from 4.8 tonnes/ha in 2013 to 4.1 tonnes/ha in 2018, then started to rise, reaching 4.9 tonnes/ha in 2022, with a growth rate of -14.9%. These indicators reflect the diverse dynamics of agricultural development in the country, including both positive and negative changes in key aspects (Table 1).

Table 1. *Trends in the development of the agricultural sector in Uzbekistan*

Value	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Growth rate, %
Share of agricultural land (% of total area)	58.9	60	58.1	58.1	58.1	58.1	58.1	58.6	59.3	59.6	101.2

Table 1, Continued

Value	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Growth rate, %
Share of the rural population (% of the total population)	49.1	49.2	49.3	49.4	49.5	49.5	49.6	49.6	49.6	49.6	101
Value added of agriculture, forestry, and fisheries (% of GDP)	27.8	28.7	29.2	29.3	28.7	26.8	24.6	25.1	25	26.9	96.8
Value added of agriculture, forestry, and fisheries (billion USD)	20.34	23.2	25.17	25.24	17.82	14.11	14.74	15.03	17.31	16.06	79
Grain yields (tonnes/ha)	4.8	4.8	4.9	4.8	4.2	4.1	4.5	4.4	4.7	4.9	102.1

Source: *compiled by the authors*

Analysis of the data indicates heterogeneous dynamics in the agricultural sector in Uzbekistan over the period under review. The share of agricultural land, the share of rural population and the value added of agriculture, forestry and fisheries show fluctuations in different years. These changes can be attributed to various factors, including economic conditions, government policies and climatic conditions. It is important to consider these trends when formulating strategic plans for the sustainable development of the rural economy and the well-being of the population. When analysing the indicators of socio-economic development, it was found that Uzbekistan is undergoing active and dynamic changes in the sphere of socio-economic development (Table 2).

Table 2. *Indicators of socio-economic development of Uzbekistan*

Value	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Growth rate, %
Gross Domestic Product (GDP), billion USD	73.2	80.8	86.2	86.1	62.1	52.6	59.9	59.9	69.2	80.4	109.8
Share of exports of goods and services in GDP (% of GDP)	18.6	16	13.8	12.3	20.7	27	28.4	24.3	23.7	27.3	146.8
Exports of goods and services, billion USD	13.61	12.94	11.9	10.6	12.85	14.21	17.01	14.55	16.41	19.31	141.9
Share of imports of goods and services in GDP (% of GDP)	23.7	20.3	17	16.9	27	44.6	44.4	37.7	40.1	44.3	186.9
Imports of goods and services, billion USD	17.34	16.41	14.65	14.56	16.76	23.47	26.6	22.58	27.76	30.67	176.9
Inflation, GDP deflator (annual %)	12	14	10.5	8.9	19.1	27	17.9	11.6	13.6	12.5	104.2
Total unemployment rate (% of total labour force)	4.9	5.1	5.2	5.2	5.8	9.3	9	10.5	9.6	8.9	181.6
GDP per capita (USD)	2419.7	2628.5	2754	2704.7	1916.8	1597.1	1784	1749.7	1983.1	3473	143.5

Source: *compiled by the authors*

Analysis of data on indicators of the socio-economic development of Uzbekistan reveals the following trends. At the beginning of the period, from 2013 to 2015, GDP grew gradually, reaching a peak in 2015 at 86.2 billion USD. However, in the following years, there was a decline in GDP, in particular, a significant drop to 52.6 billion USD in 2018. There was a recovery to 80.4 billion USD in 2022, but this level remains below the 2015 level. The share of exports of goods and services in GDP decreased at the beginning of the period under consideration, from 18.6% in 2013 to 12.3% in 2016, then started to increase, reaching 27.4% in 2022. Similar trends are observed for the share of imports of goods and services in GDP, which initially increased before reaching 69.1% in 2022. The inflation rate, as measured by the GDP deflator, fluctuates within the period under consideration, from 8.9% in 2016 to 27% in 2018, before declining to 13.1% in 2022. These changes may reflect fluctuations in economic activity and money supply. The overall unemployment rate shows a moderate increase from 2013 to 2017 and then sees a decline to 8.9% in 2022. Despite the fluctuations, GDP per capita declined in 2020, probably due to economic factors, but there is some recovery in 2022. To confirm the dependence of Uzbekistan's socio-economic development on the branching of agricultural activities in this country, a regression model of the relationship between the GDP per capita indicator and data on the state of the agrarian sector was constructed (Table 3).

Table 3. *The results of building a multifactor regression model of dependence of the socio-economic development of Uzbekistan on agriculture in the country*

Conclusions on results					
Regression statistics					
R Multiple	0.9999				
R-square	0.9999				
Normalized R-square	0.9993				
Standard error	12.7775				
Observations	6				
Dispersion analysis					
	df	SS	MS	F	Variable F
Regression	4	1124775.77	281193.94	1722.3269	0.0181
Remainder	1	163.26	163.26		
Total	5	1124939.03			
	Coefficients	**Standard error**	**t-statistics**	**P-value**	**Lower 95%**
Y-intersection	-52926.0604	56103.24	-0.94	0.52	-765785.3
X 1 variable	8.4004	12.3	0.68	0.62	-147.94
X 2 variable	954.3022	1051.95	0.91	0.53	-12411.98
X 3 variable	2.9406	60.8	0.05	0.97	-769.66
X 4 variable	1.6651	1.11	1.51	0.37	-12.39

Source: *compiled by the authors*

The results indicate a high linear relationship between the dependent and independent variables (multiple correlation coefficient R is close to 1), with the model explaining about 99.99% of the variability of the dependent variable (R-squared) with high explanatory power. Despite this, the normalised R-square is slightly lower than the standard R-square, possibly due to multicollinearity. The analysis of variance confirms the statistical significance of the model as a whole (high F-statistic and low p-value). Variable X1 indicates that when the agricultural land area increases by 1% of the total area, the GDP per capita of the country increases by 8.4 USD. Furthermore, similarly, when the share of the rural population increases by 1% of the total population, GDP per capita increases by 954.3 USD. Additionally, when the value added from agriculture, forestry and fisheries increases by 1 billion USD, the GDP per capita of the country increases by 2.94 USD. Also, an increase in crop yields by 1 kg/ha entails an increase in socio-economic development in Uzbekistan, which is accompanied by an increase in GDP per capita by 1.67 USD. However, the regression coefficients for all variables, including the Y-intercept and variables X1, X2, X3, and X4, were found to be statistically insignificant (all p-values greater than 0.05), suggesting no significant effect of these variables on the dependent variable. Thus, the analysis indicates a strong relationship between the variables, but not always statistically significant. Results may also be affected by multicollinearity or data limitations. To identify more significant agricultural factors of influence the socio-economic development of Uzbekistan, single-factor regression relationships were constructed, and the degree of relationship was determined using correlation coefficients (Table 4).

