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10008, б-р Старий, 7, м. Житомир, Україна
E-mail: info@sciencehorizon.com.ua
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Editors office address:

Polissia National University
10008, 7 Saryi Blvd., Zhytomyr, Ukraine
E-mail: info@sciencehorizon.com.ua
<https://sciencehorizon.com.ua/en>

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Determination of the effect of the enzyme and probiotic complex on animal productivity

Oksana Shkromada*

Doctor of Veterinary Sciences, Professor
Sumy National Agrarian University
40021, 160 Herasym Kondratiev Str., Sumy, Ukraine
<https://orcid.org/0000-0003-1751-7009>

Yulia Suprun

Postgraduate Student
Sumy National Agrarian University
40021, 160 Herasym Kondratiev Str., Sumy, Ukraine
<https://orcid.org/0000-0001-8035-6282>

Oleksii Fotin

PhD in Veterinary Sciences, Associate Professor
Sumy National Agrarian University
40021, 160 Herasym Kondratiev Str., Sumy, Ukraine
Biology Centre Academy of Sciences of the Czech Republic
370 05, 31 Branišovská, České Budějovice, Czech Republic
<https://orcid.org/0000-0002-1872-3341>

Larysa Plyuta

PhD in Veterinary Sciences, Associate Professor
Sumy National Agrarian University
40021, 160 Herasym Kondratiev Str., Sumy, Ukraine
<https://orcid.org/0000-0001-8935-4873>

Iryna Lifar

Postgraduate Student
Sumy National Agrarian University
40021, 160 Herasym Kondratiev Str., Sumy, Ukraine
<https://orcid.org/0009-0007-3878-7880>

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Abstract. During weaning, rabbits experience production and feed stress, which results in a decrease in body resistance. Young animals in the transition period often have gastrointestinal disorders and significant weight loss. Probiotic strains of microorganisms and enzymes are a safe alternative for stimulating growth and

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*Corresponding author

supporting rabbit immunity. The purpose of the study was to determine the effect of additives to the basic diet on the haematological status, biochemical and productive parameters of rabbits. Methods used: zootechnical, haematological, biochemical, statistical. In the experimental groups where enzymes with probiotics were used, an increase in live weight was observed on the 30th day of the experiment: in the first experimental group by 4.18%, in the second – by 9.69%, in the third – by 18.72%. At the time of reaching the slaughter age, the live weight of rabbits increased by 5.47%, in the second by 11.0%, and in the third by 12.6%. The average daily increase in the groups where the complex supplement was used was higher, respectively, by: 6.64%; 12.58%, 32.86%. During the entire period of the experiment, gastrointestinal diseases were observed in three control rabbits that received treatment. Feed conversion was better in the first experimental group by 90.73 %, in the second – by 76.58 %, in the third – by 82.92%, compared to the control. In the group where three probiotic strains were used, an increase in red blood cells by 68.19% ($P < 0.05$), haemoglobin by 28.44%, and white blood cells by 72.17% was recorded. In rabbits of the experimental groups, lipid metabolism improved against the background of cholesterol reduction in the first by 25.3%, the second – by 36.6%, and the third – by 39.4%. Protein and albumin absorption increased in the experimental groups: in the first by 15.33%, in the second – by 24.04%, in the third – by 28.57%. Mineral metabolism improved in animals of the experimental groups due to an increase in the calcium content in the first by 10.1%, the second – by 8.7%, and the third – by 17.9%. The practical significance of this study is to increase productivity and reduce gastrointestinal disorders by applying enzymes and probiotic strains of bacteria to the main diet

Keywords: alternative growth stimulants; live weight gain; feed conversion; morbidity; rabbit metabolism

INTRODUCTION

In countries where the economy has been disrupted, one of the most important problems is people's nutrition. Rabbits are herbivores that are not demanding on nutrition, can consume waste from processing plant products. In addition, rabbits reproduce and grow quickly, and can be kept in a limited area in large numbers. Rabbit meat is characterised by its high nutritional content (Cullere & Dalle Zotte, 2018) and dietary properties. To increase the productivity of rabbits, it is necessary to use safe growth stimulants. The relevance of the subject matter lies in the use of enzymes and probiotic strains of microorganisms to improve rabbit metabolism.

