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Prevention of subclinical ketosis in cows during drying off and after calving

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Abstract. Research of the frequency of increased ketone bodies in cows during the transition period three weeks before calving and three weeks after calving should determine the tendency of the Holstein breed to ketosis. It is also important to investigate the relationship between changes in blood biochemical parameters and the development and treatment of ketosis. The purpose of the study was to determine the effectiveness of using a probiotic strain of bacteria in subclinical ketosis in cows during drying off and after calving. The following methods were used: testing for determining the level of beta-ketones in the blood of cows; biochemical method of blood testing; clinical method; statistical method. A study of cows in the drying off group showed that the level of β-ketones ranged from 0.2 to 1.0 mmol/L. Application efficiency of *Bacillus Pumilus* L. A 56 in a concentration of 1×10^9, CFU/g at a dose of 30 g per animal was determined

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to be 100%. In the study of metabolic changes in the body of cows after calving patients with ketosis, the content of total protein, albumins globulins of the enzyme aspartate aminotransferase, and urea at the beginning of the study was increased and went beyond the maximum permissible limits of the reference level. After seven days of using the probiotic, the content of ketone bodies and biochemical parameters decreased to normal. It was proved that at the end of the study, the activity of alanine aminotransferase increased, the level of potassium, vitamins A and E increased. Thus, it was determined that the enzyme alanine aminotransferase is one of the metabolites, an increase in the level of which indicates the accumulation of lipids in the liver. In addition, the content of Ca, P, and vitamin D decreased during treatment, which indicates the risk of hypocationemia. In the group of cows after calving, the incidence of ketosis was 27%. The therapeutic efficacy of a probiotic of 35 g per animal in the post-calving distribution group was 73%. The practical value of the study lies in the prevention of subclinical ketosis in cows in deep drying off and after calving, reducing the cost of treating concomitant diseases, and culling animals.

Keywords: ketone bodies; probiotic; metabolic disorders; negative energy balance; enzyme activity; vitamin and mineral balance

INTRODUCTION

The period in cows three weeks before calving (late drying off) and three weeks after calving is a stressful period due to metabolic disorders such as ketosis. Ketosis is a common metabolic disease that causes substantial economic losses for dairy farms. Despite the fact that selective selection for ketosis resistance has been examined by a large number of researchers (Yan *et al.,* 2020), the genetic and biological causes of ketosis are poorly understood.

Negative energy balance is one of the causes of ketosis in the postpartum period and can cause metabolic and immunological changes in cows. The stability of the immune defence is of great importance for protecting the animal from infectious diseases (Dai *et al.,* 2023). However, there are currently no studies on how negative balance affects the resistance of the body. Milk production technology determines the profitability of production. Diseases in cows cause an increase in the cost of veterinary care. Cows after calving often face diseases such as: ketosis, fatty hepatosis, cicatricial acidosis, mastitis, subclinical hypocalcemia, placental delay, and metritis.

Negative energy balance leads to increased formation of ketones as a result of the mobilisation of a large amount of lipids in the body. Metabolic disorders lead to a decrease in fertilisation and lactation. Researchers (Zhang *et al.,* 2020) prove that propylene glycol reduces the negative energy balance through gluconeogenesis and inhibits the synthesis of ketone bodies. However, a large dose of the drug (more than 500 g/day) has toxic effects and side effects in cows. Thus, there is a need for further studies of cow metabolism after calving.

All dairy cows have a negative energy balance because, at the beginning of distribution, the need for energy for milk production is greater than is obtained with feed (Dehghan Shahreza *et al.,* 2022). Negative energy balance is not always the cause of ketosis, and the main problem is how the cow overcomes metabolic adaptation during the transition period from pregnancy to calving. However, the researchers do not offer how to help the cow during the adaptation period and restore normal metabolism.

Researchers (Pascottini *et al.,* 2020) considered possible risk factors for cows in the prenatal period. It was determined that it is important to monitor adaptive changes in cows during drying off and after calving. However, studies have not considered the predisposition of certain breeds of cattle to metabolic diseases.

In addition, one of the most common diseases of the transition period, along with metabolic disorders of dairy cows, is mastitis, which has a clinical or subclinical manifestation (Zazharska *et al.,* 2021). Subclinical mastitis can only be diagnosed by determining indicators of inflammation or mastitis pathogens in milk (Fotina *et al.,* 2018). However, there is currently insufficient information on the relationship between the development of subclinical ketosis and udder inflammation in dairy cows during drying off and after calving.

A study by researchers (Mohsin *et al.,* 2022) proves that high levels of growth hormone in the postpartum period in the blood of cows with subclinical ketosis cause lipid mobilisation, which leads to hyperketonemia. There is a decrease in the level of amino acids and glycogen, and vice versa, an excess of ketogenic and lipogenic compounds (Nazeer *et al.,* 2019; Yang *et al.,* 2022). However, these studies lack information on the mechanism of the development of postpartum metabolic disorders in dairy cows.

In a study by (Delić *et al.,* 2020), differences in metabolism in the first week after calving between healthy cows and those with ketosis were determined. It was established that metabolic shifts can be predicted by the level of ketone bodies in the first week after calving. In sick cows, the level of beta-ketones was substantially higher (10.9-18.5%) than in healthy cows (2.5-9.1%). In addition, cows with ketosis tended to have elevated levels of total bilirubin and AST. The study allowed diagnosing ketosis early in cows after calving, but no possible way to prevent the disease has been proposed.

Genetic studies, conducted by (Weigel *et al.,* 2017) showed a tendency of Holstein cows to develop ketosis, especially in the postpartum period. The researchers do not offer possible solutions to this problem in their paper. It is also known (Cao *et al.,* 2017), that cows with clinical ketosis have high hematocrit and haemoglobin values, while the number of white blood cells (neutrophils and eosinophils) was substantially lower than in healthy ones. In addition, cows with ketosis show an increase in the level of unesterified fatty acids in the blood. However, there are no studies on the association of ketosis during deep drying off and the postpartum period with the biochemical parameters of blood serum.

The purpose of the study was to investigate the effect of probiotics on cows of the drying off period and after calving for subclinical mastitis. The objectives of the study were: investigation of the development of ketosis in cows during the period of deep drying off and after calving, determination of metabolic shifts in the body of dairy cows using a probiotic.

MATERIALS AND METHODS

The studies were conducted in the period from October to November 2021 on Holstein cows in the Limited Liability Company of the agricultural firm "Lan" of the North-Eastern region of Ukraine. A total of 81 animals were involved in the study, of which 27 were heads of deep drying off period and 54 – after calving.

The effectiveness of the probiotic was tested based on an experimental sample of the *Bacillus Pumilus* L. A 56 strain in a concentration of 1×10^9, CFU/g produced by the private enterprise "Kronos Agro" company. The dosage of the probiotic for the group after calving was 35 g per animal, in the group of deep drying off – 30 g. The animals received a diet according to the production group (Table 1-3).

Table 1. *Ration for cows, depending on the production group*

Ration	Milking 7 days after calving	Milking 14 days after calving	late drying off
Number of heads	133	152	42
silo	28	28	22
haylage	12	12	-
hay	3	3	1.5
straw	-	-	1.5
canned corn	6.5	6.5	2
mixed feed No. 2	8.5	8.5	-
Mixed feed No. 4	-	-	3.5

Table 2. *Mixed feed recipe No. 2 for cows (group after calving)*

No.	Component	% of input	per 500 kg	per 1 tonne, kg	for 1.5 tonnes, kg	for 2 tonnes, kg
1	Barley+Wheat	89	445	890	1335	1780
2	Premix TC VMP CD	7	35	70	105	140
3	Probiotic	3	15	30	45	60
4	Insorb	1	5	10	15	20
	Total	100	500	1000	1500	2000

Table 3. *Mixed feed recipe No. 4 for cows (late drying off)*

No.	Component	% of input	per 500 kg	per 1 tonne, kg	for 1.5 tonnes, kg	for 2 tonnes, kg
1	Barley+Wheat	26	130	260	390	520
2	Sunflower meal	67	335	670	1005	1340
3	Insorb	1	5	10	15	20
4	Prorbiotic	1	5	10	15	20
5	Premix TC VMP CS	5	25	50	75	100
	Total	100	500	1000	1500	2000

Note: *Premix TK ВМП КС of Tekro (Czech Republic), which includes a set of vitamins and microelements, according to the production group (drying off or milking cows)*
Source: *compiled by the authors*

Examination of cows for ketosis. The level of beta-ketones in the blood of cows was determined using a KetoSens ketometer (FDA). Blood for the examination was taken in the morning before feeding. Indicators were determined in cows of deep drying off (three weeks before calving) at the beginning of probiotic use and after seven days. The level of ketone bodies in cows was also determined on the seventh and fourteenth days after calving. The level of beta-ketones was used to determine sick cows that received additional treatment.

Examination of biochemical parameters of cow blood serum. Metabolic parameters were determined in seven cows from the post-calving distribution group with elevated levels of ketone bodies at the beginning and end of the study. The content of total protein (SOP-BP-02-2017), urea (SOP-BP-03-2017), albumin (SOP-BP-25-2018), urea nitrogen, Ca/P and globulins was determined by calculation, total cholesterol (SOP-BP-07-2017), aspartate aminotransferase AST (SOP-BP-09-2017), alanine aminotransferase ALT (sop-BP-08-2017), Total Ca (SOP-BP-05-2017), inorganic P (SOP-BP-04-2017), magnesium (SOP-BP-06-2017), potassium (SOP-BP-11-2017), vitamin E (SOP-BP-12-2018), vitamin A (SOP-BP-14-2018), vitamin D (25OH) (SOP-BP-18-2020).

Statistical analysis. Statistical data were calculated using the Fischer-Student method, considering statistical errors and the probability of comparable similar indicators. Indicators were considered probable with a level of more than 95% ($p<0.05$).

All experimental studies were conducted in accordance with modern methodological approaches and in compliance with the relevant requirements and standards, in particular, they comply with the requirements of DSTU ISO/IEC 17025:2005 (2006), in accordance with directive 2010/63/EU (Hartung, 2010), which were approved by the conclusion of the commission on ethics and bioethics of the Faculty of Veterinary Medicine of Sumy National Agrarian University dated 05.03.2022. The keep of animals and all manipulations were conducted 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 for the Protection of Vertebrate Animals used for Experimental and other Scientific Purposes (European convention..., 1986).

RESULTS AND DISCUSSION

Results of the examination of cows for ketosis. The study began with the determination of the level of ketone bodies in animals during drying off and after calving (Table 4). During the experiment in all animals in the group of deep drying off (three weeks before calving) with the use of premix based on *Bacillus Pumilus* L. A 56 on the corresponding diet, the indicators fluctuated within the normal range from 0.2 to 1.0 mmol/L.

Table 4. *The level of ketone bodies in the blood of cows when using probiotic premix*

Late drying off group			Post-calving group					
No. of the animal	Start of the study	After 7 days	No. of the animal	7 days after calving	14 days after calving	No. of the animal	7 days after calving	14 days after calving
7658	1.0	0.8	7351	0.7	0	107	1.0	0
6266	1.0	0.8	6852	3.5	0.7	2522	0.9	0
6915	0.7	0.7	7658	0.7	0	3861	0.7	0
0357	0.7	0.5	1627	0.8	0	9683	0.7	0
0944	1.0	0.4	0340	1.1	1.0	6707	0.8	0
6949	0.8	0.8	6905	1.5	1.0	6896	0.5	0
7632	1.0	0.9	6266	1.1	0.8	2514	0.7	0
3061	0.7	0.6	3940	1.4	0.9	0982	0.4	0
1941	0.7	0.7	0944	0.8	0	6949	1.6	0.6
7603	0.7	0.8	6886	0.6	0	3928	0.5	0
7791	0.7	0.5	4089	0.7	0	6187	3.8	2.4
6281	0.7	0.6	6915	2.3	0.7	7633	0.7	0
6674	0.6	0.4	7497	0.6	0	2563	1.8	0.6
6870	0.6	0.7	4077	0.4	0	0357	0.7	0
1981	0.6	0.6	2545	1.3	0.7	7603	1.2	0.4
3929	0.5	0.6	3630	0.8	0	4636	0.6	0
7327	0.6	0.4	3061	1.4	0.5	7328	0.6	0
4584	0.2	0.2	19706	0.7	0	6657	1.0	0

Table 4, Continued

Late drying off group			Post-calving group					
No. of the animal	**Start of the study**	**After 7 days**	**No. of the animal**	**7 days after calving**	**14 days after calving**	**No. of the animal**	**7 days after calving**	**14 days after calving**
1008	0.7	0.7	1941	0.5	0	3853	0.7	0
6661	0.8	0.7	3086	0.6	0	7614	0.8	0
6843	0.7	0.6	6302	0.6	0	5892	0.6	0
6872	0.8	0.8	0314	0.8	0	7642	1.9	0.8
4325	1.0	0.5	7781	0.5	0	7696	0.5	0
3956	0.9	0.4	6133	0.5	0	7331	0.4	0
4853	0.7	0.6	3870	0.5	0	6674	0.3	0
1983	0.8	0.6	7640	0.8	0	9765	0.9	0
3942	0.7	0.5	3891	2.0	0.9	7791	0.4	0
Average value	0.73 ±0.03	0.60 ±0.03	Average value	-	-	-	1.79 ±0.19*	1.33 ±0.20*

Note: ** – p≤0.05, compared with similar indicators of the late drying off group with the post-calving distribution group*
Source*: compiled by the authors*

During the experiment, it was determined that in experimental animals of the late drying off group of 27 heads, the level of ketone bodies was lower than at the beginning of the study (1.0-0.2 mmol/L), and after seven days of using premix (0.9-0.2 mmol/L). There was no substantial difference in group scores at the beginning and end of the study, but the group average improved by 17.80%. The effectiveness of premix in the drying off group is 100%, no cases of increased ketone bodies were determined out of the 27 heads tested

In the milking group of 54 heads, seven days after calving, the level of ketone bodies in the blood of cows ranged from 3.5 to 0.3 mmol/L. On the 14th day after calving, the indicators ranged from 2.4 to 0 mmol/L. The difference between the initial and final values was 25.6%. In addition, out of 54 heads of the distribution group, 15 heads showed signs of clinical ketosis.

Thus, cow No. 6852 on the seventh day after calving had an 80% lower content of ketone bodies compared to the end of the study on Day 14. During the entire experiment, the level of beta-ketones decreased in animals No. 0340 by 9.09%, No. 6905 – by 33.33%, No. 6266 – by 27.27%, No. 3940 – by 35.71%, No. 6915 – by 69.56%, No. 2545 – by 46.15%, No. 3061 – by 64.28%, No. 3891 – by 55.00%, No. 107 – by 100%, No. 6949 – by 62.50%, No. 2563, and No. 7603 – by 66.66%, No. 7642 – by 57.89%, compared to the beginning of the study.

Additionally, 15 heads were treated, 14 heads were cured, and 1 head had a relapse of the disease. It should also be noted that there was a substantial difference between similar indicators of the beginning and end of the experiment in the groups of deep drying off and milking after calving. All animals in which the indicators of ketone bodies were increased were prescribed specific treatment with drugs based on hepatoprotectors and minerals, animals are better able to recover, they have a reduced indicator of ketone bodies, relapses decreased to a minimum, and all animals in which ketone bodies were increased retained milk productivity, after completing treatment gained total weight faster. The overall incidence rate is 27% out of 100%, and the effectiveness of treatment is 73%.

Results of the study of biochemical parameters of cow blood serum. For the effect of premix on the animal body, blood tests were performed at the beginning and after performing the experiment in a group of animals after calving (Table 5-7).

Table 5. *Results of biochemical studies of cow blood serum, M±m, n=3*

No.	Start of the study	Indicators							
	End of the study	**Total protein, g/L**	**Albumins, g/L**	**Globulins, g/L**	**Albumins, %**	**Globulins, %**	**(A/G), units**	**Urea, mmol/L**	**Urea nitrogen, mg/dL**
No. of the animal		**SOP-BP-02-2017**	**SOP-BP-25-2018**	**Calculation**				**SOP-BP-03-2017**	**Calculation**
1	6905	75.09 ±0.45	35.42 ±0.68*	40.67 ±0.33	46.45 ±0.62*	53.63 ±0.80*	0.84 ±0.04	8.26 ±0.50*	22.43 ±0.48*
		74.90 ±0.09	31.61 ±0.96	42.34 ±1.13	42.33 ±0.54	57.50 ±0.43	0.76 ±0.06	5.37 ±0.61	14.69 ±0.73

Table 5, Continued

No.	Start of the study / End of the study	Total protein, g/L	Albumins, g/L	Globulins, g/L	Albumins, %	Globulins, %	(A/G), units	Urea, mmol/L	Urea nitrogen, mg/dL
No. of the animal		SOP-BP-02-2017	SOP-BP-25-2018	Calculation				SOP-BP-03-2017	Calculation
2	6852	86.80 ±0.81*	31.40 ±0.58	55.20 ±0.50*	36.75 ±0.39	63.33 ±0.37*	0.58 ±0.01*	6.35 ±0.04*	17.72 ±0.15
		73.54 ±0.76	33.35 2.3.	40.66 ±0.85	45.24 ±0.43*	54.81 ±0.51	0.82 ±0.01	6.96 ±0.07	19.48 ±0.29
3	6915	79.48 ±0.30*	33.55 ±0.28	45.62 ±0.34	42.37 ±0.31	57.53 ±0.39	0.73 ±0.04	8.43 ±0.28	23.45 ±0.37
		72.88 ±0.36	32.59 ±0.37	40.60 ±0.85	43.62 ±0.57	56.03 ±0.67	0.76 ±0.06	8.21 ±0.14	23.26 ±0.39
4	7642	81.35 ±0.33*	31.18 ±0.41*	50.42 ±0.46*	38.26 ±0.40*	61.67 ±0.69*	0.63 ±0.05*	5.87 ±0.33	16.57 ±0.43
		89.19 2.3.	23.92 ±0.19	65.17 ±0.62	26, 80 ±0.75	73.11 ±0.56	0.37 ±0.02	6.31 ±0.53	17.31 ±0.50
5	6187	72.24 ±0.61*	36.42 ±0.54	35.63 ±0.83*	50.20 ±0.65*	49.84 ±0.77*	1.01 ±0.01	7.98 ±0.30*	22.18 ±0.42*
		75.63 ±0.37	32.33 ±0.48	43.31 ±0.46	42.67 ±0.71	57.36 ±0.53	0.73 ±0.04	6.18 ±0.44	17.26 ±0.49
6	2563	68.39 ±0.40*	30.70 ±0.71*	37.73 ±0.68*	44.88 ±0.18*	55.42 ±0.47*	0.83 ±0.05*	6.83 ±0.18	19.11 ±0.68
		95.70 ±0.18	24.77 ±0.72	71.08 ±0.48	25.63 ±0.41	74.22 ±0.43	0.35 ±0.04	6.53 ±0.40	18.13 ±0.93
7	3891	63.39 ±0.56*	31.81 ±0.21	31.77 ±0.53*	49.57 ±0.41*	50.26 ±0.80*	0.95 ±0.15	5.14 ±0.40	14.51 ±0.47*
		87.08 ±0.69	31.12 ±0.39	55.79 ±0.29	35.64 ±0.58	64.42 ±0.54	0.56 ±0.12	4.32 ±0.39	11.49 ±0.32
Reference values		59-85	27-43	25-45	38-50	50-62	0.6-1.1	3.30-6.70	8-20

Note: ** – p⩽0.05, compared to the start of the study*
Source: *compiled by the authors*

It was determined that the albumin level of cow No. 6905 was substantially higher by 10.7%, compared to the beginning and end of studies, but within the physiological norm. The content of urea and urea nitrogen was increased by 34.98% and exceeded the reference level. At the start of the study, the AST enzyme was substantially higher by 24.18% compared to the end of treatment.

Vitamin and mineral metabolism in animal No. 6905 was within the physiological norm, and the vitamin A content increased by 6.81% at the end of the study. In cow No. 6852, the level of total protein, globulins, and albumins was higher than the permissible limits of the reference level at the beginning of treatment. At the end of the study, all indicators returned to normal. Initial examination in cow No. 6852 showed substantially higher total protein content by 11.04%, globulins – by 8.52%, and albumins – by 14.54%. Urea and urea nitrogen levels were higher by 9.60-9.93%, respectively.

The level of the AST enzyme was higher than the reference level at the start of the study. At the end of the experiment, the level of AST substantially decreased by 12.95%. However, ALT levels at the beginning of treatment were 50.34% lower compared to data after seven days. The content of calcium and phosphorus in the animal's blood serum was within the physiological norm and practically did not differ during the entire study period. The level of potassium in the blood of cow No. 6852 at the end of the study increased by 30.52% and went beyond the upper limit of the reference level. In addition, the content of vitamin E increased by 56.30%, vitamin A – by 10.42% and vitamin D – by 29.27%. It should be indicated that the level of magnesium in the blood serum of animals with ketosis was within the physiological norm.

Table 6. *Biochemical examination of cow blood serum, M±m, n=3*

No.	Start of the study / End of the study	Indicators						
		Total cholesterol, mmol/L	AST, units/L	ALT, units/L	(AST/Alt), units	Total Ca, mmol/L	Inorganic P, mmol/L	Ca/P, units
No. of the animal		SOP-BP-07-2017	SOP-BP-09-2017	SOP-BP-08-2017	Calculation	SOP-BP-05-2017	SOP-BP-04-2017	Calculation
1	6905	5.81 ±0.47	106.45 ±3.07*	30.85 ±1.05	2.74 ±0.25	2.20±0.16	2.27±0.41	1.19±0.13
		3.51 ±0.48	80.70 ±0.84	31.687 ±0.49	3.41 ±0.35	1.98±0.26	1.79±0.13	1.11±0.06
2	6852	3.08 ±0.52	113.22 ±1.52*	18.97 ±1.19*	6.14 ±0.77*	2.93±0.14	1.93±0.18	1.54±0.40
		4.44 ±0.41	98.55 ±3.33	28.52 ±1.00	3.38 ±0.54	2.19±0.32	2.01±0.12	1.08±0.04
3	6915	4.13 ±0.47	108.47 ±4.84	24.68 ±0.54*	4.42 ±0.58	2.84±0.09	2.04±0.26	1.36±0.36
		3.10 ±0.35	101.18 ±1.17	27.16 ±0.45	3.70 ±0.22	2.13±0.30	1.88±0.20	1.18±0.37
4	7642	2.76 ±0.52	91.64 ±3.84	25.50 ±0.46*	3.65 ±0.25	2.48±0.26	2.30±0.28	1.08±0.05
		2.12 ±0.48	85.51 ±1.00	17.86 ±0.77	4.54 ±0.72	1.68±0.31	2.20±0.29	0.74±0.03
5	6187	5.62 ±0.92	147.4 ±2.46*	33.37 ±0.45	4.33 ±0.51*	2.42±0.28	2.06±0.37	1.16±0.34
		5.02 ±0.58	67.32 ±0.51	32.52 ±0.57	2.09 ±0.21	2.11±0.55	2.04±0.38	1.07±0.05
6	2563	2.09 ±0.54	113.26 ±1.55*	15.33 ±0.42	7.36 ±0.75*	1.85±0.28	2.04±0.18	0.95±0.10
		2.31 ±0.47	78.96 ±0.88	16.28 ±1.03	4.72 ±0.45	2.06±0.51	2.02±0.17	1.07±0.17
7	3891	1.88 ±0.46*	90.70 ±1.44*	17.54 ±0.40*	5.14 ±0.55	2.03±0.48	2.37±0.34	0.88±0.16
		4.39 ±0.58	79.81 ±0.7	20.81 ± 0.58	3.83 ±0.66	2.13±0.67	2.12±0.19	1.04±0.04
Reference values		2.20-6.60	2.20-6.60	48-108	17-40	1.0-3.4	1.98-3.12	1.50-2.90

Note: ** – p⩽0.05, compared to the start of the study*
Source: *compiled by the authors*

On the seventh day after calving, cow No. 6915 had an increased level of total protein by 8.30%, assumably due to an imbalance towards globulins by 15.16%, compared to albumin. After seven days of using a probiotic strain-based premix *Bacillus Pumilus* L. A 56 globulin levels decreased by 11.00%. The urea level was high and exceeded the upper limit of the physiological norm. At the end of the experiment, the content of urea and urea nitrogen decreased by 2.60% and 0.82%, respectively, but the indicators still exceeded the reference limits. The level of AST in the blood serum of cow No. 6915 at the beginning of the study was higher by 10.63%. After seven days, ALT, on the contrary, increased by 10.04%. Therewith, the AST/ALT ratio was higher by 16.28% and went beyond the reference level. Calcium and phosphorus levels were within normal limits throughout the study period. In addition, on the 14th day of the study, the level of potassium increased by 33.74%, vitamin E – by 55.18%, vitamin A – by 8.46, and vitamin D – by 15.18%, but all within the physiological norm.

Notably, in the conducted studies, the content of total cholesterol in the blood serum of cows with ketosis during the entire treatment period fluctuated in cows No. 6905, No. 6852, and No. 6915 and did not exceed the reference level. The exception was animals No. 2563 and No. 3891, whose cholesterol levels were lower by

10.52% and 133.51%, respectively, at the beginning of the study, which indicates a recovery in liver function. In addition, the cholesterol level of animal No. 7642 decreased by 23.18% at the end of the study. Therewith, the level of AST in animal No. 7642 decreased at the end of the study by 6.68%, AlLT – by 29.96%, total Ca – by 3.25%, inorganic P – by 4.34%. In addition, in cow No. 7642, the total protein content decreased by 9.63%, albumin – by 23.28%, globulin increased by 29.25%, compared to the beginning of the study. The globulin content exceeded the upper permissible limit of the reference level at the beginning and end of the study. In addition, the animal's potassium and magnesium content did not change during the studies, vitamin E increased by 25.53%, vitamin A – by 4.94%, and vitamin D decreased by 44.09% (below the reference level), compared to the beginning. The results indicate severe metabolic adaptation in cow No. 7642 during the transition period.

In animal No. 6187, the level of total protein increased by 4.69%, globulins – by 21.55%, albumins decreased by 11.23%, urea content increased by 22.55% and urea nitrogen – by 22.18%, compared to the beginning of studies and above the reference level.

Table 7. *Vitamin and mineral composition of cow blood*

No.	Start of the study / End of the study	Indicators				
		Magnesium, mmol/L	Potassium, mmol/L	Vitamin E, mcg/ml	Vitamin A, mcg%	Vitamin D (25OH), ng/ml
No. of the animal		SOP-BP-06-2017	SOP-BP-11-2017	SOP-BP-12-2018	SOP-BP-14-2018	SOP-BP-18-2020
1	6905	1.02±0.05	4.15±0.58	3.19±0.51	44.48±0.82*	22.07±0.38
		1.03±0.04	4.56±0.36	4.30±0.74	47.52±0.55	22.54±0.56
2	6852	1.11±0.08	4.39±0.37	3.41±0.35	45.10±0.63*	32.55±0.61*
		0.88±0.23	5.73±0.72	5.33±0.74	49.80±0.95	23.02±0.64
3	6915	1.01±0.09	4.15±0.14	3.43±0.35	44.43±0.45*	36.16±0.53*
		0.95±0.15	5.55±0.70	5.27±0.78	48.19±0.52	41.65±0.42
4	7642	1.08±0.20	5.03±0.87	3.87±0.84	44.25±0.34	22.52±0.64
		1.06±0.07	5.18±0.79	4.86±0.41	46.44±0.73	12.59±0.36
5	6187	0.97±0.12	4.92±0.53	3.62±0.24	44.93±0.63*	20.06±0.55
		0.90±0.14	5.60±0.70	4.72±0.57	47.94±0.54	22.35±0.66
6	2563	1.10±0.31	3.73±0.32	3.16±0.24	43.76±0.94*	43.0±0.89*
		0.79±0.07	5.62±0.71	4.90±0.65	49.19±0.63	24.94±0.51
7	3891	1.01±0.23	4.07±0.55	3.00±0.33	46.19±0.67	55.06±0.60*
		0.95±0.14	6.40±1.02	5.20±0.82	48.16±0.58	16.67±0.74
Reference values		0.70-1.23	0.70-1.23	4.0-5.3	2.0-9.0	25.0-80.0

Note: ** – p≤0.05, compared to the start of the study*
Source*: compiled by the authors*

The level of total protein in animal No. 2563 increased by 39.93%, assumably due to globulins – by 88.39%, while the content of albumins decreased – by 19.31%. The content of urea and urea nitrogen decreased by 4.39% and 10.71%, respectively. The indicators went beyond the reference level.

At the end of the experiment, the level of the AST enzyme decreased by 30.28%, and ALT increased by 6.19%. At the beginning of the study, AST and ALT levels exceeded the physiological norm. The total Ca content was 11.35% lower than standard indicators at the start of the study compared to the end of treatment. Also in cow No. 2563, the level of potassium increased by 50.67%, vitamin E – by 55.06%, vitamin A – by 12.40%, and vitamin D decreased by 42.00%.

At the end of the study, the total protein content in cow No. 3891 increased by 37.37%, globulins – by 75.60% and went beyond the reference level. Urea levels substantially decreased by 15.95% and urea nitrogen – by 20.81%, compared to the beginning of the study. The level of the AST enzyme decreased by 12.0%, alt increased by 18.64%, Ca/P ratio – by 18.18%, compared to the beginning of the study. The content of potassium substantially increased by 57.27%, vitamin E – by 73.33%, vitamin A – by 4.26%, vitamin D decreased – by 30.23%.

According to the results of the conducted studies on cows with ketosis, the positive effect of using a probiotic based on *Bacillus Pumilus* L. A 56 in a concentration of 1×10^9, CFU/g in the dry period of 30 g per animal, and 35 g per animal after calving, was proved.

The study showed that all animals in the deep drying off group had a ketone body level of no more than 1.0 mmol/L (Zhang *et al.,* 2021). Researchers (Daros *et al.,* 2020) believe that limping cows in deep drying off are at risk of developing diseases such as ketosis, metritis, placental retention, hypocalcemia, and rennet displacement. Therefore, much attention is paid to all pregnant animals on the farm, especially during the transition dry and postpartum period.

A week after calving, the ketone body levels of 54 animals increased. Seven days after applying a probiotic based on *Bacillus Pumilus* L. A 56, indicators decreased to normal, except for 15 heads. Researchers (Rodriguez *et al.,* 2022) in their studies report that ketosis in the first week of lactation in cows is due to low milk yields. In the second week of lactation, this trend was not recorded. However, the model developed by researchers is not perfect, has assumptions and is limited by current research.

Researchers (Ayemele *et al.,* 2021) determined that the introduction of amino acids, vitamins, microelements, and plant extracts into the diet of cows exposed to oxidative stress showed promising results due to the strengthening of immune functions and the repair of damaged cells.

Studies by (Denis-Robichaud *et al.,* 2022; Williamson *et al.,* 2022) confirm that the ketone body levels in the range of 1.2 to 2.9 mmol/L are a signal of possible exacerbation of ketosis and health risks during early lactation. The critical point for the occurrence of subclinical ketosis is the level of ketone bodies in the blood greater than 1.2 mmol/l, and a critical level – greater than 3.0 mmol/L usually indicates the development of a clinical form.

ALT levels have increased by the end of the study. This proves that ALT levels are associated with manifestations of ketosis in cows and can fluctuate during treatment (Pinedo *et al*., 2021).

Researchers (Gross & Bruckmaier, 2019) determined that low albumin levels usually indicate liver failure. Previous studies by researchers (Kozat & Yüksek, 2017) showed that ALT is insensitive to ketosis in cows. However, in other studies (Du *et al*., 2017), liver apoptosis and high ALT levels were observed in dairy cows with ketosis.

When investigating the biochemical parameters of blood serum in cows with signs of ketosis, it was determined that in animals the content of total protein, globulins, and albumins fluctuated within the maximum permissible limits and even went beyond them (Ha *et al.,* 2022). In addition, (Puppel *et al.,* 2019) observed increased urea and urea nitrogen content, which decreased at the end of treatment. The aspartate aminotransferase (AST) enzyme is an indicator of liver and muscle function (Ma *et al.,* 2022). An increase in AST at the beginning of treatment indicates a substantial load on the liver, while ALT increased at the end of the study (Theinert *et al.,* 2022). A study by researchers (Giannuzzi *et al.,* 2021) determined that cows with ketosis have increased levels of aspartate aminotransferase and cholesterol.

The group of animals with ketosis included cows with a body condition of more than three points, who also had complications such as placental delay and metritis. Studies (Garzón-Audor & Oliver-Espinosa, 2019) have shown that the overall frequency of ketosis in dairy cows is 26% of all animals examined.

Ca and P levels were determined to be associated with ketosis and depend on the manifestation of the disease (Pacífico *et al*., 2021). Blood magnesium levels did not change substantially throughout the experiment. The content of potassium, vitamins A and E increased at the end of treatment. Therewith, the vitamin D content decreased in all experimental cows, regardless of the severity of the metabolic adaptation of the body. It is believed that a substantial amount of vitamins and minerals was involved in the restoration of metabolism in the body of animals, and therefore their level in the blood serum was not high.

CONCLUSIONS

It was determined that in cows in the group of deep drying off on the corresponding diet, the content of ketone bodies ranged from 0.2 to 1.0 mmol/L. After using the probiotic, the average number of ketone bodies in the group improved by 17.80%. The effectiveness of using premix in the drying off group was 100%.

In the distribution group, seven days after calving, the level of ketone bodies in the blood of cows ranged from 0.3 to 3.5 mmol/L, the incidence rate was 27%. Two weeks after the probiotic was administered, the ketone level was in the range of 2.4 to 0 mmol/L, which is a 25.6% decrease compared to the start of the study.

The overall incidence rate in the post-calving distribution group was 27% out of 100%, and the therapeutic efficacy of probiotic use was 73%. 15 cows out of 54 needed additional treatment, 14 heads fully recovered, and one animal had a relapse of the disease.

Studies of metabolic shifts in the body of cows showed that the level of urea was high and went beyond the upper limit of the physiological norm. At the beginning of the study, cows had an increased total protein content of 8.30-11.04%, globulins – by 8.52-11.00%, albumins – by 10.7-14.54%. At the end of the experiment, the content of urea and urea nitrogen decreased by 2.60-0.82%. The level of AST in the blood serum of cows at the beginning of the study was higher by 6.68-10.63%. After seven days of probiotic use, ALT increased by 10.04-29.96%. Ca, P, and vitamin D levels

decreased during treatment, but potassium, vitamins A, and E levels recovered. The prospect of further research is to determine the dependence of the occurrence of ketosis in dairy cows depending on the size of the fetus and the number of lactations.

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CONFLICT OF INTEREST

None.

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Профілактика субклінічного кетозу у корів сухостійного періоду та після отелення

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Анотація. Дослідження частоти підвищення кетонових тіл у корів у перехідний період за три тижні до родів та три тижні після отелення має визначити схильність голштинської породи до кетозу. Також важливо дослідити взаємозв'язок у зміні біохімічних показників крові, розвитку і лікуванню кетозу. Метою дослідження було визначити ефективність застосування пробіотичного штаму бактерій за субклінічного кетозу у корів сухостійного періоду та після отелення. Використані методи: тест для визначення рівня β-кетонів в крові корів; біохімічний метод дослідження крові; клінічний метод; статистичний метод. Дослідження корів в групі сухостою показало, що рівень β-кетонів коливався в межах від 0,2 до 1,0 ммоль/л. Ефективність застосування *Bacillus Pumilus* L. A 56 в концентрації 1×10^9, КУО/г в дозі 30 г на тварину показало 100 %. При дослідженні метаболічних змін в організмі корів після отелення хворих на кетоз вміст загального білка, альбумінів глобулінів ферменту аспартатамінотрансферази та сечовини на початку дослідження був підвищений і виходив за межі максимально допустимих меж референтного рівня. Через сім діб застосування пробіотику вміст кетонових тіл та біохімічні показники знижувався до норми. Доведено, по завершенню дослідження збільшувалась активність аланінамінотрансферази, збільшився рівень Калію, вітамінів А та Е. Таким чином встановлено, що фермент аланінамінотрансфераза є одним з метаболітів, підвищенні рівня якого вказує на накопичення ліпідів в печінці. Крім того, вміст Са, Р та вітаміну D знизився протягом лікування, що вказує на загрозу виникнення гіпокаціємії. В групі корів роздій після отелення захворюваність на кетоз склала 27 %. Терапевтична ефективність від застосування пробіотику 35 г на тварину у групі роздій після отелення становила 73 %. Практична цінність дослідження полягає у профілактиці субклінічного кетозу у корів глибокого сухостою та після отелення, зменшення витрат лікування супутніх захворювань та вибракування тварин

Ключові слова: кетонові тіла; пробіотик; метаболічні розлади; негативний енергетичний баланс; активність ферментів; вітаміно-мінеральний баланс

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Influence of various phosphoric concentrations on tissue and intracellular metabolism of *Cyprinus Carpio* L. in aquatic habitat

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Abstract. The research relevance is predefined by the fact that under the influence of various factors of the aquatic environment, changes in the speed and direction of the metabolic processes of hydrobionts are recorded. The research aims to study the influence of different inorganic phosphorus content in the aquatic environment on the indicators of phosphorus-calcium exchange in fish. The methods of thin-layer chromatography and variational statistics were used. Glandular tissues of the gills, liver and kidneys of fish were analyzed. To study the influence of inorganic phosphorus in the water environment on some indicators of intracellular metabolism, mitochondria were isolated in osmoregulatory organs. It was found that when the concentration of phosphorus increases to 0.3-0.6 mg/L in the water environment,

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it accumulates in the liver, and gills and decreases in the kidneys, while the concentration is maintained at a relatively constant level in the blood serum of fish. An increase in the concentration of inorganic phosphorus in the water environment significantly affects the processes of energy generation in the mitochondria of fish livers. A change in the phosphorus content in the habitat of fish has a significant impact on tissue bioenergetic processes, which is manifested in a change in the adenosine triphosphate content, and alkaline phosphatase activity. Significant changes in these indicators are observed in the gills and kidneys. The research results can be used for the formation of adaptive and compensatory regulatory mechanisms in the organism of hydrobionts during their adaptation to certain conditions of cultivation and reproduction

Keywords: *Cyprinus carpio*; fish liver; gill; kidney; blood serum; bile

INTRODUCTION

All aquatic animals require minerals for their vital physiological and biochemical functions and their normal life processes. Regulation of phosphate is considered more critical than that of calcium because fish must effectively absorb and conserve phosphate in both freshwater and seawater environments.

A study by (Costa *et al.,* 2018; Boyd *et al.,* 2020) found that phosphorus is an essential nutrient in all aquatic ecosystems. The solubility of inorganic phosphorus in water systems is regulated by the physical and chemical characteristics of the water column. Zhao *et al.* (2019), and Yang *et al.* (2021) believe that, unlike terrestrial animals, which receive phosphorus compounds mainly with food, hydrobionts can assimilate it from the aquatic environment.

According to (Sugiura *et al.,* 2018; Lei *et al.,* 2021) phosphorus is one of the components of nucleic acids DNA (deoxyribonucleic acid) and RNA (ribonucleic acid) and phosphoproteins ADP (adenosine diphosphate) and ATP (adenosine triphosphate), therefore it is a necessary element for the existence of biological systems.

Ai *et al.* (2019), Zhao *et al.* (2021), and Yu *et al.* (2021), note that phosphorus is an important component of the endoskeleton of fish. More than a third of phosphorus in the body is contained in phospholipids, cell membranes and energy-rich compounds. Thus, phosphorus plays an important role in carbohydrate, lipid and nitrogen metabolism, in the metabolism of muscle and nerve tissues, as well as in various metabolic processes involving buffers in body fluids.

The effect of increased levels of inorganic phosphorus in water on metabolic processes in the body of fish was studied by (Jothy *et al.,* 2019; Zhao *et al.,* 2019; Wang *et al.,* 2022). At the same time, special attention was paid to the orientation of bioenergetic processes, since phosphate, which is utilized from water and food, can be a part of high-energy compounds that play an important role in the life support of all living organisms without exception.

According to the data obtained by (Solomatina *et al.,* 2018; Pouille *et al.,* 2018; Saurette *et al.,* 2019), the lack of mineral phosphorus compounds is a limiting factor for all hydrobionts. Phosphorus not only affects bone mineralization but also metabolic processes in fish, such as nutrient digestion and lipid catabolism in the liver. According to (Souders *et al.,* 2018; Musharraf *et al.*, 2019; Wang *et al.,* 2022), phosphorus is present in water bodies in the form of insoluble mineral compounds – tricalcium phosphate or as part of organic compounds contained in plant and animal remains and excrement of living organisms. Organic and inorganic phosphorus compounds are mineralized and solubilized by microorganisms (bacteria and fungi).

Huang *et al.* (2019), Svitelskyi *et al.* (2020), and Zhang *et al.* (2022) established that the content of mineral phosphorus in the water environment ranges from 0.02 to 0.6 mg/L. Phosphorus mineral compounds reach their maximum concentration in water in summer, as their amount formed in the process of regeneration of organic substances exceeds consumption by phytoplankton. The level of phosphates in reservoirs changes significantly as a result of anthropogenic influence.

Fedonyuk *et al.* (2019), and Xu *et al.* (2021) note, establishing the optimal concentration of phosphorus in the water is very important for the vital activity of fish. The role of phosphorus in hydrobionts is determined by the features of its entry into the body. Phosphorus ions entering the body of fish from the environment are found in large quantities in the places of penetration and absorption – gills, mucous membrane of the mouth, intestinal walls, and skin, but are also absorbed during metabolic processes. It should be noted that (Lall, 2022) experimental studies that reveal the peculiarities of the use of phosphorus by fish were carried out using radioactive and elemental phosphorus.

A review of literature sources indicates a lack of information regarding the impact of inorganic phosphorus in the aquatic environment on its accumulation in organs and tissues, as well as related changes in tissue metabolism. Therefore, the goal of this research was to establish the influence of different inorganic phosphorus content in water on metabolic processes in the body of fish.

MATERIALS AND METHODS

The research was conducted during the autumn period of 2022 in the conditions of Limited Liability Company "Skvyraplemrybhosp" of Bilotserkiv district, Kyiv

region. The study analysed 50 specimens of two-year-old carp (*Cyprinus carpio* L.) with an average weight of 255.0±9.7 g. The study of the effect of different concentrations of phosphorus in the aquatic environment on *Cyprinus carpio* L. was carried out in the glandular tissues of the gills, kidneys, liver, serum and bile after 1 and 7 days of exposure. Before the experiment, the caught fish were kept in stationary containers with a volume of 4 m^3. Aquariums were filled with settled tap water with the main mineral components' concentration: Na^+–11.7; K^+–6.4; Ca^{2+}–50-100.0; Mg^{2+}–120.0 mg/L.

Determination of the ATP (adenosine triphosphate), ADP (adenosine diphosphate) and AMP (adenosine monophosphate) levels were carried out by thin layer chromatography on Merck plates. The activity of Na^+ K^+ Mg^{2+}– adenosine triphosphatase and alkaline phosphatase was judged by the increase of inorganic phosphorus in the incubation medium, consisting of adenosine triphosphatase – 0.025 M tris – HCl; 0.1 M NaCl; 0.005 M $MgCl_2$; 0.02 M KCl, 0.001 M ATP. Incubation period – 1 hour. For alkaline phosphatase, the incubation medium consisted of 2 ml of 1% Na-β-glycerophosphate solution, 0.5 ml 0.001 M $MgCl_2$. Incubation period – 2 hours. Enzymatic activity was expressed in μg phosphorus/mg protein/1 hour. Lipid and protein phosphorus had been determined after their extraction from tissues of homogenates with chloroform-ethanol mixture and combustion in a mixture of sulfuric and nitric acids, inorganic phosphorus, and total phosphorus according. To study the impact of phosphorus in the aquatic habitat on some indicators of their intracellular metabolism in osmoregulatory organs, subcellular particles were isolated, particularly mitochondria, where the main biosynthetic and bioenergetic processes of the cell took place. To obtain mitochondria, the tissue was homogenized in a homogenizer with a Teflon pestle diluted with the environment at 1:7. Debris of the cell and nucleus were precipitated at 3000 rpm/min – 5 minutes. Isolation of mitochondria had been carried out at 12-14 thousand rpm/min. After washing twice, the mitochondria were diluted based on a ratio of 0.2 ml of environment per original gram of tissue. Mitochondria, isolated from fish liver, contained 36-40 mg of protein per millilitre and 10-15 mg from gills.

During the experiment, microscopic research methods and the thin-layer chromatography method were used. Study results were calculated as average ± standard deviation (SD). The obtained digital data were processed using standard methods of variational statistics and special computer programs MS Excel and Statsoft Statistica 6.0.

The Ethical Committee approved the use of animals in this study of the Bila Tserkva National Agrarian University on the treatment of animals in research and the educational process (protocol No. 9 of October 1, 2020) following the Law of Ukraine "On the Protection of Animals from Cruelty" (Law of Ukraine..., 2006) and Directive 2010/63/EC of the European Parliament and of the Council of 22 September 2010 on the protection of animals used for scientific purposes (Directive 2010/63/EU..., 2010).

RESULTS

The data received on the tissue content of total phosphorus confirms the conclusion about the great significance of the gills in their absorption from water. Thus, the quantity of total phosphorus in the glandular tissue of the fish's gills, contained in a habitat with 0.3 and 0.6 mg/L of phosphorus, had increased sharply, especially after keeping them for 7 days in such an environment (Table 1).

Table 1. *Influence of phosphorus various concentrations in aquatic habitat on the total phosphorus content in tissues (% dry tissue) and liquids (mg %) of the carp body*

Phosphorus concentration in water, mg/L	Day of experiments			
	1		7	
	M±m	Deviation from control, %	M±m	Deviation from control, %
Liver				
0.06 (conditional control)	1.16±0.17	–	1.43±0.07	–
0.3	0.85±0.06	-26.72	1.85±0.14*	+29.37
0.6	1.42 0.21	+22.41	1.42±0.12	–
Gills				
0.06 (conditional control)	3.36±0.24	–	3.36±0.24	–
0.3	3.32±0.27	+13.69	5.14±0.46*	+52.38
0.6	2.84±0.09	-15.48	4.02±0.20*	+19.14
Kidneys				
0.06 (conditional control)	1.37±0.18	–	2.16±0.08	–
0.3	1.65±0.04	+20.44	1.32±0*	-38.89

Table 1, Continued

Phosphorus concentration in water, mg/L	Day of experiments			
	1		7	
	M±m	Deviation from control, %	M±m	Deviation from control, %
0.6	1.29±0.06	-5.84	0.86±0.02*	-60.19
Blood serum				
0.06 (conditional control)	18.50±1.81	–	19.00±1.08	–
0.3	22.25±2.35	+20.27	19.00±1.09*	–
0.6	30.50±0.54*	+64.86	20.00±1.45	+5.26
Bile				
0.06 (conditional control)	16.00±1.09	–	10.50±1.09	–
0.3	32.50±1.27*	+103.13	7.50±0.77*	-28.57
0.6	13.00±1.09	-18.75	12.50±0.54	+19.05

Note: ** reliable result*
Source: *compiled by the authors*

With a duration increase of staying fish in water with a lower phosphorus concentration (0.3 mg/L), more phosphates are found in the gill tissue than when they had been adapted to a higher concentration (0.6 mg/L). It provides the reason to believe that with an excessive increase of phosphorus level in the water to a certain level (0.3 mg/L), the glandular apparatus of the gills not only absorb but also removes phosphates in large quantities from the body. Quite unexpectedly, the total phosphorus level in the renal tissue was reduced at its higher concentrations in the aquatic habitat. A particularly significant drop in the total phosphorus level in the fish's kidneys was observed during their prolonged stay in a high phosphate content environment. At the same time, the quantity of total phosphorus in the fish's blood serum, kept in a habitat with its level increased to 0.3-0.6 mg/L, increased in a short-term period. During long-term (7 days) carp's acclimation to such conditions, the phosphorus level in the blood serum was close to the control value. The mentioned changes in total phosphorus content in blood serum may be explained by the occurrence of such mechanisms in carp that make it possible to regulate this element quite effectively. An increase of inorganic phosphorus content in the fish' habitat to 0.3-0.6 mg/L also has caused certain changes in calcium metabolism (Table 2).

Table 2. *Influence of phosphorus in aquatic habitat on the calcium content in tissues (% dry tissue) and liquids (mg %) of the fish's body*

Phosphorus concentration in water, mg	Day of experiments			
	1		7	
	M±m	Deviation from control, %	M±m	Deviation from control, %
Liver				
0.06 (conditional control)	127.00±9.00	–	147.00±8.00	–
0.3	232.00±21.00*	+82.68	119.00±11.00	-19.05
0.6	188.00±4.00*	+48.03	71.00±5.00	-51.70
Gills				
0.06 (conditional control)	1512.00±90.00	–	1098.00±40.00	–
0.3	831.00±77.00*	-45.03	843.00±63.00*	-23.22
0.6	1280.00±23.00	-15.34	1024.00±73.00	-6.73
Kidneys				
0.06 (conditional control)	122.00±3.00	–	106.00±1.00	–
0.3	111.00±7.00	-9.02	87.00±6.00*	-17.92
0.6	159.00±16.00*	+30.33	109.00±1.00	+2.83
Blood serum				
0.06 (conditional control)	29.40±2.70	–	25.40±2.40	–

Table 2, Continued

Phosphorus concentration in water, mg	Day of experiments			
	1		7	
	M±m	Deviation from control, %	M±m	Deviation from control, %
0.3	27.90±2.10	-5.10	26.40±1.10	+3.94
0.6	32.90±2.90	+11.90	18.50±1.30*	-27.17
Bile				
0.06 (conditional control)	42.00±2.10	–	136.00±1.40	–
0.3	100.00±4.00*	+138.10	199.00±7.90*	+44.20
0.6	78.80±7.90*	+87.62	198.00±19.70*	+43.48

Note: ** reliable result*
Source: *compiled by the authors*

Thus, in the liver tissue, the calcium content was increased in one, decreased during the seven-day time day, and decreased during the seven days of the fish acclimation to the increased phosphorus levels environment. The calcium content decrease in the fish's gill tissue was noted, which was more pronounced during the fish's acclimation to a relatively low phosphorus content in water (0.3 mg/L). As for the blood serum, the calcium concentration in it practically remained at the control values level. The only exceptions are the received data during a long-term (7 days) of carp' keeping in a 0.6 mg/L phosphorus habitat when the calcium content in the blood serum was an average of 27.2%.

It should be noted, that there is not a clear dependence of the calcium content in the fish's kidneys on the phosphorus present in their habitat. Thus, during one fish acclimation in a habitat of 0.6 mg/L phosphorus, the calcium content in the renal tissue exceeds the control level by more than 30.0%. With long-term carp acclimation to a lower (0.3 mg/L) concentration of phosphorus in water, the calcium content in the renal tissue was reduced.

An analysis of received data shows that during the seven days of carp acclimation to an enriched with inorganic phosphorus environment, it accumulates in the glandular tissues of the liver and gills, and a slight decrease in the kidneys. As for the blood serum, its level is kept at a relatively constant level. The noted changes in the total phosphorus content and calcium in a carp's body during its acclimation to the increased phosphorus concentration may be due to the activation of organ regulation mechanisms, in particular, an excretory processes increase. The intensity of the phosphorus excretion process with excretion products depends on its concentration in water and the fish's residence time in such conditions. Attention should be paid to the fact that quantitatively more phosphorus and calcium are excreted from the fish body with the faeces than in the urine (Table 3).

Table 3. *Influence of phosphorus in aquatic habitat on the calcium and phosphorus excretion with fish excrement (mg/kg of weight/day)*

Phosphorus concentration in water, mg/L	Day of experiments			
	1		7	
	M±m	Deviation from control, %	M±m	Deviation from control, %
Daily urinary phosphorus excretion				
0.06 (conditional control)	2.07±0.25	–	1.34±0	–
0.3	2.03±0.31	–	1.62±0.09*	+20.90
0.6	1.19±0.23*	-42.52	2.28±0.22*	+70.15
Daily phosphorus excretion in faeces				
0.06 (conditional control)	4.05±0.33	–	3.08±0.33	–
0.3	7.81±0.14*	+92.84	2.85±0.32	-7.47
0.6	3.00±0.22*	-25.93	0.56±0.06*	-81.82
Daily urinary calcium excretion				
0.06 (conditional control)	2.85±0.32	–	2.30±0.17	–
0.3	4.04±0.27*	+47.75	2.39±0.09	+3.91
0.6	1.54±0.12*	-45.96	2.23±0.26	-3.04

Table 3, Continued

Phosphorus concentration in water, mg/L	Day of experiments			
	1		7	
	M±m	Deviation from control, %	M±m	Deviation from control, %
	Daily calcium excretion in faeces			
0.06 (conditional control)	6.89±0.21	–	7.09±0.37	–
0.3	9.33±0.16*	+35.42	9.32±0.05*	+31.45
0.6	8.20±0.20*	+19.01	9.59±0.05*	+35.26

Note: ** reliable result*
Source: *compiled by the authors*

Thus, the phosphorus excretion with urine in control fish, kept in a habitat with a 0.06 mg/L (conditional control) phosphorus level was 1.34-2.07 mg/kg of body weight/day, with faeces – 3.08-4.05 mg/kg day. With the phosphorus concentration increase in the aquatic environment to 0.3 and 0.6 mg/L, its excretion naturally increases mainly with urine, and this is especially revealed during a long period of acclimation.

It should be noted that the higher the phosphorus level in the water, the more it is excreted in the urine. During seven days of fish acclimation in a phosphorus 0.3 mg/L habitat, its excretion in urine increased by 20.9% and in 0.6 mg/L – by 70.15%. These results again confirm that the kidneys play a significant role in a fish's phosphate metabolism. The correlation between urinary phosphorus excretion and its feed intake has been shown by (Dilelis *et al.,* 2021). The phosphorus excretion dynamics through the fish's digestive system kept for a long time in an environment with an increased phosphorus level (0.6 mg/L) was reduced. In these experiments, the phosphorus excretion with urine and with fish faeces was lower than the control one during their short-term (1 day) acclimation and similar environmental conditions. However, with the same exposure, but keeping fish in a habitat with a lower (0.3 mg/L) phosphorus concentration, its excretion with the faeces increased sharply (by 92.8%). Thus, the digestive system takes an active part in the elimination of the excess phosphorus, entering the fish's body, with a short fish kept in an environment with a relatively low level of phosphorus (0.3 mg/L). It was also established that by keeping fish for 1 day in a habitat with an increased phosphorus level (0.3 mg/L), the total phosphorus content in bile sharply increases (by 103.13%). With a longer (7 days) exposure of the experiment, the excretion of phosphorus in the bile was not so high.

The fish's acclimation to a habitat with an increased phosphorus level increases calcium excretion (Table 3) through the digestive system (by 19.01-35.42%). Herewith, calcium concentration in the bile of experimental fish, increased by 43.48-138.10. It should be noted that the excretion of calcium in the urine changes to a lesser extent in fish kept in increased water phosphorus concentrations.

A significant change in the daily calcium contents in the urine was noted only in fish, and they acclimated for 1 day to an increased phosphorus content in water. So, if the phosphorus concentration in water equal to 0.3 mg/L caused an increase in the daily calcium excretion with carp urine by 47.75%, then keeping them in water with 0.6 mg/L of the element, its excretion was 45.96% lower than in the control fish. Based on the received data, it can be concluded that the increase in excess phosphorus excretion from the fish body, kept in water with its increased level of 0.3-0.6 mg/L, is accompanied by significant calcium losses, especially through the digestive system.

Features' research of phosphorus metabolism in the fish' glandular organs, involved in osmoregulation (liver, kidneys, gills) has revealed several regularities not only in the total phosphorus distribution but also in the adenyl nucleotide exchange. At the same time, changes in the high-energy phosphorus compounds level in the fish' glandular tissues, exposed to high (0.3-0.6 mg/L) phosphorus concentrations in water, are especially noticeable. Thus, the ATP content in the kidneys was reduced by 39-56%, when the fish were kept in a habitat with 0.3 mg/L of inorganic phosphorus, and the liver, by 29-42.0% at both element concentrations. A significant ATP value decrease in the gill tissue occurred by the end of the 7th day keeping fish in water with a total phosphorus concentration of 0.3 mg/L, and with an increase in its level to 0.6 mg/L – on the first day.

The influence of inorganic phosphorus increased level on adenylates in experimental fish is expressed by a large ATP concentration decrease without a significant ADP and AMP increase, which leads to their decrease. In contrast, the content of these (ADP, AMP) adenyl system components has been reduced in fish tissues, exposed to increased phosphorus levels in the water. Thus, the content of ADP decreases to the greatest extent in the carp's gill tissue, which has been kept in the habitat with both 0.3 and 0.6 mg/L of inorganic phosphorus in water (by 26.9-69.5%). At the same time, in the fish's kidneys and liver, a significant decrease in the ADP level has been noted only when a habitat is exposed to 0.6 mg/L of phosphorus. As for AMP in the researched tissues, it did not differ from the control level during fish acclimation to a lower phosphorus concentration in water (0.3 mg/L). However, with the phosphorus concentration increase in the aquatic habitat to 0.6 mg/L, the AMP level decreases only in the

carp's kidneys. In the gills and liver, the AMP level was significantly higher than the initial one.

Based on the research results, it can be concluded that during the fish' acclimation to the increased level of phosphorus in the aquatic habitat, significant changes develop in the glandular fish organs' exchange of the high-energy organophosphate compounds. This conclusion is confirmed by the energy charge calculations of the experimental fish tissue adenylate system (Table 4).

***Table 4**. Influence of increased phosphorus level in water on the content of adenine nucleotides in carp tissues (μM adenine/g dry tissue)*

Phosphorus concentration in water, mg/L	Indicators	Control	Day of experiment			
			1		7	
				Deviation from control, %		Deviation from control, %
Liver						
0.3	ATP	7.39±0.47	4.28±0.71*	-42.08	5.20±0.36*	-29.63
0.6		5.68±0.61	3.92±0.25*	-30.99	3.37±0.40*	-40.67
0.3	ADP	2.93±0.35	3.16±0.35	+7.85	2.86±0.28	–
0.6		4.50±0.33	2.70±0.35*	-40.00	3.28±0.27*	-27.11
0.3	AMP	2.27±0.23	2.09±0.20	-7.93	1.31±0.14*	-42.29
0.6		2.93±0.10	1.63±0.15*	-44.37	3.60±0.31*	+22.87
0.3	AN sum	12.52±1.28	9.74±0.87*	-22.20	9.27±0.52*	-25.96
0.6		13.01±0.81	8.37±0.51*	-35.66	10.32±0.95*	-20.68
0.3	AEC	0.70±0.03	0.60±0.02*	-14.29	0.72±0.02	+2.85
0.6		0.59±0.01	0.64±0.02*	+25.42	0.49±0.012*	-16.95
Gills						
0.3	ATP	9.43±1.40	10.12±0.44	+7.30	3.59±0.23*	-61.93
0.6		10.84±0.35	5.97±0.69*	-44.92	7.50±0.87*	-30.81
0.3	ADP	7.18±1.12	3.58±0.18*	-50.14	2.19±0.32*	-69.90
0.6		9.43±0.50	5.28±0.44*	-44.01	6.89±0.27*	-26.94
0.3	AMP	2.07±0.22	2.32±0.12	+12.08	1.91±0.32	-7.73
0.6		2.07±0.22	2.40±0.14	+5.94	2.47±0.24*	+43.48
0.3	AN sum	18.70±1.69	12.01±0.69*	-35.78	7.85±0.23*	-58.02
0.6		22.68±0.42	17.67±0.25*	-22.09	17.36±1.15*	-23.46
0.3	AEC	0.69±0.01	0.66±0.03	-4.35	0.60±0.03*	-13.04
0.6		0.69±0.01	0.70±0.012	+1.45	0.63±0.02*	-8.70
Kidneys						
0.3	ATP	11.00±0.64	6.70±0.45*	-39.00	4.84±0.26*	-56.00
0.6		8.80±0.63	8.97±0.62	+1.93	7.61±0.90	-13.52
0.3	ADP	3.42±0.71	3.52±0.56	+2.92	2.96±0.26	-13.45
0.6		6.06±0.42	4.37±0.28*	-27.89	5.28±0.22	-12.87
0.3	AMP	2.78±0.35	2.84±0.34	–	3.43±0.26	+23.40
0.6		4.38±0.35	2.50±0.28*	- 42.92	3.35±0.17*	-24.07
0.3	AN sum	17.29±1.07	13.12±0.51*	- 24.12	11.35±0.52*	-34.36
0.6		18.31±0.56	15.45±0.85	- 15.62	16.30±0.97	-10.97
0.3	AEC	0.74±0.02	0.65±0.02*	-12.16	0.56±0.02*	-24.32
0.6		0.67±0.02	0.72±0.04	+7.46	0.62±0.02	-7.46

***Note:** AN sum – the sum of adenyl nucleotides; AEC – adenylate energy charge. * – the reliable result*
***Source:** compiled by the authors*

Thus, the adenylate system energy charge in the kidneys of carp, which acclimated to a phosphorus concentration of 0.6 mg/L in water, has been maintained at the level of control fish. In the liver of these fish, with a short-term experiment exposure, the adenylate energy charge has been for 25.4% higher than the control level, while simultaneously, the AMP content in it decreased. During a seven-day carp' acclimation period to a containing phosphorus 0.6 mg/L habitat, the adenylate energy charge in the carp's liver and gills was reduced.