Table 4. *Results of construction of single factor regression models of dependence of socio-economic development of Uzbekistan on agriculture in the country*

X	Correlation coefficient	Determination coefficient	Link level
X1 Agricultural land (% of land area)	0.34	0.11	low
X2 Rural population (% of total population)	0.62	0.39	average
Y3 Agriculture, forestry, and fisheries, value-added (billion USD)	0.98	0.96	dense
X4 Grain yields (kg/ha)	0.98	0.96	dense

Source: *compiled by the authors*

Analysis of correlation and determination coefficients indicates that the variables related to value added of agricultural, forestry and fishing activities and grain yield have a strong influence on the dependent variable. The percentage of rural population also has a medium degree of influence while the percentage of agricultural land has the least effect on the dependent variable.

Accordingly, this indicates that although the country has a significant agricultural area and rural population, it is the organisation of agricultural activities that makes all the difference.

According to JJ. Robalino and J. Bathe (2022), B.I. Shapiro *et al.* (2022), Uzbekistan's agricultural sector is currently experiencing low efficiency in utilising its considerable potential. This raises the prospect of improving the socio-economic development of the country through modernisation of the agricultural sector. Two key problems are contributing to the weak state of the sector: lack of investment and shortage of highly qualified personnel. The solution to these problems can be ensured by the active participation of the state. To improve the socio-economic situation, it is necessary to implement reasonable actions aimed at a significant increase in land productivity. Special attention should be paid to increasing income per hectare of irrigated land. This includes changing attitudes towards land, intensifying investments in the sector and providing the industry with qualified personnel. Such efforts can lead Uzbekistan to take its rightful place among the world leaders.

The loss of some agricultural products due to insufficient organisation of collection, transportation, storage, and sale is also a problem. In a developing country like Uzbekistan, much production can also go to waste due to a lack of investment and infrastructure. Problems with the efficiency of irrigation, production and harvesting methods, as well as with the quality of agricultural services, transport, and storage, can be gradually overcome. This opens up prospects for increasing the share of agriculture in the formation of the country's GDP and strengthening its position as a key sector of the national economy. Supporting the processing of agricultural products at industrial enterprises and their efficient delivery to consumption should become an important part of the strategy of the state agricultural policy. Financial support of the agricultural sector through subsidies becomes an important means for the rapid development of agriculture, especially in the context of the country's integration with world markets. To attract investment, it is necessary to effectively use financial resources aimed at the activities of agricultural enterprises. At the same time, the key condition for the attractiveness of the agricultural sector for investors is to ensure the profitability of investments, which should be no less favourable than in other sectors.

Reducing the shortage of investment resources in agriculture can be achieved through improving the state policy of financing and support of the industry. Support aimed at reducing the cost of production, improving it and increasing production volumes will make products more competitive. This, in turn, favours the attraction of investment in agriculture, increases its profitability and promotes the development of the agrarian sector. The establishment of model state farms in each district with public funds is also proposed. These farms should operate using advanced agricultural practices, equipment, and innovative technologies. They should have a highly skilled workforce capable of raising yields and land productivity to world-class standards to become important modern production enterprises. These model farms will not only serve as role models for local farmers and smallholders by providing quality and affordable produce but will also provide practical assistance in various aspects of agricultural operations. They will be a key vehicle for effective agricultural and livestock development in the district, as well as fundamental organisers of productivity improvement for all farms in the district. In this way, state farms will become the engine of economic growth in every district of the country.

Additionally, the introduction of a competitive selection system for farm managers should be considered so that these positions are filled by organisers with high qualifications, experience, and integrity. These managers will not only manage the state farms but are also responsible for the overall performance of all farms in the district. Evaluation and rewarding of the manager's performance should depend on the status and dynamics of the entire agricultural complex in the district. To ensure efficiency, it is advisable to introduce a rating system based on various performance indicators among all state farms in the country. This policy, although requiring significant financial outlay, could be introduced first as a pilot project in one or more districts.

Thus, the study has established that the key sector that determines the socio-economic development of Uzbekistan is the agricultural sector. In this regard, it is recommended to implement a series of measures aimed at improving the state of agriculture in the country:

– implementation of programmes to improve the efficiency of agricultural land use through the introduction of modern agricultural technologies and innovative methods;

– creation of new jobs and supporting employment in rural areas, which helps to reduce migration to cities;

– development of industrial processing of agricultural products to increase their value and diversify the economy;

– expanding areas for agricultural and livestock purposes, including the development of new land;

– actively promoting agrarian products on the world market through the development of export opportunities and improving competitiveness;

– providing state financial support to the agricultural sector through subsidies and preferential programmes;

– attracting investments from foreign partners to modernise and technologically upgrade the agricultural sector;

– implementing a system for assessing the performance of agricultural enterprises to stimulate quality development;

– optimising state mechanisms of financing and support for the agricultural sector, considering the changing economic situation;

– integrating modern technologies, including digitalisation and smart management systems, to improve the efficiency and sustainability of agriculture.

It is important to note that the SWOT-analysis of the agricultural sector of Uzbekistan showed a high potential for development and improvement, but also revealed a range of constraints and risks (Table 5).