Research by D. Ye *et al.* (2023) showed that changes in cold and warm seasons negatively affect intestinal microflora, immunity, and productivity. Researchers have proposed strategies to mitigate the effects of off-season changes, but have not provided a way to avoid this problem. To maintain immunity in calves and prevent dysbiosis, V.A. Gryshchenko *et al.* (2023) used dietary supplements for basic nutrition. As a result of the experiment, the epithelium of the empty intestinal mucosa was restored in calves. The studies have not clarified the effect of the supplement on the microflora of the gastrointestinal tract.

An experiment by Z. Wang *et al.* (2023) on avoidance of coprophagy in rabbits demonstrated a negative impact on performance. The level of total cholesterol and triglycerides decreased, and the villi of the caecum were destroyed. The results of the study show the importance of constant restoration of microflora in the gastrointestinal tract. Z. Li *et al.* (2022) analysed the composition and amount of microflora and cytokines in the contents of the caecum. Researchers have

concluded that coprophagy is an analogue of probiotic therapy and plays an important role in the intestinal immunity of rabbits.

Research by K.A. Alayande *et al.* (2020) confirm that probiotics are a safe alternative to antibiotics to increase animal productivity. The collected information provides the basis for further testing of probiotic strains for use by farm animals. Results obtained in the paper by M.I. Hossain *et al.* (2017) have shown the ability of probiotics to synthesise hydrolytic enzymes to kill bacterial toxins. Therefore, it is necessary to search for the most effective probiotic communities for raising animals. S. Saha *et al.* (2023) showed that the addition of probiotics to rabbits' diets helped increase carcass weight, improve colour, muscle fibre structure, and taste. Studies do not provide information on the properties of probiotic strains, their dosage, administration method and mechanism of use.

The results obtained by P. Cheng *et al.* (2018) show differences in the composition of the gut microbiome and different levels of cellulose fibre digestion in pigs of different breeds of Lantang and Duroc. The paper does not consider the impact of different conditions of keeping and feeding animals. R. Du *et al.* (2018) found that the bacteria of the family *Butyricimonas* produce butyrate in the course of their life, which aids digestion in calves. There is a need to investigate what other microorganisms have a positive effect on the metabolism and final live weight of animals. Experiment by A. Daskalova *et al.* (2023) proved that an increase in the bacterial content of *Lactobacillus* and *Bifidobacterium* in the gut microbiome of broiler chickens contributes to increased productivity and feed conversion. Researchers have found that dietary supplements based on

phytobiotics have a positive effect on changes in the microbial composition and metabolism of animals and can be used as an alternative to antibiotics.

To increase the productivity of rabbits, Z. Li *et al.* (2023) tested the addition of a probiotic strain *Clostridium butyricum* to the diet. The results obtained showed a positive effect of live weight gain due to an increase in lipid synthesis in the liver. *The purpose of the study* was to investigate the effect of supplements with different compositions on metabolism and live weight gain in rabbits.

MATERIALS AND METHODS

The rabbits were kept for 36 days in accordance with animal welfare requirements. The experiment was conducted in November-December 2023 in the vivarium

of the Faculty of Veterinary Medicine of Sumy National Agrarian University. The object of the study was rabbits (Californian breed) aged 14 days in the amount of 10 units in each group. Variants of samples of experimental enzyme and probiotic complexes (EPC) were provided by Kronos Agro. The first experimental group was fed with enzyme-based EPC (xylanase, phytase, cellulase) and probiotic strains of microorganisms of the bacterium *Enterococcus spp.* For the second experimental group, EPC was based on enzymes and *Lactobacillus spp.* The enzyme and probiotic complex for Group 3 of the study consisted of enzymes and three probiotic strains of bacteria. EPC presented in powder form was given to rabbits with feed at the rate of 250 g per 1 tonne of feed, starting from the age of 14 days. The experimental design is shown in Table 1.

Table 1. Experiment design

Groups	Characteristics of groups, dosage
experimental 1	EPC: enzymes + <i>Enterococcus spp.</i>
experimental 2	EPC: enzymes + <i>Lactobacillus spp.</i>
experimental 3	EPC: enzymes + <i>Enterococcus spp.</i> , <i>Lactobacillus spp.</i> , <i>B. coagulans</i>
control	Feed without additives

Source: compiled by the authors

During the studies, rabbits did not receive any drugs other than the above.

Research of productive indicators in rabbits. The live weight of rabbits was studied by weighing on the 30th and 60th days of the experiment. Feed conversion, absolute and average daily growth, and rabbit survivability were calculated.