Dynamics change comparison in the content of adenyl nucleotides and inorganic phosphorus in the fish' tissues acclimated in a habitat with an increased phosphorus level (Table 5) gives reason to assume the activation of glycolytic processes and oppression of tissue respiration.

Table 5. *Influence of increased phosphorus level in water on the phosphorus compounds content in the fish tissues (mg% dry tissue)*

Phosphorus concentration in water, mg/L	Day of experiments			
	1		7	
	M±m	Deviation from control, %	M±m	Deviation from control, %
Liver				
Inorganic phosphorus				
0.06	527.80±11.66	–	446.92±45.302	–
0.3	394.15±14.88*	-25.30	506.10±36.62	+13.20
0.6	536.59±1.20	+1.70	698.38±18.84*	+35.00
Protein phosphorus				
0.06	248.88±12.11	–	132.70±4.74	–
0.3	347.32±11.22*	+39.60	344.27±13.15*	+159.40
0.6	366.67±3.70*	+47.30	299.52±4.80*	+125.70
Lipid phosphorus				
0.06	139.01±13.00	–	88.63±3.82	–
0.3	303.41±11.22*	+118.30	188.73±27.70*	+112.90
0.6	271.76±15.74*	+95.50	234.30±25.12*	+164.40
Gills				
Inorganic phosphorus				
0.06	689.08±74.14	–	559.22±25.29	–
0.3	629.31±4.37	-8.70	640.91±90.26	+14.60
0.6	976.70±41.50*	+41.70	571.52±88.48	+2.20
Protein phosphorus				
0.06	360.34±20.11	–	231.62±16.76	–
0.3	451.15±27.01*	+25.20	504.55±22.72*	+117.80
0.6	545.89±26.03*	+51.50	377.58±27.27*	+63.00
Lipid phosphorus				
0.06	155.17±8.04	–	118.72±7.26	–
0.3	190.80±16.67	+23.00	137.95±8.44	+16.20
0.6	237.67±14.38*	+53.20	113.33±7.88	-4.50

Note: ** reliable result*
Source: *compiled by the authors*

Switching energy metabolism in the fish's body, exposed to an increased phosphorus content in the aquatic habitat to the glycolytic path, leads to less fat usage for energy purposes, which the lipid phosphorus content has confirmed.

It was established that the lipid phosphorus level significantly increases in the carp's liver, acclimated to the content of phosphorus in water equal to 0.3 and 0.6 mg/L. The lipid phosphorus content in experimental fish's gills was increased only with a short-term (1 day) keeping fish in a habitat with 0.6 mg/L of phosphorus. The lipid phosphorus noted an increase in fish tissues, kept in an increased level of the element environment, which can occur due to its fast integration into organic compounds Huser *et al.* (2021).

An inorganic phosphorus increase in water has affected the activity of Na^+, and K^+, activated by Mg^{2+} – dependent adenosine triphosphatase of the studied fish organs (Fig. 1).

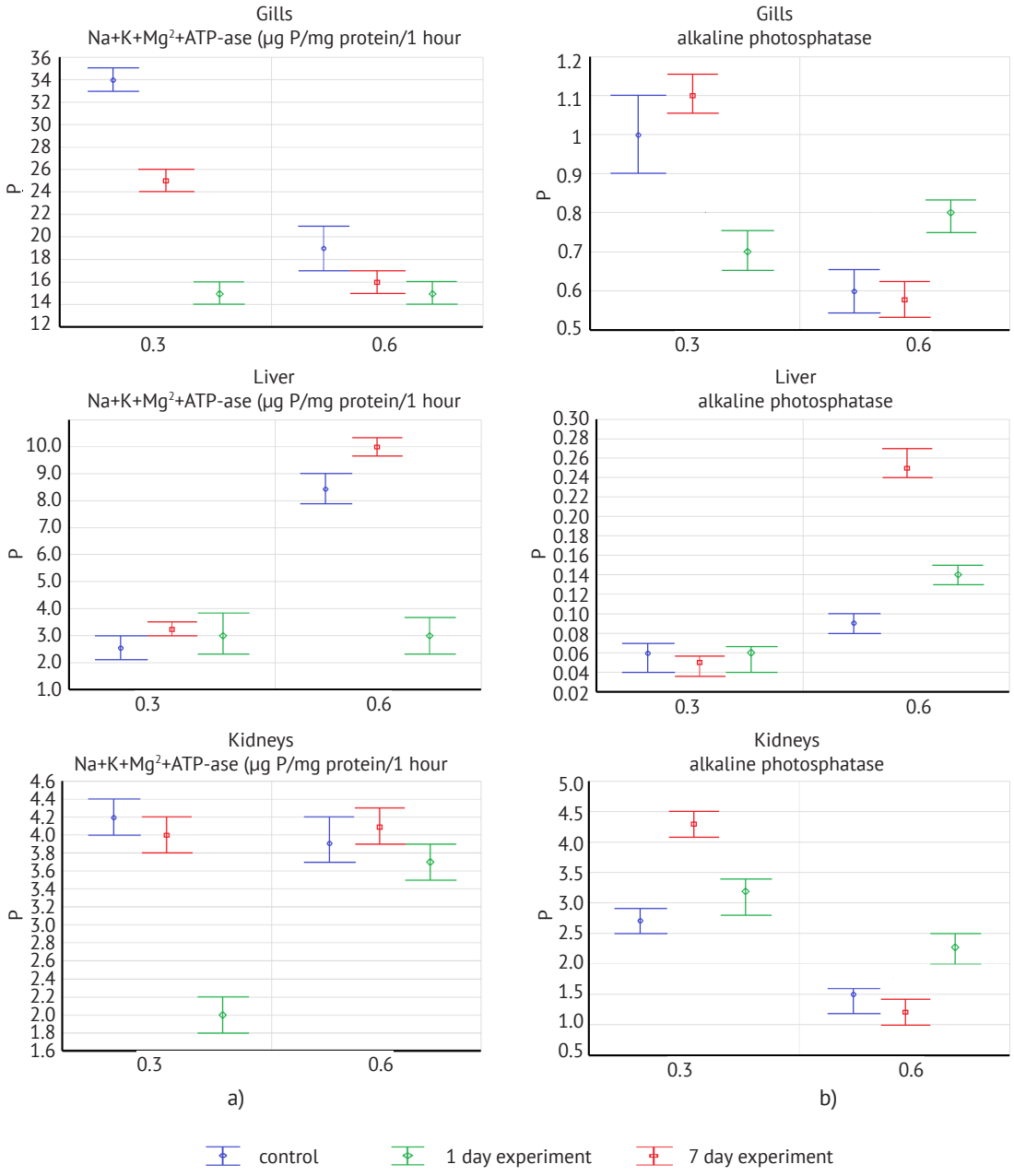

Figure 1. *The activity of Na^+ K^+ Mg^{2+}-ATP-ase (µg P/mg protein/1 hour) (a) and alkaline phosphatase (b) in carp's tissues during keeping in a habitat with an increased inorganic phosphorus concentration*

Herewith, the reactions of different tissues to the phosphates action are not the same. So, if the adenosine triphosphatase activity was reduced in the fish's gills and kidneys when they were kept in water with 0.3 mg/L of inorganic phosphorus, but in the liver, vice versa, it was much higher. At a higher inorganic phosphorus concentration (0.6 mg/L), the gills and kidneys' ATP-ase activity stayed as that at the control fish level and sharply decreased in the liver. The changes in adenosine triphosphatase activity may indicate the phosphates' transport decreases through the fish' gills at a sufficiently high content of it in the aquatic habitat. It consists of the value data of total phosphorus and phosphorus ATP in the tissues (Table 1, 4).

Under conditions of a significant phosphorus content increase in water, the tissue activity of alkaline phosphatase also changes (Fig. 1). Hence, in the gills' glandular tissue, the activity of the enzyme changed significantly only by the end of the seven-day experiment at both studied phosphorus concentrations in water. The alkaline phosphatase activity did not change in the liver during the fish was kept in a habitat with 0.3 mg/L of phosphorus. With an increase of inorganic phosphorus concentration in water up to 0.6 mg/L, the highest enzymatic activity (almost twice the control one) of glandular tissues was observed on the first day of keeping fish in such habitat. With an increase in time acclimation, the activity of alkaline phosphatase in the liver has continued to remain high. The most noticeable changes in the activity of alkaline phosphatase were registered in the renal tissue. The enzyme activity was significantly increased in the renal tissue at 0.3 and 0.6 mg/L of inorganic phosphorus in the water.

The enzymatic activity of the liver, kidneys, and gill tissues shows that its regular increase is observed only in the kidneys while keeping fish in an environment with 0.3 and 0.6 mg/L of phosphorus. In other organs, phosphatase activity increases only on particular days. An increase in alkaline phosphatase tissue activity in the kidneys may be related to eliminating excess phosphates from the fish's body, kept in a habitat with its high content (Table 3).

Thus, the research showed that with a phosphorus concentration increase in the aquatic habitat up to 0.3-0.6 mg/L, it accumulated in the liver and gills, and decreased in the kidneys, while in the fish's blood serum, its concentration was maintained. at a relatively constant level. A greater extent causes the accumulation of phosphates in fish tissues due to organic compounds, including lipid and protein fractions. In the excretion from the body phosphates, along with the kidneys, the liver plays a significant role, as evidenced by the increased calcium and phosphorus excretion with the fish's bile during their acclimation to an increased phosphorus level in the water. The phosphorus content change in the fish habitat significantly influences the tissue bioenergetics processes, which shows as the change in ATP content, the activity of ATP-ase and alkaline phosphatase. The most profound changes in these indicators have been noticed in the gills – that is the responsible organ for the intake and excretion of phosphates from the body, as well as in the kidneys, which provide a high rate of phosphates excretion.

As illustrated above, a phosphorus content change in the fish habitat has a significant influence on its tissue accumulation, as well as the high-energy phosphorus compounds supply, which has an extremely important role in bioenergetics processes. Following these data, there are also the results of the cellular processes research in the glandular organs of fish, acclimated to an increased inorganic phosphorus level in the water. At the same time, the total phosphorus content in the carp's mitochondria was in a certain dependent on this element amount in water and the time of its influence on the fish organism (Table 6).

Table 6. *Influence of increased phosphorus level, in the aquatic habitat, on the total and inorganic phosphorus content in the mitochondria of carp' gills and liver (μg/mg protein)*

Indicators	Day of experiment	0.06 (control)	Phosphorus concentrations in water (mg/L)			
			0.3		0.6	
				Deviation from control, %		Deviation from control, %
Gills						
Total phosphorus	1	6.22±0.62	5.78±1.27	-7.1	5.30±0.73	-17.4
Inorganic phosphorus		0.52±0.06	0.65±0.08	+25.0	0.35±0.03*	-32.69
Total phosphorus	7	5.50±0.38	7.63±0.50*	+38.7	2.71±0.28*	-50.7
Inorganic phosphorus		0.93±0.07	0.36±0.04*	-61.29	0.33±0.07*	-64.52
Liver						
Total phosphorus	1	5.42±0.69	3.78±0.26*	-31.7	3.70±0.36*	-31.7
Inorganic phosphorus		0.55±0.05	0.64±0.05	+16.36	0.39±0.03*	-29.09

Table 6, Continued

Indicators	Day of experiment	0.06 (control)	Phosphorus concentrations in water (mg/L)			
			0.3		0.6	
				Deviation from control, %		Deviation from control, %
Total phosphorus	7	6.98±0.91	5.91±0.37	-15.3	4.12±0.16*	-41.0
Inorganic phosphorus		0.52±0.06	0.19±0.02*	-63.46	0.29±0.01*	-44.23

Note: ** – reliable result*
Source: *compiled by the authors*

Thus, in the mitochondria of the fish's gills glandular apparatus, when they were kept for 3 days in a phosphorus habitat with 0.3 mg/L, the total phosphorus content remained unchanged and only by the end of the seventh day it has been slightly exceeded the control value. With the inorganic phosphorus level increase in water to 0.6 mg/L, the total phosphorus concentration in the mitochondria of the gills has decreased more than two times, which was especially clearly shown on the 7th acclimation day.

Although phosphorus content increases in the fish habitat, mitochondrial accumulation of phosphates has not been observed. Nevertheless, in the mitochondria of the liver and gills' glandular cells, significant changes in the energy metabolism indicators were registered, particularly in the exchange of adenyl nucleotides and the activity of Na^+, K^+, and Mg^{2+}-ATP-ase.

Thus, the amount of ATP (Table 7) in the glandular cells' mitochondria of the carp's gill apparatus, during its daily acclimation to 0.3 mg/L of phosphorus, was sharply increased in the aquatic habitat. Further, fish acclimation to the increased inorganic phosphorus concentrations in the aquatic habitat was accompanied by significant energy consumption necessary to support homeostatic balance in their body. At the same time, the high fish' requirement for metabolic energy has been provided by the reserves of ATP. This is confirmed by its content decrease in the glandular organs' mitochondria, especially during prolonged (7 days) acclimation to an environment with 0.6 mg/L of phosphorus, with a simultaneous increase of the ATP-ase activity in these cellular structures. This direction of the mitochondria' bioenergetic processes in the fish's liver and gills ensures the adaptive capacities of their body to a sharp phosphorus content increase in water.

Table 7. *Influence of increased phosphorus level in the aquatic habitat on the exchange of adenine nucleotides in the fish' mitochondria tissues (μM adenine/100 mg protein)*

Indicators	Day of experiment	0.06 (control)	Phosphorus concentrations in water (mg/L)			
			0.3		0.6	
				% concerning control		% concerning control
Gills						
ATP	1	2.90±0.18	5.40±0.65	+86.21	2.60±0.20*	-10.34
ADP		2.60±0.21	2.70±0.23*	+3.85	1.30±0.20	-50.0
AMP		0.80±0.02	1.30±0.23	+62.5	2.50±0.12	+212.5
The adenylates' amount		6.20±0.50	9.40±0,63	+51.61	6.40±0.69*	+3.23
AEC		0.66±0.015	0.71±0.031*	+7.5	0.50±01.006	-24.24
ATP	7	2.50±0.09	3.50±0.21	+40.0	1.08±0.18	-56.8
ADP		1.00±0.11	2.50±0.23	+150.0	2.67±0.033	+167.0
AMP		0.80±0.01	1.30±0.12	+62.5	1.04±0.079	+30.0
The adenylates' amount		4.30±0.11	7.45±0.33	+73.26	4.80±0.29*	+11.62
AEC		0.70±0.011	0.65±0.002	-7.14	0.50±0.015	-28.57
Liver						
ATP	1	1.50±0.017	1.30±0.08*	-13.33	1.50±0.12*	–
ADP		1.10±0.15	2.50±0.18	+127.27	1.50±0.12	+36.36
AMP		0.90±0.09	1.60±0.11	+77.78	2.06±0.20	+128.89

Table 7, Continued

Indicators	Day of experiment	0.06 (control)	Phosphorus concentrations in water (mg/L)			
			0.3		0.6	
				% concerning control		% concerning control
The adenylates' amount		3.70±0.36	5.40±0.25	+45.95	5.10±0.29	+37.84
AEC		0.56±0.019	0.48±0.036	-14.29	0.46±0.016	-17.86
ATP	7	1.70±0.08	2.20±0.06	+29.41	1.17±0.013	-31.18
ADP		0.80±0.10	1.60±0.16	+100.0	1.17±0.043	+46.25
AMP		0.60±0.04	1.20±0.10	+100.0	1.13±0.031	+88.33
The adenylates' amount		3.12±0.09	5.02±0.31	+60.0	3.44±0.037*	+10.26
AEC		0.70±0.009	0.60±0.019	-14.29	0.51±0.003	-27.14

Note: ** AEC - adenylate energy charge; * – the reliable result*
Source: *compiled by the authors*

Analysis of other adenyl system components shows that the level of ADP, and AMP is influenced by an increased phosphorus content in the aquatic habitat, the adenyl nucleotide amount has been increased. It should be mentioned that more pronounced changes in these indicators were noted during acclimation in a habitat containing phosphorus of 0.6 mg/L. The energy charge of the adenylate system, which characterizes the metabolically available energy presence in the carp's mitochondria of the glandular tissues, exposed to an increased phosphorus level in the water, has been kept at a level lower than the control level (by 7.5-31.18%). Such a decrease in the adenylate charge level contributes to the activation of various energy generation mechanisms, as a result, the ATP content in the mitochondria of the carp' gills and liver, while they were kept in a habitat with a lower (0.3 mg/L) phosphorus concentration in water, or with a short (1 day) phosphorus exposure to 0.6 mg/L, is maintained at a close to the control level.

Thus, the change in phosphorus content in the habitat of fish significantly affects its tissue accumulation, as well as the content of macroregion phosphorus compounds, which ensure the high intensity of phosphate excretion. Wang *et al.,* (2022) found that about half of the absorbed phosphorus is retained in the fish liver. A similar pattern is revealed in the fish's phosphate content indicators in their liver tissue during their acclimation to these inorganic phosphorus concentrations. However, it should be noted that the opinion of researchers regarding the dependence between the absorption of phosphorus from the aquatic habitat and its level in it is somewhat contradictory. Thus, (Dilelis *et al.,* 2021; Hrynevych *et al.,* 2022) had been shown that with phosphorus concentration increases in the aquatic environment, its accumulation by fish also increases. At the same time, a high number of phosphorus can adversely influence the branchial membranes, thereby reducing the actual absorption and phosphorus transport (Villeger *et al.,* 2017). The unequal influence of the different phosphorus concentrations that come with feed on the processes of its absorption was also shown by the works of (Costa *et al.,* 2018; Knöpfel *et al.,* 2019; Gao *et al.,* 2023).

The renal system plays a fundamental role in the phosphates' excretion from the fish organism (Wang *et al.,* 2021). The data has also confirmed the high phosphorus lability content in the fish's kidney tissue, during their acclimation to its increased concentrations in water.

The deviations found in the exchange of calcium in the carp's body acclimated to an increased phosphorus content in the aquatic habitat, show the interrelation of tissue metabolism in these elements in terrestrial and aquatic animals. In experiments on birds, an increased calcium content in the serum of chickens who get a low phosphorus content feed was observed (Fedoniuk *et al.,* 2019). With an increase in the content of phosphorus in the diet of poultry, changes in the content of calcium in the blood became less noticeable. A negative linear relationship between the amount of phosphorus absorbed by carp and the calcium content of the feed has been shown (Huser *et al.,* 2021; Lall, 2022). According to other data, the level of calcium in the blood of carp did not depend on the amount of phosphorus in the food (Saurette *et al.,* 2019). Musharraf *et al.* (2019) have observed the violation of tissue calcium metabolism with enhanced carp phosphorus excretion, fed with a phosphorus diet enriched.

The data received does not align with the previously obtained results of a study by Pouil *et al.* (2018), which showed that the phosphorus excretion from the fish's body happened mainly through the kidneys, gills and, to a lesser extent, with faeces. However, in the research (Fedonyuk *et al.,* 2019; He *et al.,* 2022), the digestive system, under normal keeping fish conditions, is assigned a significant role in phosphorus elimination from the body.

The confirmation of the glycolytic processes' activation and inhibition of such fish tissue respiration reactions are established by Wang *et al.* (2022) decreased

activity of respiratory enzymes, glycogen level and accumulation of glycolysis products in the liver and gills.

Other researchers (Solomatina *et al.,* 2018; Sugiura *et al.,* 2018; Huang *et al.,* 2019), showed that significant phosphorus reserves in aquatic organisms can be found in the form of lipid and protein compounds in the hepatopancreas. This is confirmed by the protein phosphorus amount significant (by 25.2-159.4%) increase in the liver and gills of fish, kept in an inorganic phosphorus high-level environment.

The researchers (Romanchuk *et al.,* 2018; Pinkina *et al.,* 2019; Solomatina *et al.,* 2019), also found that the mitochondrial content of inorganic phosphorus and total phosphorus was reduced in fish kept in water with elevated levels. This happens in contrast to calcium, the accumulation of which increased sharply in the mitochondria of the liver and especially in the gill apparatus with the increase of this element in the habitat. Researchers (Ai *et al.,* 2019; Wang *et al.,* 2022) found phosphorus in the aquatic habitat reduces the adsorption and transport of ions, negatively affecting the membranes of gill cells. This can explain the decrease in the accumulation of phosphates in the mitochondria of the glandular organs of the liver, especially the gills, during the maintenance of carp in a high-phosphate environment with a high level of phosphates.

Comparison of the tissue and cellular changes in the liver and glandular gills apparatus content of calcium and phosphorus, during the fish acclimation to an increased level of this element in water, reveals the unequal mitochondria participation in ensuring the adaptive organism's reactions to the ionic effects of the aquatic habitat. If, after an increased calcium intake into the fish's body from the aquatic habitat, it increases in the mitochondria of the glandular cells, then during the fish acclimation to a high phosphorus content, and vice versa, its mitochondrial content decreases. Therefore, it can be concluded that, if mitochondria play a significant role in the fish calcium metabolism, cytoplasmic structures are more important in phosphate metabolism. This proposal corresponds with the data received on the cytosol and mitochondria of the warm-blooded animals' hepatocytes when their body is loaded with inorganic phosphorus (Sun *et al.,* 2018; Wang *et al.,* 2021). Thus, after a 20-minute hepatocytes incubation with 620 mg of inorganic phosphorus, its content in isolated mitochondria has not changed, but it increased almost 2 times in the cytosol.

The above-noted deviations in the energy supply for the fish' acclimation process to an increased phosphorus level in the aquatic habitat happened due to the significant deviations in the links of mitochondrial respiration. Caused by swelling of mitochondria and uncoupling of oxidative phosphorylation Souders *et al.* (2018).

Described orientation of metabolic processes provides adaptive capabilities of the fish organism to a sharp increase in the phosphate content in the water. Thanks to this, *Cyprinus carpio* L. fish can tolerate high levels of phosphorus fluctuations in the aquatic environment.

CONCLUSIONS

As a result of the study, it was established, that with a duration increase of staying fish in water with a lower phosphorus concentration (0.3 mg/L), more phosphates are found in the gill tissue than when they had been adapted to a higher concentration (0.6 mg/L).

A particularly significant drop in the total phosphorus level in the fish's kidneys was observed during their prolonged stay in a high phosphate content environment. At the same time, the quantity of total phosphorus in the fish's blood serum, kept in a habitat with its level increased to 0.3-0.6 mg/L, increased in a short-term period.

The calcium content decrease in the fish's gill tissue was noted, which was more pronounced during the fish's acclimation to a relatively low phosphorus content in water (0.3 mg/L). As for the blood serum, the calcium concentration in it practically remained at the control values level. With long-term carp acclimation to a lower (0.3 mg/L) concentration of phosphorus in water, the calcium content in the renal tissue was reduced.

It was also established that by keeping fish for 1 day in a habitat with an increased phosphorus level (0.3 mg/L), the total phosphorus content in bile sharply increases (by 103.13%). The influence of inorganic phosphorus increased level on adenylates in experimental fish is expressed by a large ATP concentration decrease without a significant ADP and AMP increase, which leads to their amount decrease. In contrast, the content of these (ADP, AMP) adenyl system components has been reduced in fish tissues, exposed to increased phosphorus levels in the water. Thus, the content of ADP decreases to the greatest extent in the carp's gill tissue, which has been kept in the habitat with both 0.3 and 0.6 mg/L of inorganic phosphorus in water (by 26.9-69.5%).

Switching energy metabolism in the fish's body, exposed to an increased phosphorus content in the aquatic habitat to the glycolytic path, leads to less fat use for energy purposes, which the lipid phosphorus content has confirmed. In the mitochondria of the liver and gills' glandular cells, significant changes in the energy metabolism indicators were registered, particularly in the exchange of adenyl nucleotides and the activity of Na^+, K^+, and Mg^{2+}-ATP-ase. The perspective of further research is the influence of different concentrations of phosphorus in the aquatic environment on the tissue and intracellular metabolism of predatory fish species.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Вплив різних концентрацій фосфору на тканинний та внутрішньоклітинний метаболізм *Cyprinus Carpio* L. у водному середовищі існування

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Анотація. Актуальність дослідження зумовлена тим, що під впливом різних чинників водного середовища фіксуються зміни швидкості та спрямованості метаболічних процесів гідробіонтів. Метою дослідження є вивчення впливу різного вмісту неорганічного фосфору у водному середовищі на показники фосфорно-кальцієвого обміну у риб. Використовували методи тонкошарової хроматографії та варіаційної статистики. Аналізували залозисті тканини зябер, печінки та нирок риб. Для вивчення впливу неорганічного фосфору водного середовища на деякі показники внутрішньоклітинного метаболізму виділяли мітохондрії в осморегуляторних органах. Встановлено, що при підвищенні концентрації фосфору у водному середовищі до 0,3-0,6 мг/л відбувається його накопичення в печінці, зябрах і зменшення в нирках, при цьому концентрація в сироватці крові риб підтримується на відносно постійному рівні. Підвищення концентрації неорганічного фосфору у водному середовищі суттєво впливає на процеси енергоутворення в мітохондріях печінки риб. Зміна вмісту фосфору в середовищі існування риб має значний вплив на біоенергетичні процеси в тканинах, що проявляється у зміні вмісту аденозинтрифосфату, активності лужної фосфатази. Значні зміни цих показників спостерігаються в зябрах та нирках. Результати досліджень можуть бути використані для формування адаптаційно-компенсаторних регуляторних механізмів в організмі гідробіонтів при їх пристосуванні до певних умов вирощування та розмноження

Ключові слова: *Cyprinus carpio*; печінка; зябра; нирки; сироватка крові; жовч

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Ecology of soil animals (*Diplopoda* class, *Myriapoda* group)

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Abstract. Class *Diplopoda* plays an important role in natural ecosystems, because it supports biodiversity and soil stability, and a change in the number or distribution of centipede species can indicate changes in the environment, such as pollution, soil degradation, climate change, etc. The purpose of the study is to identify the existing species of soil animals of the *Diplopoda class*, as well as to determine environmental factors that can affect their distribution. Species' diversity was assessed by collecting individuals and classifying them into order, family, genus, and species. Climatic factors, namely temperature and precipitation, are also determined. As a result of the study, ecological aspects of centipede development were evaluated and their distribution and dependence on environmental factors, such as climatic, edaphic, and trophic factors, were analysed. In the southern region of Albania, 22 species of the *Diplopoda class of the Myriapoda* group were identified, among which mainly decomposers of organic remains and phytophages. The regions of Llogara and Šhašhica were noted as the regions with the highest diversity of millipedes. In addition, it was established that the variation of species is influenced by the environment, the presence of organic substances, and climatic factors. Temperature and humidity are determining factors influencing the distribution of the *Diplopoda class* in different biotopes. Species that have a large regional distribution and are most widespread in time throughout the year: *Pachyiulus cattarensis*, found in the period June-November, *Glomeris pulchra* – May-July, September-October, *Pachyiulus varius* – May-October. A less active period was noted for the following species: *Polydesmus complanatus, Glomeris latermarginata, Typhloiulus albanichus, Pachyiulus hungaricus, Glomeris pustullata.* The research, which was carried out, is of practical importance for nature conservation, as the *Diplopoda class* plays an important role in maintaining ecosystems and biodiversity and can be an indicator of the state of the environment

Keywords: millipedes; environment; plant remains; ecosystem; climate; phytophages

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INTRODUCTION

Myriapoda group are important components of ecosystems on Earth. *Myriapoda* includes the following classes: *Diplopoda* (millipedes or millipedes), *Chilopoda* (scolopendras), *Symphyla* (symphylls) and *Pauropoda* (pauropods). They have very different ecology and perform different ecological functions in soil ecosystems (Mukundan *et al.,* 2020).

The very study of the diversity and role of organisms in soil ecosystems is extremely relevant, because the soil is a living environment in which millions of different microorganisms live, performing various ecological functions, such as processing organic residues, forming humus, storing and transporting nutrients, maintaining the soil structure and protection against pests and pathogens.

In addition, the study of the diversity and ecology of these organisms helps to better understand their functions in the soil and influence the preservation and improvement of the state of soil ecosystems.

Soil animals, including the class *Diplopoda*, play a critical role in the maintenance and functioning of soil ecosystems. The class *Diplopoda*, commonly known as centipedes, are arthropods found in a variety of habitats around the world. In Albania, the density of their populations is limited, and some of them can serve as indicators of the state of the environment (Zhao *et al.,* 2020). The class *Diplopoda* has an important ecological role in soil ecosystems, which is related to the decomposition of organic matter, nutrient cycling, and soil structuring. Understanding their importance is important for ensuring the stability of soil ecosystems, which adds relevance to the research.

Study of the class *Diplopoda* in Albania is quite limited. Only more than 80 species of representatives of this class are known, which is a relatively small number compared to the area of the country. However, it is believed that the *Diplopoda fauna* in Albania may be represented by a slightly larger number of species. This expectation is based on the diversity of these species in the region and their wide distribution (Zahnle *et al.,* 2022). Research by G.L. Nunes *et al.* (2020) has established that the ecology of the class *Diplopoda* can vary greatly depending on habitat and diet. Most often, they can be found in a moist environment, for example, under fallen leaves, in the soil or under logs. Some species feed on fungi, roots and other soil organisms, which can affect the balance of the soil ecosystem.

The class *Diplopoda* can also play an important role in soil structure and humus formation. Members of this class help return nutrients back into the soil, which can improve soil fertility and plant growth. In addition, centipede activity in the soil can help enrich it with oxygen and improve water infiltration, which reduces erosion and run-off (Tóth & Hornung, 2019). C. Wang *et al.* (2020) note that invertebrate members of the class *Diplopoda* help provide the soil with important minerals. They also promote the development of fungi and other organisms that depend on the decomposition of organic matter in the soil (Wang *et al.,* 2020). According to L. Bundone *et al.* (2022), the class *Diplopoda* is an important component of soil, and understanding their role and interactions with other organisms is critical to maintaining healthy and sustainable soil ecosystems.

N. Pano *et al.* (2006) claim that an important factor that regulates the number of millipedes is external conditions. Thus, temperature and humidity affect the distribution and activity of soil animals, and the study of these factors can help in the development of strategies for the conservation and management of soil ecosystems.

Therefore, an objective study of the distribution factors and species diversity of the *Diplopoda class* can help ensure optimal conditions for the development of plants and other organisms in the soil, reduce the risk of its contamination and preserve biodiversity in soil ecosystems, which is the relevance of the study. Outlining the existing problems of the topic, the purpose of the conducted research is to identify the existing species of soil animals of the *Diplopoda class* and to determine the environmental factors affecting their distribution.

To achieve the goal, the following tasks were performed: to determine the existing species of soil animals of the *Diplopoda class*, to establish climatic, edaphic, and trophic factors that can affect their distribution, to evaluate the ecological aspects of centipede development.

MATERIALS AND METHODS

The criteria used to determine the areas of collection and the definition of soil animals are geographical location of the sites, soil types, habitat type, altitude above sea level, climatic conditions.

Sampling was carried out at different heights above sea level up to 2000 m, where soil animals were found under stones, in fallen leaves, in the bark and hollows of trees, as well as in the upper layers of the soil. All the material was collected by hand, with the subsequent sifting of the soil using a soil sieve. A soil sieve is a special tool consisting of a metal frame and a mesh with different sizes of holes. The net was placed on the frame, after which a small amount of soil was poured on it and sifted. Parts of the soil that did not pass through the mesh remain in the sieve, and soil animals that are in smaller fractions fall through the holes in the mesh. The species were collected at all times of the year, but in the summer, they were collected in limited microbiotopes, under the bark, in wet areas places or in the soil that is associated with arid period.

In order to preserve the collected living material, individuals of soil animals were preserved in 80% alcohol with the addition of ether (several drops). The addition of ether to alcohol helps to reduce the possibility of damage to soft tissues during the preservation

process, because ether affects the preservation of the morphology of animals and avoids their decomposition.

In order to reflect the diversity of soil animals in a certain environment and changes in their distribution depending on time and climatic factors, records were made about the temperature of the environment, the date of collection, the flora, and the type of locations of the samples.

The following criteria were used to determine the type of soil animals:

1. Morphological characteristics: size, body shape, colour, number of segments, presence of antennae, number of pairs of legs, presence, or absence of gonopods, etc.

2. Location and habitat type.

3. Analysis of morphological features under a microscope: Morphological features such as the presence of antennae and microscopic structures on the body were studied in more detail using a stereomicroscope.

In addition, the determination of soil types in the study was based on the appropriate methodology (Mauries *et al.,* 1997).

The climate of the research area is influenced by the geographical location and the topography of the area. However, this is a typical Mediterranean climate, in which there is sometimes a deviation from the average long-term indicators, in particular in the minimum and maximum temperature, amount of precipitation, solar insolation, etc. In the southern region of Albania, some subtypes of the Mediterranean climate are observed, namely: the lowland Mediterranean climate characteristic of the Albanian Riviera and the high-altitude Mediterranean climate, mainly on the mountain tops.

Processing of the received research results for reliability was carried out using the multivariate method of variance analysis MANOVA using Microsoft software Excel and Statistica 10 software package. Differences received results possible per level significance $P \leqslant 0.05$ according to the Student's test.

RESULTS

Diplopoda – a group of arthropods with jaws and appendages, whose body consists of several ring segments with many pairs of legs. A distinctive feature of this group is the presence of duplicated body segments or diplosegments, resulting from the fusion of two initially separate segments. Each diplosegment has two pairs of legs, hence the name of the class. Diplosegments are also visible from the inside, where there are two pairs of nerve centres in each segment. The majority of representatives of this class have black-brown colour, some can be red and orange, while spotted types are not common (Kime & Golovatch, 2000).

Diplopoda are heliophobes, sensitive to sunlight light, that's why they are hiding, to avoid it. Light and temperature as well as other environmental and physiological factors are more favourable when they are stable. It is worth noting that relatively a bit of millipedes is able to dive deep into the water, even up to 30 cm (Giribet & Edgecombe, 2019).

In the class *Diplopoda*, there are a lot of families, most of which include millipedes that live in the soil and decompose organic matter. Some of the more common families in this class include:

1. *Julidae* – the family includes most of the common millipedes that live in the soil.

2. *Spirostreptidae* – the family that includes long millipedes with a spiral body shape.

3. *Polydesmidae* – the family includes millipedes with a harder outer shell.

4. *Glomeridae* – the family includes millipedes with a hard outer shell and the ability to curl into a ball.

5. *Sphaerotheriida* – includes millipedes capable of curling into a ball, with a large, hard outer shell.

6. *Blaniulidae* – this family includes short-bodied, ground-dwelling millipedes with flat feet (Tóth & Hornung, 2019).

There are several environmental factors that influence the distribution of *Diplopoda* and other soil invertebrates. The main ones are the following:

1. Climatic conditions: the class *Diplopoda*, like most invertebrates, depends on temperature and soil moisture. They usually live in warm and humid places, but can survive in conditions of reduced humidity and temperature.

2. Soil Type: Diplopoda are usually more common in fertile soils with a high organic matter content. They can also be found in other soil types, but their numbers may be smaller.

3. Food availability: Millipedes are phytophagous and saprophagous, so their distribution may depend on the availability of food in the soil. Their number can increase in places with a high concentration of organic substances.

4. Competition with other organisms: Different organisms in the soil, such as insects and other invertebrates, can compete with millipedes for access to food and other resources.

5. The presence of predators: frogs, lizards, birds, and some invertebrates can affect the number of millipedes, limiting their distribution in some areas (Qu *et al.*, 2020).

All these factors can interact with each other and affect the distribution of the *Diplopoda class* in different areas. Understanding these factors can help to explore species diversity and distribution possibilities.

Orders, families, and species found in areas that are observed in the southern region of Albania are:

– Family *Julidae*. In the conducted study, the most representatives of this family were found, they were found in almost every type of soil. Identified genera are given below:

– Genus *Pachyiulus*: *Pachyiulus cattarensis, Pachyiulus dentiger, Pachyiulus varius, Pachyiulius valonensis, Pachyiulus hungaricus.*

– Genus *Brachyiulus: Anoploiulus apfelbecki, Brachyiulus littoralis.*

– Genus *Megaphyllum: Megaphyllum karschi.*

– Genus *Ommatoiulus: Ommatoiulus sabulosus.*

– Genus *Cylindroiulus: Cylindroiulus boleti.*

– Genus *Leptoiulus: Leptoiulus trilineatus, Leptoiulus macedonicus, Typhloiulus albanicus.*

– Family *Blaniulidae*. In the study, representatives of this family were found under leaves, rotten wood, in the soil. One genus has been identified:

– Genus *Nopoiulus: Nopoiulus kochii.*

– Family *Glomeridae:* Found in soil, under stones and in forest areas. One genus was identified in the study:

– Genus *Glomeris: Glomeris hexastica var., Glomeris pulchra, Glomeris bureschi, Glomeris balcanica, Glomeris pustulata, Glomeris latermarginata.* Family *Glomeris* is widespread in Europe, as well as in Albania. Its representatives are found in all investigated areas at an altitude of up to 2000 m.

– Family *Polydesmidae*. Soil animals are identified in the undergrowth, on the meadows, especially in wet places, are characterized by saturated colours, and were represented by two genera:

– Genus *Polydesmus*: *Polydesmus complanetus.*

– Genus *Strongylosoma*: *Strongylosoma stigmatosum balcanicum.*

Family *Julidae* is one of the richest families of the *Diplopoda class* and has about 900 species. Members of this family have a thin body with 15-100 pairs of legs that allow them to move in an ant-like manner. They feed mainly on dead plant remains and fungi, and can also be predators, preying on smaller invertebrates. Since these soil animals cannot efficiently digest leaf litter, they eat a large amount – 5-50% of their weight per day, and produce a huge amount of faeces, which are transported into the deeper layers of the soil. Together with the rainy worms, they are of great importance for the fertility of soil. In some sandy soils, poor nutritious substances and moisture, these invertebrates fully replace rainy worms and are the only one's humus formers among macrofauna (Kime & Enghoff, 2017).

It is worth noting that interrupting physiological cycle was observed in many species when the temperature dropped. Slowing down and then its stopping at 5-10°C was noticed. Such adaptation allows soil animals to experience cold periods of the year. However, at very high temperatures, their life activity also suspends, dry soils are one of the factors affecting this. In places with moderate climate, most animals of the class *Diplopoda* maintain their activity during the whole life cycle. In the completed research, it is established that during preparation for winter, they burrow deeper underground, and then stop their activity and reproduction.

A great diversity of soils was observed on the territory of the study. It is the result of the interaction of soil-forming factors (relief, climate, vegetation cover, types of breeds), which differ depending on each other from height. The most common ones were brown soils, gray brown soils and less alluvial soils. In view of all changes observed in places of research, it was noted that millipedes can be met in almost all types of soil. However, they avoid limestone soils and soils with high salinity. They are found more frequently on brown and gray-brown soils at an altitude of up to 600 m. But their dissemination depends on combinations of different other factors, for example on the type and characteristics of places of existence.

According to the data of meteorological observations, it was noticed that on the territory of research the lasted summer drought may be observed (Table 1). Indexes of temperature and quantity of precipitation were used for constructing ombrothermal diagram of Gaussen for the zone of research.

Table 1. *Climatic Indexes of the southern region of Albania (average for 2011-2022)*

Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Temperature, °C	9.2	10	11.4	14.4	18.3	22	24.1	24.2	21.6	17.9	14.1	10.8
Number of falls, mm	126	99	83.5	69.6	53.5	22.8	16.7	29	57.9	111	148	136

Source: *compiled by the authors*

The number of centipede species collected in July-August is lower compared to the number collected in May-June and September, this may be due to the influence of temperature and humidity (Table 2, 3).

Table 2. *Quantity of collected species by month*

Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
In total	3	-	34	110	168	218	101	77	146	364	123	1458

Source: *compiled by the author*

Table 3. *Quantity of found species by month*

Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
In total	1	-	3	3	7	6	5	4	7	13	5	1

Source: *compiled by the author*

The largest number of species was identified in the temperature range of 15-25°C. These temperatures, based on the collected data, are characteristic of the following months: May, June, as well as September, October. The period July-August and partially June-September is confirmed as the dry period of the year according to the ombrothermal diagram of Gaussen (Fig. 1).

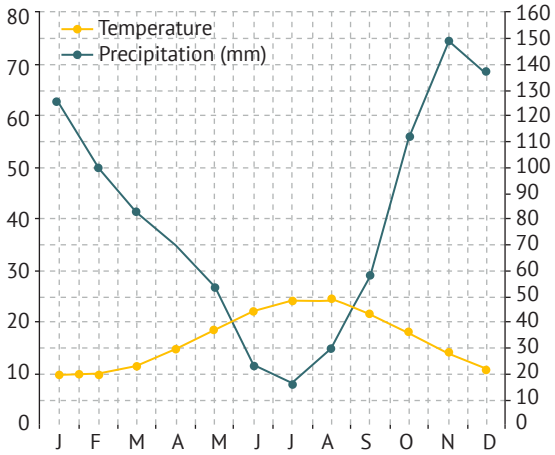

Figure 1. *Gaussen ombrothermal diagram*

Source: *compiled by the author*

For the specified species, the collection time by month is indicated and the different periods of activity of each species are clearly defined (Table 4). The absence of precipitation, that is accompanied by low temperatures, leads to low activity of soil animals and even to their falling into diapause. On the researched territories, this period is quite short in January and February due to the predominance of the Mediterranean climate. And in coastal areas, only a decrease in the activity of individuals, but not an interruption of activity, is observed.

Thus, the climate has a significant influence on the distribution and activity of soil animals of the class *Diplopoda*, especially it relates to the combination of temperature and humidity of the environment.

Table 4. *Identified species of the Diplopoda class by months*

No	Species/Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1	*Pachyiulus cattarensis*						+			+	+	+	
2	*Pachyiulus dentiger*			+	+	+		+			+		
3	*Pachyiulus various*					+	+	+	+	+	+		
4	*Pachyiulus hungaricus*										+		
5	*Pachyiulus valonensis*				+		+		+		+	+	
6	*Ommatoiulus sabulosus*	+		+	+	+			+		+	+	
7	*Anoploiulus apfelbecki*						+				+		
8	*Cylindroiulus boleti*									+	+		
9	*Megaphyllum karschi*			+					+	+	+	+	+
10	*Brachyiulus littoralis*						+	+		+	+		
11	*Leptoiulus macedonicus*										+		
12	*Glomeris hexastica*								+	+			
13	*Leptoiulus trilineatus*					+			+				
14	*Typhloiulus albanicus*					+							
15	*Nopoiulus kochii*					+			+				
16	*Glomeris Balkan*					+							
17	*Glomeris pulchra*					+	+	+		+	+		
18	*Glomeris bureschi*											+	
19	*Glomeris latermarginata*					+							

Table 4, Continued

No	Species/Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
20	*Glomeris pustulata*							+					
21	*Strongylosoma stigmatosum balcanicum*										+		+
22	*Polydesmus complanatus*					+							

Source: *compiled by the author*

Given the climatic values, it was noted that two periods are characterized by a relatively low number of collected species and individuals: the winter diapause period (January-February) and the dry season period (July-August). *Pachyiulus cattarensis* was detected in the period June, September-November, *Anoploiulus apfelbecki* – June, November, *Glomeris pulchra* May-July, September-October, *Pachyiulus varius* – May-October. The presented species are widely distributed. Such species as: *Polydesmus complanatus, Glomeris latermarginata, Typhloiulus albanichus, Pachyiulus hungaricus, Glomeris pustullata* have a shorter active period.

So, in the course of the research carried out in the southern region of Albania, 22 species of soil animals of the Diplopoda class of the Myriapoda group were identified, which are typical representatives of soil animals. The regions with the highest diversity are the districts of Llogara and Šhašhica. The presence of forest habitats, decomposing organic matter and favourable elements of the microclimate affects a high level of species variation. The influence of temperature and humidity is a determining factor of their distribution in various biotopes of the studied territory.

DISCUSSION

Soil animals of the *Diplopoda* class are useful because they participate in decomposition processes. They can be found everywhere in places where there are plant remains, in wet areas, especially in wooded areas. In these environments, they can find a sufficient amount of food and the necessary moisture for their development. However, according to N. Pano *et al.* (2006), the distribution of invertebrates is more related to hydrothermal conditions, while the type of forest and soil is of secondary importance, which was also established in the conducted study.

Another confirmation of the obtained results is found in research by V. Fontana *et al.* (2020), who note in his writings that there is a significant influence of altitude on the diversity of soil animals, and most soils and vegetation play a secondary role. According to E. Kostantinidis *et al.* (2020), only some millipedes are found in dry places, because their cuticle does not have layers that protect them from lack of water. In addition, they are very sensitive to air humidity. This is usually the main reason for choosing their place of residence. These soil animals prefer to stay in the environment of the remains of leaves, wood, under the bark of trees, stones, under tree trunks, in bird nests, worm shelters, etc. (Kostantinidis *et al.,* 2020).

The class *Diplopoda* plays an important role in soil ecology because it promotes nutrient cycling and the breakdown of organic matter. Millipedes are detritivores, that is, they feed on decaying plant remains, and other substances contained in the soil. They use their mandibles to grind food and then swallow it with their mouthparts. By doing this, they help break down complex organic molecules into simpler ones that can then be used by plants and other organisms in the soil.

Millipedes also play an important role in soil structure and aeration. By sinking into deeper layers, they create tunnels and channels that allow air and water to more easily penetrate through the soil. This helps maintain favourable soil conditions for the growth of plants and other soil organisms. In addition, centipedes can serve as an important food source for other animals such as birds and small mammals, thereby contributing to biodiversity. And in recent decades, in the light of dynamic climate changes, it is especially important to preserve biodiversity to ensure ecological sustainability and preserve valuable natural resources for future generations.

A number of scientists, including Y. Zhao *et al.* (2020), L. Gong *et al.* (2020) and W.L. So *et al.* (2022), various aspects of centipede biology and ecology were investigated, including their distribution and dependence on environmental factors. As a result of these studies, the authors found that millipedes can be found in a variety of environments, including forests, fields, water bodies, and mountainous regions. They can also spread by transferring soil, plants, and other materials, which is also reflected in the obtained results of the performed research.

In addition, research by H. Kicaj and M. Qirjo (2008) confirm that centipede activity can depend on various environmental factors, such as climatic conditions, soil type and availability of food resources. G. Giribet and G.D. Edgecombe (2019) research shows that some centipede species may be more common in temperate climates, while others may be found in more tropical regions. Also, the presence of plant cover and other food sources that can provide a sufficient level of nutrition for these soil animals is important.

L. Moritz and T. Wesener (2021) used a regression analysis of the influence of climatic factors on the number of millipedes and established that the composition of soil organisms is formed precisely from environmental changes related to water availability, energy supply, and climatic stability. Considering the active period of centipede activity, research by G.L. Nunes *et al.* (2020), shows that these animals can be active throughout the

year, although some species may be less active in winter. There is also information about the interruption of centipede activity, when they may be in a state of diapause or hibernation, which also correlates with the conducted research.

As for the number of individuals identified, this depends on many factors, including the type of environment, collection methods and the centipede's own biology. So, J.C. Means *et al.* (2021) state that the number of millipedes found can vary depending on the type of soil in which they live and the presence of plant cover. In addition, collection methods may affect the number of individuals caught, as some methods may be more efficient than others. And research by Y. Shen *et al.* (0202) shows that the use of traps can be more effective for centipede collection than methods that require active search and collection.

In addition, the own physiology of millipedes can also affect their number. For example, some species may be more susceptible to population fluctuations, while others are less sensitive to environmental changes. In addition, millipedes can have different growth and reproduction rates, which can affect their total abundance in a given environment (Tóth & Hornung, 2019).

M.E. Brookfield *et al.* (2020) believe that some centipede species are quite common and have a large range. For example, *Glomeris pulchra, Anoploiulus pusillus and Pachyiulus cattarensis* are ubiquitous, which may indicate their adaptability and ability to adapt to different environmental conditions. However, according to A. Perrigo *et al.* (2019), other species can be more specific and can be found only in certain conditions. For example, *Anoploiulus apfelbecki, Leptoiulus macedonicus, Glomeris hexastica, Typhloiulus albanichus, Glomeris balcanica*, these species probably have limited ranges and can only be found in certain ecosystems or environments with specific microclimate conditions.

The results of the performed research are also reflected in scientific works by C. Powell *et al.* (2020), who argue that centipedes are an important link in food chains that help maintain healthy and sustainable biotopes. Millipedes can be indicators of the state of the natural environment, as their presence, diversity, and number can indicate the stability of the ecosystem. Research on the study of the class *Diplopoda* helps to establish ecological processes in natural environments, which is important for understanding the functioning of ecosystems and developing strategies for the conservation and protection of biodiversity (Tyagi *et al.,* 2020).

However, L.F. Iniesta *et al.* (2020) believe that changing environmental conditions can affect the existence of millipedes, which are so necessary for the ecosystem. For example, the construction of roads or the development of territories can lead to the loss of natural habitats of centipedes, so it is imperative to make decisions about the preservation and protection of the natural distribution areas of these soil animals.

Thus, the study of soil animals of the *Diplopoda* class can help to establish the species' presence in a certain region, their interaction with the environment, their role in supporting the ecosystem, as well as the strategy of human activity aimed at the preservation and management of natural resources.

CONCLUSIONS

The class *Diplopoda* plays an important role in natural ecosystems, helping to maintain biodiversity and soil sustainability. Representatives of this class are decomposers of organic remains and can serve as a food base for various types of animals, such as birds, amphibians, reptiles and other invertebrates. Changes in the abundance or distribution of certain centipede species can indicate changes in the environment, such as pollution, soil degradation, climate change, etc.

As a result of the research, 22 species of the *Diplopoda* class of the *Myriapoda* group were identified, which were found in the southern region of Albania. Basically, typical representatives of this class include mainly decomposers and phytophages. The districts of Llogara and Shashica are the regions with the highest diversity of millipedes. The significant variation of species is influenced by the environment, the presence of organic substances and the climate. The influence of temperature and humidity is a determining factor affecting the distribution of the *Diplopoda* class in different biotopes.

Based on the temperature and humidity values in the study area, the dry season lasts from mid-June to early September. The presence of centipede species and their individual numbers significantly decreases during this period and almost stops in January-February, when they enter diapause. The greatest distribution in time during the year was characterized by the following species: *Pachyiulus cattarensis*, found in the period June-November, Glomeris pulchra – May-July, September-October, *Pachyiulus varius* – May-October. These species have a wide regional distribution. A less active period was marked by the following species: *Polydesmus complanatus, Glomeris latermarginata, Typhloiulus albanichus, Pachyiulus hungaricus, Glomeris pustullata*.

The study of the *Diplopoda* class has practical implications for nature conservation, as millipedes play an important role in maintaining ecosystems and biodiversity and can serve as indicators of environmental conditions. The prospect of further research lies in a better understanding of the biology of the class *Diplopoda* and the study of evolutionary changes in the composition and distribution of different species in different environments.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Екологія ґрунтових тварин (клас *Diplopoda*, група *Myriapoda*)

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Анотація. Клас *Diplopoda* відіграє важливу роль у природних екосистемах, оскільки підтримує біорізноманіття та стабільність ґрунту, а зміна чисельності чи поширення видів багатоніжок може вказувати на зміни в навколишньому середовищі, такі як забруднення, деградація ґрунту, зміна клімату тощо. Метою дослідження є виявлення існуючих видів ґрунтових тварин класу *Diplopoda*, а також визначення екологічних факторів, які можуть впливати на їх поширення. Видову різноманітність оцінювали шляхом збору особин і класифікації їх на загони, родини, роду та види. Визначаються також кліматичні фактори, а саме температура й опади. У результаті дослідження оцінено екологічні аспекти розвитку багатоніжок, проаналізовано їх поширення та залежність від факторів зовнішнього середовища, таких як кліматичні, едафічні та трофічні фактори. У південному районі Албанії ідентифіковано 22 види класу *Diplopoda* групи *Myriapoda*, серед яких переважно розкладачі органічних решток і фітофаги. Регіони Ллогара і Шхашица були відзначені як регіони з найбільшим різноманіттям багатоніжок. Крім того, встановлено, що на мінливість видів впливають навколишнє середовище, наявність органічних речовин, кліматичні фактори. Температура і вологість є визначальними факторами, що впливають на поширення класу *Diplopoda* в різних біотопах. Види, які мають велике регіональне поширення та найбільш поширені в часі протягом року: *Pachyiulus cattarensis*, зустрічається у червні-листопаді, *Glomeris pulchra* – травень-липень, вересень-жовтень, *Pachyiulus varius* – травень-жовтень. Менш активний період відзначений у видів: *Polydesmus complanatus, Glomeris latermarginata, Typhloiulus albanichus, Pachyiulus hungaricus, Glomeris pustullata*. Проведене дослідження має практичне значення для збереження природи, оскільки клас *Diplopoda* відіграє важливу роль у підтримці екосистем та біорізноманіття та може бути індикатором стану навколишнього середовища

Ключові слова: багатоніжки; середовище; рослинні рештки; екосистема; клімат; фітофаги

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Bacterial blight of viburnum (*Pseudomonas syringae* pv. *viburnum*): Biological features, causes, and consequences of manifestation, methods of control in the system of decorative and fruit gardening

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Abstract. Viburnum bacterial blight weakens the growth of Viburnum trees (bushes) and inhibits the physiological processes caused by the *Pseudomonas syringae* pv. *viburni* bacterium which survives in the affected stem tissue, plant remains, and soil. The purpose of the study was to examine the bioecological features of the manifestation of *Pseudomonas syringae* pv. *viburni* and development of measures to control bacterial leaf spotting in viburnum gardens. During the experiment, diagnostic methods were used to select plant leaves, identify, record, and analyse the affected leaves of viburnum plants by the *Pseudomonas syringae* pv. *viburni* bacterium. A method to avoid or reduce the risk of bacterial blights was developed. It was determined that various approaches can be used to prevent bacterial diseases in

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plants of the *Viburnum* L. genus, such as selecting more disease-resistant varieties, collecting and destroying fallen leaves and branches after pruning, and following agricultural techniques and gardening practices. For chemical control, copper-based bactericidal preparations, such as copper hydroxide or copper sulfate can be used, which are recommended for use in autumn and spring before budding. Performing these actions will help to prevent the manifestation of bacterial diseases in plants. It is proved that in the conditions of the Northern Forest-Steppe of Ukraine in the system of fruit gardening, it is advisable to grow high- and medium-resistant genotypes of Viburnum vulgaris of the Institute of Horticulture of the National Academy of Agrarian Sciences of Ukraine against bacterial leaf spotting. The practical value of the study lies in the fact that information about bacterial blight or bacterial spotting of viburnum leaves was expanded; it was proved that various species of the *Viburnum* L. genus differ in their susceptibility to *Pseudomonas syringae* pv. *viburni* bacterial damage; it is confirmed that the susceptibility of viburnum plants to this disease can be substantially reduced due to low-susceptible and resistant varieties and species of the *Viburnum* L. genus and timely technical and chemical measures

Keywords: species of the *Viburnum* L. genus; bacterial infection; features of the manifestation of bacterial disease; control measures

INTRODUCTION

Plant pathogens not only persist for centuries but also continue to appear on a global scale. S. Savary *et al.* (2017), state that direct crop growth losses due to biotic stress are about 20-40%. As noted by M.J. Landis *et al.* (2019), the representatives of multi-species *Viburnum* L. genus are no exception and substantially suffer from a number of diseases, including bacterial ones, which are among the most common and cause substantial damage to plants, causing vascular wilt (verticillosis), tissue necrosis, soft rot (mucosal bacteriosis), neoplasms or bacterial cancer, inhibit the processes of increasing viburnum gardens (Moskalets *et al.*, 2019; 2020), negatively affecting the growth, development, yield, decorativity, sometimes cause general weakening and death of plants.

One of the most dangerous bacterial diseases of Viburnum is bacterial blight, which is caused by phytopathogenic hemibiotrophic plant pathogenic rod-shaped *Pseudomonas syringae* Rod *Pseudomonas,* bacteria which, in addition, are part of a consortium of a broad evolutionary group of related species (Gomila *et al.*, 2017; Lalucat *et al.*, 2022) and lead to numerous diseases in other monocotyledonous, herbaceous dicotyledonous, and woody dicotyledonous plants worldwide (Xin *et al.*, 2018; Almeida *et al.*, 2022), causing brown mucus discharge, frostbite, fruit damage, and leaf and stem spotting (Fautt *et al.*, 2022). In particular, as noted by M. Lukas *et al.* (2020; 2022), *Pseudomonas syringae,* which was first isolated from common lilac (*Syringa vulgaris*) and described by Van Holl in 1902, produces active ice nucleation proteins (INA), which cause water to freeze in plant tissues at sufficiently low temperatures (-1.8 to -3.8°C or lower), in particular, in those that do not have antifreeze proteins, since the water in the plant can remain in a supercooled liquid state, which leads to damage to the epithelium and makes nutrients in nearby plant tissues available to bacteria.

H. Ehau-Taumaunu *et al.* (2022) claim that like other bacteria, *Pseudomonas syringae* compete for resources in a variety of environments using a range of antagonistic strategies, including the production and expression of narrow-spectrum antibacterial proteins called bacteriocins.

M. Ruinelli *et al.* (2019) quoting B. Schellenberg, note that strains of different *P. syringae* species produce phytotoxins that act as an irreversible proteasome inhibitor and promote bacterial colonisation in apoplexy by inhibiting leaf stomatal closure, and the synthesis of auxins, cytokinins, and coronatine, which can mimic plant hormones and therefore specifically interfere with the regulation of plant immune responses. According to J.S. Rufian *et al.* (2018), dynamic interactions between pathogenic, avirulent, and non-pathogenic strains occur in plants in a garden or field, and pathogenesis of *Pseudomonas syringae* depends on effector proteins that contribute to its manifestation, mainly due to inhibition of the protective properties of plants, which was well shown in the example of plant species *Arabidopsis thaliana*, *Nicotiana benthamiana*, and *Lycopersicon esculentum*. Therewith, bacterial plant pathogens compete with host plants and each develops strategies to overcome the other. Thus, because all organisms undergo phenotypic acclimatisation to various stimuli, they reverse the expression of genes and proteins to resist changes in the environment.

Phenotypic acclimatisation is evident in bacteria, during their colonisation of plants. M. Mulet *et al.* (2022) note that the phylogenetic group *Pseudomonas syringae* includes 15 recognised bacterial species and more than 60 pathovars, the largest of which are the following: *Pseudomonas syringae* pv. *aceris* (affects maple), *Pseudomonas syringae* pv. *aptata* (affects beetroot), *Pseudomonas syringae* pv. *atrofaciens* and *Pseudomonas syringae* pv. *lapsa* (affects wheat), *Pseudomonas syringae* pv. *dysoxylis* (affects kohekohe), *Pseudomonas syringae* pv. *fraxini* (causes ash cancer), *Pseudomonas syringae* pv. *quercus* (affects oak, sweet chestnut, and beech, causing the formation of Haloid outgrowths on the plants' trunks and the barks deformation (Orlovsky *et al.*, 2017),

Pseudomonas syringae pv. *japonica* (affects barley), *Pseudomonas syringae* pv. *oleae* (causes the leaves of the olive to curl), *Pseudomonas syringae* pv. *panici* (affects millet), *Pseudomonas syringae* pv. *papulans* (affects apple trees), *Pseudomonas syringae* pv. *pisi* (affects peas), *Pseudomonas syringae* pv. *syringae* (affects lilacs, beans, and some species of viburnum), *Pseudomonas syringae* pv. *viburni* (affects viburnum, including *Viburnum sargentii*), etc.

C.E. Morris (2019) notes that the manifestation of *Pseudomonas syringae* pv. *viburni* has grown substantially in recent years, and this is the main threat to tree and bush species of plantings for agroforestry, decorative, and fruit gardening purposes. Therewith, as claimed by A.C. Velásquez (2018), global climate change substantially increases the potential for bacterial diseases, including: *P. syringae*, in gardens and crops. Therefore, to reduce the risks associated with the threat to global food and environmental security, rapid detection and characterisation of the epidemic and new pathogenic foci are relevant.