Table 5. *SWOT-analysis of the agricultural sector in Uzbekistan*

Advantages	**Disadvantages**
Soil and climate potential: Uzbekistan has diverse soils and a favourable climate, creating favourable conditions for growing a variety of crops and plants.	Lack of infrastructure. Underdevelopment of modern storage, transport and processing systems can lead to the loss of part of the harvest and reduce the efficiency of agricultural production.
Water resources. The presence of rivers and irrigation systems provides access to water for irrigation, which contributes to higher yields and diversity of crops.	Weather dependence. Unfavourable weather conditions, such as droughts or abnormal temperatures, can adversely affect yields and product quality.
Labour potential. A large population creates the potential for labour force formation in the agricultural sector, which helps to maintain production capacity.	Uneven land use. Misallocation of land resources can lead to soil degradation and low crop yields.
Agricultural traditions. The rich experience and long history of agricultural activities in the country allow the knowledge to be preserved and passed down through the generations.	Low mechanisation. Weak development of modern agricultural machinery and technologies reduces labour productivity and efficiency.
Internal market. The high demand for food products within the country creates the potential to develop the domestic market and reduce dependence on imports.	
Possibilities	**Risks**
Export development: Uzbekistan can utilise its agrarian potential to increase agricultural exports, thereby strengthening its economy and increasing its visibility on the world stage.	Climate risks. Changing climatic conditions can lead to unpredictable weather events such as droughts, negatively affecting crop yields and product quality.
Infrastructure investments. The development of modern infrastructure, including storage, transport, and processing systems, will improve production efficiency and reduce product losses.	Global market competition. When entering the global market, the agricultural sector will face competition from other countries, which may affect prices and demand.
Agriculture innovations. The application of modern technologies, including genomics and bioinformatics, will increase yields and product quality, improving market competitiveness.	Environmental pollution. The use of chemical fertilisers and pesticides can adversely affect the environment and human health.
Organic agriculture development. The increased interest in organic products provides an opportunity to grow and sell natural products that meet the demands of today's consumers.	Demographic changes. A declining population in rural areas may lead to labour shortages in the agricultural sector.
Global economic factors. Economic changes at the global level may affect the demand and prices of agricultural products.	

Source: *compiled by the authors*

Thus, the SWOT-analysis has confirmed that Uzbekistan has potential for the development of the agricultural sector, but requires investment in infrastructure, modern technologies and staff training to achieve sustainable growth and successful integration into the world market.

DISCUSSION

Agriculture is a labour-intensive industry, which is important for creating new jobs and reducing unemployment. The development of this sector is important for shaping the living standards of the population, as well as for modelling social structure and social progress. Given the current global challenges, such as climate change and changing demographics, agriculture is becoming an integral part of the country's sustainable development strategy.

In this context, the findings can be compared with the studies of M. Chen and H. Wang *et.al* (2020), L. Batiuk (2020), also note that agriculture provides a wide range of jobs, from agricultural labourers to specialists in agribusiness, agricultural technology, and product processing. These jobs typically have relatively low education and training costs. The authors' research confirms that the development of the agricultural sector helps to reduce unemployment and provides employment, which also correlates with the study.

A similar view is also expressed by F. Karaca *et al.* (2019), who emphasise that the development of the rural sector helps to reduce unemployment, especially in rural areas, and job creation can provide residents with employment opportunities without the need to migrate to cities. In addition, the development of agricultural production also stimulates the development of rural infrastructure such as roads, energy, and water supply, which in turn improves the quality of life of the local population. This study also correlates with the author's view that improving the agricultural sector can have a significant positive impact on the socio-economic development of a country.

Agriculture plays a key role in shaping the prospects for the socio-economic development of many countries. Thus, O. Kravchenko *et al.* (2020) show that agriculture is one of the main sectors of the economy that can make a significant contribution to the gross domestic product of the country. Thus, with an increase in the share of the rural population by 1-2% of the total population, GDP per person increases by 900-1000 USD, and an increase in crop yields by 1-1.5 kg/ha is accompanied by an increase in socio-economic development and an increase in GDP per capita by 1.9 USD. Agricultural development also contributes to the growth of production, investment, and exports, which stimulates overall economic growth, which is also noted in the study conducted.

A study by X. Cui *et al.* (2022) emphasises the importance of agriculture for the provision of food products to the population. Sustainable development of the rural sector allows the country to reduce dependence on food imports by 25-35% and provide the population with quality and affordable food, which also confirms the study. In addition, the findings of the study resonate with the findings of D. Niyazmetov *et al.* (2021) that investment in infrastructure, modern technology and human resource training are critical steps to overcome the weaknesses and capitalise on the opportunities presented by the agricultural sector. Properly planned and implemented measures can lead to sustainable growth, improved livelihoods, and successful integration into the global market.

The results obtained are similar to those of K. Pawlak and M. Kołodziejczak (2020), according to which investments in agricultural infrastructure along with addressing income inequality through measures aimed at increasing the purchasing power of households, especially in rural areas, are key factors in improving access to food in countries around the world. A study by Y. Du *et al.* (2020) also indicates that agriculture has the potential to contribute to reducing social and economic inequalities. This is achieved by providing opportunities for small farmers and peasant households to improve their income levels and quality of life. In addition, it has the potential to strengthen rural communities, revitalise local economies and promote sustainable development at the local level.

A similar view is expressed by R.P. Pradhan *et al.* (2019), whose research shows that improving the economic status of rural residents has a positive impact on social development, education, and access to health care. Increased income of rural residents improves access to educational and health services, which contributes to the growth of human capital and improves the quality of life. In addition, X.W. Li and S.B. Xu (2020) argue that sustainable agriculture contributes to the conservation of natural resources and biodiversity, which in turn is important for the long-term development and well-being of the country. Agriculture also plays an important role in rural development by promoting infrastructure development, creating model farms, and maintaining social stability.

J. Streimikis and T. Baležentis (2020) highlight the importance of innovation and technological progress in agriculture. The application of modern methods of agricultural production, including biotechnology and information technology, contributes to increasing yields and efficiency. Studies by A. Kotvitska *et al.* (2021) and B. Ortiz *et al.* (2018) also confirm that the adoption of modern technologies in agriculture increases production efficiency and yields, which in turn contributes to GDP growth. In addition, agriculture can become one of the factors of diversification of the country's economy, reducing dependence on highly specialised industries. The development of agriculture can also contribute to increasing the country's export potential, which affects the balance of trade and has a positive impact on foreign economic relations.

The findings of the study resonate with the studies of G., Wang *et al.* (2020) and F. Karaca *et al.* (2019), which emphasise the importance of attracting foreign investment and experts for the successful development of agriculture. The certification of rural workers, including the participation of foreign experts, should be emphasised. They also recommend introducing an effective mechanism for regulating land relations, establishing sustainable economic regulatory mechanisms for optimal utilisation of land plots, and paying attention to the socio-economic well-being of the population.

Analysis of studies by L. Lombardozzi (2020), K. Pawlak and M. Kołodziejczak (2020) suggests that Uzbekistan faces a low level of economic development and several problems in agriculture. The authors highlight the inefficiency of production, storage, and distribution, which affects farmers' profitability and leads to losses at the marketing stage. The authors emphasise the importance of increasing agricultural productivity, introducing innovations, and creating infrastructure for the storage and processing of products. They propose the introduction of a state programme for the construction of vegetable storage facilities and industrial refrigerators, as well as support for less profitable sectors of the agricultural industry through subsidies, tax incentives and public contracts.