Determination of haematological parameters of blood.

On day 60, rabbit blood tests were determined: red blood cells, white blood cells, haemoglobin, lymphocytes, monocytes, neutrophils, eosinophils using an automatic analyser (Shenzhen Mindray BC3000 plus, China).

Investigation of the metabolic status of rabbits. Metabolites were determined on the 60th day of in rabbit blood serum: enzyme activity: aspartate aminotransferase (SOP-BP-09-2017), alanine aminotransferase and alkaline phosphatase (SOP-BP-08-2017), total protein, including albumin and globulin (SOP-BP-02-2017), total cholesterol (SOP-BP-07-2017), direct and indirect bilirubin, total calcium (sop-BP-05-2017), glucose.

Study of the composition of the rabbit gastrointestinal microbiome. Faecal masses were taken from rabbits of three experimental and control groups at the end of the experiment on 60th day. Faecal samples were examined by bacteriological methods to determine the quantitative composition of intestinal microorganisms in animals. The number of bacterial species was determined: *Coprococcus sp.*, *Ruminococcaceae sp.*, *Akkermansia sp.*, *Lachnospiraceae sp.*, *Clostridium sp.*, *Subdoligranulum sp.*, *Firmicutes sp.*, *Bacteroidetes sp.*, *Cyanobacteria sp.*, *Verrucomicrobia sp.*, *Proteobacteria sp.*, *Tenericutes sp.* Faecal

samples were diluted 1: 10 and inoculated on nutrient selective media. The media used were from Farmaktiv LLC (Ukraine) and Himedia Laboratories Prv. Limited (India). The species affiliation of microbial cultures and their number were determined using the R-biopharm test system, namely RIDA[®] COUNT, RIDA CHECK. LumitestPD-20; LuciPacPen, RIDASCREENVerotoxin, RIDASCREENSETA, B, C, D, (ENISO 16140), RIDASCREENCampylobacter, SureFoodBAC.

Investigation of antagonistic properties of enzyme and probiotic complex. The agar well diffusion method was used. The size of the demarcation zone in mm around the different composition of the enzyme and probiotic complex was visually determined on Petri dishes with the corresponding microorganism, as previously mentioned, for three experimental variants and a control (Garkavenko *et al.*, 2021). Each dish with meat-peptone agar was inoculated with the appropriate EPC and left for a day in a thermostat for incubation at 37°C. The size of the demarcation zone in mm around the wells with experimental EPC was determined.

Statistical analysis. For statistical analysis of the results, the Fischer-Student method (Mosteller & Fisher, 1948) was used, and data from control and experimental groups were compared with a probability of more than 95% ($p < 0.05$). The studies were conducted in accordance with DSTU EN ISO/IEC 17025:2019 (2019), in compliance with the Rules of Bioethics and Humane Treatment of Vertebrates 2010/63/EU (Hartung, 2010) of the European Convention (1986) and Law of Ukraine No. 249 (2012).

RESULTS

Results of the study of productive indicators in rabbits.

The first stage of the study was to determine the

productivity of rabbits when growing with the use of enzyme and probiotic complex (Table 2).

Table 2. Comparative data on rabbit growth ($M \pm m, n = 10$)

Indicators	Control	Research groups		
		1	2	3
Number of animals, units	10		10	
Initial live weight (14 days), kg	0.25 ± 0.08	0.25 ± 0.05	0.25 ± 0.13	0.26 ± 0.07
Live weight (30 days), kg	0.59 ± 0.06	0.62 ± 0.11	0.65 ± 0.09	0.71 ± 0.12
% to control	-	4.18	9.69	18.72
Live weight (60 days), kg	1.28 ± 0.02	1.35 ± 0.23	1.41 ± 0.14	1.62 ± 0.32*
% to control	-	5.47	10.15	61.60
Absolute gain, kg	1.03 ± 0.36	1.10 ± 0.38	1.16 ± 0.27	1.37 ± 0.56
Average daily gain, g	28.62 ± 1.34	30.53 ± 1.50	32.20 ± 2.53	38.03 ± 2.10*
% to control	-	6.64	12.58	32.86
Morbidity, units	3	-	-	-
Feed consumption, kg	13.02	13.61	13.52	12.15
Feed consumption per 1 kg of live weight gain, kg	2.05	1.86	1.70	1.57
% to control	100.00	90.73	82.92	76.58

Note: * $P < 0.05$ – relative to the control

Source: compiled by the authors

During the experiment, the live weight of one rabbit in 30 days was increased by 4.18% in the first experimental group, in the second – by 9.69%, in the third – by 18.72%, compared to the control group. On the 60th day of the study, the live weight of rabbits in the first experimental group was 5.47% higher, in the second – 11.0%, and in the third – 12.6% ($p < 0.05$), respectively, compared to the control. The average daily increase by group was higher, respectively, by: 6.64%; 12.58%, 32.86% ($P < 0.05$) compared to the control.