The purpose of the study was to examine the bioecological features of the manifestation of *Pseudomonas syringae* pv. *viburni* and develop measures to control bacterial leaf spotting in viburnum gardens.

MATERIALS AND METHODS

Accounting for damage to viburnum plants by bacterial leaf spotting was conducted at the experimental sites of the Institute of Horticulture of the National Academy of Agrarian Sciences of Ukraine (NAAS) and its research network during 2019-2021. Varieties/breeding forms of Viburnum (*Viburnum opulus* L.) of Ukrainian selection were involved in the investigation of the degree of plant damage: Ania, Uliana, Yaroslavna, Elina, Omriyana, Sonetta, Horikhova, Osinnia, Kralechka, Plododekorna (co-authors of which are T.Z. Moskalets, V.V. Moskalets *et al.*) and speciesof viburnum: Viburnum lantana; Viburnum carlcephalum; Viburnum rhytidophylloides *(Viburnum×rhytidophylloides*); Burkwood Viburnum; leatherleaf Viburnum (*Viburnum rhytidophyllum* Hemsl.); Viburnum Roseum (*Viburnum opulus* Roseum); Viburnum sargentii Onondaga (*Viburnum sargentii* Koehne Onondaga); common dwarf Viburnum (*Viburnum opulus* L.), Eskimo Viburnum (Fig. 1). Observations and records of plants were conducted during May-September (Methodology for examination of varieties..., 2016). Leaves of the examined varieties were collected twice during the growing season. During the growing season of Viburnum plants, 10-15 leaves were selected from 3 trees (bushes) of each variety/species (5 leaves x 3 repetitions).

Figure 1. *Photos of Viburnum samplesinvolvedin the study: 1 – Viburnum opulus L. Yaroslavna; 2 – Viburnum opulus Roseum; 3 – Viburnum opulus L. Eskimo; 4 – Viburnum rhytidophyllum Hemsl.; 5 – Viburnum × carlcephalum; 6 – Viburnum lantana; 7 – Viburnum lantana var. variegatum; 8 – Viburnum × rhytidophylloides; 9 – Viburnum × burkwoodii; 10 – Viburnum sargentii Koehne*
Source*: photographed by the authors*

The material was collected in parchment bags. A label indicating the sample number, place and time of collection was added to each sample of a specific variety/type of viburnum plant. Visual examinations were performed in the basal part and on the periphery along the entire vertical of the plant crown. Assessment to determine the resistance of viburnum plants was performed in three terms: the first – 10 days after the

detection of the first diseased plants in the experiment, the second – 2-3 weeks after the first, that is, during the period of the greatest development of the disease, the third – at the end of harvesting.

The degree of damage by bacterial blight of viburnum leaves was determined on a scale in points: 1 – there are no symptoms of the lesion; 3 – single spots less than 1/5 of the leaf on individual leaves; 5 – spots occupy 1/4 of the leaf surface; 7 – occupy 1/2 of the leaf surface; 9 – 2/3 of the leaf surface. Using the obtained data, the percentage of disease development (*R*) was calculated by the formula:

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

where: *a* – sum of points of the degree of damage to all plants in repetition; *b* – number of accounting plants in repetition; *9* – maximum lesion score.

The lower the degree of damage, the higher the resistance of plants of the variety (Table 1).

Table 1. *Methods for assessing the resistance of viburnum plants to diseases caused by Pseudomonas syringae pv. viburni*

Degree of damage, score	Degree of stability	Score
1	Highly resistant	9
3	Resistant	7
5	Medium-resistant	5
7	Susceptible	3
9	Very susceptible	1

Source*: (Methodology for examination of varieties..., 2016)*

A corresponding calendar on phytopathological records was designed to facilitate the study on accounting for deciduous diseases on viburnum plants (Methodology of qualification examination..., 2016), part of which is presented in the methodological part of the study (Table 2).

Table 2. *Calendar of Phytopathological records of Viburnum plants*

Time of accounting	Name of the disease	Nature of the lesion, damage	Parameter of accounting
For a noticeable detection	bacterial blight	The leaves fade, dry out, and the bark of shoots and branches dries up, ulcers or depressions form on them. When the blight rings a branch or trunk, the leaves wither, dry out but do not fall off for a long time.	Percentage of affected plants and shoots (visually), %

Source*: (Methodology for examination of varieties..., 2016)*

In parallel with the diagnosis of Viburnum plants, two experiments were conducted. The scheme of the first experiment provided for 4 options: 1 – without pruning; 2 – pruning branches in autumn; 3 – pruning branches in early spring; 4 – pruning branches in summer. The second experiment involved investigating the effect of copper preparations on the manifestation of bacterial infection. The scheme of which included two options: without processing and with 2-3 treatment sessions of plants with copper sulfate. Among the experimental plants, plants of leatherleaf Viburnum, Viburnum opulus Roseum/Buldonezh, Viburnum sargentii Onondaga, and Viburnum dwarf Eskimo variety were taken. The repetition of the above-mentioned experiments is threefold. A 2% solution of copper sulfate was used, while 2 litres of solution were prepared for young plants, 3 litres – for 4-year-olds, 4 litres of the mixture were required for 6-year-olds, and 6 litres – for older ones. Bordeaux liquid was also used to control bacterial infection in viburnum plants, which was prepared by mixing copper sulfate with slaked lime. Statistical data processing was performed using the Statistica-6.0 computer programme.

RESULTS AND DISCUSSION

Bacterial diseases caused by *Pseudomonas syringae* pv. *viburnum* progress in wet, cool weather – the optimal temperature of their manifestation is up to 25°C. Pathogenic bacteria *Pseudomonas syringae* pv. *viburnum* introduce protein and toxin molecules into plant cells and thus affect the host plant's immunity, they overwinter on infected plant tissues, including areas of necrosis, or on healthy plant tissues. In spring, due to precipitation, bacteria enter the leaves/flowers, where they reproduce and spread in the epiphytic phase of the life cycle without causing the manifestation of the disease. As soon as the bacteria enter the plant through leaf stomata or necrotic spots on leaves or stems, the pathogen begins to progress, developing in the intercellular space, causing numerous spots on the leaves and various ulcers in diameter – the bacterial blight of Viburnum. Schematically, the spread of bacterial blight of Viburnum can

be depicted as follows (Fig. 2).The symptoms of this bacterial disease are as follows. Initially, the affected areas on the leaves become glossy and covered with condensation (Fig. 3).

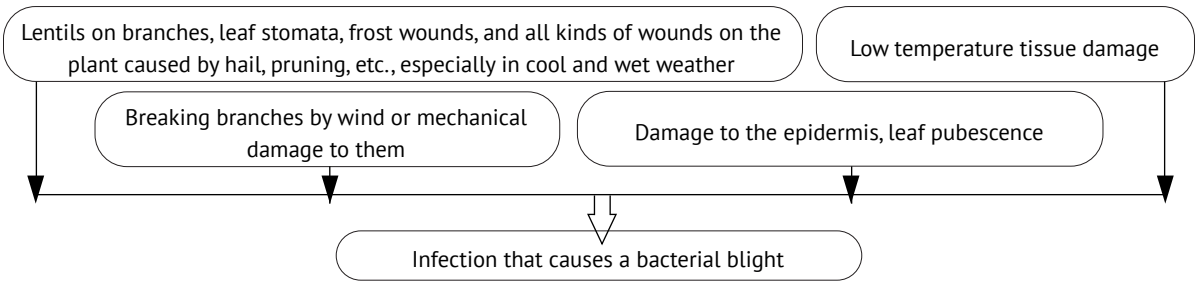

Figure 2. *Ports of entry and spread of bacterial infection in the plant body*
Source*: compiled by the authors*

Figure 3. *Manifestation of the causative agent of bacterial blight at the initial stage of the Pseudomonas syringae pv. viburni lesion on the leaves of Viburnum vulgaris dwarf (Viburnum opulus L.) Eskimo (A) and Viburnum Roseum (Viburnum opulus Roseum) (B)*

Source*: photographed by the authors*

The manifestation of bacterial blight of Viburnum is accompanied by the appearance of watery spots, which eventually turn brown, and bacterial exudate often forms along the edges. A substantial manifestation of bacterial infection can lead to the death of shoots. In connection with the above mechanisms of pathogenicity *Pseudomonas syringae* pv. *viburnum* can be divided into several categories: the ability to penetrate the plant, the ability to overcome the resistance of the host plant, the formation of biofilms, and the production of proteins with the properties of ice nucleation. In plantings of different species of Viburnum, symptoms on leaves and stems were noted that differ from common diseases. The lesions were characterised as round areas soaked in water, which after 5 days turned into irregular, wrinkled brown spots up to 3 mm in diameter. The central part of the lesions on the leaves looked barely transparent. Then, in the third week, the leaves completely dried up.

On the surface of the leaves, a layer of bacterial secretions, which makes the leaves shiny, can be observed. If a bacterial blight occurs at the beginning of the growing season, the leaves may be distorted. In severe cases, the shoots may die off (Fig. 4).

Figure 4. *Manifestation of the causative agent of bacterial blight at the initial stage of the Pseudomonas syringae pv. viburni lesion on the leaves of twigs of Viburnum sargentii Onondaga variety (Viburnum sargentiiii Koehne Onondaga)*

Source*: photographed by the authors*

The greatest manifestation of bacterial blight was noted on plants of the *Viburnum rhytidophylloides* Surin species, which manifested itself in browning and premature leaf fall. Brown spots appeared on the upper, lower, or both surfaces of the leaves. In particular, the spots on the leaves were pointy or rounded, slightly raised or recessed, and had smooth or fringed edges. Therewith, the colours of the spots varied from yellow to yellow-green, orange-red to light brown, dark brown, or black with a halo of yellow tissue around each spot (Fig. 5).

Figure 5. *Manifestation of the causative agent of bacterial blight at the initial stage of the Pseudomonas syringae pv. viburni lesion on the leaves of Viburnum rhytidophylloides Surin*
Source*: photographed by the authors*

On the same plant, there may be spots on the leaves of different sizes. Notably, smaller spots on the leaves indicated the beginning of the development of the causative agent of bacterial blight, and large spots – a long period of infection. Shoots, buds, and flowers can also turn black and be damaged by bacterial spotting. Often, in the centre of large spots on the leaves, signs of fungal pathogens, in particular, peronosporosis (*Plasmopara viburni*) could be noted, which was observed on the example of plants of Viburnum Serzhenta (Fig. 6).

Figure 6. *Manifestation of the causative agent of bacterial blight on the leaves of Viburnum sargentii*
Source*: photographed by the authors*

It was determined that according to the degree of resistance, highly resistant to bacterial blight are varieties of Viburnum vulgaris: Yaroslavna, Ania; Burkwood viburnum (degree/score of damage – 1/9), resistant – varieties of Viburnum vulgaris: Elina, Uliana, breeding forms: Omriyana, Osinnia, Kralechka, Sonetta; viburnum lantana; viburnum carlcephalum (degree/score of damage – 3/7), medium-resistant – breeding form of Viburnum vulgaris: Plododekorna, Horikhova clone; Viburnum rhytidophylloides (*Viburnum*×*rhytidophylloides*) (degree/score of damage – 5/5).

Plants of leatherleaf Viburnum seemed unstable to bacterial spotting of leaves (shoots) (*Viburnum rhytidophyllum* Hemsl.), Viburnum Roseum (*Viburnum opulus* Roseum), Viburnum sargentii Onondaga (*Viburnum sargentiiii* Koehne Onondaga), common dwarf Viburnum (*Viburnum opulus* L.) Eskimo (miniature copy of Viburnum Roseum/Buldonezh, but with a denser spherical crown) (Table 3).

Table 3. *Results of the assessment of the resistance of Viburnum plants to bacterial disease caused by Pseudomonassyringaepv. viburni, average value for 2019-2021*

Name of the species/variety (breeding form)	Degree of damage, score	Degree of stability	Lession score
Viburnum vulgaris, varieties: Yaroslavna, Ania; Burkwood viburnum	1	Highly resistant	9
Viburnum vulgaris, varieties: Elina, Uliana, breeding forms: Omriyana, Osinnia, Kralechka, Sonetta; viburnum lantana; viburnum carlcephalum	3	Resistant	7
Viburnum vulgaris, breeding form: Plododekorna, Horikhova clone; Viburnum rhytidophylloides (*Viburnum* × *rhytidophylloides*)	5	Medium-resistant	5
Leatherleaf viburnum, viburnum vulgaris Roseum/Buldonezh, Viburnum sargentii Onondaga, Viburnum vulgaris dwarf Eskimo	7	Susceptible	3
-	9	Very susceptible	1

Source*: compiled by the authors*

An experiment was conducted on pruning experimental plants to reduce the manifestation of bacterial infection on those susceptible to exposure of *Pseudomonas syringae* pv. *viburni*, (leatherleaf Viburnum, Roseum/Buldonezh, Sargent Onondaga, Viburnum vulgaris dwarf Eskimo). The experiment provided for 4 options: 1 – without pruning; 2 – pruning branches in autumn; 3 – early spring; 4 – in summer.

It was determined that pruning in autumn and early winter also contributed to more serious damage to viburnum trees (bushes) from bacterial infections caused by *Pseudomonas syringae* pv. *viburni*. Pruning trees in early spring had partial results. Summer pruning in dry weather proved more effective since almost all Viburnum species (varieties) were noted as medium-resistant with an average lesion score of 5 (Table 4).

Table 4. *Evaluation of Viburnum plants for resistance to bacterial disease caused by Pseudomonas syringae pv. viburni depending on the experiment variant, Northern fForest-Steppe, average value for 2020-2021*

No.	Species name	Plant damage option/score			
		without pruning	autumn pruning of branches	early spring pruning of branches	summer pruning of branches
1	Leatherleaf viburnum	3	3	4	5
2	Viburnum Roseum/Buldonezh	1	3	4	5
3	Viburnum sargentii (Onondaga variety)	1	3	3	5
4	Viburnum vulgaris dwarf (Eskimo variety)	3	4	3	5

Source*: compiled by the authors*

During 2020-2021, it was established that the application of copper sulfate in combination with slaked lime (Bordeaux mixture) 2-3 times is effective for reducing the damage of susceptible viburnum species by a bacterial infection caused by bacteria *Pseudomonas syringae* pv.*viburni*.

The study presents the results of examining various Viburnum species on susceptibility to *Pseudomonas syringae* pv. *viburni*. Bacterial viburnum burns can be a problem during the cool, humid spring in other parts of the country, including the Northwest and East. Bacterial infections can lead to shoot death and complete defoliation. The first reports in the 2000s about a serious manifestation of bacterial blight or bacterial spotting of Viburnum leaves are indicated in the studies of researchers from the UK (Stead *et al.*, 2006), Italy (Garibaldi *et al.*, 2005), and other countries that indicate that there is no 100% effective method of destruction *Pseudomonas syringae* pv. *viburnum*.

Information on the susceptibility of Viburnum species, in particular, *Viburnum rhytidophylloides* to bacterial blight was also obtained by researchers from the University of Oregon (USA), in particular, R. Rosetta (2019) identified that plants of the above-mentioned species were characterised as highly resistant, in contrast to leatherleaf viburnum. Phytopathologists N. Gauthier *et al.* (2022) also note that the manifestation of bacterial blight of Viburnum plants is the appearance of pointy, water-soaked spots on the leaves, which over time turn from light shades to brown or dark brown scales. A layer of bacterial cells and exudate on the surface of the leaves gives them shine. Further, the leaves are deformed, and the shoots mostly die off.

Many modern researchers on the above-described problem, including, J.W. Pscheidt (2018) note that bacterial infection in viburnum plants can also be successfully controlled by taking timely measures. The specified researcher also believes that the most common ways to combat the bacterial blight of Viburnum are the use of resistant species and varieties of Viburnum in decorative and fruit gardening, regulatory and sanitary pruning with disinfected garden tools, and the use of bactericides with compounds of copper or other metals, including iron, which can be appropriately combined with fungicides or other chemical preparations to control pests – carriers of pathogens. Combined treatment with biological and chemical preparations has been shown to be effective in controlling bacteriosis (Ni *et al.*, 2020). The aforementioned researcher also believes that chemical treatment with copper hydroxide and copper sulfate can stop the spread of *Pseudomonas syringae* pv. *viburni*, and it is best to prevent their manifestation by regularly conducting preventive measures.

E. Osdaghi (2020) claims that adding ammonium fertiliser to viburnum plants can cause metabolic changes in them, leading to resistance to *Pseudomonas syringae* bacteria. However, as noted by A.I. González-Hernández *et al.* (2019), this so-called ammonium syndrome causes an imbalance of nutrients in the plant and instead triggers a protective response against the pathogen.

Summarising the above, it can be stated that measures for early diagnosis of Viburnum plants for the appearance of bacteriosis, timely preventive measures, selection of immune varieties adapted to a specific territory, compliance with elements of agricultural cultivation techniques, control in seedling production, etc. will

reduce the manifestation of *Pseudomonas syringae* pv. *viburni* in the gardens of the examined culture.

CONCLUSIONS

It was determined that the *Pseudomonas syringae* pv. *viburni* pathogen at the initial stages 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 processes of the examined plants. However, bacterial spotting of leaves (shoots) of Viburnum should be taken seriously, since the disease for 2-4 years leads to moderate or complete loss of leaves (branches) in susceptible to bacterial disease varieties/species, affecting the reduction of growth processes and increased susceptibility to pests and pathogens of other diseases.

Varieties of Viburnum vulgaris: Uliana, Yaroslavna, Elina, Ania, Omriyana, Sonetta, Plododekorna, etc., Burkwood viburnum, Viburnum lantana, in particular, the decorative form of this species with colourful leaves, viburnum×carlcephalum (*Viburnum×carlcephalum*), Viburnum rhytidophylloides (*Viburnum×rhytidophylloides* (*Viburnum lantana×Viburnum rhytidophyllum* Hemsl.)) are resistant to bacterial blights.

Suscrptible to bacterial spotting of leaves (shoots) are plants of leatherleaf Viburnum (*Viburnum rhytidophyllum* Hemsl.), Viburnum Roseum (*Viburnum opulus* Roseum), Viburnum sargentii Onondaga (*Viburnum sargentii* Koehne Onondaga), common dwarf Viburnum (*Viburnum opulus* L.) Eskimo.

Measures to minimise bacterial blight of Viburnum plants include: exclusion, elimination, or reduction of the *Pseudomonas syringae* pv. *viburni* bacterial pathogen inoculum, the spread of genetic diversity in a certain area in the system of decorative or fruit gardening and inhibition of the mechanisms of virulence of bacterial pathogens in various ways (selection of species and varieties, compliance with the cultivation technology, including chemical protection systems, fertilisation, irrigation, tillage in the row spacing or in the trunk zone, etc.). The effectiveness of measures of pruning and 2-3 times treatment with a Bordeaux mixture of plants susceptible to bacterial blights of leatherleaf Viburnum, Viburnum Roseum/Buldonezh, Viburnum sargentii Onondaga, Viburnum vulgaris dwarf Eskimo is proved.

Due to the chemical protection of Viburnum stands against bacterial infections, it is advisable to treat plants with copper-based preparations in combination with fungicides. In the irrigation system of mother-cuttings nurseries, hybrid nurseries, if necessary, it is advisable to use only drip irrigation, avoid water getting on the leaves, and also avoid contact of the ground part with moist soil.

A promising area of further research is the involvement of immune or low-susceptible to bacterial blight species and varieties of the *Viburnum* L. genus in the breeding and production processes in the system of fruit and decorative gardening, which will correct the population characteristics or make it impossible for this disease to appear.

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CONFLICT OF INTEREST

None.

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Бактеріальний опік калини (*Pseudomonas syringae* pv. *viburnum*): біологічні особливості, причини і наслідки прояву, способи контролю в системі декоративного та плодового садівництва

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Анотація. Бактеріальний опікабо бактеріальна плямистість листків (англ. Viburnum-BacterialBlight) послаблює ріст дерев (кущів) калини, гальмує фізіологічні процеси,зумовлені бактерією *Pseudomonas syringae* pv. *viburni*, яка виживає в ураженій тканині стебла, рослинних рештках і ґрунті. Мета досліджень передбачала вивчення біоекологічних особливостей прояву *Pseudomonas syringae* pv. *viburni* і розроблення заходів щодо контролю бактеріальної плямистості листків у садах калини. Під час експерименту були використаніметоди діагностики з відбору рослинних листків, виявлення, обліку, аналізу уражених листків рослин калини бактерією *Pseudomonas syringae* pv. *viburni*. Розроблено спосіб уникнення або зменшення ризиків появу бактеріального опіку. З'ясовано, що для запобігання бактеріальних хвороб у рослин роду *Viburnum* L. можна використовувати різні підходи, такі як підбір більш стійких до хвороб сортів, збір і знищення опалого листя та гілок після обрізки, дотримання агротехніки та садівницьких практик. Для хімічного контролю можна застосовувати бактерицидні препарати на основі міді, такі як гідроксид міді або мідний купорос, які рекомендується використовувати у восени і весною до розпускання бруньок. Виконання цих дій допоможе запобігти прояву бактеріальних хвороб у рослинах. Доведено, що в умовах Північного Лісостепу України в системі плодового садівництва доцільно вирощувати високо- і середньостійкі проти бактеріальної плямистості листків генотипи калини звичайної Інституту садівництва НААН України. Практична цінність роботи полягає в тому, що було розширено відомості про бактеріальний опік або бактеріальну плямистість листків калини; доведено, що різні види роду *Viburnum* L. різняться за сприйнятливістю до ураження бактерією *Pseudomonas syringae* pv. *viburni*; підтверджено, що сприйнятливість рослин калини до зазначеної хвороби можна істотно знижувати за рахунок малосприйнятливих і резистентних сортів і видів роду *Viburnum* L. та своєчасних технічних і хімічних заходів

Ключові слова: види роду *Viburnum* L.; бактеріальна інфекція; особливості прояву бактеріальної хвороби; заходи контролю

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Photosynthetic productivity of sorghum (*Sorghum bicolor* L. (Moenh) in the conditions of the Right-Bank Forest-Steppe of Ukraine

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Abstract. Sorghum (*Sorghum bicolor* L. (Moenh) is a technical, food, and fodder crop and can be used for various purposes, given its value, the acreage should be substantially expanded in Ukraine, and the elements of cultivation technology should be thoroughly examined. The purpose of the study was to determine the effect of the growth regulator on the photosynthetic productivity of sorghum in the conditions of the Right-Bank Forest-Steppe of Ukraine. The following methods were used in the study: field, measuring and weighing, mathematical, and statistical. The study was conducted in conditions of unstable moisture in the Right-Bank Forest-Steppe of Ukraine in 2016-2019. Based on the results of the study, it was determined that the use of a plant growth regulator affected photosynthetic productivity, namely, the leaf surface area, photosynthetic potential and net photosynthesis productivity. The

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indicators for the content of chlorophylls changed. Thus, the assimilation area of leaves reached a maximum with seed treatment and spraying of crops and amounted to 8.56 thousand m^2/ha during the tillering period, during the period of stem elongation – 29.6 thousand m^2/ha, during flowering and full ripeness – 40.32 and 4.97 thousand m^2/ha. Net photosynthetic productivity in the control was the lowest – 4.67 g/m^2, the use of a growth regulator on seeds and crops contributed to its increase by 0.27 and 0.79 g/m^2. With the treatment of seeds and crops, the net photosynthetic productivity was the highest and amounted to 6.12 g/m^2. The sum of chlorophylls *a+b* had the highest rates during the tasselling period and, depending on the experiment options, ranged from 4.36 to 5.35. The yield of grain and biomass also varied depending on the use of the preparation, and was the highest in the version with seed treatment and spraying of crops (7.1 and 35.9 t/ha). The close relationship between photosynthetic productivity and the yield of sorghum is also determined. The study can contribute to the widespread use of growth regulators in sorghum crops, ensure the full development of plants, and increase grain yields and biomass

Keywords: leaf surface area; net photosynthesis productivity; chlorophyll content; grain and biomass yield

INTRODUCTION

Among the grain crops grown in Ukraine, sorghum is one of the drought-resistant and highly productive crops. It is important that at high temperatures, plants have the ability to continue the assimilation process.

According to Ortiz *et al.* (2019), Li *et al.* (2021), and Kovalenko *et al.* (2023), sorghum (*Sorghum bicolor* L. (Moenh) is a universal and promising energy culture – it is an agricultural, widely cultivated, and highly productive type C_4 plant. Kolozsvári *et al.* (2022) note that sorghum has substantial photosynthetic efficiency and can produce high grain yields and powerful energy-rich biomass in the short term. According to Davydenko *et al.* (2022) sorghum is currently used as human food, animal feed, an alternative energy source, and for industrial purposes. It ranks fifth after major grain crops and sixth in the world in terms of gross grain yield.

As researchers Alekseev (2021) and Polevyi *et al.* (2020) note, sorghum plants have great potential to adapt to growing conditions, particularly drought, soil salinity, high temperature, etc. Grains with a high starch content are valuable raw materials for the production of bioethanol, and biomass (leaves and stems) of plants can be used as solid fuels. Abreha *et al.* (2022) believe that modern technologies for growing agricultural crops are based on the theory of crop formation as a photosynthetic system and are developed considering biological characteristics, including the type of plant photosynthesis.

Grishchenko *et al.* (2020) state that the yield of crop seeds and biomass depends on the photosynthetic activity of plants, which depends on weather and climatic conditions and cultivation technology. In the first case, the factors are not controlled by humans, in the other – directly depend on their activity. Therefore, the investigation of elements of the technology of growing sorghum, in particular, the effect of the growth regulator on photosynthetic productivity in the conditions of the Right-Bank Forest-Steppe of Ukraine, is a relevant and promising area.

Researchers Davydenko and Rozhkov (2022), note that in agriculture, low-cost crop cultivation technologies are more popular, the elements of which are the use of growth regulators, biologics, microfertilisers, etc. These preparations are economical, their use helps to improve the growth and development of plants and provides a substantial increase in the yield and quality of grown products. The high efficiency of using growth regulators on grain crops is associated with their ability to increase the accumulation of macro- and microelements, increase the concentration of photosynthetic pigments, and, as a result, activate photosynthesis and increase crop productivity. In addition, they allow controlling the duration of individual phases of plant growth and development and also help to correct the state of crops due to unfavourable abiotic conditions.

Studies by Nemahunguni *et al.* (2019), Ngoroyemoto *et al.* (2020), and Gupta *et al.* (2021) proved that plant biostimulants stimulate growth in many plant species under different growing conditions, have a positive effect on photosynthetic pigments, carbohydrates, proteins, and phytohormones. Notably, their effectiveness depends on the method of application, the type of plant, the growth period, etc. According to Mazur *et al.* (2018) and Shevchenko (2017), the use of growth regulators activates the mechanism of immunity, stress resistance, and adaptability of plants. Their use affects the formation of crops with optimal morphostructural and functional indicators.

A study by Shevchenko & Tokmakova (2018), conducted on corn crops in Polissia determined that due to the growth-stimulating properties of the preparation, quantitative and qualitative parameters of the photosynthetic activity of plants increase. Its use for seed and crop treatment increases the leaf surface area by 40% and the net photosynthetic productivity of crops by 63.8%. When treated with plant growth regulators, the accumulation of photosynthetic pigments increases (by 12-24%), while the content of water-soluble sugars decreases by 9.0-17.5%, which indicates the functional activity of the photosynthetic apparatus.

In accordance with this, the purpose of the study was to investigate the effect of the growth regulator on the assimilation surface area, photosynthetic potential,

net photosynthetic productivity, and chlorophyll content in sorghum in the conditions of the Right-Bank Forest-Steppe of Ukraine.

MATERIALS AND METHODS

The study was conducted in 2016-2019 at the Bila Tserkva Experimental Station of the Institute of Bioenergy Crops and Sugar Beet of the National Academy of Agrarian Sciences of Ukraine. Soils on which the study was conducted: typical low-humus chernozems. Humus content is 3.5%, total nitrogen – 0.31%, hydrolytic acidity – 2.41 mg-eq., easily hydrolysed nitrogen – 134 mg/kg, phosphorus – 276 mg/kg, potassium – 98 mg/kg, base saturation – 90%. The scheme of the experiment provided for the treatment of seeds and vegetative plants with a growth regulator: factor A (seed treatment) – without treatment (control) and treated seeds with a growth regulator; Factor B (treatment of crops with a growth regulator) – seeds not treated + spraying of crops and seeds treated + spraying of crops with a regulator. The experiment is repeated four times. Area of the sown area is 50 m^2, accounting – 21 m^2. Crops were formed with a row spacing of 45 cm and a density of 200 thousand units/ha, sowing depth – 4-6 cm. According to the scheme, the growth regulator Vermistim was used in the experiment – a preparation made as an extract from vermicompost. It contains a complex of water-soluble fulvic acids, enzymes, vitamins, and phytohormones.

Accounting and monitoring of crops, in particular, determination of leaf surface area, photosynthetic potential, net productivity of photosynthesis, chlorophylls *a* and *b*, were conducted according to the methodology developed at the Institute of Bioenergy Crops and Sugar Beet by Roik *et al.* (2020) and Pravdyva *et al.* (2021). Weather conditions, in particular, temperature and precipitation, had deviations from long-term indicators, but were favourable for growing sorghum in the conditions of the Right-Bank Forest-Steppe of Ukraine. Correlation regression analysis was performed using a PC in Excel programme based on the obtained results.

Statistical analysis. After first undergoing an analysis of variance (ANOVA), all data were analysed with the software SAS (SAS Institute Inc., USA) to determine the statistical substantiality of the treatment effects (P=0.05 or less). Significant differences between individual means were determined using the least significant difference (LSD) test.

RESULTS AND DISCUSSION

Photosynthetic productivity of crops has a substantial impact on the yield of sorghum, which in turn depends on the leaf surface area. The yield of biomass and organic matter also depends on its size. Analysing the results, it was determined that the leaf surface area varied both by the periods of plant growth and development and by the use of a growth regulator. In general, seed and crop treatment increased the leaf surface area by 20-55% compared to the control, depending on the development phase (Table 1).

Table 1. *Effect of the growth regulator on the leaf surface area of sorghum plants (2016-2019)*

Method of preparing seeds for sowing		Leaf surface area, thousand m^2/ha, per phase:			
		tillering	stem elongation	flowering	full ripeness
Seed treatment (factor A)	Without treatment – control	6.83	20.4	33.5	3.19
	Seeds treated with a plant growth regulator	7.92	27.2	36.1	4.12
Crop treatment (Factor B)	Untreated seeds + spraying of crops with a plant growth regulator	8.15	28.6	38.9	4.68
	Seeds treated + spraying of crops with a plant growth regulator	8.56	29.6	40.32	4.97
	$LSD_{0.05}$	0.11	0.98	1.36	0.13

Source: *compiled by the authors*

During the flowering period, the leaf surface area of plants had maximum values, after which it decreased until the grain was fully ripe, and amounted to 33.5 thousand m^2/ha for control, 36.1 thousand m^2/ha for seed treatment with a growth regulator, 38.9 thousand m^2/ha in the version where only crops and 40.32 thousand m^2/ha were sprayed together with the treatment of seeds and crops. The study showed that in the control group, the leaf surface area had the lowest indicators.

The duration of functioning of the resulting area of the assimilation surface of plants is an important condition for ensuring high yields and is expressed by an indicator of photosynthetic potential. This indicator for

the growing season gives a general characteristic of the photosynthetic activity of plants and, depending on the growing conditions, varies substantially.

The photosynthetic potential varied depending on the size of the leaf surface area during the growing season. It was the highest in the version where the growth regulator was used on seeds and crops and amounted to 1.31 mln. m²×days/ha; in the variant where only seeds and crops were treated, it was lower by 3-5%. And the lowest indicator of photosynthetic potential (1.21 mln. m²×days/ha) was observed in the control group where the growth regulator was not used (Table 2). One of the most important indicators of the photosynthetic potential of plants is the net productivity of photosynthesis, which shows the ratio of the daily growth of dry matter to the area of leaves, that is, the intensity of the assimilation surface of sorghum plants. With the beginning of plant development, the productivity of photosynthesis gradually increased, which reached a maximum on the 65th day after the emergence of seedlings, after which a sharp decrease occurred. It was determined that net productivity depends on the use of a growth regulator, with the highest values obtained in the group where seeds and crops were treated with a growth regulator and amounted to 6.12 g/m². In other variants of the experiment, the net photosynthetic productivity decreased to 4.67 g/m². Photosynthetic activity of sowing is the basis for the formation of a high yield. The study determined that the use of a growth regulator substantially increases the yield of sorghum. For example, in the group where the growth regulator was used on both seeds and crops, grain yields of 7.1 t/ha and biomass of 35.9 t/ha were achieved. Slightly lower yields of grain and biomass were observed in the variant where only seeds were treated (5.2 and 32.8 t/ha) and where only crops were treated (5.9 and 33.4 t/ha). In the control group, the yield is the lowest – 4.4 and 29.2 t/ha.

Table 2. *Photosynthetic potential, net photosynthetic productivity and yield of sorghum depending on the application of the growth regulator (2016-2019)*

Method of preparing seeds for sowing		Photosynthetic potential, (mln.m²/ha)×days	Net photosynthetic productivity, g/m²	Seed yield, t/ha	Biomass yield, t/ha
Seed treatment (factor A)	Without treatment – control	1.21	4.67	4.4	29.2
	Seeds treated with a plant growth regulator	1.24	4.94	5.2	32.8
Crop treatment (factor B)	Untreated seeds + spraying of crops with a plant growth regulator	1.27	5.46	5.9	33.4
	Seeds treated + spraying of crops with a plant growth regulator	1.31	6.12	7.1	35.9
$LSD_{0.05}$		0.04	0.08	0.33	1.45

Source: *compiled by the authors*

The process of photosynthesis that occurs in leaves promotes the absorption of carbon dioxide from the external environment, due to the energy of sunlight and its conversion into chemical energy of organic substances. This function is performed by chlorophyll, which is part of the cellular composition of plant leaves. The total amount of chlorophyll and its concentration in plant leaves is an important physiological parameter. It characterises the potential power of the photosynthetic apparatus depending on the phase of crop development, the reaction of plants to the action of various factors of influence (growth regulator, natural environmental factors, mineral nutrition, etc.) and has a close relationship with the biological productivity of the plant organism. The chlorophyll content in the leaves of sorghum plants gradually increased in the growth and development phases and was maximum in the tasselling phase, and in the waxy and full ripeness phase, it intensively decreased depending on the experiment options.

The results of the study showed a substantial difference in the content of chlorophylls *a* and *b* in the leaves of sorghum plants from the tillering period to full ripeness (Table 3). The growth regulator is of great importance for the formation of chlorophylls in sorghum plants. Thus, the treatment of seeds and crops with a growth regulator, compared to the control option, increased the content of chlorophyll *a* in the phase of tasselling by 18.4% and the content of chlorophyll *b* by 18.8%. When using the preparation only on seeds and only on crops, the content of chlorophyll *a* increased by 3.30 and 6.35%, and chlorophyll *b* – by 5.88 and 13.2%. The lowest number of them was observed in the control group.

Table 3. *Dynamics of chlorophylls in sorghum plants depending on the use of a growth regulator, mg/g of dry matter (2016-2019)*

Method of preparing seeds for sowing		Phase of plant growth and development:											
		Tillering			Stemming			Tasselling			Full ripeness		
		a	*b*	*a+b*	*a*	*b*	*a+b*	*a*	*b*	*a+b*	*a*	*b*	*a+b*
Seed treatment (factor A)	Without treatment – control	2.70	0.82	3.52	2.93	0.87	3.8	3.24	1.12	4.36	1.54	0.62	2.16
Seed treatment (factor A)	Seeds treated with a plant growth regulator	2.84	0.85	3.69	3.08	0.91	3.99	3.35	1.19	4.54	1.58	0.65	2.23
Crop treatment (factor B)	Untreated seeds + spraying of crops with a plant growth regulator	2.88	0.89	3.77	3.14	0.94	4.08	3.46	1.29	4.75	1.61	0.68	2.29
	Seeds treated + spraying of crops with a plant growth regulator	2.98	0.94	3.92	3.22	0.99	4.21	3.97	1.38	5.35	1.66	0.70	2.36

Source*: compiled by the authors*

Correlation and regression analysis of data between photosynthetic potential and leaf surface area is represented by a second-order polynomial and the equation has the form $y=0.0012x^2-0.0727x+2.3316$. A strong correlation was established, with the coefficient R=0.9790, and the coefficient of determination $R^2=0.9817$ (Fig. 1a).

Between net photosynthetic productivity and the leaf surface area, a strong correlation R=0.9572 was established, and the coefficient of determination $R^2=0.9884$. The correlation-regression relationship is represented by a polynomial second order and the equation has the form $y=0.0309x^2-2.0789x+39.643$ (Fig. 1b).

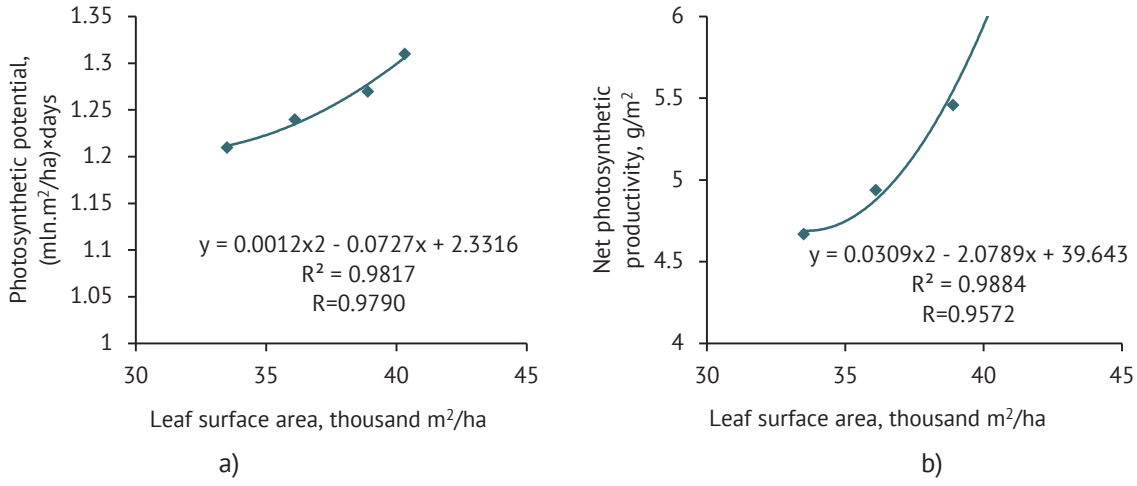

Figure 1. *Correlation-regression relationship (a) between photosynthetic potential and leaf surface area and (b) between net photosynthetic productivity and leaf surface area*

Source*: compiled by the authors*

The obtained results showed that with an increase in the net productivity of photosynthetic activity, the yield of sorghum also increased. This is confirmed by correlation and regression analysis, which proved a substantial relationship between net photosynthesis productivity and grain yield and between net photosynthesis productivity and biomass yield (Fig. 2 a, b). The coefficient of determination and correlation was $R^2=0.9905$ and R=0.9930 and $R^2=0.9444$ and R=0.9259. This dependency can also be described a second-order polynomial equation: $y=0.0436x^2+0.0506x+3.5778$ and $y=0.0303\ x^2-1.7504x+29.942$.

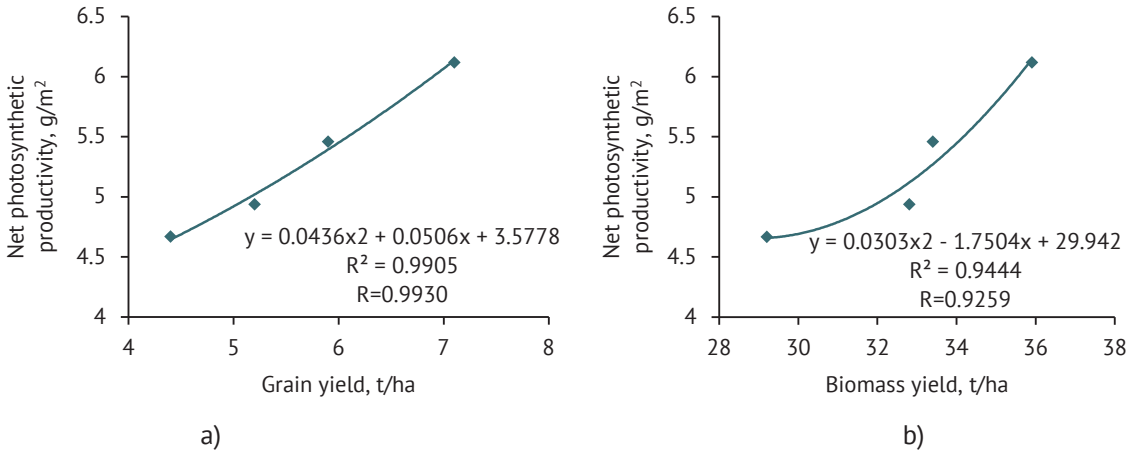

Figure 2. *Correlation-regression relationship (a) between net photosynthetic productivity and grain yield and (b) between net photosynthetic productivity and biomass yield*

Source*: compiled by the authors*

The formation of highly productive crops is a complex multi-industry process of regular changes in plant growth and development (Rozhkov & Svyrydova, 2017), which involves a large number of exogenous and endogenous factors that regulate the level of disclosure of the genetic potential of plant productivity. During ontogenesis, genetically determined natural changes occur in plants in stages, which are based on the consistent implementation of the plant development programme. The investigation of the relationship between agrotechnical factors of cultivation will allow managing the production process of sorghum crops.

A study conducted by (Davydenko & Rozhkov, 2022) proved the feasibility of using the growth stimulator Vegestim in cultivating grain sorghum. From the standpoint of agronomic efficiency, the best option was the one in which seeds were treated with this preparation before sowing and two foliar top dressing was conducted – at the beginning of tubing and tasselling. On average, over the years and the examined hybrids of grain sorghum, the yield of sorghum grain in this variant was the highest in the experiment – 5.28 t/ha.

In the studies of Karpenko & Krasnoshtan (2022), it was noted that the most favourable conditions for the formation of the content of pigments in the tissues of grain sorghum leaves are formed with the complex application of Citadel 25 OD, Endophyte L1, and Bioarsenal preparations, accompanied by an increase in the content of chlorophylls a, b, a+b, and carotenoids on average by 7.4-9.1%, 16.0-18.3%, 9.4-11.2%, and 35.5-40.2%, respectively. This indicates that the use of the Citadel 25 OD herbicide in conjunction with the plant growth regulator Endophyt L1 and the biological product Bioarsenal is an effective measure to reduce the negative effect of xenobiotic on the pigment complex of grain sorghum plants.

According to researchers Dyomin *et al.* (2021), it was determined that the variants with complex application of Agrostimulin obtained a substantial increase in the yield of perennial sorghum seeds (1.7 t/ha), which substantially exceeded the control by 0.5 t/ha and other experimental variants (by 0.1-0.2 t/ha). It was also established that the initial rates of interphase periods of growth and development of sorghum plants are reduced by the use of Agrostimulin.

Raid *et al.* (2019) show that the use of growth regulators and microelements substantially impacted the growth, development, and yield of grain sorghum. The improvement of growth parameters with preparations may be a consequence of their role in modifying various physiological and metabolic processes.

A study by Storozhyk *et al.* (2019) indicates that the highest yield of green mass was obtained with a density of 250 thousand plants/ha and seed treatment with the growth stimulator Vympel 2 (0.5 L/t) + foliar top dressing in the tillering phase (0.5 L/ha) when sowing the Dovista hybrid – 98.8 t/ha, which is 5.3 t/ha more than that of the Gulliver hybrid.

Researchers (Titarenko & Karpuk, 2022) determined that when growing a hybrid of sorghum Brigga, the best indicators of energy harvesting with grain were obtained on foliar fertiliser variants with microfertiliser Alpha-Grow-Extra, 2 L/ha in combination with the growth regulator Stimpo-116.72 GJ/ha. And for growing a Yutami sorghum hybrid with seeds on the application of foliar fertiliser with microfertiliser Alpha-Grow-Extra, in combination with both growth regulators, the minimum difference and maximum energy collection were obtained – 134.58 and 134.39 GJ/ha. Lyubich *et al.* (2020) determined that the use of a plant growth regulator positively affects the germination energy and laboratory germination of sorghum and increases them by 4-7% compared to the control option.

Thus, based on the studies conducted by other researchers, growth regulators have a positive effect on the sowing qualities of seeds, plant growth and

development, and sorghum productivity. However, the number of studies on the effect of growth regulators on the photosynthetic productivity of grain sorghum is practically nonexistent, so it requires further research.

CONCLUSIONS

Based on the results of the conducted studies, the effect of the pre-sowing treatment of seeds and crops with a plant growth regulator on the photosynthetic productivity of sorghum was established. The obtained data are statistically reliable, relevant, and characteristic for growing in various soil conditions using a growth regulator.

The leaf surface area in the experiment varied depending on the periods of plant development and the use of a growth regulator and reached 40.32 thousand m^2/ha during the flowering period in the variant with the treatment of seeds and crops. The duration of the assimilation surface is expressed by the photosynthetic potential, which ranged from 1.21 to 1.31 mln. m^2/ha×days. On average, the net productivity of photosynthesis increased to 6.12 g/m^2 per day. The highest yield in the experiment was obtained in the following variants: seed treatment + spraying of crops – 7.1 t/ha, seed treatment – 5.1 t/ha, and crop treatment – 5.7 t/ha. Treatment of seeds and crops with a growth regulator, increased the content of chlorophyll *a* by 18.4% and chlorophyll *b* by 18.8%, compared to control.

The results of correlation analysis allowed for establishing the determining factors of influence on the yield of sorghum. It is proved that with high indicators of photosynthetic productivity, the yield of grain and biomass substantially increased, while the correlation coefficient was R=0.9930 and R=0.9259.

In Ukraine, sorghum is poorly examined and sparsely distributed, and, accordingly, requires a detailed investigation of the elements of cultivation technology, namely the use of a growth regulator on seeds and crops, which will contribute to the formation of both grain and high-quality biomass. Growth regulators affect the metabolic and enzymatic processes of plants, ensuring a high intensity of photosynthesis. Currently, sorghum is considered an energy crop, the raw material used for producing ethanol and solid fuels. Therefore, the conducted study is relevant – with proper planning of crops and further use.

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CONFLICT OF INTEREST

None.

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Фотосинтетична продуктивність сорго звичайного двокольорового (*Sorghum bicolor* L. (Moenh) в умовах Правобережного Лісостепу України

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Анотація. Сорго звичайне двокольорове є технічною, продовольчою та кормовою культурою і може бути використане для різноманітних цілей, зважаючи на його цінність, посівні площі повинні бути значно розширені в Україні, а також досконало вивчені елементи технології вирощування. Метою досліджень було визначити вплив регулятора росту на фотосинтетичну продуктивність сорго звичайного двокольорового в умовах Правобережного Лісостепу України. В роботі використовували наступні методи: польовий, вимірювально-ваговий, математично-статистичний. Дослідження проводили в умовах нестійкого зволоження Правобережного Лісостепу України в 2016-2019 рр. За результатами досліджень встановлено, що застосування регулятора росту рослин впливало на фотосинтетичну продуктивність, а саме на площу листкової поверхні, фотосинтетичний потенціал та чисту продуктивність фотосинтезу. Змінювалися показники щодо вмісту хлорофілів. Так, асиміляційна площа листків сягала максимуму з обробляннням насіння та обприскуванням посівів і становила у період кущіння 8,56 тис. м^2/га, у період виходу в трубку – 29,6 тис. м^2/га, у період цвітіння та повної стиглості – 40,32 та 4,97 тис. м^2/га. Чиста продуктивність фотосинтезу на контролі була найменшою – 4,67 г/м^2, застосування регулятора росту на насінні та на посівах сприяло її підвищенню на 0,27 та 0,79 г/м^2. З обробкою насіння і посівів чиста продуктивність фотосинтезу була найвищою і становила 6,12 г/м^2. Сума хлорофілів а+в мала найвищі показники у період викидання волоті і залежно від варіантів досліду була в межах від 4,36 до 5,35. Урожайність зерна та біомаси також варіювала від застосування препарату. І найвищою була у варіанті з обробкою насіння й обприскуванням посівів (7,1 та 35,9 т/га). Також визначено тісноту взаємозв'язків між фотосинтетичною продуктивністю та врожайністю сорго звичайного двокольорового. Наукові дослідження можуть сприяти широкому застосуванню регуляторів росту на посівах сорго, і забезпечити повноцінний розвиток рослин, збільшенню урожайності зерна та біомаси

Ключові слова: площа листкової поверхні; чиста продуктивність фотосинтезу; вміст хлорофілів; урожайність зерна та біомаси

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Productivity of winter wheat depending on varietal characteristics and pre-sowing treatment of seeds with biological products

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Abstract. Winter wheat is the main food crop in the Steppe zone and the main agricultural crop in many countries of the world. The issues of intensifying grain production are inseparable from the production and use of new effective biological products for pre-sowing seed treatment, which positively affect the growth and development of winter wheat plants. The purpose of the study was to establish the effect of seed treatment before sowing with biological products on the productivity of winter wheat varieties. The study presents data on the results of an examination of 10 varieties of winter wheat for seed treatment with biological products in the conditions of the Educational and Scientific Practical Centre of the Mykolaiv National Agrarian University from 2020 to 2022. In the course of the study, generally accepted methods were used: system approach and system analysis, analysis and synthesis, field, and statistical. The influence of seed treatment with biological products and varietal characteristics of winter wheat on productivity was analysed. It was determined that the yield level depended and varied depending on the biological product used for pre-sowing seed treatment and the examined variety. Over the years of the study, biological products have affected the

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density of plants, the coefficient of productive tillering, the number of productive stems, the mass of grain per ear, 1000 grain weight, and the yield of winter wheat varieties. The best results were obtained with the combined use of the examined biological products Azotophyt-R and Phytocide-R. The conducted studies confirmed the feasibility of pre-sowing seed treatment with biological products to optimise the nutrition of plants of winter wheat varieties to form a high grain yield. The scientific achievements obtained will contribute to the widespread use of biological products for seed treatment, ensure rapid and full-fledged growth and development of winter wheat varieties, and further increase grain production and gross harvest

Keywords: soft winter wheat; grain yield; productive tillering coefficient; 1000 grain weight; grain weight per 1 ear

INTRODUCTION

One of the strategic industries for any country in the world is food production. In modern economic conditions, the importance of the agricultural sector in the economy is growing, since Ukraine's competitiveness, or gross domestic product, benefits from the sale of agricultural products. An important part of agricultural production is the cultivation of food crops. For a long time, Ukraine has been among the top ten grain producers in the world per capita.

In many countries of the world, wheat is the main agricultural crop, and in the Steppe zone it is the main food crop, so the system of agrotechnical measures should be aimed at creating favourable conditions for obtaining a high yield of this crop (Gamayunova *et al*., 2022). Worldwide, there is a growing interest in using organic farming and increasing grain production using low levels of mineral fertilisers (Petrenko *et al*., 2018). Reducing the dose of mineral fertilisers, especially nitrogen, is possible when using biological products.

The main goal of organic technology for growing winter wheat is to realise the yield potential of varieties through the rational use of natural productivity factors. In each region, it would be necessary to select such varieties, the bioecological features of which fully correspond to the natural conditions of the area (Babenko *et al*., 2018; Korkhova *et al*., 2022). Modern winter wheat varieties are characterised by high ecological plasticity, disease resistance, and grain quality (Montesinos-López *et al*., 2018; Korkhova *et al*., 2022).

In recent years, there has been an increase in interest in biological preparations, which is associated with an increase in the price of mineral fertilisers, contamination of agricultural land with chemicals and the expansion of acreage for organic farming (Kulkarni & Goswami, 2019). Biological products stimulate the growth and development of agricultural plants, increase resistance to stress, diseases, and balance nutrition. This effect is achieved due to the fact that live bacteria convert insoluble compounds into available forms, provide nitrogen nutrition, and protect plants from bacterial and fungal diseases (Panfilova & Mohylnytska, 2019).

Numerous studies by researchers around the world (Singh *et al*., 2018; Klein & Guimarães, 2018) showed that the use of complex organic fertilisers, composite growth bioregulators, inoculants, nanopreparations, biogenic elements will contribute to the regulation of plant growth and development, their resistance to stress by increasing plant immunity, activating biological processes, synthesising organic substances, increasing leaf surface area, net photosynthesis productivity, and crop yields. There is a wide range of biological products on the market, so this makes it difficult to choose them.

Grain yield is a complex trait that depends on many genetic factors and environmental changes. Successful breeding depends on information about genetic variability and the association of morphological agronomic traits with grain yield. The State Register of Varieties (2023) lists more than 600 varieties of winter wheat. For effective breeding work, raw materials must be examined in detail for compliance with specific parameters and requirements (Wu & Zhatova, 2022).

Increasing the yield of winter wheat grain in combination with reducing resource consumption and reducing the chemical load on the soil is a priority area for the development of agriculture, success in which can be achieved by greening crop production (Acharige, *et al.,* 2019; Soto-Gómez & Pérez-Rodríguez, 2022). Due to the application of excessive amounts of fertilisers, environmental pollution increases, the quality decreases, and the energy intensity of manufactured products increases (Kulkarni & Goswami, 2019).

There is insufficient information on the productivity of winter wheat in arid conditions, especially studies on modern varieties, so the creation of important traits for breeding and the organisation of breeding work is based mainly on world genetic resources or collections of cultivated plants (Lollato *et al*., 2019).

The purpose of the study consisted in establishing varietal characteristics and the influence of weather conditions during the years of the study on the productivity indicators of winter wheat, depending on the treatment of seeds before sowing with biological products.

MATERIALS AND METHODS

Experimental studies were conducted during 2020-2022 at the experimental field of the Educational and Scientific Practical Centre of the Mykolaiv National Agrarian University. The experiment scheme included the following variants: factor A – winter wheat varieties (10 variants); Factor B – biological products: control

(water treatment), Azotophyt-R, Phytocide-R, Azotophyt-R + Phytocide-R. The area of the sown plot was 50 m^2, and accounting – 26 m^2. Variants were placed using the incomplete randomisation method in four-fold repetition.

The research material was 10 varieties of soft winter wheat, owned by leading institutions of Ukraine: Antonivka, Liha odes'ka, Duma odes'ka, Versiia odes'ka, Spadshchyna odes'ka, Vidpovid odes'ka, Rodzynka odes'ka (breeding and genetic Institute-National centre for seed and variety studies); Ovidii, Khersons'ka 99 (Institute of irrigated agriculture of the National Academy of Agrarian Sciences of Ukraine), Rosynka (Institute of rice of the Ukrainian Academy of Agrarian Sciences), which are registered in the State Register of plant varieties suitable for distribution in Ukraine in 2005-2020 (State Register of Plant Varieties…, 2022). Agricultural techniques for conducting experiments were generally accepted for existing zonal recommendations for the conditions of the Southern Steppe zone of Ukraine, with the exception of factors under study. Sowing of winter wheat varieties was conducted in the first decade of October, using the seeding rate of 5 million pcs./ha.

The soil of the experimental plots is represented by southern chernozem, residual residual-lightly-alkaline heavy loamy on forest soils with a neutral reaction of the soil solution. The average humus content in the arable soil layer is 3.3%, mobile forms of nutrients: nitrates – 18, mobile phosphorus – 49, exchange potassium – 395 mg/kg of soil.

The effect of Azotophyt-R and Phytocide-R biological products was examined on the winter wheat varieties under study. Azotophyt-R is a natural biostimulator of growth, which actively fixes molecular atmospheric nitrogen, synthesises growth-stimulating substances, improves seed germination, stimulates the development of the root system and plants, improves the absorption of nutrients, and increases crop yield. Phytocide-R is a biological fungicide against fungal and bacterial diseases that protects plants from a wide range of fungal and bacterial pathogens, stimulates plant growth and development, increases resistance to adverse environmental conditions and improves the quality of crop production. The preparations are used for seed treatment before sowing at the rate of 0.8 and 1.0 L/t, respectively. Accounting of crop density was determined on test sites with an area of 1 m^2 twice during the growing season, which were placed diagonally across the registered area of the plot. For the first time, counting is conducted in the phase of full shoots, and for the second time – before harvesting.

The coefficient of productive tillering was determined by the ratio of the number of productive stems to the number of plants in a snip sample taken from an area of 1 m^2. The mass of grain from one ear was determined by dividing the mass of grain from the sheaf by the number of productive stems in the sheaf sample. 1000 grain weight was determined according to DSTU ISO 520:2015 (2015). Winter wheat harvesting was conducted with a SAMPO-500 combine harvester with each repetition. After threshing each section, the combine's threshing machine was turned off, the collected grain was weighed separately and transferred to standard humidity (14%) and purity (100%).

The obtained results in the form of analytical digital material were subjected to statistical and mathematical processing, which was performed by the method of variance and correlation analysis using Microsoft Exel and Agrostat computer programmes by the method of variation, correlation, and variance analysis.

RESULTS AND DISCUSSION

The productivity of winter wheat is influenced by many factors, including varietal characteristics, biological products for pre-sowing seed treatment and cultivation technology. Plant density is the main indicator for the formation of the future yield. According to the results of the conducted studies, it was established that the density of winter wheat plants was influenced by both varietal characteristics and the pre-sowing treatment of seeds with the examined biological products. Thus, the highest density of plants per 1 m^2 was formed by plants of the Rosynka variety – 384-424 pcs./m^2 depending on the treatment of seeds with biological products, and on average according to these biological products, the density was 398 pcs./m^2 (Table 1).

Table 1. *Plant density of winter wheat varieties in the phase of full grain ripeness, depending on seed treatment with biological products (average for 2020-2022), pcs./m^2*

No.	Factor A (varieties)	Factor B (biological products)				
		Control (water treatment)	Azotophyt-R	Phytocide-R	Azotophyt-R + Phytocide-R	Average
1	Ovidii	287	291	276	357	**303**
2	Rodzynka odeska	375	373	362	422	**383**
3	Rosynka	384	393	389	424	**398**
4	Spadshchyna odes`ka	380	392	394	415	**395**
5	Khersons'ka 99	366	396	401	414	**394**
6	Antonivka	366	367	348	405	**372**

Table 1, Continued

No.	Factor A (varieties)	Factor B (biological products)				
		Control (water treatment)	Azotophyt-R	Phytocide-R	Azotophyt-R + Phytocide-R	Average
7	Versiia odes`ka	358	370	392	410	**383**
8	Vidpovid odes'ka	353	379	375	409	**379**
9	Duma odes`ka	295	299	292	396	**321**
10	Liha odes'ka	349	375	383	409	**379**
	Average	**351**	**364**	**361**	**406**	**371**
	HIP_{05} for factor A (pcs./m²) – 2.01					
	HIP_{05} for Factor B (pcs./m²) – 5.04					

Source: *compiled by the authors*

The lowest density of plants was formed by plants of the Ovidii variety – from 276 pcs./m² in the version with the biological product Phytocide-R up to 357 pcs./m² in the version with the combined use of biological products Azotophyt-R and Phytocide-R. The coefficient of productive tillering of the examined winter wheat varieties ranged from 1.7 to 2.4, depending on the examined biological products (Table 2).

Table 2. *Coefficient of productive tillering of plants of winter wheat varieties in the phase of full grain ripeness, depending on seed treatment with biological products (average for 2020-2022), pcs./m²*

No.	Factor A (varieties)	Factor B (biological products)				
		Control (water treatment)	Azotophyt-R	Phytocide-R	Azotophyt-R + Phytocide-R	Average
1	Ovidii	2.0	2.1	2.1	2.0	**2.1**
2	Rodzynka odeska	2.0	2.0	1.9	1.8	**1.9**
3	Rosynka	1.9	1.7	1.8	1.7	**1.8**
4	Spadshchyna odes`ka	1.8	1.9	1.8	1.8	**1.8**
5	Khersons'ka 99	1.9	1.8	1.8	1.7	**1.8**
6	Antonivka	1.8	1.8	1.9	1.7	**1.8**
7	Versiia odes`ka	2.0	2.0	1.9	2.0	**2.0**
8	Vidpovid odes'ka	2.1	2.0	2.1	1.9	**2.0**
9	Duma odes`ka	2.0	2.4	2.1	1.8	**2.1**
10	Liha odes'ka	2.1	2.0	2.0	1.9	**2.0**
	Average	**2.0**	**1.9**	**1.9**	**1.8**	**1.9**
	HIP_{05} for factor A (pcs./m²) – 0.01					
	HIP_{05} for Factor B (pcs./m²) – 0.02					

Source: *compiled by the authors*

This indicator was higher (2.0) on average for varieties in the control version, and lower (1.8) in the version with the combined use of biological products Azotophyt-R and Phytocide-R. It was determined that pre-sowing treatment of seeds with biological products reduced the coefficient of productive bushiness of plants on average for the examined varieties by 0.1-0.2 pcs./m². It is established that the varieties Ovidii and Duma odes'ka formed the highest coefficient of productive tillering – 2.1, which is 0.1 more than the varieties Versiia odes'ka and Vidpovid odes'ka; 0.2 more than the variety Rodzynka odes'ka; 0.3 – than the varieties Rosynka, Spadshchyna odes'ka, Khersons'ka 99, and Antonivka.