The study by K. Sen *et al.* (2020) examines the prospects for agricultural development and socio-economic progress in Uzbekistan. The authors note that the country is facing problems of economic growth and high poverty among the population and emphasise the importance of training qualified economists who can analyse financial problems and propose solutions. They recommend state support for less profitable sectors of agriculture, the introduction of modern machinery and innovations, and the creation of a system of evaluation and rating of the performance of regional agricultural managers.

Thus, the analysis of studies by different scholars and the result of the conducted research confirms the

importance of agriculture as a fundamental element of socio-economic development, as well as emphasise the significance of an integrated approach to agricultural development and socioeconomic progress of Uzbekistan, including improvement of production efficiency, introduction of innovations, creation of infrastructure and support of various sectors of the agricultural industry. In general, the agricultural sector plays a crucial role in shaping the prospects for socio-economic development. The above-mentioned studies demonstrate that agriculture has many positive impacts on various aspects of society and the economy. It is important to emphasise that these results not only confirm the importance of the sector but also serve as a basis for the development of strategies and interventions aimed at strengthening and improving the rural sector. The formation of strategic decisions and national policy in the field of agriculture is important for ensuring the sustainable and balanced development of Uzbekistan. Introducing advanced ideas, promoting diversity of production, and supporting agrarian entrepreneurs contribute to the realisation of the goals of the national development strategy.

Considering the above, job creation, food security, sustainable resource utilisation, promotion of economic growth, economic diversification, social development, and local development are some of the aspects that confirm the significant contribution of agriculture to the future of the country. The research findings provide the scientific basis for decision-making and strategies to maximise the positive impact of the agricultural sector on social well-being and economic development.

CONCLUSIONS

The natural resources of Uzbekistan, such as fertile soils and water resources, are an essential basis for the development of agriculture. Efficient utilisation and management of these resources are becoming key factors for the successful development of the sector. The analysis of multidirectional trends in the agricultural sector of Uzbekistan for the period from 2013 to 2022 emphasises the importance of this sector for the socio-economic development of the country. The share of agricultural land varies from 58.1% to 60.0%, while the share of the rural population is 49.6% of the total population. The increase in the share of agricultural land and rural population, despite fluctuations, indicates the continued importance status of rural life. However, the decline in the value added of agriculture, forestry, and fisheries, as well as the insufficiently high growth rate of cereal yields, indicates the problems faced by agriculture.

The decline in GDP and rising unemployment rates, as well as changes in the share of exports and inflation rates, are indicative of significant challenges in the socio-economic sphere. Having started to grow gradually from 2013 to 2015 and peaked in 2015 at US$86.2 billion, GDP has faced a subsequent decline, particularly notable in 2018 when it fell to US$52.6 billion. Inflation rates ranged from 8.9% in 2016 to 27% in 2018 but then declined to 13.1% by 2022. Consequently, despite the negative trends, there has been a gradual recovery in some indicators, which may indicate a desire for improvement.

Considering these studies, it is possible to highlight the prospects for agricultural development as a key factor in improving the socio-economic condition. Particular attention should be paid to increasing land productivity, creating jobs in rural areas, processing agricultural products, and expanding production capacity. A continuous increase in the volume of exported products abroad also represents an important development path. In addition, strategic development of the agricultural sector requires additional steps, such as state financial support, the attraction of foreign investments, the introduction of a rating system of evaluation, as well as improvement of state financing policy.

The findings of the study have practical relevance, as they may have an impact on the formation of government strategies in agriculture and the identification of priority areas for investment and resource utilisation to ensure sustainable economic growth. The prospect for further research is to investigate how agricultural development can affect social spheres such as living standards, education, health, and access to social services.

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CONFLICT OF INTEREST

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Роль сільського господарства у формуванні перспектив соціально-економічного розвитку Узбекистану

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Анотація. Роль сільського господарства в забезпеченні продовольчої безпеки, створенні робочих місць і формуванні експортних доходів робить особливо актуальним аналіз впливу цієї галузі на соціально-економічний розвиток країни. Мета роботи – аналіз та оцінка впливу сільського господарства на соціально-економічний розвиток Узбекистану. Для досягнення поставленої мети проаналізовано показники сільськогосподарської сфери та соціально-економічного розвитку з 2013 по 2022 рр. Встановлено, що природні ресурси Узбекистану відіграють найважливішу роль у розвитку сільського господарства. Аналіз диверсифікованих тенденцій у сфері сільського господарства підкреслює ключову роль цієї галузі для соціально-економічного прогресу країни. Незважаючи на мінливість, зростання частки сільськогосподарських угідь і сільського населення свідчить про, як і раніше, високу значимість сільського господарства. Однак зниження доданої вартості в аграрній, лісовій сферах і рибальстві, а також низькі темпи зростання врожайності зернових, відображає актуальні виклики в цій галузі. Зростання рівня безробіття, а також зміни в експорті та рівні інфляції, вказують на складнощі в соціально-економічному середовищі. У цьому світлі особливо важливими є перспективи розвитку сільського господарства, як ключового агента в поліпшенні соціально-економічної ситуації. Ефективне ресурсне управління, підвищення продуктивності, генерація робочих місць, просування продукції та розширення виробництва – всі ці аспекти становлять важливі напрямки для майбутнього розвитку. Стратегічний підхід до розвитку сільського господарства вимагає реалізації додаткових заходів, таких як державна фінансова підтримка, мобілізація інвестицій, використання оціночних рейтингів і поліпшення державної політики. Отримані результати дослідження можуть бути використані для адаптації державних політик і програм у сільськогосподарській сфері, а також визначення пріоритетних напрямів інвестицій і ресурсів з метою сталого розвитку економіки.