The morbidity for the entire period of the experiment was three animals in the control group. Gastro-intestinal disorders were observed in rabbits, so three animals received timely treatment. The animals were

isolated from the main group and treated with antimicrobial agents. The feed intake of rabbits was higher in the control group. Feed consumption was as follows: in the first experimental group – 90.73%, in the second – 76.58%, in the third – 82.92%, compared to control. The study shows that the average daily gain of rabbits was higher in the third experimental group, where enzymes with three probiotics were added to the feed of rabbits. However, feed consumption per 1 kg of live weight gain was lower in the third experimental group.

Results of haematological parameters of blood.

Changes in haematological status in rabbits were determined during the experiment (Table 3).

Table 3. Haematological status of rabbits, ($m \pm m, n = 10$)

Indicators	Experimental group 1	Experimental group 2	Experimental group 3	Control	Reference values of laboratory
Red blood cells, $10^6/\text{ml}$	5.85 ± 0.12	5.78 ± 0.18	7.72 ± 0.10*	4.59 ± 0.25	5.3-7.1
White blood cells, $10^3/\text{ml}$	6.90 ± 0.15	8.73 ± 0.23	10.52 ± 0.24*	6.11 ± 0.13	5.1-10.7
Haemoglobin, g/dl	10.91 ± 0.19	11.75 ± 0.20	12.78 ± 0.25*	9.95 ± 0.24	9.8-14.0
Lymphocytes, $10^3/\text{ml}$	3.84 ± 0.11	4.42 ± 0.05	5.83 ± 0.06	4.73 ± 0.09	3.3-6.5
Monocytes, $10^3/\text{ml}$	0.39 ± 0.02	0.36 ± 0.04	0.28 ± 0.01	0.44 ± 0.03	0-0.5
Neutrophils, $10^3/\text{ml}$	1.31 ± 0.04	2.14 ± 0.06	1.82 ± 0.07	1.64 ± 0.09	1.5-2.3
Eosinophils, $10^3/\text{ml}$	0.04 ± 0.05	0.03 ± 0.05	0.02 ± 0.01	0.02 ± 0.01	0-0.05

Note: * $P < 0.05$ – relative to the control

Source: compiled by the authors

A significant increase in red blood cells at the end of the experiment was recorded in the third experimental group by 68.19% ($P < 0.05$), compared to the control group. However, the haemoglobin content in

the blood was also higher in rabbits of this experimental group by 28.44% ($P < 0.05$). The use of three probiotics in rabbits of the third group had a positive effect on immunity in animals. Thus, the absolute

number of white blood cells on the 60th day of the study was significantly ($P < 0.05$) higher in rabbits of the third experimental group by 72.17%, compared to the control group. The first and second experimental groups also showed an increase in red blood cells and haemoglobin compared to the control group, but the difference was not reliable. Studies have shown that

the use of an enzyme and probiotic complex in rabbits as part of the basic diet has a positive effect on immunity and erythrocytopoiesis.

Results of the study of the metabolic status of rabbits. During the experiment, the level of metabolism in the blood of experimental animals was established (Table 4).

Table 4. Biochemical analysis of blood serum, ($M \pm m$, $n = 10$)