The number of productive stems per unit area – an important indicator characterising winter wheat's productive stem. It determines the formation of the winter wheat crop in the South of Ukraine more than other indicators of productivity elements. The conducted studies determined that the number of productive stems depended on varietal characteristics and the examined biological products. Thus, this indicator is more formed in the variety Vidpovid odes'ka – 804 pcs./m², which is 9-179 pcs./m² is higher than that of other varieties examined (Table 3).

Table 3. *The number of productive stems of winter wheat varieties in the phase of full grain ripeness, depending on seed treatment with biological products (average for 2020-2022), pcs./m²*

No.	Factor A (varieties)	Factor B (biological products)				
		Control (water treatment)	Azotophyt-R	Phytocide-R	Azotophyt-R + Phytocide-R	Average
1	Ovidii	566	619	570	750	**626**
2	Rodzynka odeska	787	785	724	801	**774**
3	Rosynka	761	708	740	762	**743**
4	Spadshchyna odes`ka	723	785	749	789	**762**
5	Khersons'ka 99	732	753	762	744	**748**
6	Antonivka	709	696	697	729	**708**
7	Versiia odes`ka	752	776	785	861	**794**
8	Vidpovid odes'ka	777	795	825	818	**804**
9	Duma odes`ka	609	652	637	601	**625**
10	Liha odes'ka	768	787	805	818	**795**
	Average	**718**	**736**	**729**	**783**	**742**
	HIP_{05} for factor A (pcs./m²) – 17.2					
	HIP_{05} for factor B (pcs./m²) – 22.3					

Source: *compiled by the authors*

A higher density of productive stem (783 pcs./m²) was formed plants of winter wheat varieties in the version with the pre-sowing treatment of seeds with biological products Azotophyt-R and Phytocide-R, and the smallest amount – 718 pcs./m² in the control version with seed treatment before sowing with water. The best option in terms of the number of productive stems of winter wheat was the Vidpovid odes'ka variety for seed treatment with Phytocide-R – 825 pcs./m². The smallest number of productive stems is formed by plants of winter wheat of the Ovidii variety (560 pcs./m²) in the control version (seed treatment with water).

The second important indicator that characterises the productivity of winter wheat is the mass of grain per ear. According to the results of the study, this indicator was formed from 0.61 g/ear in the variety Versiia odes'ka for seed treatment with water to 0.93 g/ear in the varieties Duma odes'ka for seed treatment with Azotophyt-R, and Ovidii in the variant with the biological product Phytocide-R (Table 4).

Table 4. *Grain weight per 1 ear of winter wheat plants depending on the variety and seed treatment with biological products (average for 2020-2022), g*

No.	Factor A (varieties)	Factor B (biological products)				
		Control (water treatment)	Azotophyt-R	Phytocide-R	Azotophyt-R + Phytocide-R	Average
1	Ovidii	0.90	0.92	0.93	0.78	**0.88**
2	Rodzynka odeska	0.72	0.69	0.72	0.72	**0.71**
3	Rosynka	0.68	0.77	0.72	0.77	**0.74**
4	Spadshchyna odes`ka	0.72	0.70	0.72	0.72	**0.72**
5	Khersons'ka 99	0.71	0.71	0.70	0.74	**0.72**
6	Antonivka	0.71	0.74	0.72	0.72	**0.72**
7	Versiia odes`ka	0.61	0.65	0.59	0.60	**0.61**
8	Vidpovid odes'ka	0.60	0.63	0.58	0.75	**0.64**
9	Duma odes`ka	0.90	0.93	0.91	0.79	**0.88**
10	Liha odes'ka	0.73	0.73	0.70	0.70	**0.72**
	Average	**0.73**	**0.75**	**0.73**	**0.73**	**0.74**
	HIP_{05} for factor A (g) – 0.02					
	HIP_{05} for Factor B (g) – 0.06					

Source: *compiled by the authors*

The largest mass of grain per ear (0.75 g/ear) was formed on average for varieties in the variant with pre-sowing seed treatment with Azotophyt-R biological product, which is 2.7% more compared to the control variant.

All these indicators also affected the formation of winter wheat grain yield, which depended on varietal characteristics and biological products. Thus, the highest grain yield (6.09 t/ha) was formed by the Duma odes'ka variety in the version with pre-sowing seed treatment with Azotophyt-R and Phytocide-R biological products, and the smallest – 4.49 t/ha. Thus, on average, for factor B (biological products), a higher grain yield (5.85 t/ha) was formed in the Duma odes'ka variety, which is 0.19-1.09 t/ha more than in other varieties examined. Varieties Ovidii, Rodzynka odes'ka, Rosynka, Khersons'ka 99, Antonivka formed an average yield – 5.45; 5.30; 5.35; 5.26; 5.04 t/ha, respectively.

Table 5. *Yield of winter wheat grain depending on the variety and seed treatment with biological products, (average for 2020-2022), t/ha*

No.	Factor A (varieties)	Factor B (biological products)				
		Control (water treatment)	Azotophyt-R	Phytocide-R	Azotophyt-R + Phytocide-R	Average
1	Ovidii	5.10	5.71	5.29	5.71	**5.45**
2	Rodzynka odeska	5.00	5.33	5.18	5.67	**5.30**
3	Rosynka	5.07	5.35	5.22	5.76	**5.35**
4	Spadshchyna odes`ka	5.13	5.44	5.29	5.59	**5.36**
5	Khersons'ka 99	5.09	5.30	5.22	5.43	**5.26**
6	Antonivka	4.89	5.10	4.97	5.18	**5.04**
7	Versiia odes`ka	4.49	4.96	4.52	5.07	**4.76**
8	Vidpovid odes'ka	4.55	4.89	4.72	5.11	**4.82**
9	Duma odes`ka	5.46	6.08	5.76	6.09	**5.85**
10	Liha odes'ka	5.52	5.68	5.58	5.84	**5.66**
	Average	**5.03**	**5.38**	**5.18**	**5.55**	**5.29**
		HIP_{05} for factor A (t/ha) – 0.14				
		HIP_{05} for factor B (t/ha) – 0.21				

Source: *compiled by the authors*

On average, for the examined biological products, a higher grain yield was formed on average for varieties in the variant with the combined use of biological products Azotophyt-R and Phytocide-R – 5.55 t/ha, which is 0.17 t/ha more than in the variant with the biological product Azotophyt-R, 0.37 t/ha more than in the variant with the biological product Phytocide-R and 0.52 t/ha more than in the control variant (Fig. 1).

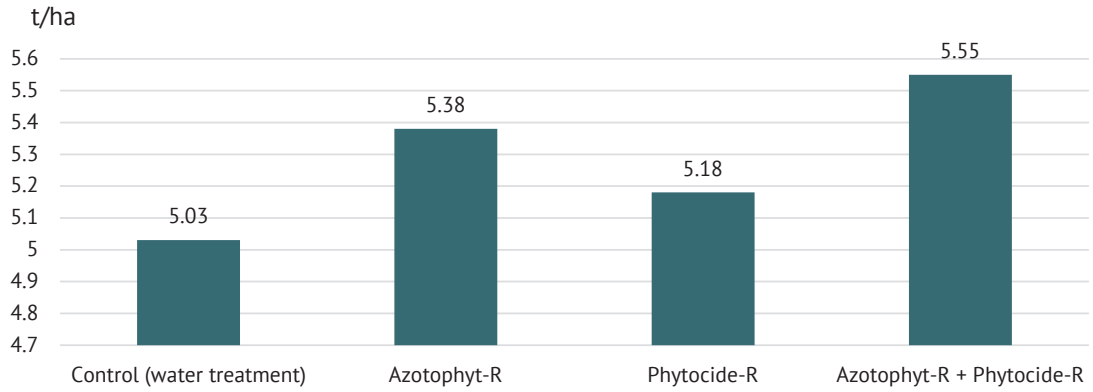

Figure 1. *Winter wheat grain yield depending on biological products (average for varieties and average for 2020-2022), t/ha*

Source: *compiled by the authors*

The lowest grain yield on average for varieties was formed in the control version – 5.03 t/ha, namely when growing the Versiia odes'ka variety, where the yield was 4.49 t/ha. The 1000 grain weight of winter wheat ranged from 30.9 g in the control version when growing the Vidpovid odes'ka variety to 45.3 g in the version with the combined use of Azotophyt-R and Phytocide-R biological products in the Ovidii variety (Table 6).

Table 6. *1000 grain weight of winter wheat, depending on the variety and seed treatment with biological products (average for 2020-2022), g*

No.	Factor A (varieties)	Factor B (biological products)				
		Control (water treatment)	Azotophyt-R	Phytocide-R	Azotophyt-R + Phytocide-R	Average
1	Ovidii	40.1	42.2	41.6	45.3	**42.3**
2	Rodzynka odeska	38.9	39.4	39.1	40.6	**39.5**
3	Rosynka	35.0	35.2	34.9	36.1	**35.3**
4	Spadshchyna odes`ka	35.1	35.9	35.6	36.8	**35.9**
5	Khersons'ka 99	34.0	34.3	33.9	34.8	**34.3**
6	Antonivka	35.9	36.1	35.3	36.5	**36.0**
7	Versiia odes`ka	40.0	40.6	40.1	41.0	**40.4**
8	Vidpovid odes'ka	30.9	33.2	32.6	33.9	**32.7**
9	Duma odes`ka	36.6	37.1	36.8	38.2	**37.2**
10	Liha odes'ka	35.7	36.4	35.9	37.2	**36.3**
	Average	**36.2**	**37.0**	**36.6**	**38.0**	**37.0**
		HIP_{05} for factor A (g) – 0.3				
		HIP_{05} for factor B (g) – 0.5				

Source: *compiled by the authors*

On average, the largest 1000 grain weight was formed by the Ovidii variety – 42.3 g, and the smallest – 32.7 g. Thus, on average for larger varieties, this indicator (38.0 g) is formed in the variant with joint seed treatment before sowing with Azotophyt-R and Phytocid-R biological products, which is 1.8 g more than in the control version, 1.0 g more than in the variant using Azotophyt-R biological products, and 1.4 g more than in the variant with the Phytocid-R biological products.

The formation of winter wheat grain yield was influenced by the interaction of productivity factors, mainly the number of productive straws, the mass of a thousand grains, and the size and quality of grains in ears (Olkhovsky *et al.*, 2019; Tsvey *et al.*, 2021). M. Lozinskiy *et al.* (2021) determined that the grain mass of a single ear, i.e. its productivity, is the result of the action and interaction of many hereditary factors that determine its components, so the main ear plays an extremely important role in shaping the productivity of wheat plants and grain yield.

Based on the results of a study conducted during 2015-2017 in the Lublin Voivodeship (Poland), it was determined that winter wheat, regardless of the year of the study, generated the highest yield of soft winter wheat varieties – 7.69 t/ha (Rachon *et al.,* 2020). In addition, a higher yield (5.91 t/ha) was obtained by research in the period 2016-2022 on average for winter wheat varieties (Korkhova *et al.*, 2023).

N.V. Pinchuk *et al.* (2022) determined that in the variants where pre-sowing inoculation of winter wheat seeds of the Skagen variety was conducted with biological products, the stem density was higher compared to the data obtained in the control variant. When using Azotophyt-R biological product for pre-sowing inoculation of seeds, the stem density was 586 pcs./m^2, which is 28.8% more than the results of studies conducted when using this biological product on average for varieties. The yield of winter wheat grain during pre-sowing seed treatment with Azotophyt-R was 5.64 t/ha, which is 6.2% less compared to the results obtained when growing the Duma odes'ka variety.

V. Gamayunova *et al.* (2022) argue that the use of biological products substantially affects the 1000 grain weight and the yield of winter wheat. The highest 1000 grain weight was obtained at 38.7 g when treated with organic balance biological products when growing the Duma odes'ka variety, which is an increase of 1.1% compared to the variant growing a similar variety with the combined use of Azotophyt-R and Phytocide-R biological products on average over the years of the study.

The studies, conducted at the Agricultural Academy of Vytautas Magnus University (Lithuania) in 2019-2020 by D. Jodaugiene *et al.* (2022), determined that the use of biological products did not substantially affect the germination of winter wheat seeds, but contributed to

an increase in plant tillering and the number of productive stems. When using biological products, there was a tendency to increase 1000 grain weight, the number of grains in the ear, the mass of grain from the ear, and the yield of winter wheat substantially increased compared to the control option.

V. Gamayunova *et al.* (2022) determined that the use of biological products affects the productivity of winter wheat. The highest yields were obtained in the variant for growing a crop of the Duma odes'ka variety with soil steaming and treatment with organic balance biological product and amounted to 7.19 t/ha, which is 1.67 t/ha or 30.3% more compared to the control version.

According to R. Vozhehova & A. Kryvenko (2019), the effectiveness of Azotophyt-R in Southern chernozems depends on the average level of their fertility. The highest efficiency was recorded on variants without fertiliser application (increments ranged from 0.18 to 0.30 t/ha), with a minimal application for the worse predecessor (an increase of 0.35 t/ha) and for background $N_{64}P_{64}K_{64}$ when growing the Knopa Variety with soil steaming (increment of 0.19-0.26 t/ha).

M. Korkhova *et al.* (2022) determined that on average for five years of the study (2018-2022), among 20 varieties of winter wheat, bearded varieties (Ozerna, Staleva, Mudrist odes'ka, Duma odes'ka, Koshova, Mariia, Zdobn, Dyvo, MIP Valensiia, Pamiati Girka, Kraievyd, Centurion) formed a 5.8% higher grain yield than unbearded – Kvitka poliv, Legenda bilotserkivs'ka, MIP Assol, Katarina, Felix, Ponticus, Faustus, and Hlaukus. Medium-early varieties (Ozerna, Staleva, Kvitka poliv, Mudrist odes'ka, Zdobna, Dyvo, and Centurion).

O.G. Berdnikova & E.M. Kucherak (2021) argue that the choice of variety is a key factor in obtaining technical indicators of high grain yield and quality. The introduction of new varieties of winter wheat into production is one of the ways to increase the profitability of its cultivation, but the average yield of this crop in Ukraine is 2.5 times lower than in Western Europe. This situation is caused by various factors, one of which is the use of low-selection and outdated varieties that do not meet the requirements of modern high-intensity agriculture.

D. Jodaugiene *et al.* (2022) determined that the use of the biological preparation did not have a substantial effect on seed germination, but contributed to tillering, an increase in winter wheat plant leaf surface area, the number of productive stems, 1000 grain weight, the ear, the mass of grain in the ear, and an increase in grain yield compared to the control.

A study by V.V. Bazalii *et al.* (2019) proved that in the conditions of the south of Ukraine, it is necessary to grow flexible wheat varieties with increased crop stability (Khersons'ka unbearded, Khersons'ka 99, Znakhidka odes'ka, Askaniys'ka, Clarysa), if strict stress limits are expected in the environmental conditions. M.K. Bondarenko & M.M. Nazarenko (2022) argue that highly productive genotypes developed yields due to additional ears, had higher resistance to lodging due to lower plant height and grain weight from the ear, respectively, and spent fewer nutrients on stem formation.

Thus, biological products for pre-sowing seed treatment under study substantially impact the productivity of winter wheat varieties, namely, the number of productive stems, the mass of grain per ear, the yield, and 1000 grain weight.

CONCLUSIONS

Studies conducted in the conditions of the South of Ukraine in the period 2020-2022 show that the yield of soft winter wheat grain largely depends and varies under the influence of pre-sowing seed treatment with biological products and varietal characteristics of the crop.

The formation of winter wheat grain yield is determined by the interaction of plant productivity elements, particularly the number of productive stems formed, the mass of grain from the ear, etc., which, in turn, depended on the examined factors. Thus, according to the number of productive stems of winter wheat, the best version was determined to be the Vidpovid odes'ka variety with seed treatment with Phytocide-R – 825 pcs./m^2. A large mass of grain per ear (0.75 g/ear) was formed on average for the examined varieties in the variant with the pre-sowing treatment of seeds with Azotophyt-R biological preparation.

The maximum grain yield of winter wheat varieties was formed by joint pre-sowing treatment of seeds with Azotophyt-R and Phytocide-R biological products. Thus, for the cultivation of winter wheat, on average for the examined varieties, 5.55 t/ha of grain was obtained for this variant of the experiment, which exceeded the indicators of other variants of the experiment by 0.17-0.52 t/ha or by 3.1-9.4%.

Varietal characteristics also affected the yield of the examined crop. Thus, on average, according to the options for pre-sowing seed treatment, the Duma odes'ka winter wheat variety formed a grain yield of 5.85 t/ha, which exceeded the indicators of other examined varieties by 3.2-18.6%.

Among the examined biological products, the highest yield was obtained by joint treatment with Azotophyt-R and Phytocide-R biological products when growing the Duma odes'ka winter wheat variety and amounted to 6.09 t/ha, and the lowest yield was formed in the Versiia odes'ka variety in the control version – 4.49 t/ha. The conducted studies confirm the feasibility of pre-sowing seed treatment with biological products to optimise the nutrition of winter wheat varieties to obtain a high grain yield.

In the future, it is planned to analyse the influence of biological products and varietal characteristics of winter wheat on the quality indicators of grain, which will give a more complete description of the examined varieties of winter wheat.

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CONFLICT OF INTEREST

None.

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Продуктивність пшениці озимої залежно від сортових особливостей та передпосівної обробки насіння біопрепаратами

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Анотація. Пшениця озима є основною продовольчою культурою у степовій зоні та основною сільськогосподарською культурою в багатьох країнах світу. Питання інтенсифікації виробництва зерна невіддільні від виробництва та використання нових ефективних біопрепаратів для передпосівної обробки насіння, які позитивно впливають на ріст та розвиток рослин пшениці озимої. Метою роботи було встановити вплив обробки насіння перед сівбою біопрепаратами на продуктивність сортів пшениці озимої. У ході проведення дослідження використовували загальноприйняті методи: системний підхід і системний аналіз,

аналіз та синтез, польовий та статистичний метод. У статті наведено дані про результати дослідження 10 сортів пшениці озимої за обробки насіння біопрепаратами в умовах Навчально-практичного центру Миколаївського національного аграрного університету з 2020 по 2022 роки. Було проаналізовано вплив обробки насіння біопрепаратами та сортових особливостей пшениці озимої на продуктивність. Встановлено, що рівень урожаю залежав та змінювався залежно від взятого для передпосівної обробки насіння біопрепарату та досліджуваного сорту. За роки досліджень біопрепарати вплинули на густоту рослин, коефіцієнт продуктивного кущення, кількість продуктивних стебел, масу зерна з одного колосу, масу 1000 зерен та врожайність сортів пшениці озимої. Найкращі результати було отримано при сумісному використанні досліджуваних біопрепаратів Азотофіт-р та Фітоцид-р. Проведеними дослідженнями підтверджено доцільність передпосівної обробки насіння біопрепаратами для оптимізації живлення рослин сортів пшениці озимої з метою формування високої врожайності зерна. Отримані наукові досягнення сприятимуть широкому застосуванню біопрепаратів для обробки насіння, забезпечать швидкий і повноцінний ріст і розвиток сортів пшениці озимої, сприятимуть подальшому збільшенню виробництва та валового збору зерна

Ключові слова: пшениця м'яка озима; урожайність зерна; коефіцієнт продуктивного кущення; маса 1000 зерен; маса зерна з 1 колосу

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Investigation of the response of sweet cherries to root mycorrhisation with biologics for sustainable horticulture development

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Abstract. Sustainable horticulture development is a priority area considering climate change, especially in the context of reduced water supply. The search for ways to regulate the resistance of fruit trees to stressors is an urgent issue for the world community. The use of beneficial microorganisms to inoculate plant roots helps reduce the use of synthetic substances and is an alternative for sustainable horticulture. The purpose of the study is to identify the specific features of the effect of root inoculation by mycorrhizal fungi on the reaction of sweet cherries to develop strategies for managing the production of fruit products. The study was conducted during 2018-2020 in the sweet sweet cherry orchard of the southern steppe subzone of Ukraine. Such research methods as field, laboratory, biochemical, physiological, and statistical were used. The regularities of the influence of mycorrhizal fungi on the total moisture content and water-holding

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capacity of sweet cherry leaves were examined. In the first year of studies on endomycorrhizal root inoculation, these indicators were higher compared to the control group. The positive effect of endo-ectomycorrhiza on the water-holding capacity of sweet cherry leaves was elucidated. The total leaf surface and the content of green pigments in the leaves were determined as one of the main indicators of the photosynthetic potential of a fruit crop. The effect of inoculation of sweet cherry roots by mycorrhizal fungi on the ratio of chlorophylls (a/b) in leaves was established. The parameters of the content of total nitrogen, phosphorus, and potassium in sweet cherry leaves were determined. The use of mycorrhizal fungi increases the adaptive properties of sweet cherry trees to stressful factors, namely, arid conditions in the south of Ukraine. The research results can be used by fruit producers to improve climate-optimised technologies, which will substantially reduce risks and possible economic losses, and preserve biodiversity

Keywords: endomycorrhiza; ectomycorrhiza; leaf area; *Prunus avium*; water-holding capacity; chlorophyll; basic elements of nutrition

INTRODUCTION

Sustainable fruit production plays a key role in ensuring food security, the well-being of the population, and the competitiveness of the country. Among the manifestations of climate change in the context of global warming, the main negative impacts on the production of fruit should be distinguished: a substantial increase in air temperature, changes in the thermal regime, fluctuations in the distribution of precipitation, increased flow of natural meteorological phenomena and extreme weather conditions. This affects the sustainable development of horticulture in most regions and requires the adaptation of cultivation technologies to these changes to reduce risks and possible economic losses. Therefore, it is now necessary to change approaches to conducting agribusiness, considering the principles of the European green course towards switching to innovative climate-optimised technologies.

Sweet cherries are among the most popular fruit crops, which consumers highly appreciate due to their pleasant taste, attractive appearance, and valuable nutritional and biochemical properties (Ivanova *et al.,* 2021). Sweet cherries can be grown in a wide range of climatic conditions (Serdyuk *et al.,* 2020; Ivanova *et al.*, 2022). Due to climate change, fruit producers are now facing challenges that pose a threat to increasing the volume of sweet cherries. The economic value of sweet cherries encourages improving the elements of its cultivation technology to enhance the conditions for plant growth and development, increase fruit production and increase quality (Gerasko *et al.,* 2022a). The use of beneficial microorganisms for mycorrhisation of plant roots helps to reduce the use of synthetic substances and is an alternative for sustainable horticulture (Nasif *et al.,* 2022). Inoculation of plant roots with beneficial microorganisms such as arbuscular mycorrhiza (AM) and rhizobacteria to stimulate plant growth and development is considered an alternative to the use of synthetic drugs (Cobb *et al.,* 2021). Arbuscular mycorrhiza, as a form of mutualistic symbiotic association, improves the supply of nutrients to the plant, increases tolerance to abiotic stresses and resistance to various pathogens and pests (Jain & Pundir, 2019; Lin *et al.,* 2021). According to researchers (Chen *et al.,* 2017; Brito *et al.,* 2021), the use of arbuscular mycorrhizal fungi (AMF) improves vegetative growth, the content of secondary metabolites, the assimilation of nutrients by plants, soil conditions for host plants by improving soil structure and promoting ecosystem sustainability.

In the study, M. Vosnjak *et al.* (2022) highlighted the physiological and biochemical reactions of the leaves of three-year-old sweet cherry trees under the influence of low temperatures in vivo 36 days after full flowering. The change in the examined physiological and biochemical parameters of leaves under the influence of low temperatures was established. A uniform and substantial decrease in gas exchange parameters, chlorophyll fluorescence, and an increase in the content of xanthophyll cycle pigments, especially seaxanthin and anteraxanthin, were observed. Despite the increase in seaxanthin, researchers noted a decrease in the content of chlorophylls.

The positive effect of mycorrhizal fungi has also been observed in studies with other types of fruit trees, crops, and wild plants. The effect of AM is particularly substantial when growing plants under unfavourable conditions (Neidhardt, 2021). The study by Zhang *et al.* (2018) found an increase in the tolerance of *Lolium perenne* plants to cadmium (Cd) under the influence of root inoculation with arbuscular mycorrhiza, as well as a decrease in the toxicity of Cd for host plants. According to researchers, root inoculation of *Glomus mosseae* can enhance the photosynthetic ability of leaves to assimilate carbon by improving the absorption of phosphorus by roots from the soil.

X. Cai *et al.* (2021) determined that complex inoculation by mycorrhizal fungus *Glomus mosseae* and bacteria *Bacillus subtilis* increased the content of nutrients in plants, total soluble protein, total soluble sugar, total content of free amino acids and reduced the damage to the root system by fusarium pathogens. In the paper of S. Gluszcek *et al.* (2020), the positive effect of organic fertilisers and mycorrhisation on the growth indicators of the root system, its colonisation with arbuscular mycorrhizal fungi, and the yield of sweet cherry trees was highlighted. Researchers noted a tendency for an increase in the raw and dry mass of roots, their diameter, the length of roots and their surface area under the

influence of inoculation with a mycorrhizal substrate compared to control trees.

Anandakumar & Kalaiselvi (2022) recorded an increase in the length of shoots and roots, leaf area, leaf surface index, shoot and root biomass, and chlorophyll content in *Vigna mungo*. According to the authors, the number of spores of AM fungi is one of the key factors affecting the percentage of mycorrhizal colonisation of the root system of plants, which impacts the growth and productivity of host plants. Jumrani *et al.* (2022) found a reduction in the negative effect of high-temperature stress on plants when soy is inoculated with arbuscular mycorrhizal fungi. Inoculated AMF soybean plants showed an increase in leaf area, stem height, root and shoot length, and dry root biomass. Researchers also noted an increase in the content of chlorophyll, the number of stomata, the rate of photosynthesis, the conductivity of stomata, the rate of transpiration, and the efficiency of water use by plants under the influence of mycorrhisation of AM roots. The results of this study confirm the high efficiency of using mycorrhizal inoculants as a biofertiliser to increase soybean productivity under high-temperature stress.

The purpose of this study is to evaluate the effect of root inoculation by mycorrhizal fungi on physiological and biochemical composition of sweet cherry leaves. The objectives of the study are to determine the total area of leaves, the specific density of leaves, total moisture content, water-holding capacity, content and the ratio of chlorophylls, the content of the main elements of mineral nutrition in sweet cherry leaves by inoculation of roots by mycorrhizal fungi.

MATERIALS AND METHODS

The study was conducted during 2018-2020 on chestnut sandy soils in the conditions of the southern steppe subzone of Ukraine. The experimental plots are located in the research orchard of the Dmytro Motornyi Tavria State Agrotechnological University (46°46'N, 35°17'e). The nitrogen content in the horizon of 0-20 cm was 5.5 mg/100 g, the content of P_2O_5 – 5.4 mg/100 g and K_2O – 6.5 mg/g of soil. The reaction of the soil solution was slightly alkaline (pH 7.1-7.4). The humus content in the upper soil layer was 0.6%. The total content of water-soluble salts did not exceed 0.015-0.024%. The soil conditions of the experimental garden are favourable for mycorrhisation since the low level of soil supply with nitrogen and phosphorus contributes to the colonisation of plant roots by symbiotic fungi.

Over the years of research, the average long-term air temperature during the growing season was favourable for the growth and development of sweet cherries (Table 1).

Table 1. *Deviations of air temperature and precipitation compared to long-term averages*

Years	Months												Mid-year
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Average monthly air temperature, °C													
2018	+1.2	+1.1	-1.5	+3.0	+3.0	+2.2	+1.1	+2.6	+1.5	+2.9	-1.1	+0.6	+1.3
2019	+1.6	+2.4	+0.7	+1.0	+1.5	+4.1	-0.6	+0.4	+0.7	+1.4	+2.3	+3.8	+1.6
2020	+2.8	+3.6	+4.7	-1.0	-1.7	+1.6	+1.3	+0.2	+3.3	+4.6	+0.7	+5.3	+2.1
Precipitation, (%)													
2018	+21	+39	+96	-84	-52	-40	+81	-82	+104	-44	-3	+74	+10
2019	+19	-68	+6	+44	+107	-73	-5	+61	-67	-42	-48	-26	-8
2020	-74	+195	-82	-71	+69	+2	+10	-39	-51	-36	-57	-91	-18

Source: *developed by the authors based on the Melitopol meteorological station of Zaporizhia region (n.d.)*

Analysis of weather conditions over the years of research indicates a warming climate – the average annual temperature was higher by 1.3-2.1°C relative to long-term indicators. Overwintering conditions for sweet cherries have become more favourable. The air temperature of the coldest month – January was higher by 1.2-2.8°C compared to long-term indicators. The average annual precipitation did not differ much from the long-term norm. Notably, precipitation was distributed unevenly over the years of the study. In September 2018 and May 2020, waterlogging was observed. There were droughts in June 2018 and 2019, and in August 2018 and 2020. This is confirmed by the calculated hydrothermal coefficient (Table 2).

Table 2. *Hydrothermal coefficient*

Years	Months						
	IV	V	VI	VII	VIII	IX	X
2018	0.1	0.4	0.5	1.1.	0.1	1.4	0.5
2019	1.4	1.8	0.2	0.6	0.8	0.2	0.5

Table 2, Continued

Years	Months						
	IV	V	VI	VII	VIII	IX	X
2020	nm	0.9	0.8	0.6	0.5	0.8	1.0
Long-term norm	1.1.	0.9	0.9	0.6	0.5	0.8	1.0

Note: *nm denotes 'not measured': the hydrothermal coefficient is not determined if the average monthly air temperature is less than 10°C*

Source: *compiled by the authors*

The hottest month of August was very dry during all the years of research, with the exception of 2019, when 56 mm of precipitation fell and the hydrothermal coefficient was higher relative to the long-term norm. June and September 2019 were exceptionally dry when the hydrothermal coefficient was substantially lower than the long-term norm. The air temperature during the active growth of sweet cherries (from April to August) in 2019 was favourable in April, May, and July, while in April and May 44-107% more precipitation fell (compared to the long-term average norm). In June 2019, there was a severe drought (the air temperature is 4.3°C above the monthly average and 73% less precipitation than normal), which continued in July. The growing conditions of sweet cherries in 2020 were extremely unfavourable in April (the average monthly air temperature was 1°C lower than the average annual norm, while precipitation decreased by 71%). May was satisfactory in terms of precipitation (69% more than the long-term norm), but unfavourable in terms of air temperature (1.7°C below the long-term norm). Frosts in May 2020 substantially damaged sweet cherry blossoms, which led to the loss of most of the crop. June and July 2020 were more favourable for sweet cherry trees compared to 2019. In August 2020, there was a typical drought for this zone.

Mid-early sweet cherry of Dilema variety (*Prunus avium* L./*Prunus mahaleb*) was planted in 2011 according to the 7×5 m scheme. The Dilema variety was bred by crossing two varieties of Drogan yellow and Valery Chkalov. In trees of the variety, the crown is slightly drooping, dense, and spreading. The fruits of the Dilema variety are convex-heart-shaped with a dark red skin and pulp. According to sensory assessment, the fruits of the variety are characterised by an excellent sweet cherryand sour refreshing taste.

The study of the effectiveness of mycorrhizal fungi was conducted according to the scheme: 1. Control (without inoculation); 2. Inoculation of sweet cherry roots with MycoApply SuperConcentrate 10 (endomycorrhiza); 3. Inoculation of sweet cherry roots with MycoApply Micronised Endo/Ecto (endo-ecticorrhiza).

The composition of Mycoappplay SuperConcentrate 10 includes spores of 4 species of arbuscular-mycorrhizal (AM) fungi – *Glomus intraradices* (*Rhizophagus intraradices*), *Glomus agregatum, Glomus mosseae*, *Glomus etunicatum*. 1.13 g of the biological product contains 0.3 million fungal spores. MycoApply Micronised Endo/Ecto consists of 4 types of *endomycorrhizae* fungi (*Glomus mosseae*, *Glomus agregatum*, *Glomus intraradices*, and *Glomus etunicatum*) and 7 types of ectomycorrhizal (*Ectomycorrhizae*) fungi *Rhizopogon villosulus*, *Rhizopogon amylopogon*, *Rhizopogon luteolus*, *Pisolithus tinctorius*, *Rhizopogon fulvigleba*, *Scleroderma citrinum* and *Scleroderma cepa*). The repetition rate in the experiment is fourfold. In each variant, there were 4 accounting trees surrounded by 14 protective trees. Mycorrhisation of the roots of sweet cherry trees with biologics was conducted in September 2018. In the trunk circle of the tree in a radius less than the crown projection, 5 punctures of the soil were made to a depth of 10 cm at an angle of 45 degrees to do this. An aqueous suspension of mycorrhizal fungal spores was poured into the holes. Mineral fertilisers and pesticides were not used at the experimental sites. Rows and near-stem strips in the garden in the experimental plots were kept under turf with natural grasses, which were mowed and left on the soil surface. The vegetation cover in the experimental areas was represented by the following varieties: shepherd's purse (*Capsella bursa-pastoris* L.), hairy vetch (*Vicia villosa*), field chamomile (*Anthemis arvensis* L.), couch grass (*Elytrigia repens* L.), and Bermuda grass (*Cynodon dactylon* L.). In the summer, the wild oat (*Avena fatua*) prevailed in the grass. In various grasses, there were small groups of medicinal plants, in particular: yarrow (*Achillea millefolium* L.), viper's-bugloss (*Echium vulgare* L.), forking larkspur (*Delphinium consolida*), and orange mullein (*Verbascum phlomoides*). In the first decade of August, when the leaf surface was fully developed on sweet cherrytrees, leaf samples were taken for analysis.

The leaf surface area was determined by die-cutting. For this, ten leaves were taken from each tree from the middle of one-year shoots on the southern side of the crown. The selected leaves were weighed and corkscrew-punched through. The area of the cut fragment was 1 cm^2. The cut-out leaf fragments were weighed. The total area of leaves (S) in the sample was determined by the formula (1):

$$S = \frac{M \times S_1}{M_1}, \quad (1)$$

where M is the mass of leaves in the sample, g; S_1 – area of one die-cut, cm^2; n – number of die-cuts, pcs; M_1 – mass of die-cuts, g.

Further, the average area of leaves from one tree was calculated.

The parameters of the water regime of the leaves (total water content and water-holding capacity) were determined by weight. The content of the total amount of water in the tissues was determined by drying 10 sheets in metal buckets in a thermostat at 105°C to a constant mass. The repetition was threefold. The total water content (V) as a percentage of the crude weight of the suspension was determined by the formula (2):

$$W = \frac{b-c}{b-a} \times 100\,, \quad (2)$$

where a is the mass of an empty weighing bottle, g; b is the mass of a weighing bottle with a raw suspension, g; c is the mass of a weighing bottle with a dry suspension, g

To determine the water-holding capacity of the leaves, the wilting method was used, which involves determining the loss of water during their drying. 10 leaves were selected (three times repeated) and weighed. The leaves were then placed in Petri dishes and placed in a thermostat at 23°C. Repeated weighings were performed after 2, 4, and 6 hours and water loss was determined. The lower the water loss, the greater the water-holding capacity. The water-holding capacity (WHC) was determined by the formula (3):

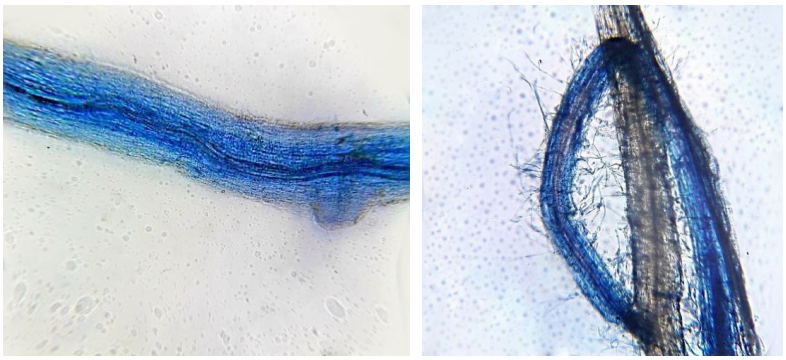
$$WHC = \frac{WL}{WC} \times 100\,, \quad (3)$$

where WC is the water content in the leaves before drying, g; WL is the water loss per unit time, g.

The quantitative content of chlorophylls a and b in sweet cherry leaves was determined spectrophotometrically in a biochemical laboratory at the appropriate wavelength. Biochemical analysis of the leaves was performed three times in accordance with generally accepted methods. Sweet cherry leaves were selected for analysis after harvesting the fruit from each repeat separately. Immediately after harvesting, the leaves were dried at 65-70°C in a drying cabinet. For analysis, dried sweet cherryleaves were crushed and weighed. Suspension of one sample of plant material – 20 g of dry matter. The content of total nitrogen in plant material was determined by the Kjeldahl method, total phosphorus – colorimetrically on FEK LMF 74M, total potassium – by the flame-photometric method after ashing of the sediment in accordance with MVV 31-497058-019-2005 (Skrylnyk & Rozumna, 2005). The analytical repeatability of measurements is threefold. Statistical processing of experimental data was conducted by the variance method using Microsoft Excel software. Mean values and standard deviations were calculated for all data series. The substantiality level was set to $p<0.05$.

RESEARCH RESULTS

Symbiotic relationships of mycorrhizal fungi with sweet cherry roots can be traced as a result of the analysis of the examined plants. The detection rate of mycorrhizal plants in the variant with root mycorrhisation was 100%. Thus, all the trees where the mycorrhizal preparation was introduced were successfully mycorrhised. During the development of mycelium of mycorrhizal fungi, their hyphae are clearly visible on the treated roots of sweet cherries. On the processed roots of sweet cherries, under a 100-fold magnification, intensive overgrowth of the roots of the 1st, 2nd and subsequent orders with root hairs was observed (Fig. 1).



A B

Figure 1. *Sweet cherry root: A – before mycorrhisation by mycorrhizal fungi; B – after mycorrhisation by mycorizal fungi (×100 light microscopy)*

Source*: compiled by the authors*

In Fig. 1 B, a substantial increase in the number of sucking hairs on the roots of the 5th order can be seen as a result of symbiosis with mycorrhizal fungi and hyphae of mycorrhizal fungi inside the roots. The penetration of mycorrhizal fungal hyphae into the roots and root hairs of the examined sweet cherry trees was also recorded, which is evidence of the development of a symbiotic association. The results of the studies show that the total moisture content and water-holding capacity of tree leaves the roots of which were inoculated with endomycorrhizal biologics MycoApply SuperConcentrate 10 were substantially higher (56.9±0.49 and 93.5±0.98, respectively) compared to control trees in 2019 (Table 3).

Table 3. *Physiological parameters of sweet cherry leaves of the Dileta variety for inoculation of roots by mycorrhizal fungi*

Variant	Total moisture content, %	water-holding capacity, %	Total area of leaves, m^2/ tree	Specific surface density of leaves, g/m^2
		2019		
Control (without inoculation)	53.5±0.98	84.6±0.84	60.1±5.23	69.1±4.35
MycoApply SuperConcentrate 10	56.9±0.49*	93.5±0.98*	50.4±4.25*	87.5±5.32*
MycoApply Micronised Endo/Ecto	52.7±0.95	96.4±0.97*	55.3±4.75	63.9±5.31
		2020		
Control (without inoculation)	57.0±0.95	95.4±0.63	44.3±3.77	93.0±5.75
MycoApply SuperConcentrate 10	55.0±0.87	95.1±0.99	55.5±4.95*	89.3±4.98
MycoApply Micronised Endo/Ecto	56.0±0.75	96.7±0.85	42.0±3.94	95.5±6.74

Note: ** – the difference is substantial at p⩽0.05*
Source*: compiled by the authors*

In 2020, mycorrhization of roots by by endomycorrhiza did not affect the total moisture content and water-holding capacity of sweet cherry leaves. Root inoculation with Micronised Endo/Ecto did not substantially affect the total moisture content in sweet cherry leaves. In the first year of research, under the influence of endo-ectomycorrhiza, the water-holding capacity of leaves increased by up to 96.4%. The water-holding ability of leaf tissues characterises the content of free moisture in them. The increased water-holding capacity of the leaves indicates the absence of drought conditions or plant tolerance to such conditions. However, there was a severe drought in June 2019 (Table 1 and 2). Therefore, it can be stated that the inoculation of roots with endomycorrhiza and endo-ectomycorrhiza contributed to the tolerance of cherry trees to drought conditions. In the first year of the study, the total area of leaves on trees where root mycorrhization was performed with MycoApply Micronized Endo/Ecto and MycoApply SuperConcentrate 10 biological preparations was smaller by 4.7 and 9.7 m^2/tree, respectively, compared to the control (Table 3). In the second year, in inoculated trees with endomycorrhiza, the leaf area increased by 11.2 m^2/tree.

In inoculated trees with endo-ectomycorrhiza, on the contrary, the leaf area decreased by 2.3 m^2/tree. Notably, in 2020, there was a substantial decrease in the total area of leaves (13.3-15.8 m^2/ tree) on all variants compared to 2019. The specific surface density of the leaves in the first year of research after root mycorrhisation with MycoApply SuperConcentrate 10 biological preparation was considerably higher by 18.4 g/m^2 compared to the variant without inoculation. In the second year, the specific surface density of leaves in inoculated endomycorrhizal trees did not substantially differ from the control trees. The increase in leaf area under the action of MycoApply SuperConcentrate 10 in the second year of research without significant loss of specific surface density confirms the positive effect of endomycorrhiza on leaf morphology. Root inoculation with MycoApply Micronised Endo/Ecto BioLogics did not substantially affect the total leaf area and specific surface density of sweet cherry leaves. The accumulation of chlorophylls in sweet cherry leaves inoculated with endomycorrhiza and endo-ectomycorrhiza was substantially lower compared to control trees (Table 4).

Table 4. *Content and ratio of chlorophylls in sweet cherry leaves by inoculation of roots by mycorrhizal fungi*

Variant	Sum of chlorophylls a and b (a + b), mg/m2 of leaf area		Chlorophyll ratio a/b	
	2019	2020	2019	2020
Control (no inoculation)	304.3±11.75	303.1±12.59	1.7±0.02	2.7±0.02
MycoApply SuperConcentrate 10	235.9±17.56*	277.7±15.82*	2.5±0.08*	2.3±0.05*
MycoApply Micronised Endo/Ecto	263.3±19.48*	244.5±13.73*	1.6±0.05*	2.0±0.02*

Note: * – the difference is substantial at p⩽0.05
Source: compiled by the authors

Over the years of research, a decrease in the content of chlorophylls *a* and *b* has been established for roots mycorrhised with MycoApply SuperConcentrate 10 at 25.4-68.4 mg/m^2 compared to the non-inoculation

variant. The decrease in the chlorophyll content in sweet cherry leaves during 2019 under the effects of endomycorrhiza can be explained by a significant decrease in their leaf area compared to non-inoculated trees. Although the inoculation of sweet cherry roots with endo-ectomycorrhiza did not notably affect the leaf area, the amount of chlorophyll was also lower than the control (without inoculation). Inoculation of roots with MycoApply Micronised Endo/Ecto reduced the content of chlorophylls *a* and *b* at 41-58. 6 mg/m^2 of leaf area compared to the control. The ratio of chlorophylls (a/b) in 2019 was substantially higher in trees inoculated with endomycorrhiza and substantially lower in trees inoculated with endomycorrhiza compared to the control. In 2020, this figure was substantially lower in sweet cherry leaves that were inoculated with endomycorrhiza and endo-ectomycorrhiza compared to trees without inoculation.

Consequently, inoculation of sweet cherry roots by both endomycorrhizae and endo-ectomycorrhizae contributed to the adaptive restructuring of the photosynthetic apparatus of leaves to overcome adverse living conditions. As for the increase in the ratio of chlorophylls (a/b) in 2019 due to the effects of endomycorrhizae, it can be assumed that it occurred due to the hormonal stimulation of trees by endomycorrhizae, which required many products of photosynthesis for its development. The total nitrogen content in sweet cherry leaves after root inoculation with endo- and ectomycorrhiza was not significantly different from the control (Table 5).

Table 5. *The content of nutrients in cherry leaves after root inoculation with mycorrhizal fungi, 2020*

Variant	Content, %		
	total nitrogen	total phosphorus	total potassium
Control (without inoculation)	1.79±0.062^{b}	0.24±0.007$^{b, c}$	0.65±0.024$^{b, c}$
MycoApply SuperConcentrate 10	1.70±0.067^{b}	0.19±0.007$^{a, b}$	0.58±0.022$^{a, b, c}$
MycoApply Micronised Endo/Ecto	1.70±0.065^{b}	0.20±0.008$^{a, b}$	0.77±0.029$^{a, b}$
* Insufficient supply	1.80±0.020	0.20±0.010	0.80±0.090
* Optimal supply	2.40±0.040	0.36±0.010	1.30±0.140

Note: ** the content of the main elements of nutrition in the leaves of fruit-bearing sweet cherrytrees in the south of Ukraine, defined as insufficient and optimal security for growth and fruiting*
^{a} - the difference with the control (without inoculation) is substantial at P≤0.05
^{b} - the difference with the content of the element at optimal supply is reliable at P≤0.05
^{c} - the difference with the content of the element in case of insufficient supply is reliable at P≤0.05
Source*: compiled by the authors*

After root mycorrhization with MycoApply SuperConcentrate 10 and MycoApply Micronized Endo/Ecto biological preparations, the content of total nitrogen in cherry leaves was 71-74% of the optimal supply of this nutrient for trees. In the leaves of sweet cherries of all the examined variants, the content of total phosphorus and potassium was substantially lower by 34-48% and 41-55%, respectively, from the optimal values. Notably, the phosphorus content in the leaves of non-inoculated trees was notably higher than the level of insufficient supply of this element. When the roots were inoculated with MycoApply SuperConcentrate 10 and MycoApply Micronised Endo/Ecto, the phosphorus content in the leaves was substantially lower than the control and corresponded to the indicator of insufficient supply of plants to these elements. In the leaves of trees that were inoculated with endomycorrhiza, the content of potassium was substantially lower than that of non-inoculated trees and the level of insufficient supply of this element. Inoculation of sweet cherry roots with MycoApply Micronised Endo/Ecto substantially increases the potassium content in the leaves compared to the control. In this variant, the potassium content in the leaves corresponds to the level of insufficient supply for plant growth and development with this element.

DISCUSSION

There are many reports in the scientific literature that mycorrhizal plants absorb more moisture and suffer less from drought (Rajesh *et al.,* 2018; Li *et al.,* 2019; Chandrasekaran, 2022). Basically, the positive effect of mycorrhizae on the water supply of symbiotic plants is explained by the fact that hyphae of mycorrhizal fungi come into association with the roots of symbiotic plants. This symbiosis substantially increases the absorption surface area of the roots due to branching, since mycorrhizal plants can have more root hairs to increase their resistance to drought stress (Zhang *et al.,* 2018).

The obtained results are consistent with the data of other authors regarding the formation of strong root branching as a result of their colonisation by fungal mycorrhiza (Chen *et al.,* 2020). Therefore, fungal mycorrhiza can mitigate plant growth restrictions caused by insufficient nutrient and moisture supply. In

the conducted studies during 2020, the effect of mycorrhization of the roots of sweet cherry trees on the total moisture content and water-holding capacity of leaves was not identified. Similar studies have been conducted on other fruit crops (Rajesh Naik *et al.,* 2018). The water-holding ability of leaf tissues characterises the content of free moisture in them. One of the known physiological responses of plants to drought is the accumulation of osmolytes, the thickening and lignification of cell walls (Sharma *et al.,* 2019). Moreover, the free moisture content decreases. That is, an increased water holding capacity indicates the absence of drought conditions or plant tolerance to such conditions. The obtained experimental data are consistent with the justifications of other researchers regarding the increase of plant tolerance in an environment with a limited amount of water due to the association of arbuscular mycorrhizal fungi with host plants (Abdel-Salam *et al.,* 2018; Madouh & Quoreshi, 2023). For the sustainable development of horticulture in conditions of insufficient moisture, it is important that mycorrhiza provides fruit crops with moisture.

It is known that symbiotic mycorrhizal fungi synthesise biologically active compounds and thereby affect the hormonal regulation of plants, activating their growth (Li *et al.,* 2019; Shao *et al.,* 2023). Yet such a positive effect of mycorrhiza on growth processes takes time to develop the mycorrhizal network. Naturally, under optimal growing conditions, the process of mycorrhizal network development is faster. However, as can be seen from the results obtained in current studies, in the arid conditions of southern Ukraine, a positive effect of endomycorrhiza on the growth of leaf area is observed in the second year after root inoculation. Moreover, in the first year after root inoculation, mycorrhiza negatively affected leaf growth. Similar effects have already been described (Jin *et al.,* 2019; Kokkoris *et al.,* 2019) previously by researchers. It was established that mycorrhiza can lead to depression of growth processes in inoculated plants. The published papers based on the results of field and greenhouse tests highlight the influence of various agricultural techniques on the colonisation of plants by mycorrhiza, and the consequences of this colonisation on the yield, biomass, and assimilation of phosphorus by plants (Zhu *et al.,* 2019). Various studies confirm the positive effect of mycorrhizal fungi in the rhizospheric soil of different plants on the growth parameters of grasses (*Cenchrus ciliaris*). The maximum increase in the height of the plant, the number of leaves on the plant, the area of leaves, and the content of chlorophyll in the *Cenchrus ciliaris* under the influence of spores from rhizospheric soil was found (Thin *et al*., 2022).

The decrease in leaf area in the second year of research cannot be explained by the influence of weather conditions in 2020. As after losing most of the crop due to spring frosts, trees that have lost fruit could grow a larger area of leaves. The absence of fruits, which are the main consumers of nutrients and water (Ayala & Lang, 2018), should contribute to an increase in the vegetative growth of trees. According to K. Rutkowski and G.P. Lysiak (2023), when growing fruit crops, it is important to maintain a balance between vegetative growth and tree fruiting. It can be concluded that the decrease in the leaf surface area in 2020 was caused by the extreme conditions of June 2019. During the period of intensive growth of shoots, extreme droughts (HTC – 0.2) and heat (the air temperature reached 36.4°C) were observed. Thus, in the arid conditions of the southern steppe of Ukraine, both negative (2019) and positive (2020) effects of endomycorrhiza on the total area of sweet cherry leaves were observed. Endo-ectomycorrhiza did not affect the total leaf area of inoculated trees. It is possible to protect sweet cherry trees from the negative impact of mycorrhiza on growth processes and accelerate the development of the mycorrhizal network by using irrigation. According to researchers, the most promising and resource-saving in the conditions of southern Ukraine is drip irrigation (Maliuk *et al.,* 2021).

The specific surface density of leaves in the first year of studies for root inoculation by endomycorrhiza was substantially higher, and the following year it almost did not differ from the control trees. It is known that the specific surface density of leaves is usually lower the larger the leaf area (Bondarenko, 2019).

The decrease in the content of chlorophyll in sweet cherry leaves under the influence of inoculation with endomycorrhiza and endo-ectomycorrhiza can be explained by the competition of natural grasses for the right to mycorrhiza with trees. Mycorrhizal fungi offer a selective advantage in supplying water, nutrients, vitamins, hormones, and enzymes to their host over competing non-host species (Zou *et al.,* 2023). It is known that natural herbs are better at establishing symbiosis with mycorrhizal fungi than cultivated plants (Trinchera *et al.,* 2019), which is probably manifested in the loss of nutrients by sweet cherry trees. In turn, less nutrient intake affects the chlorophyll content in sweet cherry leaves. Studies have established that the content of chlorophyll depends on the light, intensity of tree growth, type, variety, rootstock, and stress factors (Baslam *et al.,* 2020; Wojdyło *et al.,* 2021). A decrease in the ratio of chlorophylls (a/b) in leaves during root mycorrhisation indicates a restructuring of the photosynthetic apparatus of leaves towards the accumulation of chlorophyll b and carotenoids. This rearrangement of the photosynthetic apparatus is a well-known adaptive response of trees, which allows them to survive conditions of drought and excessive lighting (Markulj Kulundžić *et al.,* 2016).

The main reasons for a substantial decrease in the content of total nitrogen, phosphorus, and potassium in the experiment sweet cherry leaves compared to the optimal level of supply of sweet cherry trees in the south of Ukraine include: low content of basic nutrients in the soil of experimental plots; lack of mineral fertilisers; lack of irrigation; turf with natural grasses. Notably,

the total potassium content in sweet cherry leaves decreased the most due to its consumption by competitive vegetation, i.e. natural grasses. They served as live mulch in the garden. Similar patterns regarding the decrease in the content of basic nutrients are well-covered in the scientific literature (Trinchera *et al.,* 2021). Turf with natural grasses in orchards causes a lack of nutrients in the leaves of fruit trees (Gerasko *et al.,* 2022b). In the conducted studies, a negative effect of root inoculation with endo- and ectomycorrhizae on the phosphorus content in sweet cherry leaves was observed. Researchers have established the positive effect of mycorrhiza on the assimilation of nutrients by plants (Ferrol *et al.,* 2019; Chauhan *et al.,* 2022) and determined that arbuscular mycorrhizal fungi are well-known symbiotic microorganisms that improve the growth of the host plant by mobilising fixed nutrients, mainly phosphorus, from the soil (Etesami *et al.,* 2021; Neidhardt, 2021). However, under unfavourable conditions, mycorrhizal fungi compete with plants for food elements and become consumers instead of a source (Kokkoris *et al.,* 2019). Thus, mycorrhizal fungi can reabsorb phosphorus released on the periarbuscular surface and control its supply to the partner plant (Kokkoris *et al.,* 2019; Zhang *et al.,* 2023).

In the conducted studies, an increase in the potassium content in sweet cherry leaves was recorded when the roots were inoculated with endo-ectomycorrhiza compared to the control (without inoculation). This confirms the positive effect of endo-ectomycorrhizal inoculant on potassium intake by a symbiotic plant. A similar effect has been described by C. Guerrero-Galán *et al.* (2018). It remains not fully understood what type of fungi caused such a positive effect since the biological product includes four types of endomycorrhizal and seven types of ectomycorrhizal fungi. Further research may be aimed at elucidating the role of arbuscular mycorrhizal fungi in improving sweet cherry growth and yield under multiple abiotic stresses. Therefore, understanding the symbiotic relationships of mycorrhizal fungi with various plants, including fruit crops, and their response to abiotic stresses can contribute to the development and implementation of climate-optimised technologies to ensure sustainable food production and biodiversity conservation.

CONCLUSIONS

Mycorrhization of cherry roots with MycoApply Super-Concentrate 10 in the conditions of southern Ukraine contributes to the adaptive restructuring of the photosynthetic apparatus of the leaves, the improvement of the water regime of the leaves in the first year after inoculation, and the increase of the leaf surface area in the second year after inoculation.

Inoculation of the roots by endo-ectomycorrhiza did not substantially affect the total moisture content of the leaves and the total area of the sweet cherry leaves. Inoculated trees with MycoApply Micronised Endo/Ecto increased the water-holding capacity of leaves by 1.3-11.8% compared to the control. Mycorrhization of endomycorrhizal and endo-ectomycorrhizal roots contributed to the tolerance of cherry trees to arid environmental conditions.

If the soil is not sufficiently provided with the basic elements of nutrition and moisture, the negative effect of endomycorrhiza on the content of phosphorus, potassium and the amount of chlorophylls *a* and *b* in sweet cherry leaves is manifested. The inoculation of roots with endo-ectomycorrhiza reduces the phosphorus content and the amount of chlorophylls *a* and *b* in sweet cherry leaves. An increase in the potassium content in sweet cherry leaves was determined in the second year of research under the influence of root inoculation with MycoApply Micronised Endo/Ecto.

Agricultural producers who grow sweet cherries using organic technology in the south of Ukraine can be recommended to combine inoculation of sweet cherry roots with mycorrhizal fungi and application of organic fertilisers and drip irrigation. This will provide optimal conditions for the full functioning of mycorrhizal symbiosis. Further research should assess the quality of sweet cherry fruits by biochemical parameters under the influence of mycorrhisation of roots with biologics for the sustainable development of horticulture.

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CONFLICT OF INTEREST

None.

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Дослідження реакції черешні на мікоризацію коренів біопрепаратами для стійкого розвитку садівництва

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Анотація. Стійкий розвиток садівництва є пріоритетним напрямом за зміни клімату, особливо в умовах зменшення вологозабезпечення. Пошук шляхів регуляції стійкості плодових дерев до стресорів є актуальним питання для світової спільноти. Використання корисних мікроорганізмів для інокуляції коренів рослин сприяє зменшенню застосування синтетичних речовин і є альтернативою для стійкого садівництва. Метою досліджень було з'ясувати особливості впливу інокуляції коренів мікоризними грибами на реакцію черешні для розробки стратегій управління виробництвом плодової продукції. Дослідження проводили протягом 2018-2020 рр. у черешневому саду Південної степової підзони України. Використані такі методи досліджень, як польовий, лабораторний, біохімічний, фізіологічний і статистичний. Досліджено закономірності впливу мікоризних грибів на загальний уміст вологи та водоутримувальну здатність листків черешні. У перший рік досліджень за інокуляції коренів ендомікоризою ці показники були вищими порівняно з контролем. З'ясовано позитивний

вплив ендо-ектомікоризи на водоутримувальну здатність листків черешні. Визначено загальну листкову поверхню і уміст зелених пігментів у листі, як одних із основних показників фотосинтетичного потенціалу плодової культури. Встановлено наслідки інокуляції коренів черешні мікоризними грибами на співвідношення хлорофілів (a/b) у листках. Визначено параметри умісту загального азоту, фосфору і калію у листках черешні. Використання мікоризних грибів забезпечує підвищення адаптаційних властивостей дерев черешні до стресових чинників, а саме посушливих умов Півдня України. Результати досліджень можуть бути використані виробниками плодової продукції для удосконалення кліматично оптимізованих технологій, що забезпечить суттєве зменшення ризиків, можливих економічних втрат і збереження біорізноманіття

Ключові слова: ендомікориза; ектомікориза; площа листя; *Prunus avium*; водоутримувальна здатність; хлорофіл; основні елементи живлення

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Synergism of a mixture of phosphine and carbon dioxide in fumigation against bean weevils

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Abstract. The study is devoted to searching for alternatives to methyl bromide – a universal fumigant restricted in use at the request of the Montreal Protocol. Purpose: to determine the synergy of a mixture of phosphine and carbon dioxide in their various concentrations and exposures during the fumigation of leguminous products against pests at high temperatures. Methods: analytical review on the subject of research, the current regulatory framework in the field of disinfection; analysis of biological features of insect pests of leguminous products; experimental – a variation of different concentrations of phosphine, duration of exposure and temperature to establish a synergy of fumigant with carbon dioxide in laboratory conditions with appropriate equipment; mathematical and statistical – using computer mathematical functions built into the Microsoft Excel program 2003. When fumigating gas mixtures against pests at the imago stage, the optimal concentration of carbon dioxide is in the range of 110-130 g/m^3 (or 5.5-6.5% of the total air volume), regardless of the temperature indicator. While the optimal concentration of phosphine at low temperatures (21-22°C) is in the range of 0.57-0.82 g/m^3, at high temperatures – (31-32°C) – in the range of 0.21-0.36 g/m^3. With an increase in the duration of fumigation, not only the effectiveness of phosphine (standart) against the imago pests but also gas mixtures. In addition, the dependence of gas synergy on the duration of fumigation was established. Thus, at a temperature of 30°C, an increase in gas synergy in the mixture was observed by 4.4±0.66, 7.7±1.61, and 10.3±1.08% compared to the standard for exposure of 2, 4 and 6 hours, respectively. Temperature was the most determining factor influencing the value of the gas synergy index in the mixture of phosphine and carbon dioxide. Thus, an increase in temperature from 30°C to 32°C contributed to an increase in the gas

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synergy index by 9%, that is, by 2.17 times. Further establishment of lethal standards and fumigation regimes against pests, including quarantine ones, can prevent economic damage from these pests in Ukraine and will contribute to the implementation of the decisions of the Montreal Protocol aimed at protecting the environment and preventing the destruction of the ozone layer

Keywords: alternative to methyl bromide; concentration; duration of exposure; temperature; pests

INTRODUCTION

The problem of preserving crops from pests of leguminous stocks, as well as preventing economic losses from the penetration and spread of regulated quarantine species in Ukraine is extremely important. The quarantine pests of leguminous products that can enter and acclimatise on the territory of Ukraine are Chinese (Chinese *Callosobruchus chinensis* L.) and cowpea weevils (*Callosobruchus maculatus* Fabre).