Ключові слова: природні ресурси; продовольча безпека; зростання економіки; суспільний прогрес; стійкість

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Forecasting husbandry development using time series

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Abstract. Building time series models based on historical data is a pressing challenge in the agricultural sector. This is essential, as analysing and predicting processes related to the food security of the state, region, and business entities are of paramount importance in management. With the help of forecasts, enterprises can adjust their production activities in such a way as to satisfy demand and deliver products to consumers on time. The research aims to predict the trends in the growth of cattle and cow populations and identify the most suitable forecasting timeframe. Statistical methods related to autoregression are used for this type of analysis: autoregressive

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models, moving average models or a combination of both, integrated variable structure models, and models that include seasonal effects and exogenous factors with an autoregressive and moving average component in the model. Monthly statistical data on the number of cattle and cows are used, among them mean, standard deviation, minimum and maximum values, asymmetry, and kurtosis. The dynamics of the decrease in the number of cattle and cows are shown. The studied series were checked for stationarity. The time series data for the cattle population underwent a Box-Cox transformation. The optimal parameters of the models used are given. Predictive values for periods (months) were obtained and the change in the number of cattle over the last 15 years was analysed. Constructed time series are compared with the actual values, which are illustrated in the graphs. Estimates of root-mean-square deviation, and mean absolute percentage error for different forecasting terms are given. By comparing these estimates for different time intervals, the optimal period for the forecast (24 months) was determined. This study allows farms and enterprises in the industry to predict a possible number of products (milk, meat) that could be collected or obtained in the future. It helps to take the necessary management steps: plan resource needs, improve efficiency, increase profits, reduce costs, and adapt to changes in the market

Keywords: husbandry; predict; management; Box-Cox transformation

INTRODUCTION

Animal husbandry is one of the key branches of agriculture. It performs the functions of the main source of raw materials, materials of various spheres of the economy. At the same time, animal farming is the main supplier of vital products, means of forming the country's food independence, consumer of the machine-building industry, and transport industry. The relationship between animal agriculture and other sectors of the economy and economy determines the nature of the current problems of the industry, as well as management methods for overcoming them. As such, A. Chub (2021) research demonstrated that animal husbandry constitutes an integral and crucial component of Ukraine's agro-industrial complex. The importance of this branch of the economy is determined by the need to provide food products of animal origin in the population's diet.

Since 2013, the state of the industry has shown both a decline in the potential of livestock farming in the domestic environment and a decrease in its share in the global development of the industry. During the last decade, there has been a tendency to decrease the number of cattle and cows in Ukraine (State Statistics Service of Ukraine (n.d.). The development of domestic animal agriculture in the near and distant perspectives should be based on the achieved results and management experience of its rational management and following the provision of economic-technological, normative-legal, state regulation and organizational-management components at the national level, addressing the peculiarities of the management of industries in economically developed countries the world, which, in turn, requires further scientific and practical research and development (Zamula *et al.*, 2020).

A. Lavruk & N. Lavruk (2020) considered the current state of animal husbandry. To facilitate a successful revitalization and intensive growth of the animal husbandry industry, it is necessary to promote transparency in the actions of government and executive authorities. This means implementing transparent and open processes in decision-making, attracting investment, and developing policies in the industry. N. Parajua (2022) analysed changes in agriculture, livestock, woodland management, and fishing in the Spanish agricultural and food system. Said study also revealed trends, opportunities and problems related to these industries. P. Zharuk and L. Zharuk (2020) analysed the results of modern world development of sheep breeding, its state in Ukraine and development trends. Changes are taking place in sheep breeding in different countries – in some, a significant decrease in the number of livestock, in others – an increase. In the conditions of the modern world market, the production of meat and dairy products from mutton, and mutton with preservation of quality characteristics of wool, fur and fur raw materials is a promising direction of the industry development.

N. Shyian and I. Kotelnikova (2019) emphasised negative trends in the field of animal husbandry that can lead to serious problems. A decline in the cattle population, especially cows, can lead to a decrease in the industry's product output and result in unprofitability in meat and milk production. V. Zamlynskyi (2019) assessed the current status of the animal husbandry industry in Ukraine and internationally to formulate a strategic development plan. This plan aims to enhance the involvement of small and medium-sized enterprises in animal husbandry, implement programs for conserving resources, and mitigate environmental pollution. O. Shubravska and K. Prokopenko (2018) demonstrated strategies for encouraging the adoption of innovative management solutions in Ukraine's agricultural sector. It is shown that the production of organic products, along with purely health and ecological effects, is favourable to significantly increase the income of Ukrainian farmers, their ability for further innovative development, and also to improve the state's balance of payments.

The analysis covers the level and dynamics of the indicators that determine it. S. Koliadenko *et al.* (2020) examined potential avenues for Ukrainian agricultural

product exports. Employing mathematical modelling, complex economic processes were analysed, and optimal solutions were found based on available data and information. The method of a continuous system of non-periodic functions was used to address the instability of market conditions and the variability of demand, which are characteristic of the agricultural sector. This makes it possible to determine forecasts and adapt them to real conditions more accurately. M. Ribeiro & L. Coelho (2020) assessed the predictive attributes of regression ensemble models in agribusiness-related case studies and compared their effectiveness.

The research aims to forecast trends in the development of the number of cattle and cows using a model that specializes in analysing dynamics in time series and determining the appropriate forecasting period.

MATERIALS AND METHODS

Data Overview. Research data on the number of cattle (including cows) in the period from January 1, 2008, to January 1, 2023, were obtained from the website of the Main Department of Statistics in the Khmelnytskyi region of Ukraine (n.d.).

SARIMAX Models. The basis of this study is the Box-Jenkins model (Zhang, 2003; Ediger & Akar, 2007) (Autoregressive Integrated Moving Average, ARIMA), which enables forecasts based on time series, that is, historical observations. The ARIMA model integrates elements from both the autoregressive (AR) model and the moving average (MA) model.

AR (p) $$y_t = c + \sum_{n=1}^{p} \alpha_n y_{t-n} + \varepsilon_t\,, \quad (1)$$

MA (q) $$\varepsilon_t = \sum_{n=1}^{q} \theta_n \varepsilon_{t-n}\,. \quad (2)$$

Three integers are used to parameterize the model: (p, d, q). p – number of members of the autoregression; d – number of non-seasonal differences; q – number of moving average conditions.

SARIMAX (Seasonal Auto-Regressive Integrated Moving Average with eXogenous factors) is a modification of the ARIMA model. While ARIMA is based on an autoregressive integrated moving average, SARIMAX extends this model by adding seasonal changes and external factors that help account for changes in a given time series. Thus, SARIMAX is the seasonal equivalent of SARIMA and Auto ARIMA models.

Two types of parameters must be specified in the SARIMAX model parameter. The first is similar to the ARIMAX (p, d, q) model, and the second is to determine the effect of seasonality. You need to know 4 parameters: P – Seasonal AR specification; D – Seasonal Integration order; Q – Seasonal MA; s – Seasonal periodicity.

Mathematically, the model can be stated as follows:

$$\phi_p(L)\underline{\phi}_P(L^s)\Delta^d\Delta_s^D y_t = A(t) + \theta_q(L)\underline{\theta}_Q(L^s)\epsilon_t \quad (3)$$

where $\phi_p(L)$ – is the non-seasonal autoregressive lag polynomial; $\underline{\phi}_P(L^s)$ – is the seasonal autoregressive lag polynomial; $\Delta^d\Delta_s^D y_t$ – is the time series, difference d times, and seasonally differenced D times; $A(t)$ – is the trend polynomial (including the intercept); $\theta_q(L)$ – is the non-seasonal moving average lag polynomial; $\underline{\theta}_Q(L^s)$ – is the seasonal moving average lag polynomial.