Indicators	Experimental group 1	Experimental group 2	Experimental group 3	Control	Reference values of laboratory
AST, IU/l	64.92 ± 3.15	54.80 ± 5.65	72.8 ± 3.15	92.22 ± 3.55	20-120
ALT, IU/l	45.62 ± 2.67	48.53 ± 3.26	46.00 ± 4.52	47.45 ± 3.36	25-120
GGT, IU/l	6.61 ± 0.23	7.14 ± 0.35	6.51 ± 0.24	6.73 ± 0.42	0-7
Alkaline phosphatase, IU/l	6.23 ± 0.56	5.04 ± 0.20	5.22 ± 0.17	7.03 ± 0.30	0-8.6
Total bilirubin, µmol/l	5.56 ± 0.2	4.65 ± 1.15	5.39 ± 1.22	5.84 ± 0.32	0-6.8
■ Direct, µmol/l	1.43 ± 0.15	1.23 ± 0.83	1.24 ± 0.56	1.71 ± 0.16	0-1.7
■ Indirect, µmol/l	4.13 ± 0.35	3.42 ± 0.42	4.15 ± 0.81	4.13 ± 0.66	0-5.12
Creatinine, µmol/l	65.12 ± 3.45	59.04 ± 4.38	56.22 ± 4.26	78.34 ± 3.34	50-100
Urea, mmol/l	3.52 ± 0.22	3.74 ± 0.35	2.50 ± 0.20	4.21 ± 0.15	2.18-5.5
Total cholesterol, g/l	0.53 ± 0.05	0.45 ± 0.08	0.43 ± 0.05*	0.71 ± 0.20	0-0.75
Total protein, g/l	57.72 ± 4.25	65.10 ± 0.52*	74.43 ± 4.16*	55.40 ± 5.81	54-82
Albumins, g/l	33.50 ± 2.72	35.60 ± 2.01*	36.9 ± 3.52*	28.72 ± 2.67	25-37
Globulin, g/l	26.85 ± 2.23	27.76 ± 1.34	32.31 ± 2.18	25.30 ± 2.34	23-50
Calcium, mmol/l	3.14 ± 0.23	3.10 ± 0.56	3.36 ± 0.32*	2.85 ± 0.12	2.4-4.2

Note: * $P < 0.05$ – relative to the control

Source: compiled by the authors

The conducted studies show that the activity of enzymes (aspartate aminotransferase, alanine aminotransferase, gamma-glutamyl transferase and alkaline phosphatase) was within the physiological norm in animals of the experimental and control groups. The activity of the enzyme aspartate aminotransferase was studied to determine the toxic effect of the enzyme and probiotic complex on the rabbit myocardium. Studies have shown that the level of AST in the first experimental group was significantly lower by 29.60%, in the second – by 40.57%, in the third – by 21.01%, compared to the control. The content of the enzyme alanine aminotransferase in the blood demonstrates the effect of experimental EPC on the liver and kidneys of animals. ALT activity in the first experimental group was less by 3.85% and the third – by 3.05%, more in the second – by 2.27%.

An increase in the activity of the enzyme gamma-glutamyl transferase indicates damage to hepatocytes and bile ducts. According to the results of the study, it was found that GGT activity in the first experimental group was less by 1.78%, in the second – by 6.09%, in the third – by 3.26%, compared to the control. Alkaline phosphatase activity was also determined in the blood serum of rabbits to find out the effect of EPC on lipid metabolism. It was found that the activity of the alkaline phosphatase enzyme in the first experimental group was less by 11.38%, in the second – by 28.30%, in the third – by 25.74%, compared to the control.

The content of total bilirubin in the blood was interrelated with the activity of the enzymes ALT, GGT, and alkaline phosphatase. As a result of the conducted studies, it was found that total bilirubin, including direct and indirect, did not have a significant difference between the groups. The level of creatinine and urea in the blood serum corresponded to the reference indicators in rabbits of the experimental and control groups, which indicates the absence of toxic effects of EPC on the body of rabbits. The blood creatinine content of rabbits in the first experimental group was lower by 16.87%, in the second – by 24.30%, in the third – by 28.24%, compared to the control. The level of urea was lower in the blood serum of rabbits of the first experimental group by 16.38%, in the second – by 11.16%, in the third – by 40.61%.

A decrease in cholesterol levels was observed in rabbits of the first experimental group by 25.3%, the second – by 36.6%, the third – by 39.4% ($p < 0.05$), compared to the control group. There was also a significant increase in the level of total protein in animals of the experimental groups: in the first by 4.18%, in the second – by 17.5%, in the third – by 34.35% ($P < 0.05$). A positive result can also be considered an increase in albumin in the first experimental group by 15.33%, in the second – by 24.04%, in the third – by 28.57%, compared to the control. The level of globulins in the blood serum of rabbits of the experimental and control groups was within the normal range, which indicates the absence of a negative reaction to EPC from the immune system.

In rabbits of the first experimental group, the globulin content was higher by 6.26%, in the second – by 9.72%, in the third – by 27.70%, compared to the control.