Given the fact that these organisms are pests of stocks and are already present on the territory of European countries, the probability of their entry and acclimatisation on the territory of Ukraine is quite high. Therefore, as of 2021, the distribution area of *C. chinensis* occupies 7 countries in Europe, in particular, the Czech Republic and Bulgaria (CABI digital library, 2021). Furthermore, A. Singh, T. Boopathi (2022) indicate a high breeding potential of the pest. They prove that the relative growth rate of *C. chinensis* can be 0.101±0.006 mg/day. Kébé Khadim *et al.* (2017) claim that the spread of *C. maculatus* is related to the trade of its main host plant *Vigna unguiculata*. Kalpna *et al.* (2022) note that these pests can cause up to 20% of crop losses during storage. Price *et al.* (2017) during the studies, observed the adaptation of *C. maculatus* to 6 new host plants.

Fumigation in the plant protection and quarantine system is one of the most effective radical ways to control pests. Wöhr & Frey (2020) developed a detailed algorithm for limiting the use of methyl bromide until it is completely stopped. Among the existing fumigants that could be used as a substitute for methyl bromide, the choice is very limited. The most common is phosphine. Yet along with its relative safety in use, this fumigant has a number of disadvantages, in particular, pest resistance to phosphine. Thus, Nayak *et al.* (2020) established that the problem of pest resistance has worsened over the past two decades, mainly due to the lack of suitable alternatives that meet the main characteristics of phosphine, including its low price, ease of use, and compatibility with most storage conditions.

In addition, the problem is aggravated by the fact that only one fumigant is registered in Ukraine – phosphine, or its solid preparative forms with two active substances: aluminium phosphide or magnesium. Resistance of some pests to phosphine is not uncommon, which is noted by researchers. Thus, Konemann *et al.* (2017) indicate that the level of resistance in the most persistent populations of *Cryptolestes ferrugineus* was 133.5 times higher than in the sensitive laboratory population. Holloway *et al.* (2016) prove that 24 populations of *Sitophilus oryzae* were diagnosed as resistant to phosphine in Australia.

In recent years, studies have been actively conducted with mixtures of various gases to establish their possible synergy against harmful organisms. Rajendran & Somiahnadar (2020) indicate that the success of pest control lies in the individual approach and the use of several methods and/or combined treatment methods, including mixtures of gases. For example, Klechkovsky & Neamtsu (2020) prove that quarantine treatment by fumigation of fresh potato tubers with a mixture of carbon dioxide and methyl bromide against the quarantine pest – potato tuber moth is possible with the consumption rate of CH_3Br 4 times lower than its dosage applied in its pure form.

Cho *et al.* (2020) show that fumigation with ethyl formate mixtures with a concentration of 16 mg/L and PH_3 0.1 mg/L for 4 hours, can ensure the complete death of imago and nymphs of these pests. However, Kwon *et al.* (2023) focus on the fact that the phytotoxic effect of the examined gas mixtures on live plants was considerably lower, in contrast to brommethyl.

There are data on the insecticidal effect of essential oils (an alternative to the chemical method) against *C. maculatus* and *C. chinensis*. Thus, Gupta *et al.* (2023) note that the action of extracts from such plants as *Acorus calamus, Lavandula angustifolia*, and *Cedrus deodara* against *C. chinensis* at parameters of 92.18-118.54 μL/L, and *A. calamus, L. angustifolia and Pinus wallichiana* against *C. maculatus* at parameters of 204.01-312.23 μL/L, ensured 50% death of pests.

Gad *et al.* (2021) observed 100% efficiency of ozone exposure in the imago stage of these pests. However, the inactive stages (eggs and pupae) were stable. Weining Cheng *et al.* (2013) conducted experiments under two modified atmospheric conditions: (1) 2% O_2+18% CO_2+80% N_2 and (2) 2% O_2+98% N_2. Both hypoxic environments substantially affected the development and survival of all stages of the development of *C. maculatus*. Manar *et al.* (2021) present the results of studies on the 100% effectiveness of fumigation with ECO2FUME against these pests. In addition, the germination rate of fumigated legume seeds was higher than in the control group. However, the researchers did not determine the effectiveness of synergy of mixtures.

Thus, the purpose of this study is to examine the toxic effect of a mixture of phosphine and carbon

dioxide and their synergy against pests under various fumigation parameters.

MATERIALS AND METHODS

The study was conducted in the Transcarpathian Territorial Plant Quarantine Centre of the Plant Protection Institute of the National Academy of Agrarian Sciences of Ukraine in 2014-2015. The research was continued at the Institute of Electron Physics, National Academy of Sciences of Ukraine in 2021-2022.

Experiments were conducted under laboratory conditions in fumigation chambers (with a capacity of 30 litres). For this purpose, devices for measuring the concentration of fumigants were used – a PhD-Lite gas analyser, ШІ-11 interferometer, developed device (Mamontov & Romanko, 2010) for obtaining and dosing gases, measuring high concentrations of phosphine, and other necessary laboratory equipment. A thermostat was also used for fumigation at high temperatures.

When conducting laboratory tests of a mixture of phosphine and carbon dioxide, the developed neutral gas dispenser was used, which provided the required dosage in the range from 200 to 2500 ml. For conducting research, the preparative form of phosphine "Magtoxin" (tablet form), carbon dioxide in cylinders was used. Biomaterial for experiments was diluted in the laboratory.

The objects of the study were: the efficiency and synergy of mixtures of phosphine and carbon dioxide gases, the bean weevil at the imago stage (*Acanthoscelides obtectus*), as a biologically close species of quarantine pests absent on the territory of Ukraine to *C. chinensis* and *C. maculatus*.

The effectiveness of phosphine in a mixture with carbon dioxide was determined by the Abbott formula:

$$C\% = \frac{(P_k - P_0)}{P_k} * 100 \quad (1)$$

where: *C%* – pest death, %; R_k – pest death in control, %; R_o – pest mortality in the experiment,%.

The efficiency of gas mixtures was determined based on the indicator of the product of concentration by time (hereinafter referred to as PCT), which is expressed in units of hours.

The studies aimed to determine the effectiveness of phosphine gases with carbon dioxide against pests of leguminous products under various fumigation parameters: temperature conditions from 21 to 32°C, exposures from 2 to 20 hours and phosphine concentrations from 142 ppm (0.20 g/m^3) up to 702 ppm (1.03 g/m^3), carbon dioxide concentrations from 2.6 to 10.2% (i.e. 52.69 to 204.59 g/m^3), $PCT_{by\ phosphine}$ in the range of 0.95-8.08 h*g. Statistical data processing was performed using computer mathematical functions built into Microsoft Excel 2003. Studies with mixtures of gases (phosphine with carbon dioxide) were conducted at the sublethal level of poisoning to identify gas synergy or lack thereof.

The examination of the toxic effect of a mixture of phosphine and carbon dioxide in their various concentrations and exposures during the fumigation of leguminous products against pests was conducted in the following sequence:

A) First, the optimal concentrations of phosphine and carbon dioxide were determined, which would provide the highest synergy of gases. Several variants of the experiment were conducted to do this. Variants of each experiment were: *the examined mixture of gases* (phosphine with carbon dioxide), *standard* (separate action of phosphine), and *control* (non-fumigated pests that were kept at the same temperatures as fumigated ones). After fumigation was completed, species were recorded and average values of insect death were established. The value of the gas synergy indicator was established when determining the difference in insect death between *a mixture of gases* and *standard*.

Various concentrations were tested to determine the optimal concentrations of phosphine and carbon dioxide, which provided the highest synergy of gases, in particular, phosphine 0.2-0.36 g/m^3, 0.54-0.65 g/m^3 and 0.81-1.03 g/m^3, in variations with carbon dioxide 55-60 g/m^3, 110-120 g/m^3, and 200-210 g/m^3, provided that other fumigation parameters, such as temperature and exposure, are the same (Romanko & Dudynska, 2023).

B) After establishing the optimal concentrations of phosphine and carbon dioxide in the mixture, experiments were conducted to determine the effect of the duration of exposures on the synergy index of a mixture of phosphine and carbon dioxide during the fumigation of leguminous products against pests. For this purpose, at the already established optimal concentrations of phosphine and carbon dioxide, experiments were conducted at various exposures (2, 4, 6 and 20 hours). As in previous experiments, the value of the gas synergy indicator was established when determining the difference in insect death between *a mixture of gases* and the *standard*.

C) After establishing optimal concentrations of phosphine and carbon dioxide in the mixture and exposures, experiments were also conducted to determine the effect of temperatures on the synergy index of a mixture of phosphine and carbon dioxide during fumigation against pests. For this purpose, at the already established optimal concentrations of phosphine, carbon dioxide and duration of exposures, four variants of experiments were tested at different temperatures (21-22, 24, 28, 30 and 32°C), provided that other fumigation parameters, in particular, gas concentrations and exposure between the variants of experiments, are the same. As in previous experiments, the value of the gas synergy indicator was established when determining the difference in insect death between *a mixture of gases* and the *standard*.

RESULTS AND DISCUSSION

The obtained research results showed the influence of phosphine and carbon dioxide concentrations on gas synergy in the mixture against the pest at the imago stage. Thus, in experiments with mixtures of phosphine gases (average concentration of 0.81 g/m³) and carbon dioxide (52.69 g/m³), an increase in the death rate of adult pests was observed by 3.0±0.57%, compared to the standard (namely, gas synergy) with similar fumigation parameters (temperature 21-22°C, exposure for 6 hours, phosphine concentration in the range of 0.81-0.82 g/m³, $PCT_{by\ phosphine}$ within 4.85-4.93 h*g) (Fig. 1).

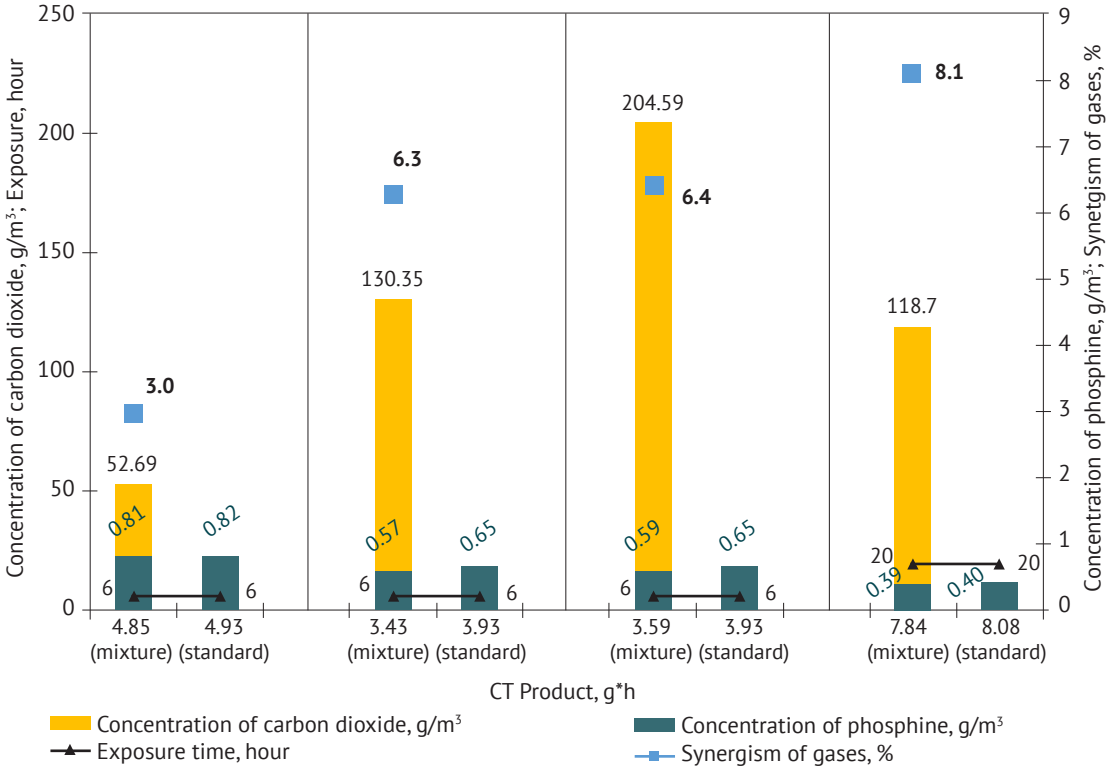

Figure 1. *Dependence of gas synergy on its concentrations and duration of exposures during fumigation against imago pests at a temperature of 21-22°C (laboratory experiments, 2014-2015, 2021-2022)*

Source: *compiled by the authors*

An increase in the concentration of carbon dioxide, even if lower concentrations of phosphine were used, contributed to an increase in the gas synergy index. Thus, in experiments with mixtures of phosphine gases (average concentration 0.57 g/m³) and carbon dioxide (130.35 g/m³), an increase in the pest death rate was observed by 6.3±0.43%, compared to the standard for similar fumigation parameters (temperature 21-22°C, exposure 6 hours, phosphine concentration in the range of 0.57-0.65 g/m³, $PCT_{by\ phosphine}$ in the range of 3.43-3.93 h*g). That is, in comparison with the previous experiment, an increase in the concentration of carbon dioxide by 2.47 times, even if lower concentrations of phosphine are used from 0.81 to 0.57 g/m³, contributed to a 2.1-fold increase in gas synergy (namely, by 3.3%) (Fig. 1).

However, a further increase in carbon dioxide concentrations above 130.35 g/m³ did not considerably affect the synergy of gases (with the same fumigation parameters: temperature 21-22°C, exposure 6 hours). Thus, in experiments with mixtures of phosphine gases (average concentration 0.59 g/m³) and carbon dioxide (204.59 g/m³) a higher pest death rate of 6.4±0.29% was observed, compared to the standard for similar fumigation parameters (temperature 21-22°C, exposure of 6 hours, phosphine concentration in the range of 0.59-0.65 g/m³, $PCT_{by\ phosphine}$ in the range of 3.93-3.59 h*g). That is, a further increase in the concentration of carbon dioxide by 1.57 times almost did not contribute to an increase in gas synergy, compared to the previous experiment, where the concentration of carbon dioxide was 130.35 g/m³.

The results of studies showed that the toxicity of gas mixtures was mainly affected by the duration of exposure, even when using phosphine concentrations below 0.59 g/m³. Thus, in experiments with mixtures of phosphine gases (average concentration of 0.39 g/m³) and carbon dioxide (118.70 g/m³) an increase in the pest death rate by 8.1±0.83% was observed, compared to the standard for similar fumigation parameters

(temperature 21-22°C, exposure of 20 hours, phosphine concentration in the range of 0.39-0.40 g/m^3, $PCT_{by\ phosphine}$ in the range of 7.84-8.08 h*g). Therefore, in comparison with the previous experiment, increasing the duration of fumigation from 6 hours to 20 not only reduced the concentration of phosphine from 0.59 to 0.39 g/m^3 and carbon dioxide from 204.59 to 118.70 g/m^3, but also increased the synergy index from 6.4±0.29 to 8.1±0.83% (1.27 times) (Fig. 1).

Thus, the average phosphine concentrations in the range of 0.39-0.82 g/m^3 were established and carbon dioxide 52.69-130.35 g/m^3, which provide a synergy of gas mixtures in the range of 3.0-8.1% against pests at the imago stage at a temperature of 21-22°C and exposure within 6-20 hours. Subsequent studies have shown the possibility of detecting gas synergy even at phosphine concentrations below 0.39 g/m^3, however, at high temperatures (Fig. 2).

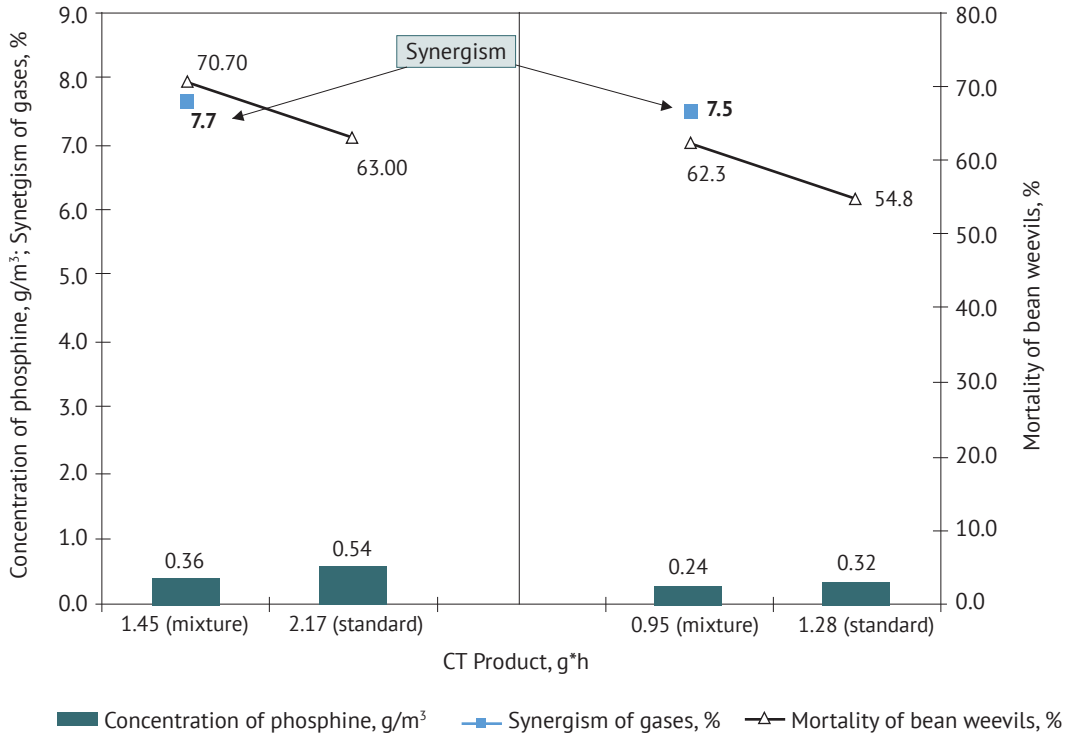

Figure 2. *A synergy of gases in the mixture during fumigation against imago pests at a temperature of 30°C (laboratory experiments, 2014-2015, 2021-2022)*
Note*: the concentration of carbon dioxide in the mixture is 116.48 g/m^3*
Source: *compiled by the authors*

Thus, in experiments with mixtures of phosphine gases (average concentration of 0.36 g/m^3) and carbon dioxide (116.48 g/m^3), an increase in the pest death rate by 7.7±0.53% was observed, compared with the standard for similar fumigation parameters (temperature 30°C, exposure of 4 hours, phosphine concentration 0.54 g/m^3, PCT of the standard 2.17 h*g). Further reduction of the phosphine concentration in the gas mixture to 0.24 g/m^3 (1.5 times) did not substantially reduce (only by 0.2%) the synergy of gases during fumigation against the pest at the imago stage (Fig. 2).

It was established that with an increase in the duration of fumigation, not only the effectiveness of phosphine (standard) against the imago pest increased, but also the efficiency of gas mixtures. Thus, for an exposure of 2 hours and a temperature of 30°C, $PCT_{by\ phosphine}$ in a mixture of 1.28 h*g; $PCT_{by\ phosphine}$ in the standard of 2.06 h*g, the death of the imago pest was observed only at the level of 35.80±1.98% (in the standard) and 40.20±2.61% (in the mixture). An increase in the duration of fumigation to 4 hours at similar PCT and the same temperature led to an increase in pest death to 63.0±3.64% (in the standard) and 70.7±3.90% (in a mixture of gases). A further increase in exposure to 6 hours contributed to an even higher efficiency of both phosphine and its mixture with carbon dioxide, where their efficiency with similar fumigation parameters was 79.8±3.07% and 90.1±4.13%, respectively.

A tendency to influence the duration of fumigation on the indicator of the synergy of mixtures of phosphine and carbon dioxide gases against pests at the imago stage was also observed. Thus, for an exposure of 2 hours and a temperature of 30°C, an increase in gas synergy in the gas mixture was observed by 4.4±0.66%

compared to the standard ($PCT_{by\ phosphine}$ in a mixture of 1.28 h*g; $PCT_{by\ phosphine}$ in the standard of 2.06 h*g). While at an exposure of 4 hours and a temperature of 30°C, an increase in gas synergy was observed at the level of 7.7±1.61%, compared to the standard ($PCT_{by\ phosphine}$ in a mixture of 1.45 h*g; $PCT_{by\ phosphine}$ in the standard of 2.17 h*g). That is, an increase in the duration of fumigation from 2 to 4 hours led to an increase in gas synergy by 3.3% (from 4.4±0.66 to 7.7±1.61%). A further increase in the duration of fumigation to 6 hours also led to an increase in the gas synergy index by 2.6% (from 7.7±1.61 to 10.3±1.08%) for similar fumigation parameters (temperature 30°C; $PCT_{by\ phosphine}$ in the mixture in the range of 1.25-1.45 h*g; $PCT_{by\ phosphine}$ in the standard of 2.01-2.17 h*g) (Fig. 3).

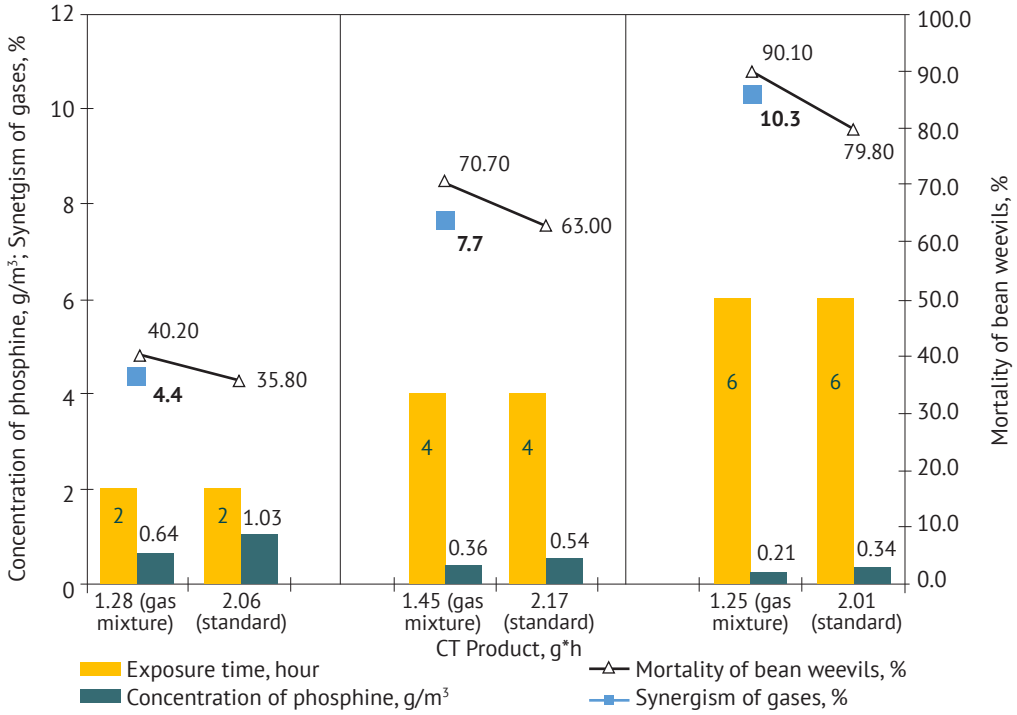

Figure 3. *Dependence of gas synergy on the duration of exposure during fumigation against imago pests at a temperature of 30°C (laboratory experiments, 2014-2015, 2021-2022)*
Note: *the concentration of carbon dioxide in the mixture is 116.48 g/m³*
Source: *compiled by the authors*

Thus, according to the results obtained, at a temperature of 30°C, an increase in gas synergy in the mixture was observed by 4.4±0.66, 7.7±1.61 and 10.3±1.08% compared to the standard for exposure of 2, 4 and 6 hours, respectively (PCT for phosphine in the mixture in the range of 1.25-1.47 h*g; PCT for phosphine in the standard in the range of 2.01-2.17 h*g).

A substantial increase in the efficiency of phosphine and its mixture with carbon dioxide depends on the temperature. Thus, at a temperature of 24°C, the death rate of an imago pest in the standard was 24.9±0.92%, and in a mixture of gases – 28.4±1.02 %. At a temperature of 28°C, the efficiency of the standard was at the level of 44.9±0.41%, and the gas mixture – 50.5±1.03%. At a temperature of 30°C, even greater efficiency was observed in the standard of 63.0±3.67 % (standard) and 70.7±3.90% (mixture of gases). The highest efficiency of phosphine and its mixture (up to 78.7±1.14 %) with carbon dioxide was observed at a temperature of 32°C.

Notably, the obtained results confirmed the influence of temperature on the synergy of mixtures of phosphine gases with carbon dioxide against pests at the imago stage. Therefore, when the temperature increased, an increase in the synergy of gases in the mixture against the pest at the imago stage was observed.

Thus, a temperature growth from 24 to 28°C led to an increase in the synergy index of gas mixtures from 3.5±0.40 to 5.6±0.73% for similar fumigation parameters (exposure of 4 hours, phosphine concentration in the standard in the range of 0.53-0.56 g/m³; a mixture of 0.32-0.35 g/m³; carbon dioxide concentration of 116.48 g/m³; for *standard* $PCT_{by\ phosphine}$ within 2.12-2.23 h*g, for *mixtures* $PCT_{by\ phosphine}$ within 1.28-1.39 h*g) (Fig. 4). A further increase in temperature by two degrees (from 28 to 30°C) led to an increase in the synergy index of gas mixtures by 2.1% (from 5.6±0.73 to 7.7±1.61% with similar fumigation parameters (exposure of 4 hours, phosphine concentration in the standard in the range of 0.53-0.54 g/m³; a mixture of 0.35-0.36 g/m³; carbon dioxide concentration 116.48 g/m³; for *standard* $PCT_{by\ phosphine}$ within 2.12-2.17 h*g, for *mixtures* $PCT_{by\ phosphine}$ within 1.39-1.45 h*g).

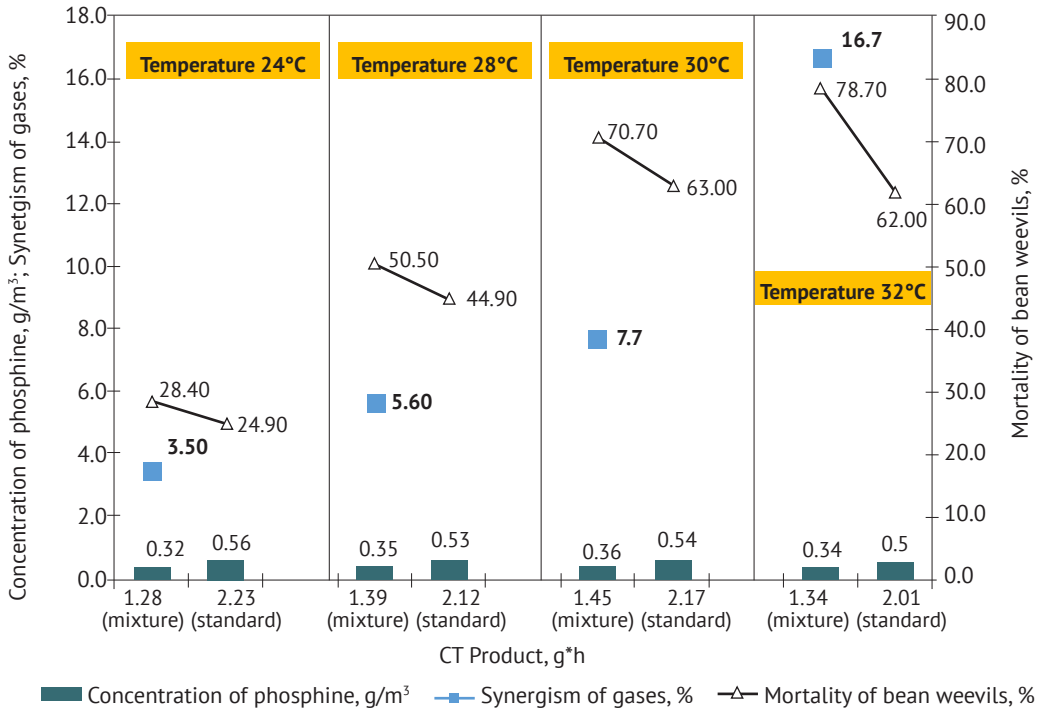

Figure 4. *Dependence of gas synergy on temperature during fumigation against imago pests (laboratory experiments, 2014-2015, 2021-2022)*
Note: *the concentration of carbon dioxide in the mixture is 116.48 g/m³, exposure time – 4 hours*
Source: *compiled by the authors*

The highest synergy of gas mixtures (16.7±0.52%) was observed at a temperature of 32°C with the following parameters: exposure of 4 hours, average phosphine concentration 0.34 g/m³, carbon dioxide 116.48 g/m³ for *mixtures* $PCT_{by\ phosphine}$ 1.34 h*g. While the average phosphine concentration in the standard was 0.5 g/m³, and the PCT is 2.01 h*g. Notably, the increase in temperature from 30 to 32°C led to an increase in the gas synergy index by 9%, that is, by 2.17 times.

Thus, at temperatures of 24, 28, 30, and 32°C, there was an increase by 3.5±0.40, 5.6±0.73, 7.7±1.61 and 16.7±0.52%, respectively, of imago *A. obtectus* mortality under the action of mixtures of phosphine with carbon dioxide in comparison with the standard. Fumigation at a temperature of 30-32°C allowed to use low concentrations of phosphine, in the range of 0.21-0.36 g/m³, which contributed to a reduction in phosphine costs by 33.3-38.6% compared to the standard.

Notably, the indicator of gas synergy can be affected not only by fumigation parameters but also by the variety of pests and disinfection methods. Thus, Klechkovsky & Neamtsu (2019) stated that a mixture of methyl bromide and carbon dioxide can provide 100% death of *Frankliniella occidentalis* Perg, reducing the dosage of fumigant by 1.6-2 times.

Whereas, Neamtsu (2018) claims that when using carbon dioxide in mixtures with methyl bromide, the lethal rate (product of concentration by exposure time) against *Aleyrodes proletella* can decrease even by 3-3.8 times. Therewith, the efficiency of 100% fumigation was observed. The author claimed that the above result was achieved due to an increase in temperature to 31°C. This is due to the fact that the heated gaseous mixture of carbon dioxide and a toxic agent (fumigant) is capable of their rapid and thorough physical mixing, as well as due to the increase in the diffusion process tenfold, active transportation to the respiratory system of the pest.

Jagadeesan *et al.* (2018) proved that fumigation with mixtures of phosphine and sulfuryl fluoride did not lead to resistance of such major grain insect pests as *Sitophilus oryzae* and *Cryptolestes ferrugineus*. In addition, the researchers determined the synergy of the mixtures, compared not only with the individual action of phosphine but also with sulfuryl fluoride. Thus, at a temperature of 25°C, fumigation with mixtures PH_3 with SO_2F_2 led to a decrease in the concentration of phosphine in the range of 2.5-4.2 times, depending on the type of pest. For example, the use of a mixture of fumigants allowed to reduce phosphine consumption from 14.2-14.5 to 5.6-6.36 mg/l and from 2.71-5.03 to 0.93-1.2 mg/l respectively, for *C. ferrugineus* and *S. oryzae*. Therewith, a high (99.9%) fumigation efficiency was observed.

Based on the above data, the synergy indicator is influenced not only by the selection of fumigation parameters but also by the variety of pests.

Jagadeesan *et al.* (2021) confirmed that the synergy of mixtures of sulfuryl fluoride and phosphine can be achieved in two ways: their joint action during continuous 168 hours (PH_3+SO_2F_2) and sequentially for two periods of 78 hours, during which the insects were first

exposed to sulfuryl fluoride and then phosphine with 12-hour aeration ($SO_2F_2 \rightarrow PH_3$). Continuous application of gas mixtures for two fumigation parameters as for sulfuryl fluoride 185 + phosphine 168 g hm^{-3}, and as for SO_2F_2 370+PH_3 84 g hm^{-3}, provided full control over imago and eggs of *Cryptolestes ferrugineus*. The above disinfection parameters were also efficient with the consistent use of fumigants. Notably, regardless of the methods of application, individual actions of the examined fumigants did not ensure the complete death of the pest, even at the imago stage.

Manivannan *et al.* (2016) examined various populations of phosphine-resistant *Rhyzopertha dominica* at different concentrations of fumigant and its mixtures with 10, 20, and 30% carbon dioxide at diverse time intervals at 25°C. Gas synergy was detected at all proposed exposures (lasting 4, 6, and 7 days) compared to a single phosphine action. Adding 30% carbon dioxide to low phosphine concentrations and a 4-day exposure time provided a better synergistic effect during fumigation. Studies have shown that carbon dioxide enhances the toxic effects of phosphine, thereby reducing the concentration and exposure time during fumigation against different populations of *R. dominica*.

Constantin *et al.* (2020) noted that fumigation of phosphine with carbon dioxide against *Cryptolestes ferrugineus* provides 2.8-fold savings in fumigant (the fumigant concentration was reduced from 16.2 to 5.8 mg/litre). A comparison of pest death data from a separate phosphine action (standard) and a pH mixture$_3$+CO_2 showed that carbon dioxide increases phosphine toxicity. These results were confirmed by three independently obtained populations of *C. ferrugineus* in field conditions, which differed in resistance. Studies have confirmed the synergy of gas mixtures observed in all the examined pest populations, including highly resistant ones. Thus, this study is consistent with the literature data, primarily on the effect of various fumigation parameters (temperature, duration of exposure, and gas concentration) on gas synergy.

CONCLUSIONS

The synergism and toxic effect of a mixture of phosphine and carbon dioxide against pests was examined under various fumigation parameters. Optimal concentrations of phosphine in the mixture at which synergy was observed during fumigation against adult pests were established: at low temperatures (21-22°C) – in the range of 0.57-0.82 g/m^3; at high temperatures (31-32°C) – in the range of 0.21-0.36 g/m^3.

The optimal concentration of carbon dioxide, at which its substantial effectiveness was shown, was in the range of 110-130 g/m^3 (or 5.5-6.5% of the total air volume), regardless of the temperature indicator. The effect of fumigation duration on the efficiency and synergy of gases in the mixture was observed. Namely, there was a clear trend: with an increase in the duration of fumigation, both the efficiency of action and the indicator of the synergy of gas mixtures increased. The highest synergism in fumigation against imago pests was 10.3±1.08%.

The temperature was the most substantial factor influencing the value of the gas synergy index in a mixture of phosphine and carbon dioxide. The highest rates of the synergy of gas mixtures were noted precisely at high fumigation temperatures (32°C) against imago pests (16.7±0.52%).

The use of high temperatures and relatively long exposures allowed using low concentrations of phosphine in a mixture of gases in the range of 0.21-036 g/m^3, and, as a result, this contributed not only to reducing the cost of phosphine to 38.6% compared to the standard, but it also did not affect the decrease in the value of the synergy indicator of gas mixtures.

The results obtained indicate the need for further research, in particular, the investigation of the toxic effect of gas mixtures against different populations of pests at their various stages of development. It is also vital to establish the possibility of obtaining 100% pest death, including at the pupal and egg stages with the prospect of using mixtures of phosphine and carbon dioxide and in quarantine fumigation.

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None.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Синергізм суміші фосфіну та вуглекислого газу при фумігації проти зерноїдів

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Анотація. Робота присвячена пошуку альтернатив бромистому метилу – універсального фуміганта, який був обмежений у застосуванні на вимогу Монреальського протоколу. Мета: визначити синергізм суміші фосфіну та вуглекислого газу у різних їх концентраціях та експозиціях при фумігації зернобобової продукції проти зерноїдів за високих температур. Методи: аналітичний огляд з тематики досліджень, чинній нормативно-правовій базі у галузі знезараження; аналіз біологічних особливостей комах-шкідників зернобобової продукції; експериментальний – варіювання різних концентрацій фосфіну, тривалості експозиції та температури для встановлення синергізму фуміганта із вуглекислим газом у лабораторних умовах за відповідного обладнання; математико-статистичний – за допомогою комп'ютерних математичних функцій, вбудованих у програму Microsoft Excel 2003. При фумігації сумішей газів проти зерноїдів на стадії імаго оптимальна концентрація вуглекислого газу знаходиться в межах 110-130 г/м^3 (або 5,5-6,5 % від загального об'єму повітря) незалежно від температурного показника. Тоді як оптимальна концентрація фосфіну за невисоких температур (21-22 °С) – в межах 0,57-0,82 г/м^3, а при високих (31-32 °С) – в діапазоні 0,21-0,36 г/м^3. При збільшенні тривалості фумігації підвищувалася не лише ефективність фосфіну (еталону) проти імаго зерноїда, а також і ефективність сумішей газів. Крім того виявили залежність синергізму газів від тривалості фумігації. Так, за температури 30 °С спостерігали підвищення синергізму газів у суміші на 4,4±0,66, 7,7±1,61 та 10,3±1,08 % порівняно з еталоном за експозиції 2, 4 та 6 годин відповідно. Температура виявилася найбільш визначальним фактором, що впливав на значення показника синергізму газів у суміші фосфіну з вуглекислим газом. Так, підвищення температури з 30 до 32 °С сприяло збільшенню показника синергізму газів на 9 %, тобто у 2,17 разів. Подальше встановлення летальних норм та режимів фумігації проти зерноїдів в тому числі і карантинних дозволяють запобігти економічних збитків від даних шкідників в Україні і будуть сприяти виконанню рішень Монреальського протоколу, спрямованого на охорону довкілля і запобіганню руйнування озонового шару

Ключові слова: альтернатива бромистому метилу; концентрація; тривалість експозиції; температура; зерноїди

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Codling moth (*Cydia Pomonella*) control using sex pheromones and environmentally friendly insecticides

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Abstract. The research relevance on *Codling moth* peculiarities is predefined by it being a main threat to apple culture. The sensitivity of apple cultivars that have been planted so far and continue to be planted to this pest diverges in different cultivars. The research aims to determine the main elements of *Cydia Pomonella* control using sex pheromones and environmentally friendly insecticides. To achieve the goal, an experiment was conducted in the village of Dvoran in the Korcha region on three apple cultivars: Golden Delicious, Star King, and Granny Smith. On the trees of these varieties, traps with sex pheromones were used and environmentally friendly insecticides were utilised. The study found that using sex pheromone traps to monitor *Cydia Pomonella* is simple and less expensive for apple growers. The Spinosad medicine is the most effective

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in terms of protection against the pest, the second being Indoxacarb. Golden Delicious and Granny Smith cultivars had the lowest level of pest infestation, while the Star King cultivar was the most affected by *Cydia Pomonella*. It has also been established that apple fruits do not contain toxic residues, and the ecosystem remains clean. Additionally, the use of sex pheromones can be part of an integrated pest management approach that combines different control methods to sustainably manage pest populations in gardens. The practical significance of the obtained results is that they provide apple growers with a safe and effective method of controlling *Cydia pomonella* populations in their orchards. In addition, the scientific basis for the use of sex pheromones as a method of pest control can contribute to the implementation of sustainable control methods in apple production

Keywords: codling moth; chemical preparations; bioinsecticides; pheromone; environment

INTRODUCTION

The Codling moth (*Cydia pomonella*) is a pest that causes significant damage to fruit crops. It can destroy fruits, affect their size, deteriorate crop quality, and cause various diseases (Kadoić *et al.,* 2020). Therefore, studying and developing methods of protection against *Cydia pomonella* defines the research relevance.

Codling moth in times was and remains the most troublesome pest that damages apple production worldwide (Pajač *et al.,* 2011). Scientific sources claim that it originates from the Palearctic regions but has spread along with the cultivation of apples in warm regions, namely New Zealand, Europe, China, Australia, and America (Bradley *et al.*, 1979). Albania has very favourable conditions for the development of its entire life cycle, giving two to three generations per season. Affected fruits can be distinguished from healthy ones, as they are smaller and more intensely coloured. These fruits usually fall on the ground prematurely.

One of the most effective methods for controlling *Cydia pomonella* is the use of sex pheromones. These are special substances that are produced by female *Cydia pomonella* individuals and attract males. Sex pheromones can be used to set traps, which allows for the capture of males and reduces their population (Nottingham *et al.,* 2022).

Following A.L. Knight *et al.* (2019), the use of sex pheromones can be an effective means of controlling *Cydia pomonella* populations. This is a safe and environmentally friendly method that can be used as a standalone control method or in combination with other methods, such as biological control. It is worth noting that pheromone control is safe for the environment and does not harm beneficial insects. In addition, this method is effective in the cultivation of organic crops, as it does not involve the use of chemical pesticides (DuPont & Strohm, 2019).

R.T. Carde *et al.* (2018) and Brunner *et al.* (2018) showed that the use of a combination of sex pheromones and natural insecticides reduced the *Cydia pomonella* population by 75% compared to the control group, which used only chemical insecticides. In addition, this application reduced insecticide use by 90%, which helped reduce the negative impact on the environment and human health.

M. Murray highlighted that a combination of mating disruption and the use of environmentally friendly insecticides can be an effective strategy for managing *Cydia pomonella* populations. Thus, the use of such methods resulted in a significantly lower level of pest damage for apple orchards in the state of Washington (USA) compared to the use of conventional insecticides (Murray *et al.,* 2022). In France, a study was conducted in which the use of sex pheromones reduced the number of summer caterpillars (second-generation *Cydia pomonella*) by 92% compared to the area without the use of pheromones (Paul *et al.,* 2020).

Similar data were obtained in a study on the use of environmentally friendly insecticides and in the studies by V.S.V Santos. Both insecticides were found to effectively reduce *Cydia pomonella* populations without harming beneficial insects or the environment using Bacillus thuringiensis and Spinosad (Santos *et al.,* 2020). In the case of sex-based destruction, L. Xing *et al.* (2021) also note positive results. Thus, the authors found that the use of synthetic sex pheromones reduced the number of laid eggs of *Cydia pomonella* by 95%, which led to a decrease in the total population of the pest from 62% to 96%.

A similar study on apple trees was conducted by B.M. Kadoić *et al.* (2020) according to which the use of pheromone traps helped reduce the *Cydia pomonella* population by 60-80% compared to the control group, which did not use pheromone traps. Jaffe & Landolt (2019) and M. Preti *et al.* (2021) in their research using the bacterial insecticide Bacillus thuringiensis, noted that the drug is effective in controlling *Cydia pomonella* and can reduce the pest population by 55-65%. However, the conditions and methods of application should be considered. Given the harmfulness of the Codling moth (*Cydia pomonella*) and the damage it can cause to farming, studying the possibilities of regulating its population, especially by ecological means, is particularly relevant today.

The research aims to determine the main elements of the control of the codling moth (*Cydia Pomonella*) with the help of sex pheromones and the use of environmentally friendly insecticides.

MATERIALS AND METHODS

Research structure. The experiment was conducted in the village of Dvoran, Korça region, using the three main apple cultivars: Golden Delicious, Star King and Granny Smith, for three years of study: 2019, 2020 and 2021. The age of the trees in production was 14 years. The total number of trees was 60 (including 15 trees on which environmentally friendly insecticides were applied and 5 trees of each cultivar as control variants on which no insecticides were applied).

Factor A with three levels: a1, a2, and a3 represented by the three cultivars Golden Delicious, Star King and Granny Smith. The three blocks represented the three replications. Ten apple trees of each variant were used to represent a single cultivar. Trees of each variant were labelled. Factor B with three levels: b1, b2 and b3 represents three types of drugs: 1. (Madex) a.i. Granulosevirus CpGv, 2. (Avaunt), a.i Indoxacarb and 3. Spinosad. Spraying was carried out with a backpack pump.

The first-generation treatment was carried out at the end of May, while the second-generation, was conducted in the third week of July. The treatments were carried out 4-6 days after the maximum capture of the moth in the sexual pheromones. The plot which served as a control block was left untreated with preparations. The main pheromones that are widely used are of three main types: sexual attraction pheromones, alarm behaviour pheromones, and recruitment pheromones (Regnier and Law, 1968).

The description of the FAD gene, which acts in the biosynthesis of codlemon, was carried out, and 27 FAD genes correspond to different functional classes that were identified in insects and Lepidoptera (Lassance, 2021). Sexual pheromones are emitted by the female pest to attract the male pest. "Delta Traps" produced by the Andermatt Biocontrol company were used for the experiment.

The placement and monitoring of sexual pheromone traps for the first generation were conducted in the middle of May, where two traps with the Phero Norm® pheromone were placed in a total of nine traps in the three years of the study, in the three apple cultivars taken for analysis: Star King, Golden Delicious and Grand Smith. The traps were placed inside the crown of apples at a height of 160-170 cm from the ground. Their control was carried out every day, at 10.00. The placement and monitoring of traps with sexual pheromones for the second generation was carried out after July 10th and for their monitoring, the same procedure was followed as for the first generation. The pheromone capsule was changed once for each generation, a total of 6 pheromone capsules were used for each study year.

Average temperatures and air humidity were recorded for a period of 4 months, a period which coincides with the development of the life cycle for the generations of codling moths: May, June, July, and August, for the three years: 2019, 2020, and 2021.

Research limitations. The drugs used are included in the integrated pest and disease plant protection recommendations (Biological Control Program, 2022).

Madex is used in many developed countries as a biocontrol agent for controlling codling moths as a very serious pest, especially in apple production in both organic and integrated programmes. This Bioinsecticide is environment friendly. The challenge to the successful application of this drug against the codling moth is the development of resistance against some commercial products of CpGV (Wennmann *et al.*, 2021). Granuloviruses are enclosed within a protein capsule, which protects the virus from UV radiation. The size of a viral particle is about 400 nm. Within 2-4 days, the virus infects the pest's organs, the larvae stop feeding and die. 100 ml/ha is used.

Avaunt (a.i Indoxacarb) is a dual-action drug, administered through contact and food. It was used with 0.035%, dissolved in 600 litres of water. The drug is effective during contact with the pest and when swallowed. It has a neurotoxic action by blocking sodium channels. The active substance causes the bioactivation of metabolites and gives neurotoxic effects. After the bioactivation of the active substance, the pest stops eating and then dies.

Avaunt is widely used in Integrated Pest Management programmes that include biological, agrotechnical, cultural and genetic practices which aim to prevent and reduce the economic damage that the pest may cause. Integrated Pest Management programmes include a series of practices such as finding pests in the field, identifying and monitoring pest populations, rotating insecticides and applying them when the critical action threshold determined at the local level is reached.

To avoid the development of resistance by codling moths, it is recommended to apply AVAUNT insecticide only once per generation of the codling moth. It is recommended that for the control of other generations of the pest, effective drugs with different active ingredients than the AVAUNT preparation should be used.

A natural bioactive product with very high values, this product is characterised by a complex chemical structure in its construction, which includes spinosins A and D, as well as molecules synthesised by the actinomycete *Saccharopolyspora spinosa*. The larval control activity of spinosad is a solution developed to control pests of several agricultural plants including the key apple pest codling moth as well as the control of species that transmit various diseases, including *Aedes aegypti* (Santos & Pereira, 2020). This drug is also widely used in agriculture to control a variety of pests, including codling moths. This Bioinsecticide is very friendly to the environment.

Spinosad is an insecticide with contact and eating action, causing insect paralysis. It belongs to the group of bioinsecticides. Spinosad is a natural substance

produced by soil bacteria, but it also has a toxic effect on insects. It consists of a mixture of two chemical substances called spinosyn A and spinosyn D. It has been used by dosing 25 grammes per 100 litres of water.

Statistical analysis. At the beginning of July, for the first generation and at the end of August for the second generation, 10 fruits per 10 labelled apple trees for each cultivar were analysed, for a total of 100 fruits. The percentage of infection indicates the number of affected fruits in 100 analysed fruits. The percentage of infection was calculated using the formula (1):

$$P = \frac{n \times 100}{N} \quad (1)$$

where P – infection percentage; n – is the number of fruits affected by the codling moth; N = the total number of fruits analysed for each variant.

The effectiveness of the tested preparations in reducing the number of pests was calculated using the equation (2):

$$E = \frac{(A-B) \times 100}{A} \quad (2)$$

where E_∂ – reduction of pest density after treatment, %
A – density of insects before treatment, units/m^2; B – density of insects after treatment, units/m^2

The statistical processing of the data is based on the analysis of variance ANOVA. Regression analysis predicts the outcome depending on the indicators: Cultivars (Golden Delicious, Star King and Granny Smith), the three years of the experiment 2019, 2020 and 2021 and the preparations tested Granulovirus CpGv, Indoxacarb and Spinosad.

RESULTS

During the research, 60 trees were examined, 20 trees for each cultivar. *Cydia pomonella* larvae were found in the fruits. In addition, the study established different densities of apple tree cultivars by *Cydia pomonella* larvae (Fig. 1). Thus, the lowest percentage of infection with larvae was observed in the Golden Delicious and Granny Smith cultivars and averaged 7.8% and 8.5%, respectively, over the years of research.

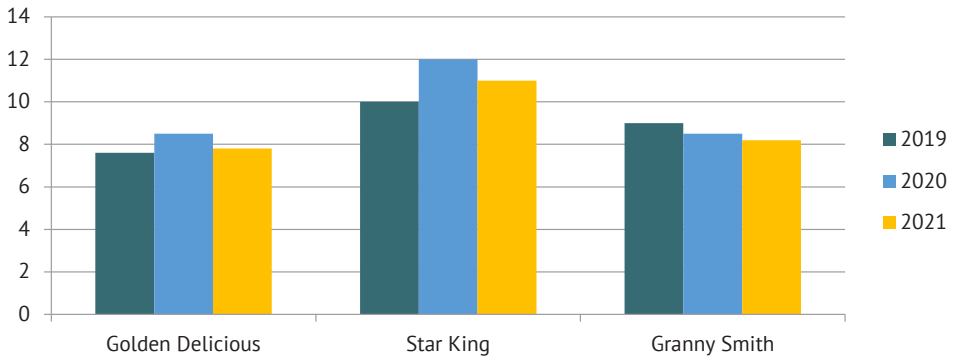

Figure 1. *Percentage of Cydia pomonella infection of apple cultivars (2020-2021)*

The emergence of *Cydia pomonella* larvae in apple varieties is associated with the choice of the female pest for egg-laying. Therefore, the characteristics of the host plant are important. Since the Star King apple variety has a high number of fruits, *Cydia pomonella* females prefer it for egg-laying. In addition, according to research, α-farnesene in fruit also affects the olfactory system of females and provokes egg-laying (Apple varieties, 2023).

The study also suggests that *Cydia pomonella* larvae may prefer the Star King variety because its fruits have a lower concentration of polyphenols compared to other varieties. Moreover, the choice of larvae could be influenced by apple fruit phytoncides and primary metabolites amino acids, sugars, etc. The data recorded from sexual pheromone traps and treatments with preparations were shown in separate tables (Table 1).

Table 1. *Pheromone trap data for 2019, 2020 and 2021*

Year	Development Stages	Cultivars					
		Star King		Golden Delicious		Granny Smith	
		First Generation	Second Generation	First Generation	Second Generation	First Generation	Second Generation
2019	Beginning of flights	21 May	14 July	20 May	15 July	21 May	15 July
	Max. flights	27 “	19 “	25 “	20 “	26 “	20 “
	Spraying	30 “	25 “	30 “	25 “	30 “	25 “
2020	Beginning of flights	18 “	14 “	19 “	16 “	22 “	14 “
	Max. flights	25 “	21 “	26 “	21 “	26 “	19 “
	Spraying	30 “	25 “	30 “	25 “	30 “	25 “

Table 1, Continued

Year	Development Stages	Cultivars					
		Star King		Golden Delicious		Granny Smith	
		First Generation	Second Generation	First Generation	Second Generation	First Generation	Second Generation
2021	Beginning of flights	19 "	15 "	19 "	16 "	20 "	15 "
	Max. flights	24 "	19 "	25 "	20 "	25 "	19 "
	Spraying	29 "	24 "	29 "	24 "	29 "	24 "

Source: *compiled by the authors*

The results show that the first flights, for both generations in the three apple cultivars, were caught almost at the same time. This coincides with May 20, for the first generation and the middle of August month for the second generation, for all three years studied. The maximum catch of male butterflies coincides with May 24 for the first generation and after August 20 for the second generation. Chemical treatments were carried out at the end of May for the first generation and after August 24 for the second generation. The sprayings gave results as they were carried out qualitatively better, with a centrifugal pump, using 1500 litres of solution per ha and the sprayer type 0.8 mm. Taking advantage of days with average daily temperatures of 16°C -19°C, no wind and no rain, the sprays gave maximum effect (Table 2).

Notably, the temperature is important for the development of *Cydia pomonella*. For example, the warmest year with the lowest humidity for the Korcha region over all the years of research was 2021, so the pest infestation was higher. In addition, the lowest temperatures and highest humidity were recorded in 2019, when the infestation was low.

Table 2. *Damage analyse data on the three cultivars studied for the three study years 2019, 2020 and 2021*

Year	Generation	Drug	Factor	Golden Delicious a1					Star King a2					Granny Smith a3				
				P1	P2	P3	∑	Avar	P1	P2	P3	∑	Avar	P1	P2	P3	∑	Avar
2019	1	Granulosevirus	b1	1	0	1	2	1.3	2	1	3	6	2	1	1	1	3	1
		Indoxacarb	b2	0	0	0	0	0	0	1	1	2	0.6	0	1	0	1	0.3
		Spinosad	b3	0	0	0	0	0	0	3	0	3	1	0	1	0	1	0.3
		Control		7	8	7	22	7.3	6	9	8	23	7.6	4	6	6	16	5.3
	2	Granulosevirus	b1	2	3	1	6	2	0	4	3	7	2.3	2	2	3	7	2.3
		Indoxacarb	b2	0	0	0	0	0	1	1	1	3	1	0	0	0	0	0
		Spinosad	b3	0	1	0	1	0.3	1	1	0	2	0.6	0	0	0	0	0
		Control		8	11	6	25	8.3	10	9	8	27	9	7	6	6	19	16.3
2020	1	Granulosevirus	b1	1	1	3	5	1.6	2	2	2	6	2	1	1	1	3	1
		Indoxacarb	b2	0	0	0	0	0	2	1	3	6	2	0	0	0	0	0
		Spinosad	b3	1	0	0	1	0.3	1	1	2	4	1.3	0	0	1	1	0.3
		Control		3	7	11	21	7	7	10	8	25	8.3	10	8	12	30	10
	2	Granulosevirus	b1	2	2	0	4	1.3	0	2	2	4	1.3	1	2	1	4	1.3
		Indoxacarb	b2	0	0	0	0	0	3	2	3	8	2.6	0	0	0	0	0
		Spinosad	b3	0	1	0	1	0.3	1	1	1	3	1	0	0	0	0	0
		Control		9	5	7	21	7	6	8	7	21	7	5	10	7	22	7.3
2021	1	Granuloseviru	b1	1	2	1	4	1.3	3	3	3	9	3	1	3	1	5	1.6
		Indoxacarb	b2	0	1	0	1	0.3	2	2	0	4	1.3	1	2	0	3	1
		Spinosad	b3	0	1	0	1	0.3	2	3	1	6	2	1	1	1	3	1
		Control		7	11	8	26	8.6	16	13	10	39	13	10	6	11	27	9
	2	Granulosevirus	b1	1	3	2	6	2	2	2	2	6	2	6	2	1	9	3
		Indoxacarb	b2	0	1	1	2	0.6	3	1	4	8	2.6	0	1	2	3	1
		Spinosad	b3	1	0	0	1	0.3	1	1	1	3	1	1	0	0	1	0.3
		Control		5	4	9	18	6	12	11	10	33	11	11	11	13	35	11.6

Source: *compiled by the authors*

Even though the lowest percentage of apple codling moth larvae infestation was found in Golden Delicious and Granny Smith, the experimental trees of all varieties were exposed to the pest. That is why biological insecticides were applied to all apple trees in the experiment, except for the control. Insecticide spraying was repeated three times, and no massive moth flight was observed at this time. Spraying had an impact on the number of pests, which determined the effectiveness of insecticide application (Table 3).

Table 3. *The efficiency of application of environmentally friendly insecticides, %*

Year	Drug	Golden Delicious	Star King	Granny Smith
2019	Granulosevirus	97.3	94.5	94.1
	Indoxacarb	97.7	96.4	97.6
	Spinosad	99.2	98.5	99.4
2020	Granulosevirus	96.1	95.4	93.3
	Indoxacarb	97.4	96.8	96.9
	Spinosad	99.1	98.1	99.4
2021	Granulosevirus	95.4	95.6	95.0
	Indoxacarb	98.4	98.2	97.2
	Spinosad	99.8	99.4	99.8

Source: *compiled by the authors*

Thus, the highest level of pest protection efficiency was demonstrated by Spinosad, which on average over the years of research showed 99.3% efficiency for Golden Delicious, 98.6% for Star King, and 99.5% for Granny Smith. The second most effective product was Indoxacarb. Thus, the combination of pheromones and environmentally friendly insecticides is an effective method of controlling *Cydia pomonella* in the apple tree protection system.

DISCUSSION

A study by F. Wan *et al.* (2019) evaluated the effectiveness of mating disruption based on pheromones in commercial apple orchards. The authors found that the use of pheromone dispensers reduced the number of *Cydia pomonella* caught in traps and the number of larvae found in fruits, resulting in improved fruit quality and increased yield.

L. Xing *et al.* (2021), who investigated the behavioural response of male codling moths to different pheromone blends, showed that males can distinguish different pheromone blends and that the ratio of pheromone components affects their response. Researchers also found that the effect of pheromone blends significantly reduces the success of mating and the number of eggs laid by females.

A. Gümüşsoy *et al.* (2020) conducted a study in which they studied the effect of pheromone dose on the behaviour of male Codling moth (*Cydia pomonella*). The authors found that higher doses of the pheromone mixture led to the stronger attraction of *Cydia pomonella* males, but also to faster habituation and reduced population over time. It is important to note that integrated pest management is an approach that combines several methods of pest control, including the use of sex pheromones and environmentally friendly insecticides, and it also involves monitoring and maintaining the garden's ecosystem. This approach can reduce reliance on synthetic insecticides and promote sustainable pest management practices.

Research by I. Pajač *et al.* (2011), V.S.V. Santos and Pereira (2020) focused on combining pheromone-based management strategies with environmentally friendly insecticides to develop integrated Codling moth (*Cydia pomonella*) control programmes. The authors note the reduction of pest populations while minimising the use of chemical pesticides, which leads to improved pest control and reduced environmental impact, which is also reflected in the research conducted (Santos & Pereira, 2020).

According to the results of M.K. Balasko *et al.* (2020), sex pheromones can be used to disrupt the mating behaviour of *Cydia pomonella* by confusing males and preventing them from finding females to mate with. This approach is effective because it does not kill the pests, but instead prevents them from reproducing, reducing the number of offspring produced. S. Yadav *et al.* (2019) note that environmentally friendly insecticides such as spinosad and Bacillus thuringiensis can also be used to control *Cydia pomonella* populations. These insecticides are derived from natural substances and do not harm people or the environment. They work by targeting specific insect pests while leaving beneficial insects unharmed, as confirmed by a study also performed.

Similar results were obtained by C.G. Adams *et al.* (2017) according to which spinosad acts by affecting the nervous system of pests, causing paralysis and, ultimately, death. Spinosad is effective against various

insect pests, including *Cydia pomonella*, and is relatively safe for non-target organisms and the environment. The results of the performed research are also echoed in the scientific works of P.M. Lösel *et al.* (2000) argue that the use of sex pheromones and environmentally friendly insecticides provides an effective, sustainable, and environmentally friendly approach to managing C*ydia pomonella* populations in fruit crops.

However, R.T. Carde *et al.* (2018) note that although environmentally friendly insecticides are effective in controlling *Cydia pomonella* populations, they should be used in conjunction with other pest management strategies, such as cultural practices and biological control, to ensure the most effective and sustainable pest control.

CONCLUSIONS

Studies on the regulation of *Cydia pomonella* by sex pheromones have shown that this method can be effective in reducing the damage caused by this pest.

The method of using sexual pheromone traps to control the codling moth is simpler and less expensive to use by apple growers. The start of the first flights for the first generation of the pest coincides with the dates after May 15 for the first generation and after July 15 for the second generation. Maximum flights occur on the third day of May for the first generation and the beginning of July (the first week) for the second generation. Interventions with preparations against codling moths are carried out at the end of May for the first generation and after July 20 for the second generation.