The evaluation measure used for time series forecasting in this study is root mean square deviation (RMSE) and mean absolute percentage error (MAPE) (Hyndman & Koehler, 2006, Zhang X *et al*, 2015):

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(E_t - F_t)^2}, \quad (4)$$

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\frac{|E_t - F_t|}{E_t}, \quad (5)$$

where E_t and F_t are actual and predicted values, n – number of values.

To apply the technique of time series forecasting, it is necessary to test the series for stationarity using the Dickey-Fuller (ADF) test (Dickey & Fuller, 1981). This test detects the presence of stochastic trend behaviour in time series using a hypothesis test.

H_0: process is non-stationary;

H_1: process is stationary.

If the series is non-stationary, then the Box-Cox transform can be used to obtain a series that will satisfy the conditions of stationarity (Atkinson & Corbellini, 2021; He *et al.,* 2019). The basis of the Box-Cox Transformation is the exponent and the coefficient λ, which varies from -5 to 5. All values of λ are considered and the value that gives the best approximation of the normal distribution curve is selected. The transformation of Y has the form:

$$y(\lambda) = \begin{cases} \frac{y^{\lambda}-1}{\lambda}, if\ \lambda \neq 0; \\ y,\ if\ \lambda = 0. \end{cases} \quad (6)$$

Software used for calculations and visualizations: *Jupyter Notebook*.

RESULTS AND DISCUSSION

Predicting the future of the agricultural sector, a pivotal component of the economy holds significant importance for both developed and developing nations. Moreover, it enables the formulation of future agricultural policies, facilitates investment planning, and allows for the implementation of necessary measures. In the immediate future, estimating the number of farm animals has many advantages for management decisions. The most successful forecast using monthly data can be obtained by improving seasonal forecasting methods. In this research, the SARIMAX forecasting method was used for predicting monthly cattle and cow populations. The proposed method is focused on finding the most relevant values of past observations through identical estimates. In addition, conducts tests for all relevant seasonal factors, enhancing the effective modelling of seasonality within the dataset.

Time series models of the dynamics of changes in the number of farm animals in this study were built considering the RMSE and MAPE values. Using the proposed method, monthly changes in the number of cattle and cows for Ukraine until 2025 were predicted. The dynamics of changes in the number of cattle (including cows) in the period from January 1, 2008, to January 1, 2023, in the Khmelnytskyi region were considered (Fig. 1).

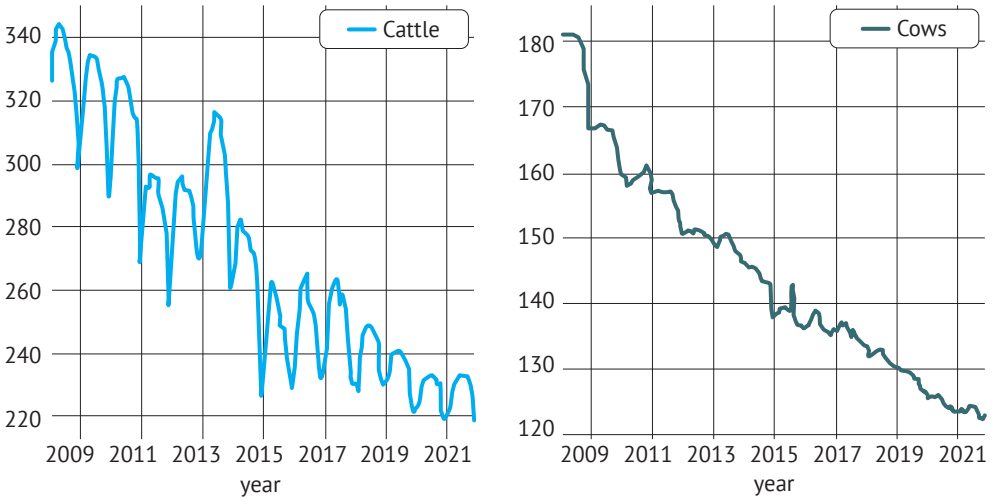

***Figure 1**. Dynamics of changes in the number of cattle and cows (thousands of heads) from January 1, 2008, to January 1, 2023*
***Source:** authors' elaboration from (Main Department of Statistics in the Khmelnytskyi region of Ukraine, n.d.)*

Figure 1 shows that over the last 15 years, the population of cattle and cows has a general tendency to decrease. The trend and seasonality are visible on the graph of the cattle population. Table 1 shows the summary monthly statistical data for the above-mentioned period of the number of agricultural animals.

***Table 1.** Statistical data on the number of cattle and cows*

Metrics	N	Mean	Std.	Min.	Max.	Skew.	Kurt.
Cattle	180	267.15	36.69	217.5	344	0.52	-1.04
Cows	180	143.12	16.33	121.7	182.6	0.62	-0.46

***Source:** author's elaboration*

The table shows the minimum, maximum, mean, skewness, and kurtosis for the monthly data set used in this study to characterize the number of cattle and cows. Thus, the maximum number of cattle was 344,000 heads in May 2008. And already in November 2012, it reached its minimum value of 217.5 thousand heads. A positive sign in the skewness coefficient indicates that most of the data is greater than mathematical expectation, and a negative kurtosis coefficient indicates that the curve of the theoretical distribution has a lower peak than the curve of the normal distribution. Also, the correlation coefficient between cattle and cows is 0.941, which indicates a high dependence between the values. Let's check for the stationarity of the series using ADF (augmented Dickey-Fuller test) (Table 2).

***Table 2.** The results of the test for stationarity using the Dickey-Fuller test*

	p-value	conclusion
Cattle	0.6104	non-stationary
Cows	0.0139	stationary

***Source:** author's elaboration*

The authors apply the Box-Cox Transformation to the time series of the number of cattle. The optimal parameter λ=-1.9767. Table 3 presents the best SARIMAX models for predicting cattle and cow populations using the AIC criterion (Akaike information criterion). In Figure 2 shows the actual value of the time series and the value of the constructed models for the time series. It can be seen visually that the models fit the actual values well, which indicates the optimality of the found model parameters.