An important indicator of metabolism is the level of calcium, which was higher in the blood of experimental animals by 10.1%, the second – by 8.7%, the third – by 17.9% ($p < 0.05$), compared to the control. The results obtained showed that the use of the enzyme and probiotic complex affected the biochemical and haematological parameters in rabbits. Addition of EPC to the feed also had a positive effect on the increase in live weight of rabbits.

Results of the study of the composition of the microbiome of the gastrointestinal tract of rabbits. Studies were conducted to determine the effect of the enzyme and probiotic complex on the microflora of the gastrointestinal tract of rabbits. It is known that a violation of the normal composition of the microbiome can lead to dysbiosis. As a result, diarrhoea, impaired food absorption, weight loss, intoxication, and death of the animal occur. The results obtained will affect the final version of the EPC composition, which will be proposed for use in rabbit breeding (Fig. 1).

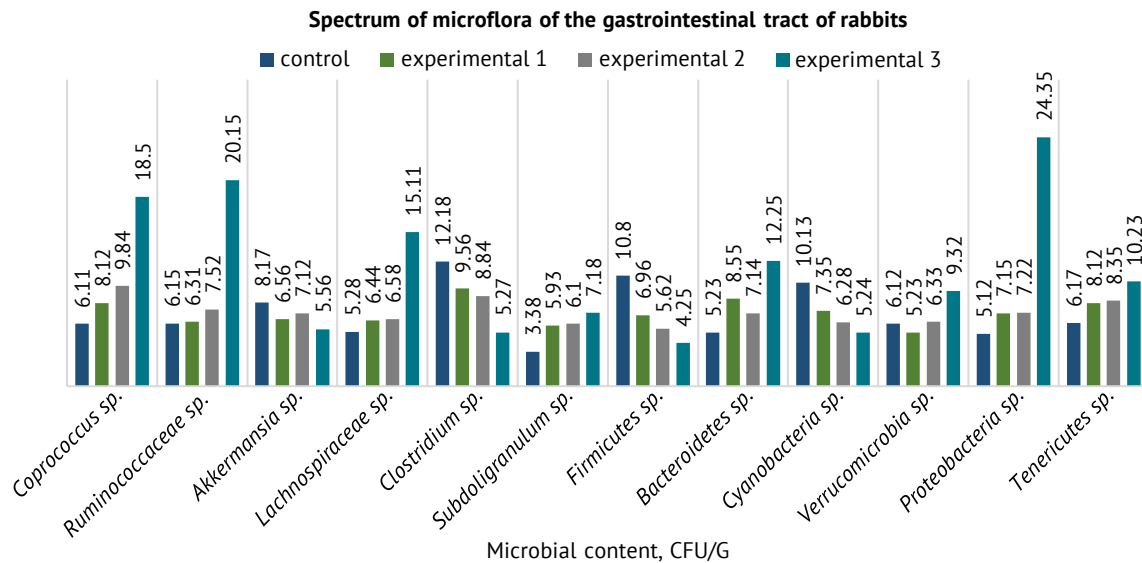


Figure 1. Spectrum of microflora of the gastrointestinal tract of rabbits when using an enzyme and probiotic supplement

Source: compiled by the authors

According to the results of the study, it was established that the content of *Coprococcus sp.* was higher in the first experimental group by 32.89%, in the second experimental group – by 61.04%, in the third experimental group – by 202.78%, compared to the control. The content of *Ruminococcaceae sp.* in the first experimental group was 2.60% higher, in the second – 22.27%, in the third – 227.64%. Number of bacteria of the species *Akkermansia sp.* was less in the first experimental group by 19.70%, in the second – by 12.85%, in the third – by 30.84%, compared to the control group. The content of bacteria of the species *Lachnospiraceae sp.* in rabbits of the first experimental group was 21.97% higher, in the second – 24.62%, in the third – 186.17%. The content of *Clostridium sp.* tended to decrease compared to the control in the first experimental group by 21.51%, in the second – by 27.42%, in the third – by 56.73%. The content of *Subdoligranulum sp.* in the intestine did not differ significantly between experimental and control animals and ranged from 3.38-7.18 CFU/g of faecal mass. However, the content of *Firmicutes sp.* was lower in the first experimental group by 35.55%, in

the second – by 47.96%, in the third – by 60.64%, compared to the control. The addition of an enzyme and probiotic complex does not directly change the composition of the rabbit gut microbiome, but it does affect the amount of bacteria of the same species.