The higher level of effectiveness for protection from the pest results from the preparation Spinosad, statistically proven at the level of 99%, and the second preparation is Indoxacarb. The lowest rate of infection by the pest results in the cultivar Golden Delicious and Granny Smith, while the cultivar Starking is considered the most favoured by codling moth infection. The warmest year and the lowest humidity for the Korce region for all three years of study were in 2021, therefore the codling moth infection was higher. While the lowest temperatures and the highest humidity were in 2019, where the infection was also at a low level. The percentage of infection is slightly higher during the second generation. Apple fruits don't have toxic residues and the ecosystem remains clean.

In addition, the use of sex pheromones can be used as part of an integrated pest management approach that combines different control methods to sustainably manage pest populations. Combining the use of sex pheromones with other control measures, such as cultural practices, biological control, and insecticides, enables effective control of *Cydia pomonella* populations while minimising negative environmental impacts.

The practical significance of the research results is that they provide apple growers with a safe and effective way to control *Cydia pomonella* populations in their orchards. By providing a scientific basis for the use of sex pheromones as a method of pest control, this study may contribute to the introduction of sustainable control methods in apple production.

Further research should determine the optimal timing and placement of pheromone dispensers in orchards to maximise disruption of mating behaviour and minimise the risk of resistance developing in *Cydia pomonella* populations. This can help increase the effectiveness of the pest control method and reduce the cost of pheromone application.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Боротьба з яблуневою плодожеркою (*Cydia Pomonella*) за допомогою статевих феромонів та використання екологічно чистих інсектицидів

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Анотація. Плодожерка є ключовим шкідником у культурі яблуні, тому актуальним є дослідження її особливостей. Чутливість сортів яблуні, які висаджувалися і продовжують висаджуватися до цього шкідника, відрізняється у різних сортів. Метою дослідження було визначення основних елементів контролю *Cydia Pomonella* за допомогою статевих феромонів та застосування екологічно безпечних інсектицидів. Для досягнення мети було проведено експеримент у с. Дворан Корчинського району на трьох сортах яблуні: Голден Делішес, Стар Кінг та Гренні Сміт. На деревах цих сортів використовували пастки із статевими феромонами та проводили обприскування екологічно чистими інсектицидами. Дослідження показало, що використання пасток із статевими феромонами для моніторингу *Cydia Pomonella* є простим і менш витратним для виробників яблук. Препарат Спіносад має найвищий рівень ефективності захисту від шкідника, а другий препарат – Індоксакарб. Сорти Голден Делішес і Гренні Сміт мали найнижчий рівень зараження шкідником, тоді як сорт Стар Кінг був найбільш уражений *Cydia Pomonella*. Також було встановлено, що плоди яблук не містять токсичних залишків, а екосистема залишається чистою. Крім того, використання статевих феромонів може бути частиною інтегрованого підходу до управління шкідниками, який поєднує різні методи контролю для сталого управління популяціями шкідників у садах. Практичне значення отриманих результатів полягає в тому, що вони надають виробникам яблук безпечний та ефективний метод контролю популяцій *Cydia pomonella* в їхніх садах. Крім того, наукове обґрунтування використання статевих феромонів як методу боротьби зі шкідником може сприяти впровадженню сталих методів контролю у виробництві яблук

Ключові слова: яблунева плодожерка; хімічні препарати; біоінсектициди; феромон; навколишнє середовище

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Analysis of the structure and fertility of agricultural land in western Ukraine and its monetary assessment

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Abstract. An important sector of the Ukrainian economy is agriculture, which is based on the fertility of agricultural land, in particular, the land of the western region of Ukraine. Analysis of the structure, fertility of agricultural land, and its monetary valuation can provide insight into its productivity and potential for agricultural development. The purpose of the study is to analyse the structure and fertility indicators of agricultural land in the west of Ukraine, demonstrate their main characteristics, and compare land prices in the western regions of Ukraine. In the study, the materials of the land directory of Ukraine and regional reports on the state of the environment of the west of Ukraine were used, involving analysis and comparison of the state of land resources by the content of humus, mobile compounds of phosphorus and potassium, easily hydrolysed nitrogen, their material and monetary assessment. After analysing the structure of the land fund of the

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west of Ukraine (13125.5 thousand hectares), it was identified that agricultural land accounts for more than half of the total area (56.1%), and forests and other wooded zones – about a third of the total area (32.8%). Built-up land, open wetlands, open land without vegetation cover or with little vegetation cover, and other land account for less than 10%. Among agricultural land, the largest share is arable land, a little less is hayfields and pastures, and the least is perennial plantations and fallows. The total value of agricultural land in the western administrative regions is markedly different. The highest land value is in Khmelnytskyi and Ternopil regions (1.71 and 1.09 billion USD), and the smallest – in Ivano-Frankivsk and Zakarpattia (489.90 and 317.21 million USD). 1420223 shares were leased on the territory of western Ukraine. The largest number of them was leased in Khmelnitsky and Ternopil regions (25.2 and 20.7%), and the smallest – in Zakarpattia (1.0%). Thus, the total area of land cultivated by farmers is 330.8 thousand hectares, the largest in the Ternopil and Khmelnytskyi regions (23.3 and 22.7%). The findings of the study will contribute to the adoption of managerial decisions on conducting efficient agriculture and the preservation of soil fertility of agricultural lands in the region under study. Monetary assessment of these territories is useful for the country's population in the context of changes in the law on the land market in Ukraine, and in the implementation of an environmentally balanced agricultural policy

Keywords: land fund; pastures; humus; land shares; agricultural land; administrative region

INTRODUCTION

Agricultural land is vital for the development of society, as it is the main means of production for agriculture. The study of the structure and fertility of such lands is becoming increasingly relevant in the context of global climate change, as it affects the solution of a number of the following tasks, such as: ensuring food security, rational and environmentally safe land use, and environmental conservation. In addition, it is crucial to establish the material and monetary assessment of land in the context of changes in the law on the market land in Ukraine.

Agricultural land, due to climatic, social, and economic conditions, may be suitable, partially suitable, and unsuitable for farming (Kowalczyk *et al.*, 2019, 2021). A detailed examination and analysis of such features are of great importance for rational farming and reliable production (Ambros & Granvik, 2020) of agricultural products for the population in sufficient quantity.

During the last decades, the management of agriculture in Ukraine has sometimes been irrational. Often there is non-compliance with crop rotations, depletion of the soil due to the cultivation of rapeseed, corn, sunflower, and soybeans, and a substantial decrease in the application of organic and mineral fertilisers, which reduces soil fertility. The state of the fertility of agricultural land (Demianenko, 2022) depends on many indicators: the content of nutrients, the level of productivity of the arable soil layer, the conditions of land exploitation and measures for its preservation. Therefore, a detailed analysis of these indicators of individual territories can demonstrate the expediency, prospects, and even threats of conducting a particular agricultural activity there.

According to data (Demianenko, 2022), humus losses in Ukraine due to processes of mineralization and water and wind erosion have already affected about 15 million hectares of agricultural land (35% of their total area), and humus losses range from 32 to 33 million tonnes, which amounts to losses in the financial equivalent of 2 billion USD. Thus, in the future, as a result of such processes, Ukraine may lose its humus potential, which will lead to an environmental catastrophe. It will not be possible to restore it through land reclamation, agrotechnical, organisational, economic, and environmental measures, which will lead to a decrease in the agrotechnical potential of the land and soil degradation.

The purpose of the study is to analyse the structure, indicators of agricultural land fertility and its monetary valuation in the Volyn, Rivne, Lviv, Ternopil, Khmelnytsky, Zakarpattia, Ivano-Frankivsk, Chernivtsi administrative regions of Ukraine, that is, the entire territory of western lands of Ukraine.

The following research tasks were set to achieve this purpose: analyse the structure of the land fund and the structure of agricultural land in the west of Ukraine and individual administrative regions; establish the normative and monetary evaluation of agricultural land, determine the share of soil areas by the content of humus, mobile compounds of phosphorus, potassium and easily hydrolysed nitrogen, in the territory of the west of Ukraine and in certain administrative regions.

LITERATURE REVIEW

In the twenty-first century, agriculture in Europe has been affected by a substantial number of global indicators. Thus, as a result of the application of fertilisers, and pesticides, the growth of agricultural plants, the chemical composition of soils and mineral metabolism in the soil changes (Hader *et al.,* 2022), which in certain cases can contribute to the emergence of negative natural phenomena (reduction of biodiversity, soil degradation, wind and water erosion).

The European Union recently announced a new soil strategy until 2030 that provides a framework and measures to protect and restore soils and ensure their sustainability (Montanarella & Panagos, 2021; Köninger *et al.,* 2022). This will eventually have a positive impact on soil

conservation and the introduction of ecological farming. Yet such processes require a fairly long period of time, so effective planning of such work is constantly relevant. Similar developments are also needed for agricultural land in Ukraine, even at the level of individual territories.

Researchers actively investigate the problem of preserving soil fertility, publish information on this subject in the studies, and present it at conferences. Researchers thoroughly examine the soil fertility in the territory of Ukraine by natural zones, administrative regions, districts, and territorial communities. In the west of Ukraine (Kyrylchuk *et al.,* 2022), special attention is paid to exploring changes in soil fertility. Thus, changes in soil fertility occur due to various factors that can negatively affect the productivity of agricultural land, biodiversity, and ecosystem services provided by the soil. Preserving and restoring soil fertility is one of the main tasks of researchers and practitioners. It is necessary to develop soil management methods that will help prevent the negative consequences of changes in fertility to do this.

The soil cover of the Carpathian region is the basis for agriculture and forestry, and the life and traditions of the local population. However, the current state of the soil and the need for investments (Pozniak *et al.,* 2020) require an assessment of the investment potential of soils. Factors such as the complexity of the soil structure, dependence on weather conditions, imperfect infrastructure and legislation contribute to the low investment attractiveness of soils.

Researchers (Ma *et al.,* 2020) from all over the world are engaged in the analysing of soil degradation and desertification within a particular region. Factors such as population growth, socio-economic land-use changes, and climate change can contribute to this. Similar phenomena were recorded by researchers during studies in the Mediterranean region of Europe in the form of chemical (soil organic matter, pollution, salinity), physical (soil compaction, compaction, erosion), and biological degradation of Mediterranean soils (Ferreira *et al.,* 2022). Therewith, it was identified that the most recorded degradation processes are soil erosion, and the least is the loss of biodiversity. Therefore, the researchers propose to create a national and regional soil monitoring system to analyse its degradation and determine the economic and environmental consequences. This should facilitate management decisions in accordance with the sustainable development goals of the region.

Processes that also have a very negative impact on the soil (Brannigan *et al.*, 2022) and, as a result, on the deterioration of agricultural conditions, include wind and water erosion.

Wind erosion causes soil degradation and is one of the main threats (Bartosz *et al.*, 2023) for European soils. This problem is constantly being investigated in virtually all regions of Europe: the semi-arid Mediterranean region (Teng *et al.*, 2019; Bartosz *et al.*, 2023) and the temperate continental climate region of southern European countries using the example of Romania's adjacent to the studied region area (Niacsu *et al.,* 2019), and Ukraine (Tarariko *et al.*, 2021). The consequences of wind erosion are a decrease in soil fertility, which in turn negatively affects the yield of agricultural crops, and, as a result, leads to a decrease in the economic efficiency of agriculture (Abuzaid *et al.*, 2023). All this encourages farmers and politicians to pay more attention to solving this problem. Foreign experience can be used to solve these issues. For example, in northern China, (Ma *et al.,* 2022) precisely to prevent wind erosion, the way of large-scale management of human land use is quite effective, that is, increased control over the management of agriculture Such goals and objectives should also be solved in Ukraine, because according to Ukrainian researchers, information on the state and changes of soils is minimal, and it is received once every few years.

As a result of water erosion, particles of nitrogen, calcium, and other elements are washed away from the soil, which negatively affects soil fertility (Brannigan *et al.,* 2022; Panagos *et al.,* 2022). Researchers (Panagos *et al.,* 2021) developed 19 possible global climate models of water erosion rates. As a result of modelling, it was determined that in agricultural areas of Europe and the United Kingdom, it is necessary to increase the area of pastures and, accordingly, reduce arable land. A similar issue (Land Directory of Ukraine, 2020) is very acute in Ukraine.

Detailed examination of the structure of agricultural land in certain administrative regions of Ukraine and assessment of agricultural work there help prevent negative natural phenomena, such as soil degradation, wind and water erosion, and reduced biological diversity. This is possible only under the conditions of taking scientifically based measures to prevent these negative phenomena and implementing agroecological policy in Ukraine based on the principles of balanced nature management.

MATERIALS AND METHODS

Materials of environmental passports of administrative regions were used to analyse the structure of the land fund, which are available on the official website of the Ministry of Environmental Protection and Natural Resources of Ukraine (Ministry of Environmental Protection and Natural Resources of Ukraine, 2023), materials of the state Geodetic cadastre (State Service of Ukraine..., 2023) as of 01.01.2023.

Analysis of the structure of the land fund of the west of Ukraine (Volyn, Rivne, Lviv, Ternopil, Khmelnytsky, Zakarpattia, Ivano-Frankivsk, Chernivtsi regions) was conducted in such categories as: agricultural land, forests and other forest-covered areas, built-up land, open wetlands, open land without vegetation cover or with little vegetation cover (sands, ravines, land occupied by landslides, rubble, pebbles, bare rocks), other land.

Geographical coordinates of the extreme points of the research region: in the north 25°15'33", 51°58'09", south 24°53'05", 47°43'26", west 22°08'31", 48°25'43" and the east 27°54'05", 49°11'10". The following administrative regions belong to the territory of western Ukraine (Fig. 1): Volyn (1), Rivne (2), Lviv (3), Ternopil (4), Khmelnytsky (5), Zakarpattia (6), Ivano-Frankivsk (7), and Chernivtsi (8). The construction of a map scheme for the west of Ukraine was conducted using Geoinformation technologies *MapInfo Professional 12.3. beta*.

Figure 1. *Diagram-map of the research region*

Source: *compiled by the authors*

For a more detailed comparison of the distribution of agricultural land throughout the study area, the following distribution was used: arable land, fallows, perennial plantings, hayfields, and pastures. The materials of the land directory of Ukraine were used (Land directory of Ukraine, 2023) to analyse the number of land plots (shares) and farms, compare the normative and monetary evaluation of land, the cost of renting 1 ha of public and private agricultural land.

Indicators in US dollars were used to conduct a normative and monetary evaluation of agricultural land in western Ukraine (arable land and perennial plantings), and to determine the cost of hayfields and pastures, the arithmetic mean between them was taken. Objective data on geographical, genetic-morphological, agrochemical, agrophysical, and other characteristics of soil composition and properties on various land plots and their suitability for farming are based on data from a large-scale soil survey (State standard of Ukraine, 4362:2004).

The indicator of soil fertility is considered, that is, its ability to meet the needs of plants for nutrients, water, air, and heat in sufficient quantities for their normal development, which together are the main indicator of soil quality. It is necessary to constantly monitor land to do this, that is, check the state of land to identify changes in a timely manner, assess them, prevent and eliminate the consequences of negative processes (State standard of Ukraine, 4362:2004). The above data are presented and compared in the study on the example of certain regions of western Ukraine.

The following classifications were used according to DSTU 4362:2004 to characterise soils by humus content: very low <1.1; low 1.1-2.0; medium 2.1-3.0; increased 3.1-4.0; high 4.1-5.0; very high >5.0 (State standard of Ukraine, 4362:2004). To analyse the degree of availability and grouping of soils by the content of mobile forms of easily hydrolysed nitrogen, the following distribution was used: very low <100; low 101.0-150.0; medium 151.0-200.0; increased >200 (State standard of Ukraine, 4362:2004).

The following classifications were used to characterise soils by the content of mobile phosphorus compounds: very low <20; low 21-50; medium 51-100; increased 101-150; high 151-200; very high >200 (State standard of Ukraine, 4362:2004). To analyse soils by the content of mobile potassium compounds, the following distribution was used: very low ⩽20; low 21-40; medium 41-80; increased 81-120; high 121-180; very high >180 (State standard of Ukraine, 4362:2004).

Materials from the land directory of Ukraine (Land directory of Ukraine, 2020) were used to analyse the normative and monetary evaluation of agricultural land and the number of shares of farms. The analysis of statistical materials and calculation of additional indicators was conducted using the Microsoft Excel 2020 computer programme.

RESULTS AND DISCUSSION

The land structure was formed as a result of the recognition of the independence of Ukraine and the approval of the administrative division of the state's territory. The total area of Ukraine is 60.3 million hectares, and agricultural land accounts for 41.4 million hectares, of which arable land is 32.7 million hectares, that is, the level of ploughed land is 54%, which is a much higher indicator compared to other European countries.

Therewith, such indicators may differ markedly at the level of different regions and regions of Ukraine. A detailed analysis of the structure of the land fund of certain regions of western Ukraine has shown that the largest total areas (more than 2 million square meters) are in Volyn (2014.4 thousand hectares), Rivne (2005.1 thousand hectares), Lviv (2183.1 thousand hectares), and Khmelnytskyi (2062.9 thousand hectares) regions (Table 1).

Table 1. *Structure of the land fund of the regions of western Ukraine, as of 01.01.2023*

Administrative region	Indicators	Total area of the region	1. Agricultural land	2. Forests and forest-covered areas	3. Built-up land	4. Open wetlands	5. Open land without vegetation cover or with little vegetation cover	6. Other land
Volyn	thousand hectares	2014.4	1047.6	697.7	61.2	115.8	14.5	77.6
	%	100.0	52.01	34.63	3.04	5.75	0.72	3.85
Rivne	thousand hectares	2005.1	926.2	805.8	59.6	106.6	31.9	75.0
	%	100.0	46.19	40.19	2.97	5.32	1.59	3.74
Lviv	thousand hectares	2183.1	1240.0	694.7	115.6	9.4	30.5	92.9
	%	100.0	56.80	31.82	5.30	0.43	1.40	4.25
Ternopil	thousand hectares	1382.4	1046.2	201.7	63.7	5.9	18.5	46.4
	%	100.0	75.68	14.59	4.61	0.42	1.34	3.36
Khmelnytskyi	thousand hectares	2062.9	1566.2	287.6	85.1	20.2	24.1	79.7
	%	100.0	75.92	13.94	4.13	0.98	1.17	3.86
Zakarpattia	thousand hectares	1275.3	451.0	724.0	48.2	0.8	14.8	36.5
	%	100.0	35.36	56.77	3.79	0.06	1.16	2.86
Ivano-Frankivsk	thousand hectares	1392.7	621.2	635.7	63.4	2.5	22.4	47.5
	%	100.0	44.60	45.65	4.55	0.18	1.61	3.41
Chernivtsi	thousand hectares	809.6	469.7	258.0	40.1	1.2	9.8	30.8
	%	100.0	58.02	31.87	4.95	0.15	1.21	3.80
Total	thousand hectares	13125.5	7368.1	4305.2	536.9	262.4	166.5	486.4
	%	100.0	56.14	32.80	4.09	2.0	1.27	3.70

Source: *official website of the Ministry of Environmental Protection and Natural Resources of Ukraine (Ministry of Environmental..., 2023)*

Notably, among these territories, the largest share of agricultural land falls on the Khmelnitsky region (75.92 %), while in other regions this indicator ranges from 35.36 to 75.68%. That is, as an example, in this area, it is necessary to conduct more enhanced control of the fertility of agricultural land and constantly fight various erosion processes. The share of the land category "forests and other forest-covered areas" in this region is the smallest – 13.94%, while in other western regions, the average percentage is about 36%. This once again underlines the importance of enhanced research and control of wind erosion in the region.

Slightly smaller land area is in Ivano-Frankivsk (1392.7 thousand hectares), Ternopil (1382.4 thousand hectares), Zakarpattia (1275.3 thousand hectares) regions, and the smallest in Chernivtsi (809.6 thousand hectares). In the Ternopil region, the second most important category of land is agricultural land – 75.68% and forests and other forest–covered areas – 14.59% are of the lowest value. That is, in this area, there is also a need for increased control over the management of agriculture, as in the above case.

The built-up land category in all regions of western Ukraine does not differ substantially – from 2.97 to 5.30%. The situation is similar to open lands without vegetation cover or with little vegetation cover – from 0.72 to 1.61%. Only in two regions (Volyn and Rivne), does the category of "open wetlands" account for the

maximum indicators (5.75% and 5.32%, respectively), while in other regions, this value ranges from 0.06 to 0.98%.

The share of the other lands category in the examined areas ranges from 2.86% to 4.25%. This analysis showed the difference in the land structure of various administrative regions of Ukraine and, importantly, where exactly it is necessary to implement soil conservation measures constantly.

A detailed analysis of the structure of agricultural land and its distribution by categories "arable land", "fallows", "perennial plantings", "hayfields and pastures" in the regions of western Ukraine is presented in Table 2. Thus, the distribution of agricultural land in the west of Ukraine is quite diverse. The largest area is arable land (69.77% of the total area of agricultural land) and hayfields and pastures (27.69%). The share of fallows (0.14%) and perennial plantings (2.40%) is insubstantial.

Table 2. *Distribution of agricultural land areas by administrative regions of western Ukraine, as of 01.02.2023*

Administrative region	Total area of the region thousand hectares	Indicators	Agricultural land				
			Total	including			
				arable land	perelogs	perennial plantings	hayfields and pastures
Volyn	2014.4	thousand hectares	1047.6	672.6	-	11.7	363.3
		%	100.0	64.20	-	1.12	34.68
Rivne	2005.1	thousand hectares	926.2	656.8	3.5	11.7	254.2
		%	100.0	70.91	0.38	1.26	27.45
Lviv	2183.1	thousand hectares	1240.0	770.9	-	22.8	446.3
		%	100.0	62.17	-	1.84	35.99
Ternopil	1382.4	thousand hectares	1046.2	856.4	3.4	15.7	170.7
		%	100.0	81.86	0.32	1.50	16.32
Khmelnytskyi	2062.9	thousand hectares	1566.2	1252.7	1.2	41.6	270.7
		%	100.0	79.98	0.08	2.66	17.28
Zakarpattia	1275.3	thousand hectares	451.0	200.2	-	27.3	223.5
		%	100.0	44.39	-	6.05	49.56
Ivano-Frankivsk	1392.7	thousand hectares	621.2	400.6	2.2	15.5	202.9
		%	100.0	64.49	0.35	2.50	32.66
Chernivtsi	809.6	thousand hectares	469.7	330.7	-	30.3	108.7
		%	100.0	70.41	-	6.45	23.14
Total	**13125.5**	thousand hectares	**7368.1**	**5140.9**	**10.3**	**176.6**	**2040.3**
		%	100.0	69.77	0.14	2.40	27.69

Source: *official website of the Ministry of Environmental Protection and Natural Resources of Ukraine (Ministry of Environmental..., 2023)*

The share of arable land from the total area of agricultural land in the structure of all the administrative regions examined is the largest. The maximum share of arable land is in Ternopil (81.86%) and Khmelnytskyi (79.98%) regions. A slightly smaller share of these lands is represented in Rivne (70.91%), Chernivtsi (70.41%), Ivano-Frankivsk (64.49%), Volyn (64.20%), Lviv (62.17%), and Zakarpattia (44.39%) regions, respectively.

The area of hayfields and pastures throughout the west of Ukraine is 2040.3 thousand hectares. Thus, the share of this category of land in administrative regions ranges from 16.32% (Ternopil region) to 49.56% (Zakarpattia region) of the total area of agricultural land.

The total area of perennial plantings in the west of Ukraine is 176.6 thousand hectares. Thus, its share in administrative regions varies from 1.12% (Volyn region) to 6.45% (Chernivtsi region). The area of fallow areas is insubstantial (10.3 thousand hectares). This category of land occurs only in Rivne (3.5 thousand hectares), Ternopil (3.4 thousand hectares), Ivano-Frankivsk (2.2 thousand hectares), and Khmelnytskyi (1.2 thousand hectares). Its share in the represented regions ranges from only 0.08% to 0.38%.

For the economically rational conduct of agricultural work in a certain territory, it is also necessary to constantly carry out its normative and monetary evaluation.

A comparison of the value of different categories of agricultural land in the administrative regions of western Ukraine clearly illustrates certain features. The normative and monetary evaluation is one of several types of assessments provided for by the law of Ukraine "On Land Valuation", the calculation of which is based on rental income from the use of a land plot for a certain period of time. The normative and monetary evaluation of agricultural land in administrative regions of western Ukraine is presented in Table 3.

Table 3. *Normative and monetary evaluation of agricultural land in administrative regions of western Ukraine, USD/1 ha**

Administrative region	Cost, USD/ ha				
	Arable land	Perennial plantings	Hayfields	Pastures	Middle ground between hayfields and pastures
Volyn	888.2	1684.3	246.0	182.4	214.2
Rivne	893.6	1510.1	206.6	150.7	178.7
Lviv	875.4	1103.5	236.2	166.6	201.4
Ternopil	1182.7	2323.2	255.8	230.1	243.0
Khmelnytskyi	1241.4	2148.9	275.5	214.2	244.8
Zakarpattia	1110.7	1510.1	265.7	214.2	239.9
Ivano-Frankivsk	1062.6	1510.1	196.8	182.4	189.6
Chernivtsi	1354.9	2555.5	226.3	206.2	216.3
Average	1076.2	1793.2	238.6	193.4	216.0

Note: **As of 01.01.2020, the average exchange rate of 1 dollar was 24.55 UAH*
Source: *Land directory of Ukraine (Land directory of Ukraine, 2020)*

Thus, the value of land according to the normative and monetary evaluation in the examined administrative regions varies substantially. The average value of arable land is $1,076.2, perennial crops – $1,793.2, hayfields – $238.6, pastures – $193.4. The total value of agricultural land in western Ukraine is about 6.3 billion dollars (Table 4). Thus, among them, arable land costs the most – 5.543 billion dollars, and the value of perennial plantations (330.47 million dollars) and hayfields and pastures (436.46 million dollars) is much lower.

Table 4. *Normative and monetary evaluation of agricultural land in administrative regions of the west of Ukraine, USD million, as of 01.01.2023*

Administrative region	Category of agricultural land			
	Arable land	Perennial plantings	Hayfields and pastures	Total
Volyn	597.42	19.71	77.82	694.95
Rivne	590.05	17.67	45.42	653.13
Lviv	674.88	25.16	89.87	789.90
Ternopil	1016.88	36.47	41.47	1094.82
Khmelnytskyi	1556.62	89.40	66.28	1712.30
Zakarpattia	222.36	41.22	53.62	317.21
Ivano-Frankivsk	428.02	23.41	38.47	489.90
Chernivtsi	448.08	77.43	23.51	549.02
Total	5534.31	330.47	436.46	6301.23

Source: *compiled by the authors*

The total value of agricultural land in western administrative regions varies. Thus, the highest value of these lands is in Khmelnytskyi (1.71 billion dollars) and Ternopil (1.09 billion dollars) regions. The value of agricultural land is slightly lower in Lviv (USD 789.90 million), Volyn (USD 694.95 million), Rivne

(USD 653.13 million), Chernivtsi (USD 549.02 million), Ivano-Frankivsk (USD 489.90 million), and Zakarpattia (USD 317.21 million) regions, respectively.

The cost of renting private and state-owned agricultural land in the examined administrative regions is also different (Fig. 2). Thus, the average cost of 1 ha of state land costs 3553 UAH, and private 1497 UAH. The cost of renting state-owned agricultural land in the west of Ukraine ranges from UAH 1442 (Volyn region) to UAH 7781 (Khmelnitskyi region).

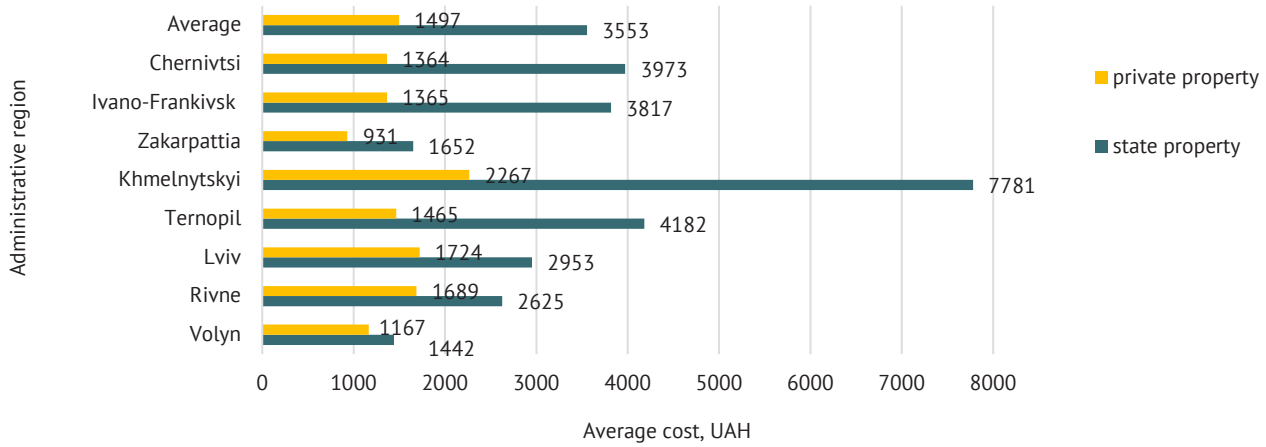

Figure 2. *The cost of renting agricultural land in the administrative regions of western Ukraine, UAH*
Source: *Land directory of Ukraine (2020)*

The cost of renting private agricultural land in the research region varies from UAH 931 (Zakarpattia region) to UAH 2267 (Khmelnytskyi region). On the territory of western Ukraine, 1420223 shares were leased. Thus, the largest number of shares was leased in Khmelnytskyi (25.2% of the total number of units on the territory of the research facility) and Ternopil regions (20.7%). Slightly less in the Lviv region – 17.9%. The share of leased units in Ivano-Frankivsk, Rivne, Volyn, and Chernivtsi ranges from 6.2 to 11.5%, and the least in the Zakarpattia region – only 1.0% (Table. 5).

Table 5. *Distribution of the number of shares and their area in the administrative regions of western Ukraine, as of 01.01.2023*

Administrative region	Number of shares		Area	
	thousand units.	%	thousand hectares	%
Volyn	109.1	7.68	212.0	8.93
Rivne	139.4	9.81	280.0	11.80
Lviv	253.6	17.85	312.0	13.15
Ternopil	294.1	20.71	513.0	21.62
Khmelnytskyi	358.2	25.22	803.0	33.84
Zakarpattia	13.6	0.96	20.0	0.84
Ivano-Frankivsk	163.7	11.53	123.0	5.18
Chernivtsi	88.6	6.24	110.0	4.64
Total	1420.3	100	2373.0	100

Source: *compiled by the authors*

Comparative analysis of arable land areas (Table 2) and the area of shares showed that the largest providers of land for lease are Khmelnytskyi (64.1% of the total amount of arable land in the region) and Ternopil regions (59.9% of the total amount of arable land in the region).

In Volyn, Rivne, Lviv, Ivano-Frankivsk, and Chernivtsi regions, the share of land leased ranges from 30.7% to 42.6%, and the smallest in the Zakarpattia region – 10%. There are 7 105 farms operating in the west of Ukraine (Table 6). Most of these farms are concentrated in Ternopil (19.5% of the total number

of farms on the territory of the experimental facility), Khmelnytskyi (18.8%), Zakarpattia (18.6%), and Lviv (16.2%) regions. A slightly smaller share of farms is concentrated in Volyn (10.7%), Rivne (9.0%), and Ivano-Frankivsk (6.1%) regions, and the smallest in Chernivtsi region (1.1%).

Table 6. *Distribution of the number of farms and the area of land that they cultivate in the administrative regions of Ukraine, as of 01.01.2023*

Administrative region	Number of farms		Total land cultivated by farms		On average, per farm
	units	%	thousand hectares	%	thousand hectares
Volyn	759	10.68	67	20.25	0.088
Rivne	642	9.04	33	9.98	0.051
Lviv	1149	16.17	52	15.72	0.045
Ternopil	1386	19.51	77	23.28	0.056
Khmelnytskyi	1339	18.85	75	22.67	0.056
Zakarpattia	1324	18.63	9.3	2.81	0.007
Ivano-Frankivsk	430	6.05	17	5.14	0.040
Chernivtsi	76	1.07	0.5	0.15	0.007
Total	7105	100.0	330.8	100.0	0.04

Source: *Land directory of Ukraine (2020)*

The total area of land cultivated by 7 105 farms is 330.8 thousand hectares. Thus, the largest share of these lands is concentrated in Ternopil (23.28% of the total area of land cultivated by farmers on the studied territory), Khmelnytskyi (22.67%), Volyn (20.25%), Lviv (15.72%), Rivne (9.98%) regions. In the Ivano-Frankivsk, Zakarpattia, and Chernivtsi regions, this share ranges from 0.15 to 5.14%.

On the studied territory, on average, one farm accounted for 0.04 thousand hectares. Thus, the largest average land area of farms was recorded in Volyn (0.088 thousand hectares), Ternopil (0.056 thousand hectares), Khmelnytskyi (0.056 thousand hectares), Lviv (0.051 thousand hectares), Rivne (0.045 thousand hectares), and Ivano-Frankivsk (0.040 thousand hectares) regions, respectively. In the Zakarpattia and Chernivtsi regions, this figure is 0.007 thousand hectares.

Humus is the main source of nutrients in the soil. The higher the humus content in the soil, the greater its fertility. The preservation and accumulation of humus is the basis of soil fertility. Constant monitoring of the proportion of soil areas with different humus content, mobile compounds of phosphorus and potassium is of great importance in examining the efficiency of land resource use. The analysis of the presented data for various administrative regions of western Ukraine shows that most of the areas are occupied by groups with average and increased levels according to all three characteristics. Therewith, there are certain features in particular areas that must be considered in detail.

Thus, for example, in terms of humus content in the Volyn region, very low (18.2%) and low (69.7%) levels substantially exceed all other levels for this region, and for other regions, the value for the very low level ranges from 0 to 2.1%, and the low level is more substantial – from 1.3 (Ternopil region) to 43.6% (Rivne region).

Significant indicators of the share of humus content reaching a high level were recorded in five regions at once: Lviv (7.7%), Ternopil (4.9%), Khmelnytskyi (7.3%), and Zakarpattia (7.8%). The maximum share value for this level is typical for the Ivano-Frankivsk region (15.0%), and the minimum value is typical for the Volyn region (0.1%). In the other two areas, this value ranges from 1.2% to 3.5%. The share of land with a very high level of humus content in the soil is completely absent in the Volyn and Ternopil regions. However, in all other regions, the share of such soils is insubstantial and does not exceed 4.8% (Lviv region).

The weighted average humus content is most valuable in Ternopil (3.25 mg/kg), Khmelnytskyi (3.24 mg/kg), and Ivano-Frankivsk regions (3.17 mg/kg). The minimum value of this indicator is typical for the Volyn region (1.53 mg/kg). In all other regions, the weighted average humus content is more or less similar and ranges from 2.26 to 2.73 mg/kg (Table 7). On average, for the examined region of western Ukraine, this indicator is 2.7 mg/kg.

There is a similar case with the distribution of the proportion of soil areas in the examined areas by the content of mobile phosphorus compounds. Most areas have the largest share for the average and increased groups. Only in the Zakarpattia and Ivano-Frankivsk regions, high values are typical for the very low (26.7 and 20.8%) and low (15.5 and 21.3%) groups. For the group "high" level of the content of mobile phosphorus compounds, the highest value was determined for

the Volyn (24.0%), Rivne (23.1%), and Lviv (26.6%) regions. In all other regions, the indicators are slightly lower and range from 5.9% (Ternopil region) to 15.7% (Ivano-Frankivsk and Chernivtsi regions).

The maximum and rather substantial share for the "very high" level is set for the Lviv region (14.3 %). In all other administrative regions, from 0 % (Ivano-Frankivsk region) to 7.1% (Rivne region). The weighted average index for the content of mobile phosphorus compounds in all eight regions ranges from 81 mg/kg (Ivano-Frankivsk region) to 136 mg/kg (Lviv region). The average for the entire examined region of western Ukraine is 105.5 mg/kg.

Comparison of mobile potassium compounds in the regions of the examined region of western Ukraine showed that the maximum values for the different levels differ in virtually all regions. Thus, the maximum value for a low level of the content of mobile potassium is typical for Volyn (43.2%) and Rivne (33.4%) regions. For the medium level group, the maximum share is set for the Volyn (34.2%) region. Increased potassium levels are observed in Ternopil (53.4%) and Khmelnytsky regions (55.6%) high – in Ivano-Frankivsk (32.0%) and Chernivtsi (44.9%).

Areas, where there are no mobile potassium compounds, were identified. For example, in the Ternopil region, there are no areas with very low and low levels, in Khmelnytskyi – very low, and in Ivano-Frankivsk – very high levels of potassium content (Table. 7).

Table 7. *The share of soil areas by the content of humus, mobile compounds of phosphorus and potassium in the administrative regions of western Ukraine, as of 01.01.2023, %*

Administrative region	very low, %	low, %	medium, %	increased, %	high, %	very high, %	weighted average index, mg/kg
Humus content							
Volyn	**18.2**	**69.7**	**11.3**	0.8	0.1	0.0	1.53
Rivne	1.7	**43.6**	**40.7**	**12.6**	1.2	0.2	2.26
Lviv	1.7	**25.5**	**32.6**	**27.7**	7.7	4.8	2.80
Ternopil	0.0	1.3	**26.4**	**67.4**	4.9	0.0	3.25
Khmelnytskyi	0.1	4.6	**30.4**	**57.4**	7.3	0.2	3.24
Zakarpattia	2.1	**28.1**	**40.3**	**18.5**	7.8	4.2	2.73
Ivano-Frankivsk	0.1	10.0	**37.4**	**34.6**	**15.0**	2.9	3.17
Chernivtsi	0.0	**29.0**	**51.3**	**14.7**	3.5	1.5	2.50
Average for the experiment region	3.0	26.5	33.8	29.2	5.9	1.7	2.7
Content of mobile phosphorus compounds							
Volyn	0.6	8.9	**31.9**	**34.3**	**24.0**	0.3	120.0
Rivne	8.6	14.0	**27.5**	**19.7**	**23.1**	7.1	114.9
Lviv	0.7	3.7	**26.3**	**28.4**	**26.6**	14.3	136.9
Ternopil	0.0	0.3	**34.3**	**59.4**	5.9	0.1	112.0
Khmelnytskyi	0.1	3.1	**39.2**	**43.4**	9.4	4.8	107.8
Zakarpattia	26.7	15.5	23.7	13.3	14.6	6.2	88.4
Ivano-Frankivsk	20.8	21.3	28.0	14.2	15.7	0.0	81.0
Chernivtsi	8.1	18.0	27.1	25.8	15.7	5.3	83.0
Average for the experiment region	8.2	10.6	29.8	29.8	16.9	4.8	105.5
Content of mobile potassium compounds							
Volyn	8.1	43.2	34.2	12.2	2.4	0.0	47.8
Rivne	30.7	33.4	18.4	10.8	5.8	0.9	75.2
Lviv	3.1	19.4	28.4	24.9	16.9	7.3	79.1
Ternopil	-	-	2.9	53.4	**43.2**	0.5	118.0
Khmelnytskyi	-	0.1	27.5	55.6	14.6	2.2	97.5
Zakarpattia	6.3	1.3	18.0	28.2	27.7	18.5	140.0
Ivano-Frankivsk	3.6	24.3	21.4	18.7	32.0	-	94.0

Table 7, Continued

Administrative region	very low, %	low, %	medium, %	increased, %	high, %	very high, %	weighted average index, mg/kg
Chernivtsi	2.4	7.7	11.9	13.3	44.9	19.8	149.0
Average for the experiment region	6.8	16.2	20.3	27.1	23.4	6.2	100.1

Source: *official website of the Ministry of Environmental Protection and Natural Resources of Ukraine (Ministry of Environmental..., 2023)*

Thus, the results of the conducted studies show differences in the soils of the western regions of Ukraine in the content of humus, mobile compounds of phosphorus and potassium. It is essential information for the practical introduction of agriculture there.

According to the analysis of the distribution of soil areas in the western regions of Ukraine by the content of easily hydrolysable nitrogen (Table 8), it was established that for the "very low" group, the maximum value is typical for the Volyn region (75.6%). Ivano-Frankivsk (63.6%), Zakarpattia (47.5%), Chernivtsi (43.5%), and Rivne (42.1%) regions also have quite high indicators of areas with a very low level. That is, in these five areas, it is necessary to handle the problem of increasing the nitrogen content right now. In the other three regions examined, this share is noticeably lower – Khmelnitskyi (18.7%), Lviv (16.5%), and in the Ternopil region, this indicator is minimal and amounts to only 3.5%. However, for this region, the maximum value of a low level (75.4%) was recorded. The minimum value of a low level is typical for the Volyn region (12.8%), while only there the values are several times smaller than all other regions, ranging from 35.3 to 65.5%.

Table 8. *The share of soil areas by easily hydrolysed nitrogen content in the administrative regions of the west of Ukraine, as of 01.01.2023 %*

Administrative region	very low	low	medium	increased	Weighted average index, mg/kg
Volyn	**75.6**	12.8	1.5	10.1	122.3
Rivne	**42.1**	**36.3**	12.3	9.3	125.3
Lviv	16.5	**65.5**	13.5	4.5	121.9
Ternopil	3.5	**75.4**	20.9	0.2	137.0
Khmelnytskyi	18.7	**55.7**	24.7	0.9	121.0
Zakarpattia	47.5	**40.7**	10.3	1.5	107.2
Ivano-Frankivsk	63.6	35.3	1.1	0.0	95.0
Chernivtsi	43.5	**50.6**	4.8	1.1	107.0
Average for the experiment region	**38.9**	**46.5**	**11.1**	**3.5**	**117.1**

Source: *official website of the Ministry of Environmental Protection and Natural Resources of Ukraine (Ministry of Environmental..., 2023)*

The lowest values of the nitrogen fraction of the average level are typical for Volyn (1.5%), Ivano-Frankivsk (1.1%), and Chernivtsi (4.8%) regions. In all other administrative regions, this share ranges from 10.3 to 24.7%. The highest values of the share of land with an increased level of nitrogen were recorded for Volyn (10.1%) and Rivne (9.3%) regions. Although they are not substantial, they are several times higher than in other areas where there is a fluctuation in the content of easily hydrolysed nitrogen in the range from 0.2 to 4.5%.

In the examined territory of the west of Ukraine, it is necessary to constantly introduce a scientifically based and ecological-reclamation system of farming, since in its absence, certain negative consequences of soil cover destruction, reduced soil fertility, reduced crop yields and, as a result, an increase in economic losses for both the state and private farms are possible.

It is vital to conduct economically sound agriculture, especially in areas where soil conditions are already deteriorating and further negative changes are possible, such as wind and water erosion of the soil, increased land use and high levels of ploughed land. It is advisable to constantly monitor degraded land, reduce the area of unproductive soils, and identify areas that are subject to conservation and need reclamation.

Since 01.07.2021, the agricultural land market has been functioning in Ukraine. Thus, in the first stage, agricultural land up to 100 hectares per individual can be bought or sold (Transitional Provisions..., 2021). During the implementation of this reform, about 28 million

hectares of agricultural land is privately owned, and 56% is leased. In the process of their lease, a certain disproportionality arose between landowners and land users. In such circumstances, it is necessary to control the use of these lands by the state regarding their appropriate use and implementation of the environmental strategy. This experience can be learned from many foreign countries (Gorgan & Hartvigsen, 2022). For example, Maxim Gorgan and Morten Hartvigsen analysed the development of agricultural land markets in Eastern Europe and Central Asia based on materials from the Food and Agriculture Organisation of the United Nations (FAO).

The results of the study on agricultural land are to a certain extent confirmed by the findings of other researchers. In particular, Muzyka *et al.* (2019) establishes that the area of agricultural land in the west of Ukraine decreased by 29.8 thousand hectares (when comparing the area of agricultural land in 2023 with 2018). The largest decrease in agricultural land areas was identified in Lviv (20.8 thousand hectares), Ivano-Frankivsk (8.7 thousand hectares), Khmelnytskyi (2.0 thousand hectares), and Zakarpattia (0.3 thousand hectares) regions, while in Chernivtsi region it remained unchanged. The decrease in this category of land is caused by a change in its intended purpose. However, the area of agricultural land in some regions, on the contrary, increased: in Volyn (0.1 thousand hectares), Rivne (1.5 thousand hectares), and Ternopil (0.4 thousand hectares) regions by 2 thousand hectares. This may be caused by Russia's invasion of Ukraine, which has led to an increase in the area of agricultural land in the rear areas, as a substantial part of the land in the north, east, and south of Ukraine, where active military operations took place or are being conducted (World Bank, 2022), has become unusable.

According to Eurostat (Eurosta statistics..., 2020), as of 2020, there are 9.1 million farms in the European Union. In particular, the number of farms cultivating less than 5 hectares of agricultural land is 63.8% of the total number of farms in the EU. The area of farms in the EU depends on the geographical location (Thompson, *et al.*, 2022; Ulukan, *et al.,* 2022: Staniszewski, *et al.,* 2023), which is influenced by geomorphological, climatic conditions, and the location of the farm. The average area of farms in western Ukraine varies from 7 hectares (Zakarpattia and Chernivtsi regions) to 88 hectares (Chernivtsk region). In general, the average farm rate in the study region is 40 hectares, which is 8 times higher than in the European Union.

Ballabio *et al.* (2019; 2022) in their study developed a mapping of the chemical properties of the upper soil layer by the following chemical properties: pH, pH (CaCl), cation exchange capacity, calcium carbonates ($CaCO_3$), C:N ratio, nitrogen (N), phosphorus (P) and potassium (K). These chemical indicators vary within the limits of the indicators of the European Union countries. Thus, on the territory of agricultural land in Italy, there is an increased level of phosphorus, its content is affected by the application of phosphorous and other types of fertilisers used in agriculture.

To optimise the use of agricultural land in western Ukraine, it is crucial to conduct an ecological and landscape organisation of the experimental territory, which includes four components. First, it is necessary to develop the territorial and landscape organisation of agroecosystems to ensure their optimal use. Secondly, an important stage is the agroecological evaluation of land, which will allow assessing the state of natural complexes and determining the possibility of their use for agricultural purposes. Third, it is important to conduct environmental optimisation of the structure of agricultural landscapes to ensure more sustainable and efficient use of land resources. Fourth, it is necessary to plan, organise, and manage the state of agroecosystems, ensuring their rational use and conservation.

CONCLUSIONS

The largest share is represented by agricultural land (56.14% of the total area of the land fund), while forests and other forest-covered areas account for slightly less (32.80%). The area of built-up land (4.09%), open wetlands (2.0%), open land without vegetation cover or with little vegetation cover (1.27%) and other land (3.70%) is small.

It was established that the largest share is represented by arable land – 69.77% of the total area of agricultural land and hayfields and pastures (27.69%), the rest is occupied by perennial plantings (2.40%) and fallows (0.14%). The total value of agricultural land in western Ukraine is 6.3 billion dollars. Among them, arable land costs the most – 5.53 billion dollars, and the value of perennial plantations (316.68 million dollars) and hayfields and pastures (436.46 million dollars) is much lower.

The average cost of renting state agricultural land in western Ukraine ranges from UAH 1442 in the Zakarpattia region to UAH 7781 in the Khmelnytskyi region, while the cost of renting private land varies from UAH 931 in the Zakarpattia region to UAH 2267 in Khmelnytskyi Oblast. 1 420.3 shares were leased in the west of Ukraine. The largest number of shares was leased in Khmelnytskyi (25.22%) and Ternopil (20.71%) regions, and the smallest in the Zakarpattia region – 0.96%. There are 7105 farms operating in western Ukraine. Most farms are concentrated in Ternopil (19.51% of the total number), Khmelnytskyi (18.85%), Zakarpattia (18.63%), and Lviv (16.17%) regions, and the least – in Rivne (9.04%), Ivano-Frankivsk (6.05%), and Chernivtsi (1.07%).

The largest average land area of farms was recorded in Volyn (0.088 thousand hectares), Ternopil (0.056 thousand hectares), Khmelnytskyi (0.056 thousand hectares), Lviv (0.051 thousand hectares), Rivne (0.045 thousand hectares), and Ivano-Frankivsk (0.040 thousand hectares) regions, respectively. In the

Zakarpattia and Chernivtsi regions, this figure is 0.007 thousand hectares. On the territory of western Ukraine, the shares of soil areas in terms of humus content in various administrative regions differ markedly. The average value of the share of soil areas of the study region by humus content with the highest indicators was determined for the following levels: average (33.8%), high (29.2%), and low (26.5%). Other levels are characterised by substantially lower indicators: high (5.9%), very low (3.0%), and very high (1.7%).

The distribution of the proportion of soil areas by the level of phosphorus and potassium compounds for both the entire region under study and individual regions also differs substantially. The highest proportion of phosphorus and potassium compounds is: medium (29.8 and 20.3%), increased (29.8 and 27.1%), high (16.9 and 23.4%), respectively, the lowest – very low (8.2 and 6.8%), low (10.6 and 16.2%), and very high (4.8 and 6.2%). When dividing the proportion of soil areas by the content of easily hydrolysed nitrogen, certain differences are also established. Thus, the largest share for the entire studied region falls on the "very low" (38.9%) and "low" (46.5%) levels, and the smallest values – on the "average" (11.1%) and "high" levels (3.5%).

Thus, to preserve and increase soil fertility, and its protection on the research territory, it is necessary to introduce scientifically based systems and technologies for using fertilisers and chemical land reclamation based on data from agrochemical certification of agricultural land. Further studies should be aimed at preserving soil fertility and the balanced use of agricultural land in Ukraine.

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Absent.

CONFLICT OF INTEREST

Absent.

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Анотація. Важливим сектором економіки України є сільське господарство, яке базується на родючості сільськогосподарських земель, зокрема земель західного регіону України. Аналіз структури, родючості сільськогосподарських земель, їх грошова оцінка може надати уявлення про їх продуктивність та потенціал для розвитку сільського господарства. Метою роботи є аналіз структури та показників родючості сільськогосподарських земель заходу України, демонстрування їх основних характеристик та порівняння цін на землю в західних областях України. Під час написання статті використовували матеріали земельного довідника України та регіональних доповідей про стан навколишнього середовища заходу України, послуговуючись методами аналізу та порівняння стану земельних ресурсів за вмістом гумусу, рухомих сполук фосфору та калію, азоту, що легко гідролізується, їх матеріально-грошової оцінки. Проаналізувавши структуру земельного фонду заходу України (13125,5 тис. га) було становлено, що сільськогосподарські угіддя становлять більше половини загальної площі (56,1 %), а ліси та інші лісовкриті площі – близько третини загальної площі (32,8 %). Забудовані землі, відкриті заболочені землі, відкриті землі без рослинного покриву або з незначним рослинним покривом та інші землі становлять менше 10 %. Серед сільськогосподарських земель найбільшу частку становить рілля, дещо менше припадає на сіножаті та пасовища, а найменше – на багаторічні насадження та перелоги. Загальна вартість сільськогосподарських земель у західних адміністративних областях помітно відрізняється. Найвища вартість земель у Хмельницькій та Тернопільській областях (1,71 і 1,09 млрд. дол), а найменша – в Івано-Франківській та Закарпатській (489,90 і 317,21 млн. дол). На території заходу України здано в оренду 1420223 паїв. Найбільша їх кількість здана в Хмельницькій та Тернопільській областях (25,2 та 20,7 %), а найменша – у Закарпатській (1,0 %). Так, загальна площа землі, що обробляється фермерськими підприємствами, становить 330,8 тис. га, найбільша частина зосереджена в Тернопільській та Хмельницькій областях (23,3 і 22,7 %). Результати досліджень сприятимуть прийняттю управлінських рішень ведення ефективного сільського господарства та збереження родючості ґрунтів сільськогосподарських земель досліджуваного регіону. Грошова оцінка даних територій є корисною для населення країни в умовах зміни закону про ринок землі в Україні, а також під час здійснення екологічно виваженої аграрної політики

Ключові слова: земельний фонд; пасовища; гумус; земельні паї; сільськогосподарські угіддя; адміністративна область

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Ukrainian agricultural production profitability issues

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Abstract. The research relevance is predefined by the need to find ways to increase the profitability of agricultural production in the difficult economic conditions of Ukraine. The research aims to analyse the profitability of agricultural production, influencing factors and determination of directions for its improvement. The methodological approach is based on the analysis of statistical data on changes in production profitability; method of average values – to obtain the average value of indicators; comparison method – to compare data on profitability and productivity between types of products; graphic method – to display the results; method of generalization – for summarizing information about agricultural production. The main results that were obtained within the scope of this study should cover the analysis of the profitability of agricultural production by its types and crop yield and regions of the country in the conditions of the impact of negative

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factors on the agricultural sector during the period of martial law (in particular, the reduction of land suitable for agriculture, blocking many ways to sell products, complicating the supply of mineral fertilizers and other goods necessary for the functioning of the agrarian sector) and highlight directions for increasing profitability, namely increasing the yield of certain types of crops; reduction of feed costs for feeding animals by growing feed and electricity production efficiency through the use of renewable energy sources (sun, wind, biomass energy); development of pig meat production by increasing their population and quality of nutrition; creation of added value from products obtained by the producer on his own land, which will contribute to increased profitability and successful development of agriculture. Analysis of the supply and demand balance of grain and leguminous crops showed that their production exceeds the need for consumption of all types of grain. The results and conclusions have practical significance for agricultural producers in business management, as well as for the government in developing areas of support for the agricultural sector

Keywords: profitability; productivity; influencing factors; supply and demand balance; export volumes; creation of added value

INTRODUCTION

Ukraine is one of the leading countries whose agricultural products are necessary to ensure food security in the world. The high fertility of the land and the favourable climate in Ukraine allows for the successful development of crop and animal husbandry. However, since 2012, the development trends in this area indicate a low level of profitability and many negative factors that prevent manufacturers of products from obtaining sufficient profit. With the beginning of hostilities on the territory of Ukraine in 2014, and then their intensification in February 2022, agriculture suffered large losses and a decrease in the profitability of production due to the loss of a large land area, markets, the complication of the supply of fertilizers and other products necessary for agricultural development. Despite these events, Ukraine remains among the top five world leaders in the export of wheat, corn, sunflower oil, and barley (Negrei & Trofimtseva, 2022). To support the agricultural sector in difficult times for the state, it has become necessary to study the profitability of agriculture to determine the efficiency of investing monetary resources and the rationality of their use, as well as to develop proposals for increasing the profitability of production.

Ukrainian, English, Polish and other scientists studied the question of the profitability of agricultural production. The role of the agricultural sector of Ukraine in the world food market was considered by the Ukrainian scientist M. Negrei and O.V. Trofimtseva (2022), who studied the prospects for the development of the agricultural sector in the post-war period and determined that the key factor in this direction is human capital, the creation of reliable sales markets, increasing the competitiveness of products, environmental sustainability of agriculture, informatization and digitization of the agricultural sector.

As B. Khahula (2022) emphasizes, the condition for accelerating scientific and technical progress in the agricultural sector is the mastering of innovative technologies by producers, which creates a certain effect that is manifested in the production of additional products and obtaining additional income.

I. Kryukova (2022) also defined the key strategic guidelines for the development of the agricultural sector, which outlined the main elements of the structure of such development, considering world and national priorities and strategic tasks of rural regions.

V. Yuryev (2020) considered the impact of the diversification of the activities of agricultural enterprises on the current state of the agro-industrial complex. Among the directions of diversification, the author identified the formation of various industries for the processing of agricultural products, the organization of new types of production (growing new crops, improving the environmental friendliness of products), and expanding the range of products as necessary key elements.

The importance of the organization of procurement logistics as one of the tools for ensuring the competitiveness of agricultural enterprises was considered by O. Varchenko *et al.* (2022). The scientist proved that among the main tasks of logistics in this case are quality improvement, optimization of the composition and structure of material resources used in production activities, and strengthening of competitive advantages in target market segments.

The main problems of the Ukrainian agrarian sector development during martial law were considered by T. Dobrunik and O. Kuznetsova (2022), who noted the need to transform the current model of the agrarian sector of Ukraine, considering the priority of small business development.

A study on the relationship between environmental sustainability and prices for agricultural products was conducted by the English scientists Y. Vittis *et al.* (2021), the results of which showed that food prices will continue to decrease under conditions of strict environmental policies.

However, despite the significant contribution of scientists to the study of this issue, the issue of increasing the profitability of agricultural production remains debatable and requires a more detailed study. The research aims to analyse the factors affecting the profitability of

agricultural production, the state of productivity by types of crop production and regions, the level of costs by their types in the field of crop production and livestock production, the determination of promising directions for the development of livestock production, the balance of demand and supply for certain types of products, and as well as the development of proposals for increasing the profitability of agricultural activity in Ukraine.

MATERIALS AND METHODS

The basis of the methodological approach is a combination of statistical data analysis methods, the method of average values, the comparison method, the graphic method, and the generalization method. The research involves the analysis of the profitability of agricultural production and the identification of directions for its increase in the conditions of the negative influence of external factors during the period of martial law and requirements for increasing competitiveness.

The theoretical basis of this research is based on the works of Ukrainian, American, Romanian, Australian, Polish, Czech, German and scientists from other countries, who considered the problem of the profitability of agricultural production and determined directions for its improvement.

Statistical information on the profitability of agricultural production, the productivity of crop production, volumes of dairy, meat products and eggs, production costs by product types, the cost structure of crop production and livestock production was researched based on the data of the State Statistics Service of Ukraine (The level of profitability..., 2022).

The application of the statistical data analysis method allowed to investigate the change in profitability indicators of the most common types of livestock and crop production in Ukraine, their volumes, and costs for the period 2012-2021, as well as the changes that occurred in these indicators in 2022. Data on the production and consumption of grain crops in the world for 2022, as well as the forecast for grain production and trade in the international market for 2023, were analysed based on information from the Food and Agriculture Organization (Food and Agriculture Organization) (hereinafter – FAO) (World Food Situation, 2022).

The analysis of data on the export of grain and legumes from Ukraine was carried out based on information published on the official website of the Ministry of Agrarian Policy and Food of Ukraine (Export of grain..., 2023). Information on crop and livestock products for 2022 was obtained from the website of the State Service of Ukraine on Food Safety and Consumer Protection (Information on the export..., 2023).

Using the average values method, the median value of productivity and costs for certain types of crop production was calculated. At the same time, the range of data was the values of productivity and costs per unit of production across the regions of Ukraine. The comparison method made it possible to compare information on profitability by types of agriculture and productivity of products by regions of the country, as well as compare data on production and consumption of agricultural products and analyse the balance of supply and demand of grain and leguminous crops for 2021-2022.

Using the graphical method, the data obtained in the research process on the dynamics of the production of the main types of meat, milk, eggs, and wool for 2012-2021 are displayed in the form of a graph.

The application of the generalization method allowed to summarize the results obtained in the research process regarding the level of profitability of agricultural products in Ukraine and the factors affecting the profitability of its production; formulate conclusions that act as a final reflection of these results, namely: substantiate proposals for reducing production costs of plant and livestock production and increasing the profitability of production and determine further approaches to the study of the problems of the development of agricultural production in Ukraine in the conditions of the war period.

RESULTS

Agriculture is one of the most important branches of the national economy of Ukraine. Approximately 25% of the world's black soils, which have high fertility, are concentrated in Ukraine. Of the total land area of Ukraine, 71.9% belongs to agricultural land (World Food Situation, 2022).

The types of agricultural production in Ukraine are represented mainly by crop and animal husbandry. The main crops include wheat, sunflower, corn, barley, sugar beet, legumes, fruits, and vegetables. Ukraine holds a leading place among grain exporters in the world (about 25-35 million tons per year), including corn 14.4 million tons, wheat – 9.2 million tons, barley – 1.8 million tons and others (Export of grain..., 2023). The main types of livestock production are meat products from cows, pigs, goats and sheep, milk, eggs, and wool.

Changes in prices on the world market, the negative impact of hostilities that have taken place in Ukraine since 2014, the full-scale Russian invasion of the territory of Ukraine since February 2022, and other factors that affect the production and sale of agricultural products in Ukraine have proven the need assessment of the profitability to find ways to increase it in modern conditions.

Profitability refers to the ratio of profit received and costs incurred in the process of activity. The level of profitability of different enterprises or different types of activity allows to compare their efficiency and determine the expediency of activity and ways of development. To determine the priority types of agricultural activity in Ukraine, their profitability by type should be considered and analysed (Table 1) (The level of profitability..., 2022).