Table 3. *SARIMAX model parameters and AIC-criterion values for time series characterizing cattle and cows*

	Model	AIC
Cattle	SARIMAX(0, 1, 0) × (0,1, 1, 12)	-4071.359
Cows	SARIMAX(1, 1, 9) × (1,1, 1, 12)	465.673

Source: *author's elaboration*

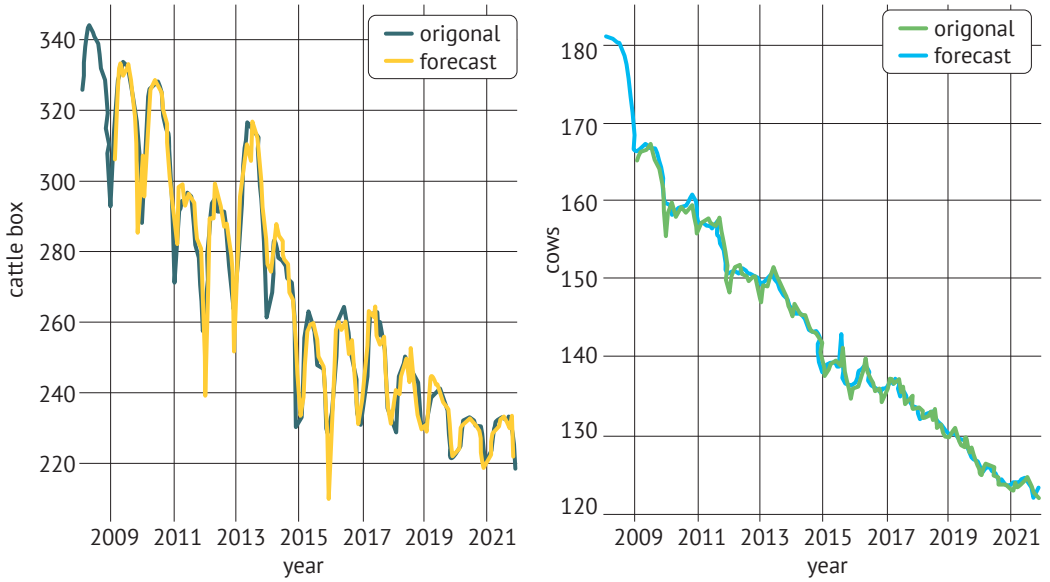

Figure 2. *Original and forecast values of time series*

Source: *author's elaboration*

The forecasting time horizon (comparing the size of the receiver window size (RWS) sliding window) was set to 24 months (Table 4) since this value of RWS has the lowest root mean squared error (RMSE) and mean absolute percentage error (MAPE) estimates and the best average absolute percentage accuracy (MAPA) for both time series.

Table 4. *Rolling window size comparison*

	Cattle			Cows		
RWS	**RMSE**	**MAPE**	**MAPA (%)**	**RMSE**	**MAPE**	**MAPA (%)**
12	2.928	0.008	99.2	0.605	0.005	99.5
24	2.178	0.005	99.5	0.529	0.004	99.6
36	2.201	0.006	99.4	0.570	0.005	99.5
48	3.052	0.008	99.2	0.630	0.005	99.5

Source: *author's elaboration*

In this context, accuracies have been calculated using MAPA and MAPE.

$$MAPA\ \% = (1 - MAPE) * 100$$

since it is a percentage-based metric, it offers easier interpretation compared to RMSE.

Tables 5 (5.1 and 5.2) show the forecasted monthly values of cattle and cow numbers, respectively.

Table 5. *Forecast monthly values of the number of cattle and cows*

Table 5.1 Forecast monthly values of the number of cattle, thousand units

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2023	211	217	234	248	240	227	220	221	236	245	236	218
2024	212	217	235	249	241	227	220	222	237	246	236	218

Table 5.2 Forecast monthly values of the number of cows, thousand units

2023	121	122	122	122	122	122	122	121	121	120	120	120
2024	120	120	120	120	121	120	120	119	119	119	118	119

Source: *author's elaboration*

For more accurate forecasting of the number of farm animals, it is possible to use an ensemble of methods that consider not only seasonality but also the specifics of this business. To accurately forecast information, it is necessary to consider the regional affiliation of enterprises and the number of cattle in the given region. When there are significant fluctuations in the number of farm animals, it is possible to predict the average number of animals more accurately. This will help in making informed management decisions about land for livestock grazing, marketing, trading, and storage of livestock products.

Agribusiness requires effective management decisions, the preparation and adoption of which can provide forecasting based on hindsight and considering the multifactorial impact. Management, knowing the forecast for a certain period, can use information about forecasted prices to protect their positions, keeping the number of farm animals within acceptable limits. It is crucial to acknowledge that time series forecasting has its limitations. Forecast results may be inaccurate if unforeseen events or changes occur that are not accounted for in the model. Therefore, to make management decisions regarding development, it is worth combining time series analysis with other methods and considering expert experience to obtain more accurate forecasts. In the context of livestock production, time series can be based on various factors, such as the production of milk, meat, and eggs, the number of animals, the costs of feeding and treating animals, and so on. To forecast the dynamics of the development of animal husbandry, historical information on relevant indicators over a certain period will be needed.

According to S. Lv *et al.* (2022), the vital step in time series forecasting is comprehending the data model and identifying the specific business questions that need to be addressed using that data. By delving into the problem area, developers can differentiate between random fluctuations and stable, consistent trends in historical data more effectively. This understanding is invaluable when fine-tuning a forecasting model to generate optimal predictions. It is also crucial when deciding which forecasting method to employ. Y. Abdullayev and M. Baxtiyor (2020) and A. Durmanov *et al.* (2019) conceptualized and employed a systematic approach to forecasting, relying on a mathematical model depicting the potential evolution of animal husbandry in farms. Mathematical models of prognostic-analytical problems are proposed, which allow, based on endogenous parameters of models at the level of the economy, to investigate and forecast the production of livestock products at the regional level in an integrated manner.

Forecasting the dynamics of livestock development using time series can be a useful management tool for analysing and predicting trends in the livestock sector (Chen *et al.*, 2020). To precisely capture the seasonal fluctuations in the observed sequence and achieve superior prediction outcomes, the production values for animal husbandry and fishery in various quarters spanning from 2018 to 2021 were forecasted and examined using the grey seasonal model (GSM). The findings highlighted the relatively high prediction accuracy of GSM. R. Mutwiri (2019) introduced a Seasonal Autoregressive Integrated Moving Average (SARIMA) model, specifically tailored for forecasting tomato prices. The model was constructed using monthly data spanning from 1981 to 2013 in Kenya. Tomato price forecasting from January 2003 to December 2016. The SARIMA $(2,1,1) \times (1,0,1)$ 12 model was identified as the best model. The following accuracy estimates were obtained: RMSE=32.063, MAPE=125.251, and MAE=22.3. P. Manigandan *et al.* (2021) conducted a study to forecast the seasonality and growth trend of natural gas production in the USA up to the year 2025. SARIMA and SARIMAX models were analysed. The SARIMA model showed the best RMSE and MAPE accuracy estimates: RMSE=131.73, MAPE=15.93.