The content of *Bacteroidetes sp.* in the first experimental group was 63.47% higher, in the second – by 36.52%, in the third – by 134.23%. The level of *Cyanobacteria sp.* was less in rabbits of the first experimental group by 27.44%, in the second – by 38.00%, in the third – by 48.27% on the 60th day of research. The content of *Verrucomicrobia sp.* was not affected by the addition of EPC. So in the first experimental group, *Verrucomicrobia sp.* was less by 14.54%, in the second and third – more by 3.43-52.28%, respectively. The content of *Proteobacteria sp.* in the first experimental group exceeded the indicators of rabbits in the control group by 39.64%, in the second – by 41.01%, in the third – by 375.58%. The level of *Tenericutes sp.* was higher by 31.60% in the first experimental group, in the second – by 35.33%, in the third – by 65.80%, compared to the control. Thus, the same types of microorganisms were

isolated in all animals of the experimental and control groups, but in different quantities. The study proves that the composition of the gut microbiome affects the productivity and metabolism of rabbits.

Investigation of antagonistic properties of enzyme and probiotic complex. The antagonistic activity of EPC was

determined against microorganisms that were isolated from the faecal masses of rabbits. Isolates of microorganisms that are not pathogens were selected, but an increase in their content can lead to diseases in rabbits in the form of metabolic disorders and gastrointestinal disorders (Table 5).

Table 5. Antagonistic properties of EPC, ($M \pm m$), $n = 10$

Microbial cultures	Enzyme and probiotic complex		
	experiment 1 (enzymes + <i>Enterococcus spp.</i>)	experiment 2 (enzymes + <i>Lactobacillus spp.</i>)	experiment 3 (enzymes + <i>Enterococcus spp.</i> , <i>Lactobacillus spp.</i> , <i>B. coagulans</i>)
Size of the growth retardation zone, mm			
<i>Coprococcus sp.</i>	3.34 ± 0.04	6.50 ± 0.07	6.45 ± 0.15
<i>Firmicutes sp.</i>	9.25 ± 0.04	11.15 ± 0.02	26.33 ± 1.22*
<i>Clostridium sp.</i>	3.45 ± 0.03	5.87 ± 0.12	25.38 ± 1.18*
<i>Cyanobacteria sp.</i>	4.76 ± 0.15	5.50 ± 0.10	5.49 ± 0.20
<i>Subdoligranulum sp.</i>	3.45 ± 0.06	5.36 ± 0.08	8.89 ± 0.12
<i>Akkermansia sp.</i>	8.36 ± 0.08	9.15 ± 0.15	22.50 ± 1.45*

Note: * $P < 0.05$ – relative to experiment 1

Source: compiled by the authors

Based on the results obtained, it was found that in Petri dishes with the bacterium *Coprococcus sp.* in the second experiment, the growth retardation zone was 4.61 % larger, in the third – by 3.11%, compared to the first experiment. That is, the growth retardation zone in all EPC prototypes was almost the same. Demarcation zone in Petri dishes with *Firmicutes sp.* it was higher in the second experiment – by 20.54% and in the third – by 184.65% ($P < 0.05$). In the second experiment with *Clostridium sp.* growth retardation zone, it was an increase of 29.85%, in the third – by 635.65% ($P < 0.05$). In the dishes with *Cyanobacteria sp.*, the growth retardation zone was almost the same in all experiments and ranged from 4.76 to 5.49 CFU/g. Demarcation zone with bacteria *Subdoligranulum sp.* in the second group was 55.36% more, in the third – by 157.68%, compared to the first experiment. A significant proportion of the rabbit gut microbiome is made up of the species shown in Table 5, but an increase in any bacteria at the expense of other beneficial microflora has a negative impact on gut health and performance. Thus, the demarcation zone of *Akkermansia sp.* growth retardation in the second experiment was 9.45% larger and 169.13% larger in the third experiment ($P < 0.05$) compared to the first experiment.

Notably, in all experiments with EPC, despite the difference in the constituent components, antagonistic properties were manifested. The maximum antagonistic effect was achieved in the third experiment, where the EPC included three probiotic strains: *Enterococcus spp.*, *Lactobacillus spp.*, *B. coagulans*. The conducted studies have proven that the use of an enzyme and probiotic complex is aimed at improving metabolism, haematological parameters, restoring gastrointestinal microflora, and increasing the live weight of rabbits.