Table 1. *The level of profitability of production of agricultural products in Ukraine for 2012-2021*

Product name	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Grain and leguminous crops – altogether	15.2	1.5	25.8	43.1	37.8	25.0	24.7	11.8	20.0	44
Including										
Wheat	11.8	2.4	28	36.4	31.7	26.8	24.6	7.3	21.5	40
Corn for grain	19.8	1.5	26.2	50.3	45.7	23.7	27.2	17.8	21.3	35
Barley	11.4	0.6	18.3	28.3	25.4	24.0	25.6	2.3	12.1	18
Rye	5.5	-15.3	-5.6	21.9	24.6	20.2	-2.2	9.9	14.4	16.1
Oat	9.9	-2.6	10.7	21.5	34.4	21.2	10.3	8.8	14.7	20
Buckwheat	24.5	-1.3	29.5	100	87.5	32.7	-17.2	6.6	54.7	63
Millet	-12.5	3	40.7	58.4	30.2	24.5	34.7	20.2	6.1	8
Dried legumes	9.3	-5	30.2	55.3	33.1	22.4	-5.4	-11.5	-0.1	2.1
Soybeans	23.4	15.8	34.5	38.6	52	28.8	21.0	13.3	30.2	40
Flax seeds	2.9	6.4	25.2	32.7	10.1	-10.8	18.6	8.6	78.0	80
Rapeseed and colza seeds	21.4	8.6	29.2	44.3	45	43.6	31.1	9.4	17.2	20
Sunflower seeds	45.8	28.5	36.5	80.5	63	41.3	32.5	23.5	39.4	52
Factory sugar beet	15.7	2.7	17.9	28.2	24.3	12.4	-11.4	-15.4	-13.5	10
Hop cones	-48	-11.6	-9.5	39.9	100.4	17.7	60.9	9.0	-	5
Potato	-21.5	23	9.2	24.2	-3.2	10.0	6.8	15.4	11.0	13
Vegetable crops in open soil	-6.8	7	16.7	47.5	19.7	15.6	16.7	7.0	8.3	8.5
Vegetable crops in closed soil	-0.1	3.7	12.4	14.1	7.7	1.7	8.5	-4.9	7.4	7.9
Grape	72.6	101.7	61	102.4	74.6	51.6	22.6	-7.2	-16.2	15
Fruit crops	8.8	154.7	68.2	52.6	12	27.3	3.4	0.2	12.4	8.9
Berry crops	5.1	13.6	11.2	86.2	104	85.9	19.5	19.8	54.1	18.6
Cattle raised for meat	-29.5	-43.3	-35.9	-17.9	-24.8	3.4	-17.7	-27.1	-24.2	12.7
Pigs raised for meat	2	0.2	5.6	12.7	-4.5	3.5	6.9	4.7	2.6	8.6
Sheep raised for meat	-39.7	-42.8	-52.1	-29.4	-35.1	-40.0	-16.7	-38.9	-38.6	17.3
Goats raised for meat	-70.5	-31	-79.7	-59.7	-43.4	-14.4	-13.8	-58.9	-62.7	16.1
Poultry raised for meat	-7.2	-10	-15.4	-6.1	5	7.0	5.7	-3.7	-0.2	3.1
Wool	-61	-72.7	-75.1	-61.9	-31.8	-69.8	-69.5	-71.1	-72.0	-73
Milk from farm animals of all kinds, raw	2.3	13.6	11	12.6	18.2	26.9	16.1	20.6	20.4	17.5
Poultry eggs in the shell, fresh (without eggs for incubation)	52.6	47.6	58.8	60.9	0.5	-9.0	5.4	-23.5	-19.2	15
Honey is natural	-29	-29.9	-30.6	-5.4	4.8	-16.4	-27.4	-32.2	-25	-10

Source: *compiled based on data (The level of profitability..., 2022)*

The data in Table 1 show that for the analysed period, the largest increase in profitability indicators was observed in 2015 (an increase compared to the previous year by 20.8%) and 2021 (an increase by 22.8%) (The level of profitability..., 2022). The highest profitability indicators during 2012-2021 were: grain and leguminous crops buckwheat, corn for grain, as well as sunflower, open-ground vegetables, and soybeans. Rye, sugar beet and hop cones were less profitable.

On the other hand, animal husbandry during 2012-2021 was unprofitable in almost all species (mainly sheep and goats for meat (up to -79.7%), wool production (up to -75.1%)). However, in 2021, the profitability of animal husbandry amounted to 12.7% for breeding cattle, dairy breeds increased by 14.6% (from 13.3% to 27.9%), and pigs – by 6.1% (from 2.5% to 8.6%) (The level of profitability..., 2022).

However, the continuation of the increase in the profitability of agricultural production, which was observed in 2021, became practically impossible in 2022 due to the start of hostilities (combat) in the entire territory of Ukraine in February 2022. The yield of

different types of products depends on the regions of the country where they are grown. To analyse the economic efficiency of the production of agricultural products, it is necessary to compare productivity indicators with production costs (Table 2) (The level of profitability..., 2022).

Table 2. *Yield and costs of individual crop production by regions of Ukraine in 2021*

Name of the region	Wheat		Corn		Sugar beet		Vegetables of the open soil		Buckwheat	
	productivity, cwt from 1 ha	costs (per 1 cwt of products, hryvnias)	productivity, cwt from 1 ha	costs (per 1 cwt of products, hryvnias)	productivity, cwt from 1 ha	costs (per 1 cwt of products, hryvnias)	productivity, cwt from 1 ha	costs (per 1 cwt of products, hryvnias)	productivity, cwt from 1 ha	costs (per 1 cwt of products, hryvnias)
Vinnytsia region	56.8	392.2	100.2	400.7	456.3	91.6	219.0	2929.5	16.1	879.4
Volyn region	44.9	357.2	97.8	311.0	450.3	81.9	217.3	539.5	11.4	713.1
Dnipropetrovsk region	44.1	357.1	51.7	477.1	511.2	-	198.1	984.4	8.8	1025.5
Donetsk region	40.6	313.5	44.3	420.7	256.5	-	171.9	675.4	12.6	1515.9
Zhytomyr region	49.6	374.0	92.0	329.1	444.9	90.7	211.0	614.1	14.5	2188.5
Transcarpathian region	33.8	532.0	50.6	226.5	-	-	212.6	-	12.4	1139.7
Zaporizhzhia region	38.8	367.2	75.1	395.2	-	-	176.6	789.3	10.9	-
Ivano-Frankivsk region	51.6	423.1	84.3	324.9	553.7	-	172.2	655.2	11.8	-
Kyiv region	52.6	413.2	95.2	391.7	432.7	123.0	201.8	1159.9	16.8	745.2
Kirovohrad Region	49.8	386.5	70.0	508.7	460.3	119.0	152.3	622.1	13.6	874.1
Luhansk Region	39.2	320.5	29.1	352.5	-	-	277.8	-	7.1	1105.8
Lviv region	50.1	365.0	94.4	319.5	524.5	67.7	194.3	578.6	11.1	1403.1
Mykolaiv region	42.3	455.5	50.7	493.1	-	-	336.1	161.5	11.5	1424.4
Odesa region	40.5	749.6	62.7	569.5	-	-	156.4	380.8	10.0	2445.2
Poltava region	49.1	346.5	67.5	358.8	402.9	79.4	231.0	630.1	9.1	577.0
Rivne region	48.2	349.0	88.9	269.6	518.3	70.5	207.6	-	11.9	955.8
Sumy region	48.5	309.9	72.8	241.0	-	-	178.8	1895.0	12.0	830.3
Ternopil region	57.9	363.6	101.7	276.5	525.0	74.6	232.5	1777.9	12.2	634.9
Kharkiv region	48.6	293.0	52.8	304.6	407.0	92.4	160.7	1809.7	10.2	873.8
Kherson Region	42.5	386.4	90.7	333.4	-	-	283.2	183.1	6.9	974.8
Khmelnytskyi Region	62.2	364.0	110.7	275.9	497.3	87.8	210.5	520.2	18.2	895.5
Cherkasy region	55.8	437.7	90.1	539.3	465.1	113.1	170.2	690.3	14.3	845.9
Chernivtsi region	52.7	409.2	74.5	361.0	-	-	195.2	-	9.1	1201.2
Chernihiv region	51.6	328.8	95.2	264.4	411.6	146.6	167.0	-	5.8	-
Average value	48.0	391.4	76.8	364.4	457.4	95.3	206.6	926.1	11.6	1107.1

Source: *compiled based on data (The level of profitability..., 2022)*

The data in Table 2 show that Vinnytsia, Khmelnytskyi and Ternopil regions have the highest wheat yields, and their costs per 1 centner of production are within the national average – UAH 391.4. The lowest costs for growing wheat in the northern regions are Sumy, Kharkiv and Chernihiv. However, there are regions with lower productivity, for example, Zakarpattia (33.8 t) and Odesa regions (40.5 t), but their costs are almost twice as high as the average – UAH 532 and UAH 749.6, respectively (The level of profitability...,

2022). This means that wheat production is less profitable in these regions of the country.

The situation is similar with other crops by region: corn is more profitable to grow in Vinnytsia, Ternopil, and Khmelnytskyi regions, and less so in Dnipropetrovsk and Kirovohrad regions, buckwheat is more profitable in Vinnytsia, Kyiv, and Khmelnytskyi regions, and less profitable in Odesa, Mykolaiv, and Lviv regions.

Indicators of yield level and production costs play an important role in increasing the profitability of crop production. For example, the cultivation of sugar beet during 2018-2020 was unprofitable, and only in 2021, the production showed profitability. The analysis of sugar beet productivity by region shows that in seven of them, this indicator is at a level below the average. It is possible to increase productivity by increasing the use of fertilizers to nourish the soil, which in turn will contribute to an increase in the production and export of sorghum, the world prices of which tend to increase. Thus, in 2022, according to the FAO, the average value of the sugar price index increased by 4.7% compared to 2021 and was the highest since 2012 (World Food Situation, 2022).

The dynamics of livestock production volumes can be analysed by species and periods (Fig. 1) (The level of profitability..., 2022).

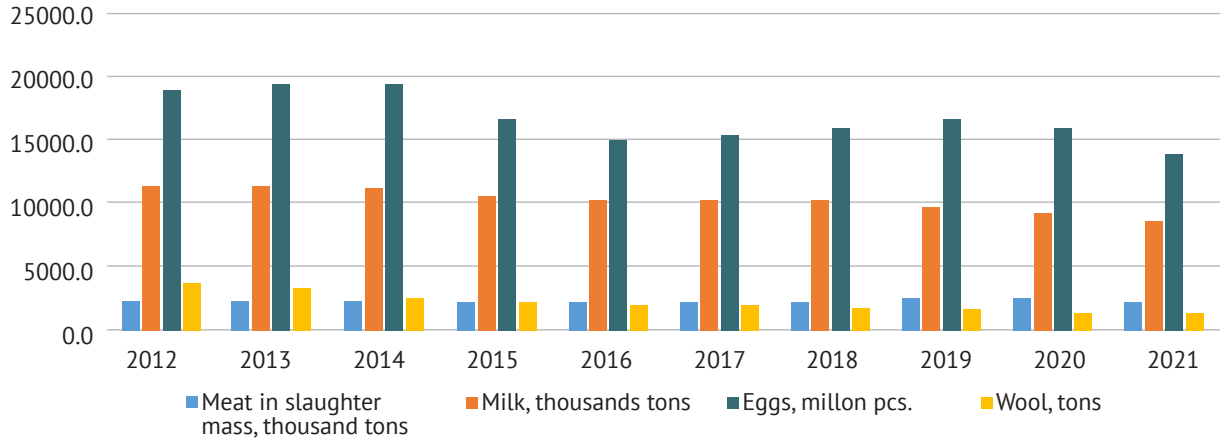

***Figure 1**. Production of the main types of animal husbandry products for 2012-2021*

The data in Figure 1 shows that during 2012-2021, the production of livestock products had a gradual downward trend. Thus, the decline in milk production amounted to 23.4%, eggs – 26.4%, and wool – 59.8%. On the other hand, meat production increased by 10.4% (The level of profitability..., 2022), which indicates the increased interest of agricultural producers in this type of product. Analysis of the production of livestock products by region will reveal which regions of Ukraine produce more or less of it (Table 3).

***Table 3.** Production volumes of livestock products by regions of Ukraine in 2021*

Name of the region	Live weight of animals sold for slaughter, thousand tons	Gross volume of milk, thousand tons	Number of eggs from poultry, million pcs	Gross shearing of wool, t
Ukraine	3462.3	8728.8	14071.3	1497
Vinnytsia region	652.5	686.1	708.7	9
Volyn region	162.5	338	207.1	18
Dnipropetrovsk region	329.1	246	720.8	5
Donetsk region	120.4	144.2	602.1	43
Zhytomyr region	84.5	487.5	718.5	21
Transcarpathian region	83.3	312.3	377.4	158
Zaporizhzhia region	62.3	180.6	372.5	54
Ivano-Frankivsk region	135.2	393.3	275.8	20
Kyiv region	287.5	368.3	3323.2	5
Kirovohrad Region	71.7	269.4	468.8	1
Luhansk Region	14.2	102.1	78.4	27
Lviv region	180.2	425.3	598.8	14
Mykolaiv region	45.6	245.7	156.9	100

Table 3, Continued

Name of the region	Live weight of animals sold for slaughter, thousand tons	Gross volume of milk, thousand tons	Number of eggs from poultry, million pcs	Gross shearing of wool, t
Odesa region	54.5	291.4	137.4	705
Poltava region	90.9	690.7	630.4	32
Rivne region	77.1	298.5	634.2	21
Sumy region	66.0	354.6	349.3	21
Ternopil region	83.3	462.8	533	5
Kharkiv region	125.6	427.5	481.1	46
Kherson Region	59.9	237.5	657.7	72
Khmelnytskyi Region	90.6	653.8	725.4	5
Cherkasy region	468.1	435.9	753.4	1
Chernivtsi region	64.8	235.8	279.5	107
Chernihiv region	52.5	441.5	280.9	7
Average value	144.3	363.7	586.3	62.4

Source: *compiled based on data (The level of profitability..., 2022)*

The data in Table 3 show that the largest production of meat is in Vinnytsia and Cherkasy regions, milk – in Vinnytsia, Poltava and Khmelnytskyi regions, eggs – in Kyiv, Khmelnytsia and Cherkasy regions, and wool – in Odesa, Zakarpattia and Chernivtsi regions. The level of profitability of agricultural products depends on the amount of production costs. An analysis of the cost structure in the field of plant and animal husbandry will allow identifying areas of cost that can be reduced (Table 4) (The level of profitability..., 2022).

Table 4. *The structure of costs for the production of agricultural products by type in 2020*

Types of expenses	Production costs			
	crop production		animal husbandry	
	million hryvnias	% to the amount	million hryvnias	% to the amount
Expenses of everything	278990.6	100.0	90323.0	100.0
Direct material costs	136622.4	49.0	68796.1	76.2
including				
seeds and planting material	27423.5	9.8	x	x
feeds	x	x	53333.1	59.0
of them are purchasable	x	x	21958.5	24.3
other agricultural products	2716.6	1.0	3498.7	3.9
mineral fertilizers	45878.4	16.4	x	x
fuel and lubricants	22230.4	8.0	1336.9	1.5
electricity	1793.0	0.6	1982.8	2.2
energy and fuel	1081.9	0.4	626.4	0.7
spare parts, construction materials for repair	14717.0	5.3	2514.9	2.8
labour costs	18147.2	6.5	7703.1	8.5
Other direct costs of all	77742.7	27.8	8064.4	8.9
Including				
deductions for social events	4000.9	1.4	1690.6	1.9
rent for:				
land shares	38510.0	13.8	x	x
property shares	619.9	0.2	3.5	0.0
amortization	24604.2	8.8	4958.0	5.5
Total expenditures	46478.3	16.7	5759.4	6.4

Source: *compiled based on data (The level of profitability..., 2022)*

From the data in Table 4, in the structure of costs to produce plant products, most of them belong to the costs of fuel and lubricants (16.4%) and seeds and planting material (9.8%), and animal husbandry – to the costs of purchasing fodder (59%) (The level of profitability..., 2022). Therefore, to increase the profitability of production, it is necessary to consider ways to reduce the specified cost areas.

A feature of plant and animal products is their rapid spoilage, which does not allow them to be stored for too long. Therefore, for the production to bring profits, and not losses in the form of crop loss, it is necessary to study the real demand for these products to form the appropriate volume of its supply. A comparison of the volumes of production and consumption of grain crops on the world market is necessary for correct conclusions regarding the volumes of products that will be exported and balancing the domestic market.

According to the FAO, the forecast of grain production and trade in the world for 2022 predicts the lowest volumes in the last three years, namely: 2.756 million tons, which is 2% (57 million tons) below the indicator of the previous period, which is mainly due to the indicators of corn and wheat (World Food Situation, 2022).

The global volume of grain consumption in 2022-2023 is predicted the level 2.777 million tons, which is 0.7% (21 million tons) lower than the level of 2021-2022. This projected decrease is due mainly to a reduction in the consumption of feed – especially corn, as well as barley and sorghum – and the consumption of corn as an industrial raw material. Grain stocks in the world at the end of the 2023 season are expected to be 839 million tons, while they are 2.2% (18.5 million tons) lower than last season. The forecast volume of world grain trade in the 2022-2023 season is expected to be 472 million tons, which is 1.9% (9.2 million tons) below the record level of the 2021-2022 season (World Food Situation, 2022).

For Ukrainian grain, the main sales markets remain in four regions – the countries of Asia, the European Union, Africa, and the CIS, which account for about 97% of the value of agricultural exports. In 2022, an increase in exports was observed only to the European Union. An analysis of the supply and demand of grains and legumes allows us to estimate how much Ukrainian producers need to produce (Table 5) (Export of grain..., 2023).

***Table 5**. Balance of demand and supply of cereals and legumes in 2021-2022*

Index	Cereals and legumes (thousand tons)								
	everything	wheat	barley	corn	oat	rye	buckwheat	millet	other cereals
1. Offer, including:	88788	33864	9876	42323	541	695	151	201	1137
production	83809	32102	9445	40000	481	602	103	182	894
2. The need, including:	84751	32312	9366	40623	491	625	136	161	1037
internal consumption	19292	7012	3881	6858	325	463	126	81	546
export	65459	25300	5485	33765	166	162	10	80	491
The difference between supply and consumption	4037	1552	510	1700	50	70	15	40	100

***Source:** compiled based on data (Export of grain..., 2023)*

As shown in Table 5, in Ukraine in 2021-2022, the supply of grain crops exceeded the need for their consumption for all types of grain by 5-11%, and for millet – by almost 25% (Export of grain..., 2023).

With the beginning of hostilities on the territory of Ukraine in February 2022, there was a deterioration and decline in all spheres of activity. The vulnerability of the agricultural sector was most evident in (Dobrunik & Kuznetsova, 2022): the impossibility of conducting fieldwork in the war zone; blocking sea routes for exporting products; destruction of the infrastructure intended for production, processing, and storage of products; deterioration of agricultural supply with fuel and lubricants, seeds, fodder and other material and technical means; the impossibility of uninterrupted operation due to periodic power outages.

However, Ukrainian agribusiness demonstrates its ability to withstand external threats. Since the beginning of the 2022/2023 marketing year, the export of grain and grain crops amounted to 5291 thousand tons, including 3174 thousand tons of corn (60.4%), 1651 thousand tons of wheat (31.2%) and 447 thousand tons of barley (8.4%) (Information on the export..., 2023).

Regarding the export of livestock products, in 2022, the export of poultry meat brought in an income of 852.9 million dollars, which is 18.6% more than in 2021. However, the export of meat and edible poultry offal in 2022 amounted to 413.2 thousand tons, which is 10.3% less compared to the previous year. During the period of martial law, the number of producers that received the right to export products of animal origin to the countries of the European Union (hereinafter referred to as the EU) increased by 10% (from 385 to 418), of which: 11 more suppliers of dairy products, 6 more suppliers of fish products, and 5 – suppliers of snails (Information on the export..., 2023).

It should be noted that among animal husbandry products, the production of pig meat during 2012-2021 was unprofitable, and in some periods (2016) even unprofitable. However, this activity is underestimated in Ukraine, because it has prospects and conditions to develop and enter the world market. After all, pork consumption in the world is growing every year and, according to FAO forecasts, will increase by 33% by 2030 (from 11 to 16.5 million tons) (World Food Situation, 2022). About 45% of this volume falls on the EU countries, however, the concentration of pig farms in these countries has already reached a critical limit. If compare the number, Belgium keeps 6 million pigs on its territory, the Netherlands – 12 million pigs, as well as Denmark, whose area is approximately the same as the area of the two regions of Ukraine. On the other hand, there are only about 3 million pigs in Ukraine. In Europe, large amounts of money are spent on the purchase of fodder for pigs, and in Ukraine, significant volumes of grain are exported for sale instead of creating added value from raw materials obtained on the ground. More than 70% of grain and oil crops are exported as raw materials to other countries (In 2022, the export…, 2022). Importing countries process Ukrainian raw materials into high-value-added products, thereby earning a much higher profit than Ukrainian farmers who grew the products.

Regarding the measures that manufacturers should consider in reducing production costs, in modern conditions, one such measure is the transition to alternative energy sources renewable ones. Due to the destruction of critical infrastructure facilities during the martial law period, which led to permanent power outages, many enterprises use generators for power supply, which is much more expensive than power supply from the general power grid. This led to a significant increase in production costs and a forced increase in the prices of products by manufacturers. To improve the situation, manufacturers should transfer their production to alternative sources of energy supply, which will not be as expensive as, for example, diesel generators. Renewable energy sources include biomass, wind, and solar energy, which can be regenerated. The use of this type of energy allows you to obtain lighting, heating, and hot water, as well as reduce production costs and emissions of pollutants into the environment.

Summarizing the above, it is worth noting that the development of the agricultural sector is influenced by many factors, in particular climatic conditions, prices for agricultural products on the world market, wartime conditions in Ukraine, and others. To reduce the impact of these factors and increase the profitability of crop and livestock products for Ukrainian producers, it is necessary to increase the yield and quality of products to expand the assortment for export, which will allow for an increased profit from activities and competitiveness; reduce production costs, in particular by using home-grown fodder for feeding animals that are raised for meat, which will reduce the cost of purchasing feed, as well as switching to alternative energy sources, which will reduce electricity costs; develop meat production, as one of the areas of positive development at the international level; create added value from raw materials obtained on land to increase the profitability of producers.

DISCUSSION

Analysis of the profitability of agricultural products in Ukraine allowed to determine that the profitability (unprofitability) of certain types of crop and livestock production depends on various conditions and factors. Modern challenges require agricultural producers to implement certain changes in their activities, the application of which will increase the profitability of products. The results obtained during the research show that the proposals provided during the research are aimed at improving the development of agriculture in Ukraine and increasing the profitability of its products.

According to the results of the study, it is emphasized the need to increase the productivity of crops to increase the profitability of their cultivation. A similar conclusion was reached by the Pakistani scientists T. Liliane and M. Charles (2020), who proved that the yield and mass of harvested plant products in a specific area are affected by several factors that can be grouped into three categories: technological (agricultural practices, management decisions), biological (diseases, pests) and environmental (climatic conditions, soil fertility, topography, water quality). These factors can explain the difference in productivity in different regions of the country.

The issue of government strategies that will increase agricultural productivity and improve the profitability of farmers was considered by the Indonesian scientists K. Heryanda and N. Yuliarmi (2021). Such strategies are building infrastructure (roads, irrigation canals, markets for agricultural products), providing financial assistance through banks, using technologies that support agriculture, creating marketing networks, etc. These proposals are appropriate for use in Ukraine as they are a powerful tool for increasing the profitability of agriculture.

It should be noted that soil fertility is important for increasing productivity. A similar point of view is supported by the Ukrainian scientist A. Kucher (2020), who showed the influence of soil fertility and financial support of enterprises on the formation of their sustainable competitiveness. The author substantiated that the increase in financial support for agricultural production can help increase productivity.

To find ways to increase productivity, Australian scientists Z. Hochman *et al.* (2020) studied crop rotations (repeated sequences of crops) in Australia. The scientist studied the possibility of producers choosing crop rotations that have a lower income than optimal crop

rotations and found that for most of the region, crop rotation optimized agricultural profits.

To improve productivity and the probability of increasing production, the English scientists C. Panoutsou and E. Alexopoulou (2020) evaluated the production costs of fourteen crops and analysed how their profitability could be affected by increasing productivity and cultivation on low-quality land, because of which the existence of profitable options was proven at current market prices and types of land.

Turkish scientists E. Ertürk and H. Ağır (2022) researched the determination of productivity, quality characteristics, comparison of production costs and profitability of summer and winter varieties of sugar beet and winter sugar beet in Turkey. Fully supporting the opinion of the scientist who showed the differences in variable costs, and net and relative profit between summer and winter varieties of sugar beet, it should be noted the need to plan winter production to ensure constant income in both periods. Polish scientist Z. Krzysiak (2021) also carried out a comprehensive analysis of the costs of growing sugar beets in individual peasant farms in Poland, who proved that growing sugar beets is characterized by a high cost, which absorbs 82.5% of the total income.

The productivity and profitability of sugar beet cultivation in Germany were evaluated by German scientists S. Wimmer and J. Sauer (2020). It is worth supporting the scientist's point of view that the increase in overall production productivity partially compensates for the losses. The results of the analysis of the profitability of buckwheat cultivation in Serbia, conducted by the Serbian scientists Z. Sredojevic *et al.* (2020), showed that the production of buckwheat is economically justified from the point of view of the producer, but organic production achieves better effects compared to traditional production. In the process of research, it is emphasized that animal husbandry is unprofitable for most species and requires measures to increase this indicator. Scientists who studied the profitability of milk and egg production agree.

Thus, the American scientists Y. Walsh *et al.* (2020), who studied the influence of factors on the profitability of organic farms in the United States, noted that these are: feed management, farm size, milk price and resource costs. In turn, the Turkish scientists D. Sarica *et al.* (2022) emphasized that among the costs, the largest share in the total cost of production is the cost of feed (72.86%) and labour (7.12%). At the same time, with an increase in the size of the farm, the production costs per animal unit decreased, and the net profit increased. This conclusion is also confirmed in the research of the Romanian scientists R. Chetroiu *et al.* (2022), who substantiated that the size of farms and the level and cost of milk production are in direct correlation with profitability, and the unit cost of production is inversely correlated. Nigerian scientists S. Johnson *et al.* (2020) identified the following as key factors affecting the profitability of poultry egg production in southwestern Nigeria: the age of the farmer, the size of the farm, the price per box of eggs, the cost of drugs, and the location of the farm. In turn, an assessment of the profitability of meat production and ways to maximize profits among small farmers was carried out by the Tajik scientists F. Jobirov *et al.* (2022), who rightly emphasized that the potential for increasing profitability is significant if available resources are effectively coordinated, and production costs, in particular costs for feed and medical care, are reduced to a minimum.

At the same time, it is worth agreeing with the Chinese scientists A. Memon *et al.* (2020) that sufficient financial resources significantly contribute to innovation and environmental efficiency. It is proved in the work that the costs of fodder occupy a significant part of their total amount. The scientific community is actively discussing the issue of reducing feed costs and finding alternatives to expensive feed. Thus, the African scientists A. Ouédraogo *et al.* (2022) note that the production of improved fodder is a viable alternative to expensive ones. The study of the Ukrainian scientists V. Petrychenko *et al.* (2021) is devoted to the formation of a market for high-protein fodder for farm animals in Ukraine in the context of European integration processes, as well as to the justification of the use of such fodder by Ukrainian producers.

Among the areas of agricultural expenses that need to be reduced, there are also expenses for electricity, for which it is proposed to use renewable energy sources. A similar proposal is supported in the study of the Ukrainian scientists I. Ivashkiv *et al.* (2020). One such source is the biomass of highly productive bioenergy crops, as well as the commissioning of new capacities of renewable energy facilities, the use of which will make it possible to gradually replace traditional types of fuel with renewable energy sources. Prospects for growing energy plants in Ukraine were considered by the Ukrainian scientists O. Triboy *et al.* (2021), who noted that unused agricultural land can be used for this purpose.

Regarding the need to deploy sustainable renewable technologies in agriculture, the Iranian scientists S. Gorjian *et al.* (2022) and the Mexican scientists Y. Acosta-Silva *et al.* (2019), who proved the advantages of using solar and wind renewable energy in agriculture, note. Completely agree with the author, it is expedient to emphasize that the use of a wind-solar-renewable energy system to manage the greenhouse environment reduces fuel consumption.

Determining promising directions for the development of animal husbandry, the work emphasizes the feasibility of finding ways to increase the profitability of pig meat production. At the same time, other scientists also note the importance of studying the factors affecting this indicator. So, for example, the African researchers S. Fakudze *et al.* (2021) emphasize the need for farmers to improve their qualifications by attending

training seminars to keep abreast of new developments in this field. African scientists J. Nabikyu and D. Kugonza (2016) emphasize that the production of pork meat can be made more profitable if groups of farmers are created, with the help of which they can save money and create capital for further investment. At the same time, Brazilian scientists L. Alves *et al.* (2022) proposed a mathematical model to estimate the costs of pig meat production, which facilitates the interpretation of the results and the economic evaluation of the system. It should be agreed that such a model can be used in the process of decision-making and cost control.

To increase profitability in agriculture, it is proposed to focus on creating added value from raw materials obtained on land, as an important tool for increasing profitability (Shahini *et al,* 2022a; 2022b; 2022c). Carrying out research in the same direction, the American scientists J. Clark *et al.* (2020) determined the characteristics of the agricultural sector with added value: (1) consumers make purchases that simultaneously provide utility and a price premium; (2) the common principles of the firms' activities and their mutual relations support the distribution of values; (3) supply chain participants demonstrate commitment to the community.

The importance of the profitability of agriculture in Ukraine to ensure food security both in the country and in the world is considered by the Romanian scientist V. Câmpeanu (2022), who analyzed the impact of risk factors from the hostilities that began on the territory of Ukraine in February 2022, which may cause global food crisis.

Supporting the point of view of the Czech scientist Ł. Kryszak (2021), should be noted that the increase in production relative to the farm's capital plays a decisive role in the growth of profitability, which is especially important for small enterprises. Analyzing the demand and supply for agricultural products, French scientists M. Desquilbet *et al.* (2017) assessed how intensive and extensive farming systems affect land use under market equilibrium. The scientist proved the advantages of implementing "active" land conservation through zoning and emphasized that the main effect of higher prices associated with extensive agriculture is a reduction in animal feed production, which has a higher price elasticity of demand. One should agree with the point of view of the Ukrainian scientists O. Osaulenko and N. Reznikova (2020), who claimed that the competitiveness of agriculture is transformed under the influence of the challenges of sustainable development, which is reflected in the strategies of international economic security.

As such, the analysis of the results of scientists' research on the issue of the profitability of agricultural production in Ukraine confirms the conclusions and proposals made in this work on increasing profitability and determining the directions of agricultural development. The proposed measures to reduce certain areas of expenditure of agricultural enterprises, increase productivity in the crop sector, and create added value for products will allow to maximize the profitability of agricultural producers and increase their resistance to negative factors that affect agribusiness during the state of war in the country.

CONCLUSIONS

The conducted research shows that the profitability of agricultural products of Ukrainian producers is an important tool for maintaining food security, both in the country and in the world.

The goal set in this study and the analysis of the main problems that affect the profitability of agricultural production allowed to formulate the following proposals. It has been proven that one of the ways to improve the profitability of crop production is to increase the yield of sugar beet, which will allow to increase its profitability and the profitability for the economy of Ukraine from the sale of sugar on the world market. Measures are proposed to reduce the cost of purchasing fodder for feeding animals, which can be achieved if producers use products of their cultivation, as well as the transfer of production to the use of renewable energy sources, which will reduce electricity costs and contribute to increasing the profitability of production. The proposal to expand the business of growing pigs for meat in Ukraine, the demand for which in the world market during 2020-2022 is constantly increasing, is substantiated. To increase the profitability of this production, it is necessary to increase the number of animals and improve the quality of their nutrition using grain crops grown in Ukraine. It was revealed that one of the sources of increasing the profitability of Ukrainian agriculture is the creation of added value from raw materials grown on the lands of agricultural producers through their processing and obtaining additional profit.

The main directions of further research in this direction will be the study of methods of increasing the profitability of agricultural production in the conditions of climatic changes, as well as the resistance of grain crops to natural disasters.

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CONFLICT OF INTEREST

None.

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Проблеми рентабельності сільськогосподарського виробництва в Україні

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Анотація. Актуальність дослідження зумовлена необхідністю пошуку шляхів підвищення рентабельності сільськогосподарського виробництва в складних економічних умовах України. Метою роботи є аналіз рентабельності сільськогосподарського виробництва, факторів впливу та визначення напрямів її підвищення. Основу методологічного підходу складає: аналіз статистичних даних щодо зміни рентабельності виробництва; метод середніх величин – для отримання середнього значення показників; метод порівняння – для співставлення даних про рентабельність та урожайність між видами продукції; графічний метод – для відображення результатів; метод узагальнення – для зведення інформації про сільськогосподарське виробництво. Головними результатами, які були отримані в межах цієї праці, слід вважати аналіз рентабельності сільськогосподарського виробництва за його видами та урожайності рослинних культур та регіонами країни в умовах впливу негативних факторів на аграрний сектор в період воєнного стану (зокрема, зменшення земель, придатних для ведення сільського господарства, перекриття багатьох шляхів для збуту продукції, ускладнення постачання мінеральних добрив та інших товарів, необхідних для функціонування аграрного сектору) та виокремлення напрямів підвищення прибутковості, а саме: підвищення урожайності окремих видів культур; зменшення витрат на корми для годівлі тварин шляхом вирощування власних кормів та витрат на електроенергію через застосування відновлювальних джерел енергії (енергію сонця, вітру, біомаси); розвиток виробництва м'яса свиней шляхом підвищення їх поголів'я та якості харчування; створення доданої вартості із продукції, отриманої виробником на власній землі, що сприятиме підвищенню прибутковості та успішному розвитку сільського господарства. Аналіз балансу попиту та пропозиції зернових та зернобобових культур показав, що їх виробництво перевищує потребу у споживанні по всім видам зернових. Результати та висновки мають практичну значимість для сільськогосподарських виробників при управлінні бізнесом, а також уряду – при розробці напрямів підтримки аграрного сектору

Ключові слова: прибутковість; урожайність; фактори впливу; баланс попиту та пропозиції; обсяги експорту; створення доданої вартості

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Strategy of investment attraction for the development of rural areas for the economic restoration of the agricultural sector

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Abstract. The research aims to study the implementation of a strategy for attracting investments to develop rural areas, which, based on the use of an investment platform and stimulation of business processes, allows for accelerating the reconstruction of infrastructure facilities in the countryside, involving interested investors in the cycle of economic restoration of the country's agrarian sector. The research was conducted using the following methods: analysis of indicators in the structure of foreign investments; analogies and comparisons of directions of capital investments by private investors for the development of rural areas; inducing macro factors that hinder the implementation of investment policy; synthesis of indicators of the profile matrix of SWOT analysis and PEST analysis; creation of spatial models of landscapes of investment sites. The results of this study are the identification of priority foreign investment companies of the countries

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of the world, which ensure the attraction of direct foreign investments in the agricultural sector of the economy of Ukraine. Based on SWOT-analysis and PEST-analysis matrix profiles, macro-factors of the internal and external investment environment of rural areas are determined, which have a significant impact on the acceleration (inhibition) of the implementation of the investment platform and stimulation of business processes for the reconstruction of infrastructure facilities. A three-level profile of the landscape of the platform of investment and stimulation of business processes for the reconstruction of infrastructure objects of rural areas in Ukraine was modelled

Keywords: infrastructure facilities; rural areas; capital investments; strategic planning; budgetary investments; private investors

INTRODUCTION

Existing state regulation tools for ensuring the stability of investment infusions for the development of rural areas in the country prove their inability to influence positive changes due to the negative consequences of the war, which multiplied the risks and further worsened the socio-economic condition of rural communities that are on the verge of "survival". Moreover, the existing trend of economic cycles, from the point of view of attracting and distributing investment flows in the state for the development of rural areas, cannot ensure the stability and efficiency of their use even in the short term (Lobas, 2012; Usova, 2013).

Therefore, the restoration of rural areas requires intensive measures aimed at expanding the format of the investment landscape between the centres for the distribution of investment resources for the village restoration under the currently existing mechanisms and models for the implementation of the strategy of attracting investments with their maximum return in the income structure of rural communities. This reduces the dependence of the development of rural areas not only on the economic cycles of the agricultural sector but also on the influence of the internal and external macro-environment of the country, in particular export-import relations, the number of financial structures, population migration outside the country, etc.

It should be noted that at the stage of restoration of rural areas, considering the peculiarities of modern macroeconomic trends, investments should be made by those entities of economic activity and institutions that can accelerate rural infrastructure development. The study of innovative systems of the agrarian sector of the economy and the principles of cyclical investment development of rural areas was carried out by Haji (2021), who focused on modern and future trends in the development of rural infrastructure.

At the same time, authors such as Abreu *et al.* (2022), Woollett *et al.* (2022), and Carson *et al.* (2022) focus on the use of investment platforms as a new form of safe financing for the development of rural areas, provided that the agricultural sector is economically viable. At the same time, in modern scientific practice, there is a lack of complex studies on the structural development and functionality of the investment platform of rural areas, considering the modern development of the agrarian sector of the economy. O. Lazareva (2021) believe that the functioning of each rural settlement, the development of its infrastructure and the income of its inhabitants should be ensured at the expense of optimizing the use of agricultural land, regulating prices for agricultural products, organizing the agricultural market, that is, at the expense of the agricultural sector.

A. Marushchynets (2018) considers the transformation of the agrarian sphere as a process of changing the institutional, sectoral, and territorial character in the system of infrastructural and socio-economic development of the region, caused by the transformation of the entire economic system. Key attention from the point of view of social geography during the consideration of transformational processes in the agrarian sphere of the region should be devoted to the improvement of investment policy directions in the territorial aspect.

The priority of this research is the justification of the strategy of attracting investments for the development of rural areas, which, based on the use of the investment platform and stimulation of business processes, makes it possible to accelerate the reconstruction of infrastructure facilities in the village by attracting additional investment flows from the public-private sector, which plays an important role at the formation stage of innovative, profitable agricultural production in Ukraine.

MATERIALS AND METHODS

The information base of the study consisted of statistical data from the electronic library "OECD International Direct Investment Statistics", search results from the official website agroportal.ua, reports of the State Statistics Service of Ukraine from the official website ukrstat.gov.ua regarding capital investments by sources of financing. Data on the formation of Ukrainian territorial communities' budgets from the independent research platform Tableau Public were also used. In particular, the statistical data of the Ministry of Finance of Ukraine regarding the formation of the state budget of Ukraine from 2016 to 2021 and the Ministry of Communities and Territories of Ukraine were analysed in detail. 2021 regarding the review of state budget expenditures in the field of regional development in terms of supporting the formation of the infrastructure of united territorial communities.

The study on problematic aspects of the research topic employed economic and macroeconomic laws, principles of strategic planning and the integration of external and internal factors of investment flows in

the strategic environment. In particular, the works of British, Czech, Spanish, Chinese, Japanese, Tanzanian, Australian, American, and Ukrainian scientists were studied regarding research and analysis of long-term differentiated investment impact on the development and modernization of the infrastructure in rural areas.

To achieve the research goal, a set of general scientific research methods was used, in particular the analysis method, comparative analysis of indicators in the structure of attracting direct foreign investment from various countries of the world to the Ukrainian agrarian sector with indicators of capital investments for the development of rural areas financed by venture funding funds; the analogy and comparison method – characterization and substantiation of the private investors' operation vectors and directions of capital investments for the development of Ukrainian rural areas during 2014-2021 with indicators of capital investments for the development of rural areas financed by loans from banking institutions of Ukraine.

The induction method – the identification of macroeconomic factors that prevent the implementation of the investment platform and the stimulation of business processes regarding the economic revival of the agricultural sector, in particular the socio-economic growth of the village. Synthesis method – substantiating the values and indicators of the profile matrix of SWOT analysis and PEST analysis of macro factors of acceleration (inhibition) of the implementation of the investment-incentive platform for the reconstruction of rural infrastructure objects in Ukraine. Modelling method – employment of specialized MATLAB software with the basics of three-dimensional spatial analysis to create spatial models of investment platform landscapes and to stimulate business processes of reconstruction of infrastructure objects in rural areas of Ukraine according to various structural elements.

RESULTS

The models of attracting venture funds for the implementation of investment platforms and stimulation of business processes to promote additional investment resources for future projects for the development of rural areas can be presented in the following form (Kovalchuk & Kozenkova, 2017; Wightman, 2021): market model (developed financial market with high availability of venture capital); corporate-state model (high level of state management, presence of large companies, efficient banking system); cluster model (connection between all participants in the process, phased implementation of the project from stage to stage, mutually beneficial relations between the state and business); meso-corporate model (stages of investment attraction in innovative processes, aimed at rapid implementation of agro- and biotechnologies).

When forecasting the dynamics of attracting investments for the development of rural areas, the nature of their cyclicality in the period is established. The economic cyclicality of the Ukrainian agricultural sector functioning depends on international economic relations with a purposeful European vector of attracting investments for the development of rural areas and is based on mandatory rules and regulations for access to investment resources without restrictions, within the framework of rate quotas for export and import of agricultural products. That is, the exchange of resources with EU countries provides Ukraine with 83.1% rate lines in the process of exporting agricultural raw products to their territory and 35.2% rate lines when importing European agricultural products to the territory of Ukraine (Vdovenko *et al.,* 2021; Merrell *et al.,* 2022).

It should be noted that the geographical transformation of Ukraine's agricultural exports and imports during the signing of international agreements contributed to changing the conditions for the obligation fulfilment by the EU countries and the world regarding the attraction of foreign investments in the country's agricultural sector (Rogach *et al.,* 2019). This ensured the formation of a new powerful investment platform and stimulation of business processes in the country for the revival of infrastructure facilities in rural areas. Thus, in 2010-2021, according to the geographical structure of attracting foreign direct investment in the agricultural sector of Ukraine, investments by companies registered in Cyprus, the Netherlands, Austria, Switzerland, Korea, Seychelles, Belize, the Virgin Islands, Panama, USA (Fig. 1).

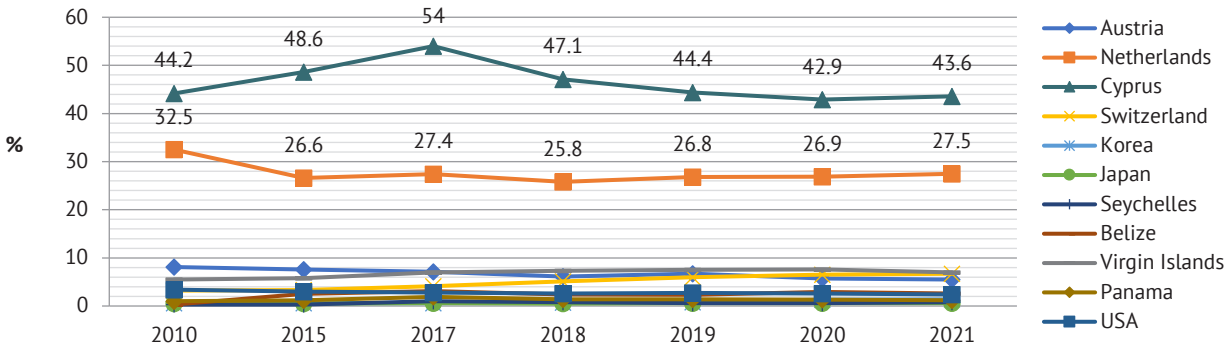

Figure 1. *The structure of the attraction of foreign direct investment from the countries of the world in the agricultural sector of the economy of Ukraine for 2010-2021, %*

Source: *completed by the authors based on (OECD, 2021; State Statistics Service of Ukraine, 2021)*

However, in 2021, compared to 2010, investment companies of the Netherlands reduced their share of investment in the agricultural sector of Ukraine by 5%, Austria – by 2.6%, Cyprus – by 0.6%, and the USA – by 1%. In the same period companies, located in Switzerland, Korea, Belize, and the Virgin Islands, increased the number of investment resources in agricultural production reproduction objects by 3.5%, 0.8% 2.3% and 1.5% respectively. At the same time, the change in the global geopolitical landscape with the weakening of external and systemic risks in 2018-2021 caused an inflow of investments for the development of rural areas of Ukraine from venture financing funds G-7 of the country's world (Ukraine in figures..., 2021; Verner, 2021). Their specific weight in 2020-2021 was 1.4-1.7%, while in 2018-2019 it was equal to 2.1-3% (Fig. 2).

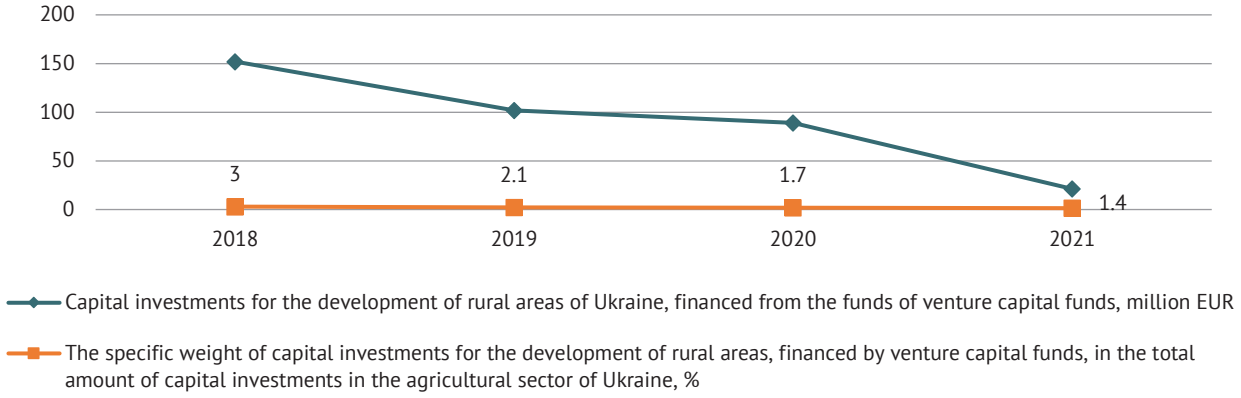

Figure 2. *Capital investments for the development of rural areas, financed at the expense of venture financing funds for 2018-2021*
Source: *compiled by the authors based on (ULEAD with Europe, 2021; Ministry of Finance of Ukraine, 2021)*

The largest number of rural infrastructure facilities were modernized and reconstructed in the cycle of budgetary and fiscal decentralization. This is confirmed by the dynamics of private investors' capital investments decreasing in the rural areas in the period 2018-2021. As such, if in 2018 the amount of investment of private companies in the infrastructure of rural settlements amounted to 13.43 billion EUR (70.8% specific weight of the total volume of capital investments for the development of rural areas), then already in 2021, it was equal to only 12.74 billion EUR (Fig. 3).

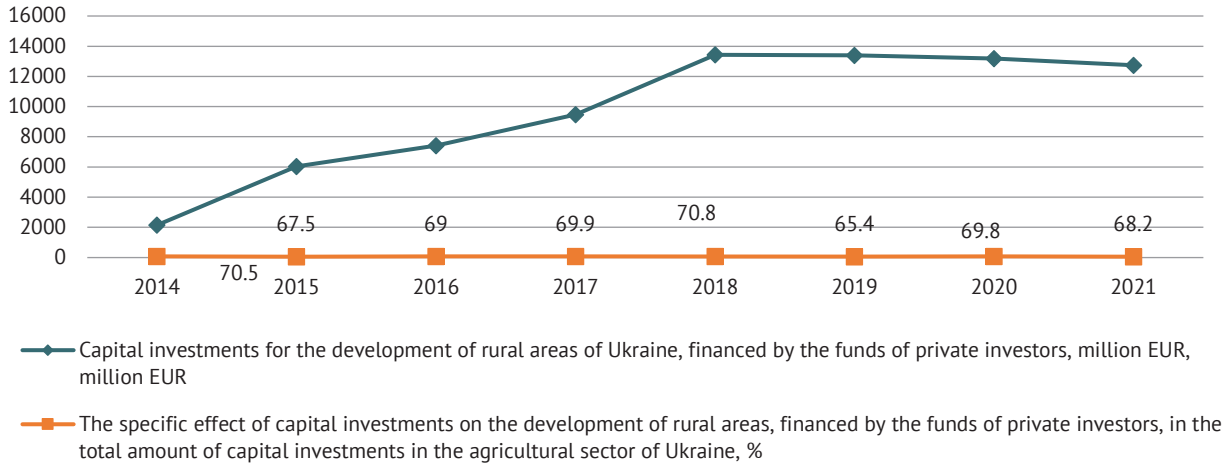

Figure 3. *Capital investments for the development of rural areas, financed from the funds of private investors of Ukraine for 2014-2021*
Source: *completed by the authors based on (Ministry of Development of Communities and Territories of Ukraine, 2021)*

During 2014-2021, banking institutions increased crediting of investment projects for the development of rural areas and, on the contrary, reduced it (Fig. 4). The largest amount of credit support for investment projects for the reconstruction of infrastructure facilities in rural areas was carried out in 2018-2021 – from 1353.6 million EUR to 2226.2 million EUR from a partial compensation of financial costs for the payment of credit interest at the expense of state and local budgets.

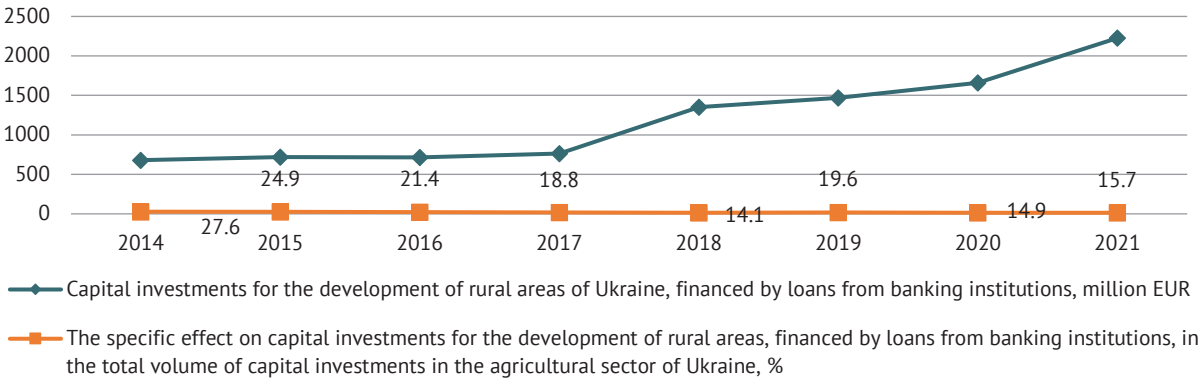

Figure 4. *Capital investments for the development of rural areas, financed on account of loans from banking institutions of Ukraine for 2014-2021*

Source: *completed by the authors based on (ULEAD with Europe, 2021; Ministry of Finance of Ukraine, 2021)*

With the constant change in the economic restoration of the country's agrarian sector, it is necessary to focus on the investment risks that are present in the socio-economic system of rural areas in the event of negative trends in the cycles of economic revival of the country's agrarian sector, which weaken the strengths of the regions, and, as a result, inhibit the introduction of investment platforms and stimulation of business processes for the reconstruction of infrastructure objects (Smaliukh, 2017).

It is appropriate to analyse the negative macro-factors that prevent the implementation of the investment platform and stimulation of business processes: currency and inflation risks; military conflict in the country; the imperfection of regulations for foreign investors; corruption; bureaucracy and regulation of business processes; lobbying of individual investment projects; economically unreasonable and excessive tax pressure; low transparency and inconsistency of the procedure for providing and developing investments; dispersion of elements of the investment environment, etc.

To determine the macro-factors of the internal investment environment of rural areas, which have a significant impact on the acceleration (inhibition) of the implementation of the investment platform and the stimulation of business processes for the reconstruction of infrastructure facilities, a SWOT-analysis profile matrix (Table 1) was used, which assessed the importance of each macro-factor on business processes and the overall result – their weighted assessment (Q_i).

Table 1. *Profile matrix of SWOT-analysis of macro-factors accelerating (inhibiting) the implementation of the investment and stimulation platform of reconstruction of infrastructure facilities in rural areas in Ukraine*

The name of the environmental factor	v_i	b_i	Q_i
Strengths			
Favourable natural and climatic conditions	0.07	2	0.15
Advantageous geographical location	0.11	3	0.33
A mechanism for supporting investment projects for the development of rural areas by Ukrainian and foreign partners	0.11	3	0.33
Approval at the city and regional levels of investment attraction programs for the development of rural areas and improvement of the investment climate in rural areas	0.11	3	0.33
An opportunity for investors to rent a plot of land, movable and immovable property, privatization of land plots	0.07	2	0.15
Competitive cost of labour	0.11	3	0.33
Availability of customs in ports and international airports of cities	0.11	3	0.33
Implementation of measures to improve the investment climate of rural areas at all levels	0.07	2	0.15
Availability of state support, stable state investment and financing from local budgets, venture capital funds	0.11	3	0.33
Active reinvestment of private investors' resources	0.11	3	0.33
Total		27	2.76
Weaknesses			
Variability of the regulatory field	0.08	3	0.23
Insufficient information provision for the population, entrepreneurs and civil servants about the state, trends, and problems of the investment environment of rural areas	0.05	2	0.10
The lack of information on the development of investment projects for the development of rural areas complicates the stages of evaluating their effectiveness	0.05	2	0.10

Table 1, Continued

The name of the environmental factor	v_i	b_i	Q_i
Suspension of special (free) economic zones on the territory of Ukraine	0.08	3	0.23
Low level of development of legal and judicial protection of investors' rights	0.08	3	0.23
Insufficient level of qualification of managers in the investment field	0.05	2	0.10
Negative investment image and investors' mistrust of the authorities	0.08	3	0.23
Low level of capitalization of profits of private investors	0.05	2	0.10
The imperfection of the investment risk insurance system	0.08	3	0.23
The formality of the actions of state institutions regarding the promotion of the coordination of actions within the framework of the implementation of the policy of attracting investments for the development of rural areas	0.08	3	0.23
Insufficient level of harmonization of interests in public-private partnership regarding investment support for the development of rural areas	0.08	3	0.23
The procedure for exemption from taxation is rather complicated and long-term	0.05	2	0.10
Insufficient financing of investment projects for the development of rural areas from the state and local budgets	0.08	3	0.23
Insufficient level of strategic planning and implementation of investment projects leads to a delay in the development of allocated allocations for the development of rural areas	0.05	2	0.10
Total		39	2.67
Opportunities			
Creation of conditions for a positive investment image of rural areas	0.10	3	0.29
Improving the level of qualification of investment project managers	0.10	3	0.29
Activation of mechanisms of activity of private investors	0.10	3	0.29
Using the experience of international investment funds and venture financing funds in the field of preparation of investment projects for the development of rural areas	0.06	2	0.13
Stimulation of entrepreneurial activity in rural areas	0.10	3	0.29
Preservation and creation of new jobs in rural areas	0.10	3	0.29
Development of the information support system for investment business processes for the reconstruction of infrastructure facilities in rural areas	0.06	2	0.13
Consolidation and coordination of the actions of institutions of the investment environment of the agrarian sector of the economy with institutions of local self-government	0.10	3	0.29
Establishing communications between the state, entrepreneurial businesses, and investors	0.06	2	0.13
Improvement of mechanisms for attracting investments for the development of rural areas	0.06	2	0.13
Expanding and improving the terms of credit support for investment projects for the reconstruction of infrastructure facilities in rural areas	0.06	2	0.13
Formation of a single platform for investment and stimulation of business processes for the reconstruction of infrastructure objects in rural areas to agree, coordinate and consolidate actions regarding the distribution of investment resources between private investors, budget investment and venture financing funds, banking institutions and specialized centres (business incubators)	0.10	3	0.29
Total		31	2.68
Threats			
High level of inflation	0.07	2	0.13
Currency restrictions on the domestic market	0.07	2	0.13
Internal destabilization of the socio-economic system of the agrarian sector and its dependence on external creditors	0.07	2	0.13
Military conflict	0.10	3	0.30
Imperfect regulations for foreign investors	0.10	3	0.30
High probability of inappropriate and inefficient use of investments	0.10	3	0.30
Bureaucracy and high regulation of business processes	0.10	3	0.30
Lobbying by the state of certain investment projects for the development of certain rural areas that are of commercial interest	0.07	2	0.13
Economically unreasonable support of the country's agricultural sector	0.07	2	0.13
Fiscal policy rigidity	0.10	3	0.30
Existence of monopolization in agricultural markets	0.07	2	0.13
Low transparency of operations in the investment environment of rural areas	0.10	3	0.30
Total		30	2.58

Source: *compiled by the authors*

Following the data in Table 1, the strengths of the internal investment environment of rural areas slightly prevail over the weaknesses (weighted scores: 2.76 and 2.67 respectively). By focusing on the identified opportunities of the external investment environment, it is possible to minimize the impact of threats and mitigate the effects of weaknesses. The macro-factors of the external investment environment of rural areas were structured and their influence on the platform of investment and stimulation of business projects for the reconstruction of infrastructure facilities was assessed using the PEST analysis. Following the data in Table 2, it is proved that the negative direction of influence of the investigated sets of macro-factors prevails. Thus, the final scores for a set of political macro-factors are (-17), economic – (-181), social – (-74) and technological – (-73). The low political macro-factor indicator is determined by the fact that the effect of negative metrics is compensated by the effect of positive macro-factors, which are caused by the results of the decentralization of rural areas. The structure of the landscape of the platform for investment and stimulation of business processes for the reconstruction of infrastructure facilities in rural areas of Ukraine is formed from the volume of capital and foreign investments.

Table 2. *Profile matrix of PEST-analysis of macro-factors of construction and development of the platform of investment and stimulation of business processes for the reconstruction of infrastructure objects of rural areas in Ukraine*

The name of the environmental factor	x_i	y_i	U_i	S_i
Political factors				
Military conflict	3	5	–	-15
Sharp changes during international economic relations of the state concerning the cycle of agrarian sector restoration	2	4	–	-8
Ambiguity in the interpretation of acts of the regulatory legal framework and gaps in the legislation regarding the development of rural areas	2	3	–	-6
Insufficient level of initiative, authority and responsibility of state authorities and local self-government in the field of attracting investments for the development of rural areas	2	4	–	-8
The unpredictability of political changes at the international level regarding the movement of investment capital	2	3	–	-6
State participation in international cooperation programs and agreements in the field of investment promotion and mutual protection, settlement of investment disputes	3	4	+	+12
Regulatory and financial obligations to external creditors	2	4	–	-8
Development of the investment infrastructure of the agrarian sector of the economy and the development of rural areas	3	4	+	+12
Corruption	3	4	–	-12
Membership of Ukraine in the WTO	2	3	+	+6
Integration in the EU	2	3	+	+6
Transformation of customs regulation	2	4	+	+8
Availability of processes of lobbying the interests of local self-government bodies at the state level	2	3	–	-6
Lack of appropriate funding and support at the state level for initiative groups and investment projects for the development of rural areas	3	4	–	-12
Development of investor protection	2	2	+	+4
Variability of investment guarantee conditions	2	3	–	-6
Possibilities of applying the preferential investment regime of the agricultural sector of the economy and rural areas	2	4	+	+8
Nationalization of capital does not apply to foreign investors	2	4	+	+8
Privatization opportunities for investors	2	3	+	+6
Total				-17
Economic factors				
A significant level of inflation	2	4	+	+8
Devaluation processes	2	4	–	-8
Decrease in the creditworthiness of the population	2	3	–	-6
Reduction of parity of purchasing power and demand	2	3	–	-6
Increase in tariffs, prices for goods and services	2	3	–	-12
Expansion of the shadow sector of the economy	3	4	–	-12
Increase in unemployment	2	3	–	-6
Decrease in business activity	2	3	–	-12
Liquidity crisis and bankruptcy of private investors	3	4	–	-12

Table 2, Continued

The name of the environmental factor	x_i	y_i	U_i	S_i
Reduction of reinvestment volumes	3	4	–	-6
Reduction of lending, an increase of credit and accounting rate	2	3	–	-6
Inequality of economic development by region	2	3	–	-15
Reduction of the country's GDP	3	5	–	-12
Growth of budget debt	3	4	–	-6
Imperfect market infrastructure	2	3	–	-12
Significant tax and administrative pressure on business processes, stopping long-term investment	3	4	–	-12
Capital outflow from the country	3	4	–	-12
Export-oriented production and its dependence on foreign market conditions	2	3	–	-6
Production with a low level of added value	3	4	–	-12
Total				-181
Social factors				
The forced migration of the population and its significant differentiation by regions	2	4	–	-8
Insufficient level of formation of civic consciousness	2	3	–	-6
Low standard of living of the population	3	4	–	-12
High tendency to corruption	2	3	–	-6
Negative attitude towards institutions, public distrust of the authorities	2	3	–	-6
The outflow, and as a result, a shortage of personnel	3	4	–	-12
Demotivation of employees	2	3	–	-6
Non-compliance of working conditions and safety equipment with international standards	1	2	–	-2
Financial illiteracy	2	4	–	-8
Mentality and changing values of society	1	2	+	+2
Culture of consumption and savings	1	3	+	+2
Insufficient provision of information to the population regarding investment alternatives	2	3	–	-6
Inadequacy of education to the needs of the labour market	2	3	–	-6
Total				-74
Technological factors				
The backwardness of technological infrastructure facilities in rural areas	3	4	–	-12
Imperfect state policy regarding structural and technical modernization and reconstruction of settlements in rural areas	2	4	–	-8
A significant level of depreciation of fixed assets	3	4	–	-12
Low level of funding of the National Research and Development Institute for the revival of the agricultural sector and rural areas at the state and regional level	2	4	–	-8
Demotivation of private investors to implement innovations in rural areas	2	3	–	-6
The imperfection of intellectual property protection	2	3	–	-6
Insufficient integration of digital IT systems into the spheres of life of the population of rural areas and the agrarian sector of the economy	3	3	–	-9
Reduction in the number of university graduates in technical and economic specialities	2	3	–	-6
The low percentage of development of new agricultural and biotechnologies	2	3	–	-6
Sum				-73

Source: *completed by the authors*

From the perspective of a spatial approach, a qualitative analysis of the structural landscape of the investment platform and stimulation of business processes for the reconstruction of infrastructure objects in rural areas in Ukraine was carried out. Since the one-dimensional space limits the understanding of the structural landscape of the platform, the three-dimensional space (Sokolov & Mykhailov, 2017) with its visualization was analysed in the MATLAB system.