Y. Chi (2021) using soybean data from January 1990 to January 2021 and an ensemble of SARIMA (Seasonal AutoRegressive Integrated Moving Average) and NARNN (Nonlinear Autoregression Neural Network) time series models forecast monthly soybean prices. The comparative analysis demonstrated that the Hybrid-LM model, comprising 8 neurons in the hidden layer and 3-time delays, exhibited superior accuracy compared to the NARNN-LM model with similar specifications and the SARIMA model (ARIMA $(0,1,3) \times (0,0,2)$). This conclusion was drawn based on the Hybrid-LM model's lowest MSE in the study. In U. Sirisha *et al.* (2022), ARIMA, and SARIMA models, as well as a Long Short-Term Memory (LSTM) deep learning model were chosen to forecast the time series of financial data of online companies. It was shown that the best RMSE and MAPA estimates were achieved with the LSTM algorithm. Received an accuracy of 97.01%.

S. Raju *et al.* (2022) compared the predictive accuracy of various models, including stacking (STACK), gradient boosting regression (GBR), extreme gradient boosting regression (XGBR), and random forest regression (RFR) ensembles. Additionally, it evaluates the performance of multilayer perceptron neural networks (MLP), extreme learning machines (ELM), and support vector regression (SVR) as reference models for forecasting demand. The comparison encompasses several stages, including data preprocessing, data transformation, standardization, feature selection, cross-validation, and the implementation of a regression ensemble framework. Analysing historical data allows us to make informed management decisions, guiding business strategies and providing insights into future trends. (Abraham *et al.*, 2020; Atalan, 2023). This research compares traditional time series forecasting techniques with artificial neural networks.

From the aforementioned studies, it is evident that selecting an appropriate model depends on the

characteristics of the subject under investigation, the volume of historical data, and the presence of seasonality. Seasonality in agriculture (and in animal husbandry) plays a key role. Managing seasonality in livestock production can be an important aspect for agricultural enterprises to optimize production and maximize the benefit of peak periods of productivity and market demand.

CONCLUSIONS

The results obtained as a result of this study show that the number of cattle (including cows) has a clear tendency to decrease. SARIMAX (0; 1; 1) × (0; 1; 0; 12) and SARIMAX (1; 1; 9) × (1; 1; 0; 12) models were built, which were chosen to determine the number of farm animals for the next 2 years, show that by the end of 2024 there will be a gradual decrease in the number of cattle (including cows). The conducted research included the study of trends in the development of cattle and cows and, the determination of the stationarity of the studied time series. The Box-Cox method was used to transform data on the number of cattle. The optimal parameters of the models used for forecasting were determined. Forecast values for different periods (in months) were obtained, and an analysis of the dynamics of the number of cattle during the last 15 years was carried out. Constructed time series were compared with the actual data displayed on the graphs. Estimates of root mean square deviation and mean absolute error in percentages for different forecast periods were also provided.

Monthly statistical data on the number of cattle and cows are mean, standard deviation, minimum and maximum values, asymmetry, and excess. The dynamics of the decrease in the number of cattle and cows are shown. The optimal period for the forecast was determined (24 months). This research contributes to the formulation of strategies and actions that are critical to effective management: resource planning, productivity improvement, profitability maximization, cost optimization, and adaptation to changes in market conditions. These research results allow businesses to make informed decisions aimed at increasing their competitiveness and sustainability in a changing economic environment.

The presented research results of this article show such properties of time series as trends, seasonality, and variability. Therefore, the SARIMAX model was used. A promising avenue for future research involves exploring ensembles of time series, leveraging larger historical datasets, and conducting comparative analyses of various time series construction models. This will make the analysis and forecasts more accurate and reliable, as well as reveal more regularities in the dynamics of the number of cattle and cows.

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CONFLICT OF INTEREST

None.

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Прогнозування розвитку тваринництва на основі часових рядів

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Анотація. Побудова часових рядів з використання історичних даних є однією з актуальних проблем управління в аграрному секторі, оскільки аналіз і прогнозування процесів, пов'язаних з продовольчою безпекою держави, регіону, суб'єктів господарювання має вирішальне значення. За допомогою прогнозів підприємства можуть налаштовувати свою виробничу діяльність таким чином, щоб задовольнити попит і вчасно постачати продукцію споживачам. Метою цього дослідження є прогноз динаміки розвитку поголів'я великої рогатої худоби та корів та визначення оптимального періоду прогнозування. Для такого типу аналізу використовуються статистичні методи, пов'язані з авторегресією: авторегресійні моделі, моделі ковзного середнього або комбінації обох, інтегровані моделі зі змінною структурою та моделі, які включають сезонні ефекти та екзогенні фактори з авторегресійним і ковзним середнім компонентом у моделі. Наведені помісячні статистичні дані кількості великої рогатої худоби і корів: середнє, середнє квадратичне відхилення, мінімальне і максимальне значення, асиметрія і ексцес. Показана динаміка зниження поголів'я великої рогатої худоби і корів. Досліджені ряди перевірені на стаціонарність. До часового ряду кількості великої рогатої худоби застосовувалось перетворення Бокса-Кокса. Наведені оптимальні параметри моделей, що використовуються. Отримані прогнозні значення для часових проміжків (місяці) та проаналізована зміна кількості поголів'я великої рогатої худоби за останні 15 років. Побудовані часові ряд зіставляються з фактичними значеннями, що проілюстровано на графіках. Наведені оцінки середньоквадратичного відхилення, середньої абсолютної похибки у відсотках для різних термінів прогнозування. Порівнюючи ці оцінки для різних часових інтервалів, був визначений оптимальний часовий період для прогнозу (24 місяці). Дане дослідження дозволяє господарствам і підприємствам у галузі розуміти, яка кількість продукції (молока, м'яса) може бути зібрана або отримана в майбутньому. Це допомагає зробити необхідні управлінські кроки: планувати потреби в ресурсах, покращити ефективність, збільшити прибуток, знизити витрати і адаптуватися до змін на ринку

Ключові слова: тваринництво; моделювання; управління; перетворення Бокса-Кокса

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