The spatial dynamics of the studied data for 2014-2021 indicate a slight recovery of the investment attractiveness of rural areas in Ukraine. The main plane of the landscape structure is formed by the capital investment volume growth from the state and local budgets, as well as from financial investments of private investors, including the banking sector of the economy. The structure of the multidimensional space of the investment landscape indicates its heterogeneity based on

the various types of investments formed. To clarify the structure of the surface response, indicators describing the platform landscape were considered in pairs.

Figure 5 shows the surface of two components, namely the volume of capital investments from state and local budgets, as well as private investors' resources. The obtained surface of the structural components of the landscape of the investment and stimulation platform shows a linear dependence of capital investments on the number of financial investments of private investors since their growth rates are almost the same.

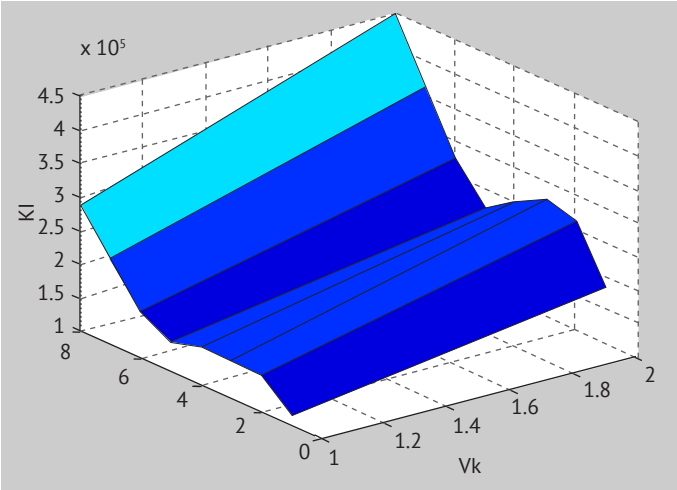

Figure 5. *The landscape of the platform for investment and stimulation of business processes for the reconstruction of infrastructure objects of rural areas in Ukraine by structural components: KI, Vk*
Source: *completed by the authors*

In Figure 6, the pair of structural components of the platform landscape, namely the volume of capital investment and foreign direct investment are considered. The resulting surface is smooth, characterised by the change in the investment volume of projects for the reconstruction of infrastructure objects in rural areas and reflects the ratio of points in time. This indicates minor fluctuations in the dynamic cycle of investment attraction.

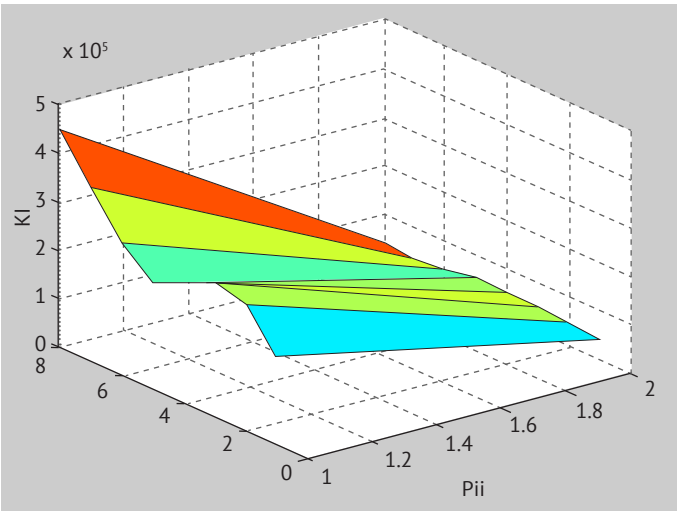

Figure 6. *The landscape of the platform for investment and stimulation of business processes for the reconstruction of infrastructure objects of rural areas of Ukraine by structural components: KI, Pii*
Source: *completed by the authors*

In Figure 7, another pair of structural components of the landscape of the investment platform and stimulation of business processes for the reconstruction of infrastructure objects of rural areas in Ukraine were reviewed, namely the number of private investors' resources and direct foreign investments from the venture capital fund.

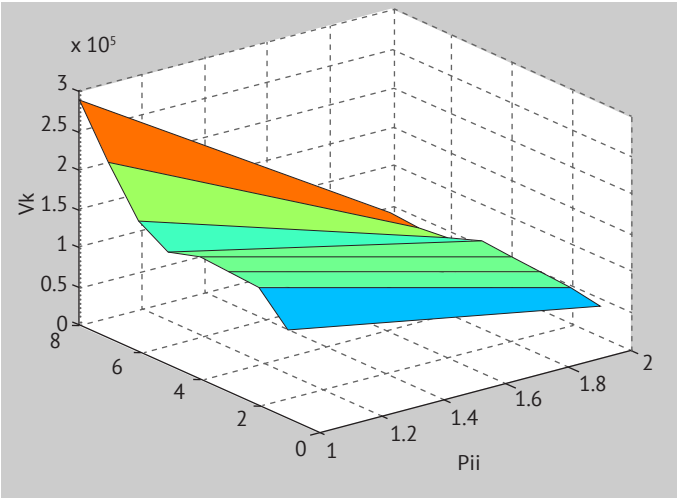

***Figure 7**. The landscape of the platform for investment and stimulation of business processes for the reconstruction of infrastructure objects of rural areas of Ukraine by structural components: Vk, Pii*
***Source:** completed by the authors*

Analysing the results of calculating the Figure 6-7 data, it is established that the constructed graphs are almost similar and show smooth surfaces with a slight break, which was recorded at the level of 2018-2019. The turning point changed the dynamics of the amount of investment in projects for the reconstruction of infrastructure facilities in rural areas in Ukraine and their growth rates. Thus, after hacking, domestic investment has a much faster growth rate than foreign investment, which is visible from the obtained surfaces.

The proposed approach to the analysis of the spatial landscape of attracting investments for the development of rural areas makes it possible to ensure the systemic character of investment business processes at the regional level of the country, to equalize investment flows following modern economic realities. The three-dimensional structure of the platform landscape smooth's investment heterogeneity is determined using means and technologies of financial compensation and mechanisms of territorial redistribution of investment resources in projects of reconstruction of infrastructure facilities and necessitates the search for tools to eliminate the shortcomings of the investment image of rural areas.

DISCUSSION

The main concepts of investment policy are formed following the main transformational changes of the agro-industrial complex in a specifically defined region, in particular rural areas. At the same time, the interrelationship of environmental, economic, and social problems is considered and the understanding that their solution is possible only on a comprehensive basis, considering the balance of the interests of the development of nature and society.

Given the importance of the agrarian sphere both in Ukraine and in many other countries, the dependence of the socio-economic development of the territory and the state of the agrarian sphere on the intensity of investment flows is characterized by the following factors: active development and agriculture are based on labour, incomes of rural residents and relevant investment assets from the public-private partnership.

The stable and rapid development of the agricultural market has a significant impact on increasing the financing of the construction and maintenance of social infrastructure facilities. The system of rural settlement, transport service, administrative structure, and management are closely interconnected, and the development of the agrarian sphere has always been identified with the improvement of rural settlements.

Scientists from the Czech Republic, A. Vaishar and M. Šťastná (2019), considered the regional development strategy of the Czech Republic, highlighting economically and socially threatened rural regions. The authors analyse in detail the economic situation in regions with different geographic locations. Their research aimed to differentiate rural areas internally, which allows focusing attention on areas that require increased investment rates for appropriate infrastructural development. During the study of two separate peripheral regions, the geographical analysis and synthesis methods, as well as the investment planning method, were used to determine their most significant strengths and weaknesses, as well as possible strategies for further development. In particular, the most effective direction of rural development was the increase of investment flows in the field of agritourism.

The opinion of Czech scientists is justified. However, they did not analyse the field of agrarian tourism as an important direction for attracting investment flows and rural development. It is also important to note that the operation of agrotourism must be included in the business process, which necessarily requires the modernization of the infrastructure of the village.

Researchers from Spain E. González-González and S. Nogués (2019) examined the main principles of the relationship between European and national transport policy, which requires effective territorial unity and adequate funding. Long-term transport impact assessments in under-explored areas covering large areas of Europe play an important role in identifying problematic issues related to transport investments. In more detail, scientists analysed the consequences of the transport policy development and the corresponding investment in the North-Western region of Spain, where about 95% of municipalities are considered rural. The results show that the gap in accessibility between urban and rural areas has been eliminated by an active investment policy in the infrastructure development of rural areas, through the formation of an extensive transport system and corresponding accessibility to the market for services and goods. However, these improvements are only one of the few steps to break the so-called inertia of rural areas and reduce their socio-economic disadvantages.

The research results of scientists should be supported regarding the need for the development of transport infrastructure due to the increase in investment indicators in this area. However, they are relying more on the economic restoration of rural areas through the development of the agro-industrial complex of the region. And in this case, the transport industry is one of the areas of modernization of infrastructure facilities of rural communities.

Scientists from China, Q. Zhou *et al.* (2022) examine the impact of the environmental situation on the domestic investment attractiveness of rural regions, which in recent decades has been characterized by an increase in direct residential CO2 emissions (DRCE), which are still growing rapidly. Thus, the study of the relationship between the growth of DRCE on population density in rural areas and the realization of rural revitalization includes the study of the relationship between infrastructure investment, household income and DRCE using Granger non-causality tests and systemic mediation analysis. Spatial development analysis indicators reflect geographic convergence between rural DRCEs and rural infrastructure investments. That is, rural households depend on the development of the electricity grid infrastructure. The regression results show that the positive impact of rural infrastructure investment on rural DRCEs varied following the structure of the investment. With a 1% increase in investment flows in the development of rural energy and transport infrastructure, the DRCE indicator, which affects the population density in rural areas, increases by 0.041%. In turn, when investment attractiveness increases by 1% of the volume from other investments in rural infrastructure, in particular water supply, wastewater disposal, waste processing and environmental sanitation, the DRCE indicator increases by 0.169%. That is, the implementation of a balanced climate policy requires urgent countermeasures regarding the effective reorganization and modernization of specifically defined infrastructural elements of rural areas. In general, the result of the study is the provision of information on the analysis and prospects for the implementation of low-carbon revitalization in rural areas, considering existing investment flows.

In this research, the issue of greening in the territory of rural settlements, as it is shown in the results of research by Chinese scientists was not separately analysed, but the importance of considering the basic principles of climate policy when it comes to the use of natural land resources, which are the basis and resource in agriculture is completely relevant. In particular, the importance of the economic effect on the output of business processes in the agricultural sector cannot be underestimated, as it directly includes the minimization and assessment of possible environmental losses, given the attraction of priority European investments.

Researchers from Japan and Tanzania Y. Tsuchiya *et al.* (2020) point out that one of the directions for increasing investment flows in the development of village infrastructure with the active involvement of agricultural lands, which are currently characterized as unproductive or degraded, is the possibility of designing solar photoelectric plants. Currently, this type of alternative source of electricity is spreading in sub-Saharan Africa and many other countries of the world. The authors investigated several cases of photovoltaic systems in the production and use of electricity in rural Tanzania using a life cycle assessment. The energy payback time calculated based on the use of photovoltaic systems, considering the inventory data of the International Energy Agency revealed unsatisfactory performance. In particular, the actual electricity production figures at the facilities significantly exceeded the expected solar radiation calculations based on the values. In one location, the payback time for the electricity even exceeded the lifetime of the photovoltaic panel, indicating that energy recovery is not possible. As for the return on investment, the profit obtained from investment flows made to increase the rate of return on current operating costs indicates a negative return on investment. Conversely, diesel power generation has proven more suitable in these regions due to low and volatile electricity demand. Thus, it is necessary to carry out research in the direction of increasing the efficiency of the photovoltaic system and reducing the payback period through the improvement of service, and management, as well as increasing the electricity demand (Sava, 2017; Vdovenko, 2021).

The development of electricity supply infrastructure and energy consumption using alternative energy sources, which are located precisely within rural regions, was not considered in the research. However, this is an effective, modern method of providing rural settlements with energy resources, with the predominance

of the economic restoration of the agricultural sector, which in turn requires large amounts of electrical energy, considering maximum resource conservation and smart investment.

CONCLUSIONS

A rural territory with an untapped potential for investment and with a certain type of economic activity in the investment mode can establish business relations with entities belonging to related types of service to other rural communities, and thus ensure the manifestation of a large-scale absorption effect of a certain territory. The rural population is slowly getting involved in the development and implementation of development programs. The success of the implementation of investment projects for the development of rural areas is directly dependent on the interested participation of the local population in the formation and implementation of regional development programs.

However, unfortunately, the principle of participation is often ignored, which leads to the decline of the economy of rural areas of the country. Due to the war, their internal reserves are limited, so special importance should be given to the issue of increasing foreign investment income and developing self-organization processes to attract them. The expectation of an increase in investment income and, as a result, the development of new agricultural and biotechnologies, which will increase the number of jobs, led to the introduction of new mechanisms for the development of certain territories, types of economic activity, where, under certain conditions, the state organized special preferential regimes (tax, customs, and others).

The efforts of the state, business, population, and other interested groups of investors should be consolidated through cooperation, development of local self-government and activities of public organizations in Ukraine to increase the efficiency of the functioning of infrastructure facilities with a large-scale resource provision, which will be integrated through international economic relations. This will make it possible to transform and modernize the transport system, improve the logistics of investment flows in communication innovations and telecommunication services, and increase state support for rural areas for the development of priority investment projects.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Стратегія залучення інвестицій у розвиток сільських територій для економічного відновлення аграрного сектору

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Анотація. Метою дослідження є вивчення реалізації стратегії залучення інвестицій для розвитку сільських територій, яка на основі використання інвестиційної платформи та стимулювання бізнес-процесів дозволяє прискорити реконструкцію інфраструктурних об'єктів на селі, залучивши зацікавлених інвесторів до циклу економічного відновлення аграрного сектору країни. Дослідження проведено з використанням таких методів: аналіз показників у структурі іноземних інвестицій; аналогії та порівняння напрямів капітальних вкладень приватних інвесторів на розвиток сільських територій; індукування макрофакторів, що стримують реалізацію інвестиційної політики; синтез показників профільної матриці SWOT-аналізу та PEST-аналізу; створення просторових моделей ландшафтів інвестиційних майданчиків. Результатами даного дослідження є визначення пріоритетних іноземних інвестиційних компаній країн світу, які забезпечують залучення прямих іноземних інвестицій в аграрний сектор економіки України. На основі матричних профілів SWOT-аналізу та PEST-аналізу визначено макрофактори внутрішнього та зовнішнього інвестиційного середовища сільських територій, які мають суттєвий вплив на прискорення (гальмування) реалізації інвестиційної платформи та стимулювання бізнес-процесів з реконструкції об'єктів інфраструктури. Змодельовано трирівневий профіль ландшафту платформи інвестування та стимулювання бізнес-процесів реконструкції інфраструктурних об'єктів сільських територій в Україні

Ключові слова: інфраструктурні об'єкти; сільські території; капітальні інвестиції; стратегічне планування; бюджетні інвестиції; приватні інвестори

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Credit and Investment support for the development of Ukraine's agricultural and economy sector

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Abstract. One of the key problems of the modern agricultural sector of the national economy is the achievement of stable economic growth. In this context, the system of credit and investment support occupies the main place in the expanded reproduction of this priority industry for the economy of Ukraine. The research aims to review the main trends in credit and investment provision of the agrarian sector of the national economy and to determine further investigations in this direction. It has been established that for the formation of an effective system of credit and investment support for the agricultural sector, it is necessary to consider such positions as the influence of bank lending and climate shocks on the investment decisions of farmers, global and regional trends in the direction of the gross accumulation of fixed capital and fixed assets in agriculture, mechanisms for fixing conditions for the transfer of investment resources for use by agro-industrial companies, financial inequality between the

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urbanized and rural areas. It has been proven that bank lending is the key tool in all forms of credit and investment support for the agricultural sector. This is especially true during the period of martial law in Ukraine. Using the method of economic and mathematical modelling, it can be argued that bank lending is a strategic financial resource in the formation of credit and investment support for the agricultural sector. A system of credit and investment support is proposed, which is primarily based on the improvement of the system of state regulation of the agrarian sector. It has been proven that to increase the level of effectiveness of the system of credit and investment provision of the agricultural sector, attention should be paid to such an instrument as project financing and a review of the very structural composition of the state regulation of agricultural production, considering the practice of European Union. Such approaches can be used by state authorities when developing a strategy for the development of the agrarian sector in the conditions of martial law and the post-war period, as well as making infrastructural changes in the process of interaction between the banking and agrarian sectors of the national economy

Keywords: agricultural business; bank lending; state financial support; investment; financial resources; martial law; profitability

INTRODUCTION

The agrarian sector of an economy is increasingly in need of financial investments necessary for the renewal and technological modernization of production. At the same time, despite the continuation of martial law, it is necessary to develop a clear action plan for credit and investment support of the agricultural sector of the economy, reconstruction of destroyed agrarian infrastructure, restoration of land fertility, further introduction of innovative production technologies and agrarian business.

The large-scale war launched by russia against Ukraine had a significant impact on the economy and its agricultural sector. L. Vdovenko (2022) singled out the key challenges for the agrarian industry in the conditions of martial law, among which the reduction of sown areas; the blocking of agricultural product sales markets; the impossibility of functioning of seaports of Ukraine; destruction of the infrastructure of agro-industrial production; processing and storage. I. Osadchuk *et al.* (2020) stated that Ukraine, despite an unfavourable general economic climate, can use the experience of countries that managed to achieve significant success in the development of innovative activity and increasing the competitiveness of the agricultural sector, namely the USA, France, England, Poland, Germany, Japan.

S.K. Dary and H.S. James Jr. (2019) considered the relationship between investments in trade credits and the profitability of U.S. agricultural and food companies for the period 2001-2014. The authors concluded that investing in trade credit significantly increases the profitability of agricultural-food companies, which is consistent with financial, transactional, operational, and commercial theories of trade credit. A. Grau and A. Reig (2018), who analyzed the impact of trade credit on the determinants of profitability during the crisis in Europe, reached the same conclusion. Modelling method results confirmed that trade credit affects firm profitability depending on the state and such indicators as size, specificity (industry), market share, and firm reputation.

In the example of China, Z. Chen *et al.* (2022) built a model that suggests, in terms of overall impact; formal financial lending in rural areas improves the performance of family farms, whereas informal financial lending in rural areas had little effect on the efficiency of family farms. They proved that family livestock farms and mixed-family farms are more positively affected by formal rural financial lending than family horticultural farms. M. Donckt *et al.* (2022) presented a new analytical database of aggregate investment flows to fixed assets in agriculture, forestry, and fisheries. The main finding of the study is the regions with the highest average growth rates of investment flows between 1995 and 2017 (i.e., Asia-Pacific and Africa) have shown the most significant increase in their contribution to global agricultural value added. S. Newman and F. Tarp (2020) emphasize the need of considering the impact of climate shocks on farmers' investment decisions. The research results showed that farm households, on average, manage to balance consumption after climate shocks by reducing savings and borrowing. In the long run, households exposed to climate shocks invest less in productive assets, leading to lower consumption levels.

When forming an investment strategy for the development of the agricultural sector, it is important to select investment instruments, which can be used to manage innovative transformations. A. Mykhalov *et al.* (2021) proposed a mechanism for fixing the conditions for the transfer of investment resources for use by agro-industrial companies. C. Lin & L. He (2020) examined the impact of Targeted Easing (TE), an unconventional monetary policy instrument initiated by the Chinese Central Bank to lower reserve requirements for targeted agricultural financial institutions (banks). Agricultural enterprises with lower agency costs, greater financial constraints and higher levels of creditworthiness are found to benefit significantly more from TE policies than their competitors. An indisputable scientific development is an issue raised by A. Daoud *et al.* (2019) regarding the mandate and competence of the International Monetary Fund (IMF) that extends to the policy in the field of food and agriculture, but there is unofficial evidence that IMF still conducts such a policy. It was found that

about 2% of all IMF conditions (1,105 out of 58,406) directly relate to issues of food and agriculture.

The research by L. Tang & S. Sun (2022), using regional-level panel data from 2004 to 2018, estimates the impact of agricultural financial support on the income gap between urban and rural areas in China. It is shown that due to fiscal incentives, financial institutions have more incentives to increase agricultural credit, and income inequality between urban and rural areas has decreased significantly throughout the study period, especially in underdeveloped areas.

The research conducted by M. Patynska-Popeta & T. Zinchuk (2022) on the management of the financial potential of territorial communities, including rural ones, created an algorithm for post-war restoring of local finance, which includes the estimation of military damage, renovation of 'central government – local authorities' communications, formation of effective management levellers and its synchronization with the tasks set according to the EU membership plan. N. Tanaklevska & V. Oliynik (2019) proposed a methodical approach to determining the volume of investments required for the agrarian sector of the economy and evaluating the effectiveness of the investment program for the development of the agrarian sector of the region. When determining the key positions of investment and credit provision of the agrarian sector of the economy, the methods and forms of state financial support are an important lever. In this direction, studies conducted by L. Petliuk & N. Miedviedkova (2021), T. Sokolovska *et al.* (2020), and P. Nesenenko (2022) deserve attention.

The research aims to analyse the development of theoretical and methodological approaches to the substantiation of prospective directions of credit and investment provision of the agrarian sector of the economy of Ukraine.

CONCEPTUALIZATION OF THE CREDIT AND INVESTMENT SUPPORT SYSTEM FOR AGRIBUSINESS

To start with, it is advisable to define the main concepts of the research topic. I. Berzhanir (2020) defines the crediting mechanism of the agro-industrial complex as economic relations to provide agro-industrial enterprises with a source of financing under the conditions of return, payment, security, term, aimed use and differentiation, accompanied by the specificity of agro-industrial enterprises. S. Arzhevitin *et al.* (2021) consider agricultural credit as an independent form of credit relations. Its specificity lies in the fact that lending takes place on preferential terms, which requires a strict accounting of the budgetary and extra-budgetary resources spent on it and an assessment of the effectiveness of their use; the purpose of the loan, consideration of the needs of the borrower; requires predicting potential risks, as well as planning costs and calculating profits.

Considering the security investment component, the definition provided by Yu. Kyrylov and V. Hranovska (2019) deserve attention: it is a complex dynamic system, the purpose of which is to encourage and support the continuous growth and advancement of agriculture and the economy by seeking the attraction, distribution, and investment of monetary, material, and intellectual resources of various origins, considering the combined influence of macro- and micro-environmental factors to achieve promising socio-economic goals. Based on the above, the authors of the paper formed a system of credit and investment support for the agricultural sector of the economy (Fig. 1).

Accordingly, to perform further research, it is necessary to form an empirical base and analyse the use of forms of credit and investment support in the agricultural sector. According to the results of the "Survey on War Damage in the Agriculture of Ukraine", prepared by the Center for Research on Food and Land Use of KSE Institute together with the Ministry of Agrarian Policy and Food of Ukraine, the total losses due to the full-scale war in agriculture reached 6.6 billion dollars (2022). In the structure of damages, the largest losses are recorded as a result of the destruction or partial damage of agricultural lands and unharvested crops – 1.9 billion dollars; the total amount of losses due to damage or destruction of agricultural machinery is estimated at 2.9 billion dollars, granaries – 1.1 billion dollars; the estimated value of the dead livestock is more than 362.5 million dollars, perennial plantations – 349 million dollars, other factors of production – 95.4 million dollars.

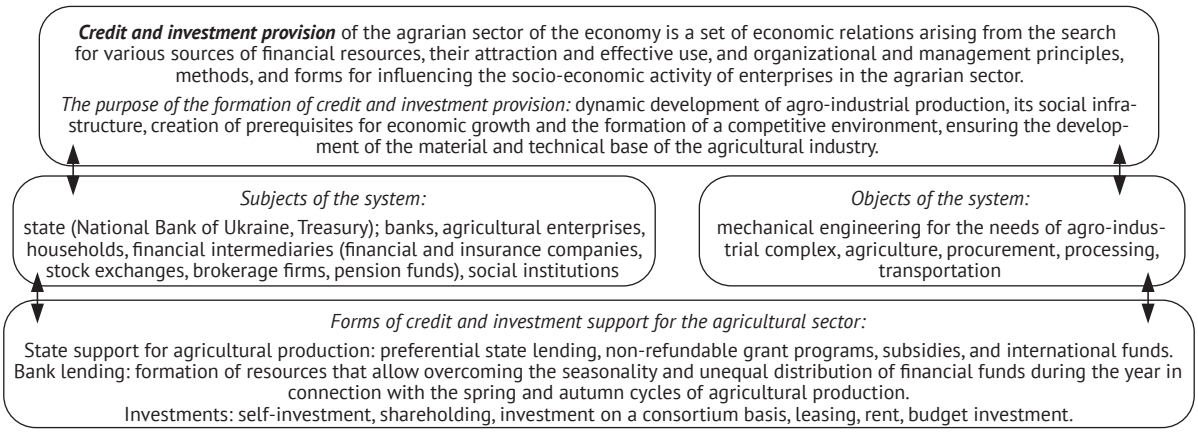

Figure 1. *The system of credit and investment provision of the agrarian sector of the economy*
Source: *systematized by the authors*

Direct damage cannot be done before the end of the hostilities. However, comprehensive financial support is necessary for the formation of the financial potential of agrarian sector enterprises through the mechanism of state financial support and bank lending. Current forms of state support for the agricultural sector of the national economy are presented in Table 1.

Table 1. *Characteristics of forms of state financial support of the agricultural sector of the national economy*

The direction of financial state support	Characteristic
Grants for business creation (as of February 17, 2023) UAH 1.3 billion has been included in the 2023 state budget. At the end of 2022, 70 applications for the development of gardens and 7 applications for the construction of greenhouses with a total cost of UAH 371 million were signed.	Grants for greenhouse farming UAH 76.90 million (area – 18.93 ha), including by regions: Dnipropetrovsk – UAH 27.9 million (area – 6.65 ha); Zakarpattia – UAH 14.0 million (area – 3.22 hectares); Vinnytsia – UAH 7.0 million (area – 1.62 ha); Volyn – UAH 7.0 million (area – 1.6 ha); Kyiv – UAH 7.0 million (area – 1.6 hectares); Zhytomyr – UAH 7.0 million (area – 1.76 hectares).
	Grants for horticulture, berry growing and viticulture 344.4 million UAH (area – 1143.21 ha), including by regions: Odesa – 25.81 million UAH (area – 60.29 ha); Kyiv – UAH 46.08 million (area – 228.88 hectares); Lviv – UAH 41.71 million (area – 151.08 hectares); Volyn – UAH 9.75 million (area – 15.72 hectares); Chernivtsi – UAH 266.54 million (area – 41.82 hectares); Ivano-Frankivsk – UAH 35.36 million (area – 81.25 hectares); Zakarpattia – UAH 68.20 million (area – 191.83 ha); Cherkasy – UAH 0.40 million (area – 10 hectares); Rivne – 4.73 million UAH (area – 20.93 ha); Khmelnytskyi – UAH 10.00 million (area – 25 hectares); Poltava – UAH 10.00 million (area – 25 hectares); Zhytomyr – UAH 153.20 million (area – 46.91 ha); Dnipropetrovsk – UAH 27.23 million (area – 91.12 ha); Vinnytsia – UAH 10.00 million (area – 25 hectares); Ternopil – UAH 11.2 million (area – 28 ha).
Support of farms and other producers of agricultural products	– budget subsidy per unit of cultivated agricultural land (1 hectare) for carrying out agricultural activities – in the amount of UAH 3100 per hectare, but not more than UAH 372 000 for one recipient; – special budget subsidy for keeping cattle (cows) in all productivity areas – in the amount of UAH 5,300 per cow, but no more than UAH 530 000 for one recipient. In 2022, budget subsidies (ha) were provided to 21 467 recipients on 424 631.9 ha; special budget subsidies for keeping cows – to 10 247 recipients for 62 090 cows.
Grant support from FAO and EU (2023)	FAO will provide producers with investment funds in the amount of: – up to 370 000 hryvnias (10 000 USD) for small farms; – up to 925 000 hryvnias (25 000 US dollars) for agricultural small and medium-sized enterprises, agricultural cooperatives, and associations of producers. Grant support is provided for Lviv, Ivano-Frankivsk, Zakarpattia and part of Chernivtsi regions.
Farming support	Partial compensation of costs to farms related to the provided agricultural advisory services (except for newly created ones), for 90% of the cost, but not more than UAH 10 000. Financial support for newly created farms to obtain agricultural advisory services (provided once in an amount not exceeding 36 000 hryvnias, subject to a contract previously concluded by the end of the current budget period). The program "Granting loans to farms" – provides financial support on a revolving basis in an amount not exceeding UAH 500,000 for a period of up to five years with the provision of the obligation to return budget funds.
Credit program "5-7-9"	The credit limit increased from UAH 60 million to UAH 90 million. In 2022, under the "5-7-9" program, UAH 90.85 billion in loans were issued to more than 40,000 farmers. In March of last year, the government expanded this program: farmers received up to UAH 60 million at 0% annual interest, and 80% of the amount could receive state guarantees against the grain. Among the TOP-5 regions in terms of loans received are Kyiv Region (UAH 14.9 billion), Vinnytsia Region (UAH 8.8 billion), Kirovograd Region (UAH 8.3 billion), Dnipropetrovsk Region (UAH 6.5 billion), Odesa Region (5.8 UAH billion). The largest number of loans to farmers were issued by PrivatBank, Oschadbank, Raiffeisen Bank, Ukrgasbank, Ukreximbank, Kredi Agricole Bank, and PUMB. The Entrepreneurship Development Fund concluded agreements with 44 banks.

Source: *systematized by the authors based on Ministry of Agrarian Policy and Food of Ukraine (2023); KSE (2022); AgroPolit.com (2023)*

Regarding bank lending to the agricultural sector of the national economy, it should be noted that despite the martial law in Ukraine, the volume of lending by banks is constantly growing (Table 2).

Table 2. *Dynamics of the volume of bank lending to the agricultural sector and indicators characterizing the creditworthiness of the industry in 2016-2022*

Indicators	Year						
	2016	2017	2018	2019	2020	2021	2022
Volumes of loans granted (total)	829 932	822 114	859 740	744 648	724 157	752 324	754 371
Volumes of lending to the agricultural sector	55 374	59 706	67 675	61 600	61 486	82 600	118 504
The output of agricultural products, UAH million	634 040	703 893	842 925	838 038	887 822	1 359 369	–
Total profitability (loss) of the industry, %	24.7	16.0	13.7	16.1	13.6	36.4	–
Share of loans to the agricultural sector, %	6.67	7.26	7.87	8.27	8.49	10.98	15.71
The efficiency of production of agricultural products per UAH 1 of credit provision for the agricultural sector	11.45	11.79	12.46	13.60	14.44	16.46	–

Source: *calculated by the authors based on State Statistics Service of Ukraine (2023); National Bank of Ukraine (2023)*

Despite the lack of official data on the development of the agricultural sector of the national economy in 2022, it is still possible to state the utilization of received loans by agricultural enterprises is effective. This is evidenced by the efficiency index of agricultural production per UAH 1 of credit support for the agricultural sector, which is increasing annually. It is also going about the overall level of creditworthiness of the industry, which is confirmed by the level of overall profitability, growing over the analysed period. Finally, it is advisable to analyse the volume of capital investments in the agricultural sector of Ukraine (Table 3).

Table 3. *Dynamics of capital investments in the agricultural sector of the national economy, thousand UAH*

Year	Capital investments (total)	Including:								The share of capital investments in the agricultural sector in the total amount, %
		Capital investments in tangible assets	including:				Capital investments in intangible assets	including:		
			Land plots	Existing buildings and structures	Construction and reconstruction of buildings	Machinery and equipment		Concessions, patents, licenses, trademarks, and similar rights	Purchase of software	
2016	49497.7	49231.6	95.4	572.2	7452.9	37676.5	266.2	2.5	34.6	14.05
2017	63262.9	62664.5	152.6	8400.2	9648.1	48433.0	598.4	10.8	49.6	14.32
2018	65559.6	64252.9	192.9	2162.6	12152.8	44844.0	1306.6	5.2	56.5	11.42
2019	59332.9	57936.3	316.6	1085.6	11988.2	37537.1	1396.7	41.2	38.3	9.48
2020	36442.1	35756.7	4243.1	6800.6	1656.9	23056.0	685.4	10.0	33.886	8.68
2021	49127.4	48198.6	7888.5	7431.4	2655.1	32576.2	928.8	843.6	85.2	9.29

Source: *calculated by the authors based on State Statistics Service of Ukraine (2023)*

According to the research results, during 2016-2021, capital investments in agriculture had a changing trend in terms of total volumes, and in 2021 they decreased by 0.75%, although compared to 2020, they increased by 34.81%. According to the share of the volume of capital investments in the total volume of investments in the economy of Ukraine, a gradual decrease is observed. Thus, in 2021, compared to 2016, the weight decreased by 4.76%.

CREDIT AND INVESTMENT DRIVERS OF THE AGRICULTURAL PRODUCTION

For the quantitative assessment of the relationship and the degree of influence of bank loans on the efficiency of agricultural business, indicators of the effectiveness of agricultural enterprises were chosen (Table 4). It should be noted that interruptions in the work of statistical accounting in 2022, which are related to war events, do not allow data to be operated later than

2021. This imposes certain restrictions on the depth and representativeness of the sample and directly affects the degree of extrapolation of the results obtained by the authors in connection with the military transformation of the economy and industry. However, the available data panel reflects the generalized level of the financial and economic state of the agricultural business of Ukraine on the eve of the war. First, it is necessary to establish the presence and density of a statistical relationship between indicators of the agricultural enterprises' activity and bank crediting of agribusiness, which was performed using the calculation of the correlation coefficient and its interpretation according to Chaddock's scale.

The data presented in Table 4 show that most of the presented indicators of the efficiency of agribusiness functioning are undoubtedly directly related to bank lending – the closest connection is shown by the general indicators of the industry's performance (gross value added, output). The relatively weak relationship between lending and profitability indicators can be explained, from the authors' point of view, by the peculiarities of these indicators' formation: expenses (operational or general) in the denominator include mandatory items and expenses of future periods, which disperse the received in current time result (net or operating profit).

Table 4. *Correlations between bank lending and performance indicators of agricultural enterprises in Ukraine for the period 2008-2021*

Indicators	Correlation coefficients	Direction and tightness of correlations
1. Gross value added	0.950472	direct, very high
2. Output	0.950275	direct, very high
3. Capital investments	0.901215	direct, very high
4. Financial result before taxation	0.806742	direct, high
5. Net profit	0.820935	direct, high
6. Profitability from operating activities	0.421955	direct, moderate
7. General level of profitability	0.512578	direct, noticeable

Source: *developed by the authors based on State Statistics Service of Ukraine (2023); National Bank of Ukraine (2023)*

Unfortunately, the available retrospective database does not allow for a more thorough analysis of the relationship of indicators or to obtain a reliable model of the impact of bank lending on agribusiness: the data set consists of 14 annual observations. To remove this restriction, it is necessary to determine the indicators with reliability and greater frequency (since credit data are monthly). Among open data satisfying this condition, quarterly values of gross value added and gross operating surplus (mixed income) of agricultural enterprises were obtained (Fig. 2). Thus, the sample contains 56 observations of each variable.

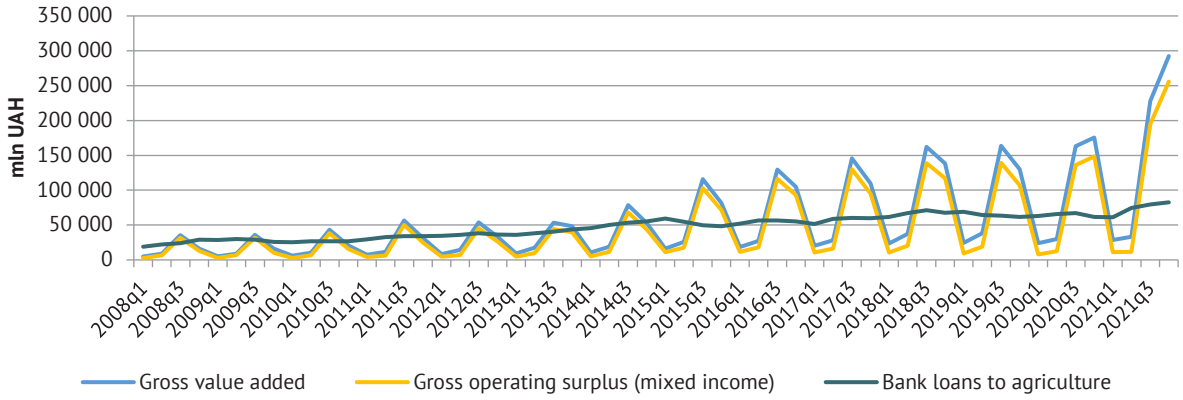

Figure 2. *Dynamics of bank loans, gross value added and gross operating surplus of agriculture of Ukraine in 2008-2021*

Source: *developed by the authors based on State Statistics Service of Ukraine (2023); National Bank of Ukraine (2023)*

Figure 2 shows that the gross value added, and gross operating surplus have a pronounced seasonality, while the dynamics of lending are not so closely related to the quarterly frequency. In this case, seasonality must be smoothed concerning the performance of other econometric procedures. This task was performed using the TRAMO/SEATS method without manually configuring the module. The smoothed series are presented in Figure 3.

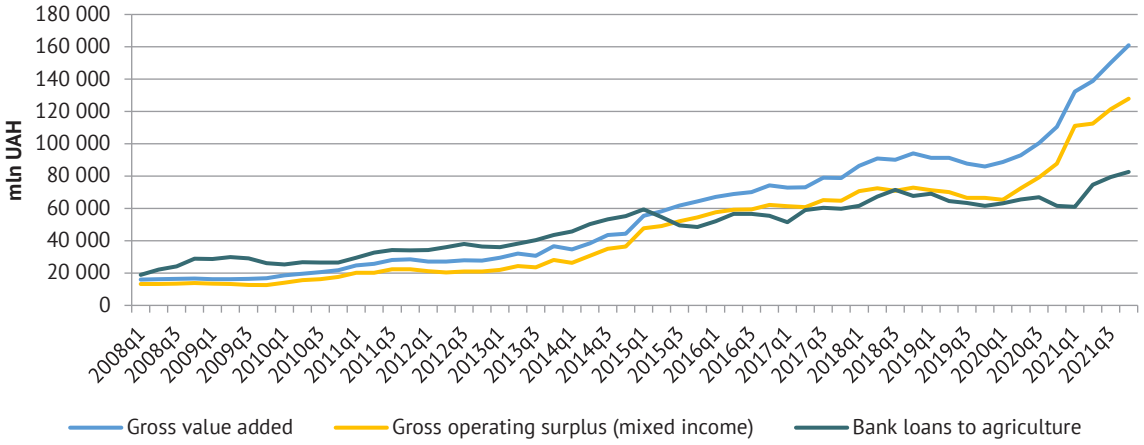

***Figure 3**. Seasonally adjusted dynamics of bank loans, gross value added and gross operating surplus of agriculture of Ukraine in 2008-2021*

***Source:** developed by the authors based on State Statistics Service of Ukraine (2023); National Bank of Ukraine (2023)*

Since the indicators are presented in actual prices (excluding inflation), the curves in Figure 3 show a pronounced upward trend. It is interesting that up to 3Q 2015, the volume of loans exceeded other curves: this may indicate not so much the low efficiency of agricultural lending, but distorted statistics of real agricultural production to avoid "excess" taxation. Thus, the comparison of lending volumes with official data on the results of the industry is the simplest indicator for evidence of "shadowing" the economy, as the authors wrote earlier e.g. (Kovalenko *et al.*, 2022).

Next step the presence of correlation between the variables should be analysed and the strength of the relationship between them should be interpreted (Table 5).

***Table 5.** Correlations between bank loans and generalized indicators of the agricultural economy of Ukraine in 2008-2021*

Indicators	Gross value added							
	no lag	**1**	**2**	**3**	**4**	**8**	**12**	**16**
1. Loans, total	0.931	0.919	0.904	0.889	0.896	0.914	**0.951***	0.911
2. Loans, the domestic currency	0.932	0.917	0.898	0.876	0.875	0.884	0.944	**0.976***
3. Loans, foreign currency	0.716	0.698	0.690	0.691	0.712	**0.725***	0.686	0.617
4. Short-term loans	**0.886***	0.878	0.869	0.859	0.871	0.881	0.800	0.738
5. Long-term loans	0.862	0.840	0.819	0.802	0.805	0.838	0.932	**0.934***
	Gross operating surplus (mixed income)							
	no lag	1	2	3	4	8	12	16
1. Loans, total	0.926	0.912	0.897	0.883	0.888	0.909	**0.941***	0.885
2. Loans, the domestic currency	0.921	0.902	0.881	0.858	0.854	0.866	0.938	**0.967***
3. Loans, foreign currency	0.726	0.712	0.708	0.712	0.736	**0.745***	0.673	0.571
4. Short-term loans	0.878	0.874	0.870	0.864	0.880	**0.898***	0.798	0.713
5. Long-term loans	0.859	0.832	0.808	0.788	0.787	0.819	**0.918***	0.909

***Note:** * – the highest correlation coefficient in a line*

***Source:** developed by the authors based on State Statistics Service of Ukraine (2023); National Bank of Ukraine (2023)*

Examining the data in Table 5 using Chaddock's scale, it can be concluded there is a direct, mostly high, and very high interdependence between the gross value added and gross operating surplus of agricultural enterprises on the one hand, and bank loans for agribusiness (in terms of currencies and ranges) – with another. The correlation analysis is conducted considering the presence of lags between the provision of a loan and the realization of its effect on the indicators of the agricultural sector. It is worth noting that lags are quarterly, so 2 lags are half a year, 4 lags are a year, 8 lags are 2 years, etc.

The relationship between gross added value and lending illustrates the strategic nature of external financing of agriculture: the closest dependence between indicators is realized 3-4 years after a loan provision. It is also necessary to determine the presence of processes of connections' fade after 9-12 months after providing a loan compared to the immediate effect. Gross value added shows the closest relationship with loans in domestic currency after 4 years, while foreign currency loans, in general, have a much weaker effect. This testifies to the predominantly hryvnia lending nature of agriculture, which is explained by its export orientation: for the purchase of fertilizers and equipment abroad, agribusiness uses its foreign exchange earnings, while loan funds are directed to financing the internal expenses (seed material and livestock feed, wages, lease payments, taxes). The correlation coefficient between the value added and lending in terms of maturity also seems very logical: short-term loans have the greatest effect immediately after borrowing, and long-term financial instruments are used for investment purposes that pay off after a few years.

The relations between gross operating surplus (mixed income) and indicators of agribusiness lending generally repeat the correlation map of gross value added, although they are characterized by less strength. Logical contradictions are observed only when considering loans by maturity: statistically the strongest relationship between profit and "short" crediting is observed with a lag of 2 years, while with long-term loans the best ratio is observed 3 years after the grant. These controversial results can be explained by the complex nature of the indicator: the gross surplus combines the financial results of many agricultural corporations, some of which in the current period could receive losses.

Using obtained in Table 5 results of correlation analysis one-factor regressions of the dependence of agricultural indicators on bank lending (in terms of currencies and maturity) can be constructed. The characteristics of the models estimated by the method of least squares are presented in Table 6.

***Table 6**. The main characteristics of the estimated models of the dependence of gross value added and gross surplus of agriculture of Ukraine on bank loans*

Dependent variable (Y)	Independent variables (X)	Lag of X	Coefficients		Adjusted R^2, %	Neutral level of X (Y = 0), million UAH
			X	constant, million UAH		
Gross value added	Loans, total	-12	2.35	-31 841.21	90.13	13 550.29
	Loans, the domestic currency	-16	4.13	-41 913.70	95.15	10 160.56
	Loans, foreign currency	-8	4.80	1 252.73*	51.49	-260.97
	Short-term loans	–	4.22	-27 922.48	78.02	6 611.16
	Long-term loans	-16	4.20	-25 874.46	86.82	6 157.35
Gross operating surplus (mixed income)	Loans, total	-12	1.88	-25 304.04	88.20	13 451.83
	Loans, the domestic currency	-16	3.31	-33 464.05	93.40	10 118.99
	Loans, foreign currency	-8	3.99	-839.04*	54.56	210.10
	Short-term loans	-8	4.23	-24 929.06	80.22	5 891.91
	Long-term loans	-12	2.75	-14 794.89	83.90	5 379.79

***Note:** * – p-value is greater than the critical value (0.1)*
***Source:** developed by the authors based on State Statistics Service of Ukraine (2023); National Bank of Ukraine (2023)*

Presented in Table 6 data show that most of the obtained models are quite adequate (adjusted R^2>75%), and the coefficients for the variables are significant (p-value significantly below 0.01). At the same time, models with loans in foreign currency, as expected, have middling quality, explaining about 50% of the dynamics of dependent variables with a statistically insignificant constant (Fig. 4).

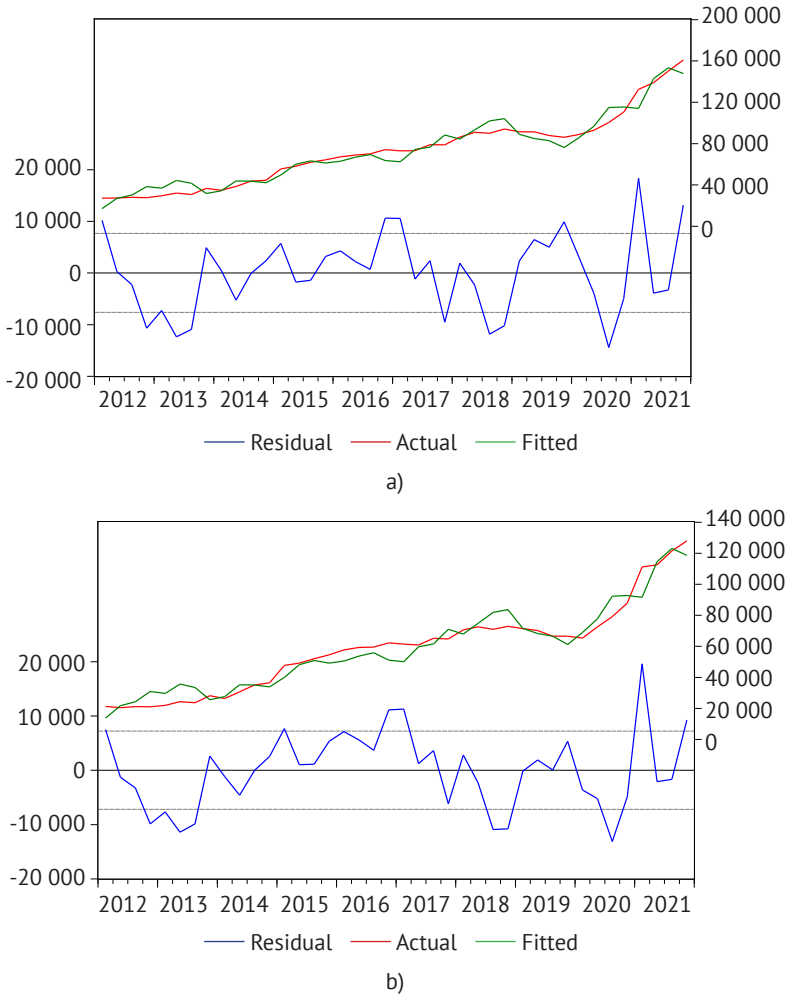

Figure 4*. Actual and fitted level of (a) gross value added and (b) gross surplus of agriculture of Ukraine in 2012-2021*
Source: *developed by the authors*

The influence of bank lending on agribusiness is best explained by the model of dependence of gross value added on loans in national currency (Fig. 4a). Focusing on the estimated coefficients and the neutral level of the regressor, it can be argued that the neutral level of lending (at which the current contribution of the industry to GDP will remain) is slightly more than UAH 10 billion every quarter, and each hryvnia of credit to agricultural corporations above the neutral level will bring UAH 13 to gross value added 4 years later. The equation for the same explanatory variable turned out to be the most accurate in terms of the impact on gross surplus (Fig. 4b): to maintain the current level of profitability of agriculture, it is necessary to credit it for 40 billion hryvnias annually, and each hryvnia of additional bank lending after 4 years will bring 3.31 UAH gross surplus.

STRENGTHENING THE ROLE OF CREDIT AND INVESTMENT SUPPORT IN AGRICULTURE

As the authors have already proved, bank lending, which is present both in state financial support measures and in the investment mechanism, is the key to almost all forms of credit and investment mechanisms for the development of the agrarian sector. This is especially obvious during the period of martial law in Ukraine. Therefore, it is appropriate to consider this fact when determining the strategic directions of credit and investment support for the agricultural sector from the standpoint of not only providing agricultural enterprises with the necessary financial resources but also forming an effective state mechanism for supporting banks in this process. This is confirmed by Yu. Aleskerova *et al.* (2018) note that preferential lending to the agricultural sector occupies a special place in the state support system. However, the formation of an effective system of credit mechanisms to support the agricultural sector requires appropriate legal support and a guarantee of its application for a long period. Therefore, the system of credit and investment provision of the agricultural sector must be formed precisely from the position of state financial support (Fig. 5).

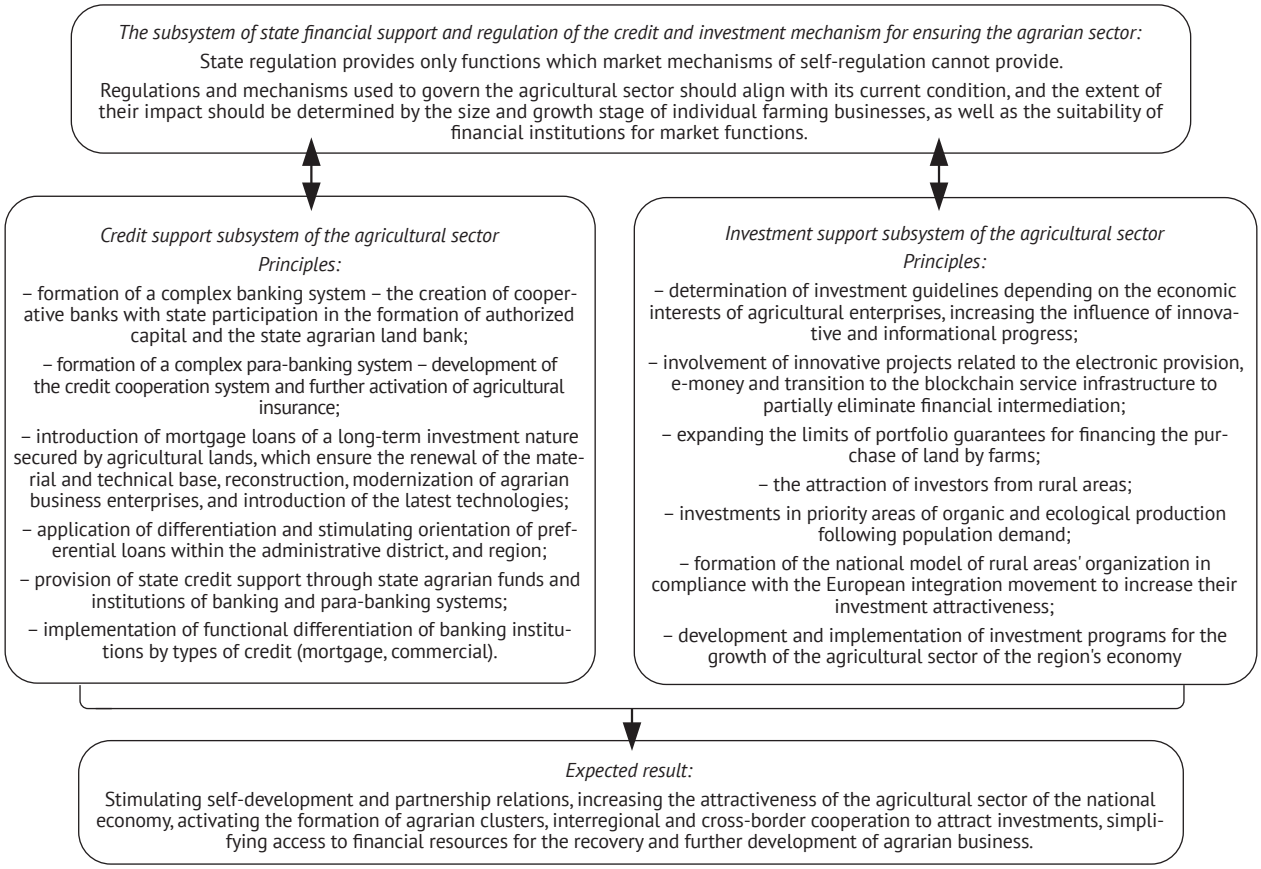

Figure 5. *The system of credit and investment support for the development of the agrarian sector of the national economy*

Source: *created by the authors*

It should be noted that the implementation of the presented system of credit and investment support is impossible without state regulation of these processes. Therefore, it is advisable to review the strategy of the agrarian sector development, considering challenges of the martial law and the post-war period in Ukraine. In particular, the ways to overcome the existing limitations of agricultural development, proposed by L. Vdovenko (2022), are appropriate, in particular, the creation of an alternative logistics network for the export of agricultural products; minimization of bureaucratic procedures for agricultural enterprises (producers' requests to obtain the necessary licenses and certificates); regulation of price policy regarding means of agro-industrial production; free access to factors of production and sales for all subjects of agrarian business; expansion of bank lending programs for small and medium-sized businesses under conditions acceptable to farmers; the use of foreign investors' funds for the development and restoration of the agricultural sector of the economy.

The financial condition of agricultural enterprises in terms of martial law in Ukraine is also affected by such a fact as territorial binding, which excludes relocation; the acute shortage of labour resources is associated with migration and mobilization of the rural population; working capital; fuel; plants treatment products; fertilizers and seeds; blocking the export of grain leads to the lack of funds for farmers to finance their activities; forecasts regarding the future harvest do not inspire certain hope, because of a large number of cultivated areas in the regions of Ukraine are either under occupation or under shelling in the active phase of hostilities (Sakun *et al.*, 2022).

The issue of the introduction of project financing as a form of credit and investment support for the agricultural sector, which is partially investigated in the scientific works of S. Naumenkova *et. al.* (2020), M. Kamysbaev *et. al.* (2019), requires in-depth research at the level of state support for the agrarian sector. The system of state regulation of the agricultural sector itself is also in need of further research and measures for alignment with EU standards. The agrarian policy of EU member states is aimed at supporting the income of agricultural enterprises at a level sufficient for extended reproduction, provision of food products for the population, processing, and light industry. The decisive role in EU agrarian policy is occupied by product programs, which are inherently much more complex and involve the use of various support mechanisms for certain producers in the sector.

CONCLUSIONS

The analysis of leading research and specialists in the field of agricultural production allows to conclude that the system of credit and investment provision of the agricultural sector is a complex concept, which should be understood as a set of economic relations arising from the search for various sources of financial resources, their attraction and effective use of organizational and management principles, methods, forms for influencing the socio-economic activity of agrarian enterprises. State financial support for agricultural production, bank lending and investment are defined as the main formats of credit and investment provision. The analysis of the presented forms proved that the key instrument is a bank loan. Based on the study of the impact of bank credit on the performance indicators of agricultural enterprises, it was proved that this relationship depends on the terms of granting and the type of currency. It has also been established that the relationship between gross value added, surplus, profitability and crediting is strategic in the external financing of agriculture. It has been proven that the formation of an effective system of credit mechanisms to support the agricultural sector requires appropriate legal support and a guarantee of its application for a long period. Therefore, the system of credit and investment provision of the agrarian sector must be formed precisely from the position of state financial support. At the same time, the forms and methods of regulation must correspond to the real state of the agricultural sector, and the scale of influence depends on the level of development of agrarian business and the functional suitability of financial institutions. In the conditions of martial law, the role of the state is increasing concerning the need to create an agricultural-food system considering the challenges and directing financial policy vectors to the financial support of the agrarian sector of the national economy through the improvement of existing credit and investment instruments, giving them weight in terms of impact on the results of the activities of agricultural enterprises, which contributes to the national and global food security following the latest practice in the field of state regulation of the agrarian sphere of European Union.

Prospects for further research consist in determining effective forms of credit and investment support for the agricultural sector to increase the level of its financial stability, based on the introduction of unconventional and innovative instruments, for instance, project financing, secondary mortgage, purchase order financing, and escrow-based lending.

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CONFLICT OF INTEREST

None.

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Анотація. Однією з ключових проблем сучасного аграрного сектору національної економіки є досягнення стабільного економічного зростання. У цьому контексті система кредитно-інвестиційна підтримка посідає головне місце у розширеному відтворенні даної пріоритетної галузі для економіки України. Метою статті був огляд основних тенденцій кредитно-інвестиційного забезпечення агарного сектору національної економіки та визначення подальших розвідок у цьому напряму. Для проведення дослідження були використані загальнонаукові та спеціальні методи пізнання, а саме: системний та діалектичний підходи; розрахунково-аналітичний та коефіцієнтний аналіз; кореляційно-регресійний аналіз; логічного узагальнення та інші. Встановлено, що для формування дієвої системи кредитно-інвестиційного забезпечення аграрного сектору слід враховувати такі позиції як вплив банківського кредитування, кліматичних шоків на інвестиційні рішення фермерів, глобальних та регіональних тенденцій у напрямку валового накопичення основного капіталу та основних фондів у сільському господарстві, механізми фіксації умов передачі інвестиційних ресурсів для використання агропромисловими компаніями, фінансової нерівності між містом та селом. Доведено, що у всіх формах кредитно-інвестиційного забезпечення агарного сектору, ключовим інструментом є банківське кредитування. Особливо це прослідковується у період воєнного стану в Україні. З використанням методу економіко-математичного моделювання аргументовано, що банківське кредитування виступає стратегічним фінансовим ресурсом при формуванні кредитно-інвестиційного забезпечення аграрного сектору. Запропоновано систему кредитно-інвестиційного забезпечення, яка впершу чергу спирається на удосконалення системи державного регулювання аграрного сектору. Доведено, що для підвищення рівня дієвості системи кредитно-інвестиційного забезпечення аграрного сектору, слід звернути увагу на такий інструмент як проєктне фінансування та перегляд самої структурної композиції державного регулювання сільськогосподарського виробництва з урахуванням практики Європейського Союзу. Такі підходи можуть використовувати органи державної влади при розробці стратегії розвитку аграрного сектору в умовах воєнного стану та повоєнний період, а також внесення інфраструктурних змін у процес взаємодії банківського та аграрного секторів національної економіки

Ключові слова: агробізнес; банківське кредитування; державна фінансова підтримка; інвестування; фінансові ресурси; воєнний стан; рентабельність

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