DISCUSSION

The use of an enzyme and probiotic complex for rabbits had a positive effect on the increase in live weight at days 30 and 60. This result is associated with better absorption of nutrients through the use of enzymes. Probiotic strains of bacteria also help maintain microflora in the gastrointestinal tract. In rabbits of the experimental groups, a decrease in feed intake was observed against the background of an increase in live weight gain, compared with the control.

Research by M.M.Y. Elghandour *et al.* (2020) proved positive impact of *Saccharomyces cerevisiae* on the gut microbiota and an increase in the number of white blood cells. The study by O. Shkromada *et al.* (2022) found that adding *B. megaterium* to the diet of cows reduced the inflammatory process in the udder and increased protein absorption. A study of the haematological status of rabbits showed a significant increase in red blood cells, haemoglobin, and white blood cells in the study group, which used enzymes and three strains of probiotics. According to L. Kadja *et al.* (2021), when using three probiotic strains, a similar result was obtained to increase the productivity of rabbits and improve haematological parameters.

Gastrointestinal disorders were observed in only 3 animals of the control group during the entire study period. The result shows a positive effect on the immunity of rabbits and intestinal microflora. K. Amoah *et al.* (2019) and S.S. Xing *et al.* (2019) found that the use of probiotic strains as a supplement to the main diet of animals reduces gastrointestinal diseases in young animals. In addition, the study by C. Maltecca *et al.* (2020) confirmed that the composition of the intestinal microflora is an important indicator that affects animal feed intake and metabolism. Consequently, the relationship

between the composition of the gut microbiome and the final weight of rabbits can be traced.

The study of the biochemical composition of the blood serum showed the activity of enzymes (aspartate aminotransferase, alanine aminotransferase and alkaline phosphatase) within the physiological norm, indicating no toxic effects on the body. The positive effect of EPC was manifested in lowering cholesterol levels in all research groups. An increase in the level of total protein and albumins was observed in all experimental groups compared to the control group. A.A. Abdel-Wareth *et al.* (2021) have shown that the use of probiotics in rabbits together with fenugreek seeds contributed to protein absorption and increased carcass weight.

Mineral metabolism in animals is also a very important indicator. Studies have shown that in the experimental groups where the enzyme and probiotic complex was used, the level of calcium was higher compared to the control. Microbiological studies have established that the amount of beneficial microflora: *Coprococcus sp.*, *Ruminococcaceae sp.*, *Lachnospiraceae sp.*, *Cyanobacteria sp.*, *Proteobacteria sp.* in the gastrointestinal tract of rabbits, was most common in the third experimental group, where rabbits received enzymes and *Enterococcus spp.*, *Lactobacillus spp.*, *B. coagulans*.

Research by A.J. Wolf and D.M. Underhill (2018) proved that the content of microorganisms *Coprococcus*, *Ruminococcus* and *Lachnospiraceae* in the gastrointestinal tract of rabbits, have a direct correlation with the productivity and growth of rabbits of meat breeds. These results are confirmed by S. Dabbou *et al.* (2020) who reported that a sufficient content of *Ruminococcus* microorganisms in the gut of rabbits has a positive effect on their resistance. On the contrary the number of bacteria *Akkermansia sp.* in the intestinal contents were significantly lower in rabbits of the experimental groups. A. Bohatko and M. Utechenko (2024) found that an elevated content of *Akkermansia sp.* in the gastrointestinal tract negatively affects the final weight of rabbits.

S.Y. Chen *et al.* (2019) proved that the types of *Cyanobacteria*, *Firmicutes*, *Bacteroidetes*, *Verrucomicrobia*, *Proteobacteria* are the most dominant bacteria in the rabbit microbiome, regardless of breed. In addition, M. Velasco-Galilea *et al.* (2020) showed that incomplete feeding and the use of antibiotics directly affect the content of microflora in the gastrointestinal tract. The studies revealed an increase in the content of *Bacteroidetes sp.* in the faeces of rabbits treated with the enzyme and probiotic complex, which coincides with the results obtained by N. Grosu and L. Caisin (2020). In research groups, the level of *Firmicutes sp.* was lower than in the animals of the control group, which proves the positive effect of EPC on rabbit metabolism. This is confirmed by the results of the study by K.A.O. Gandy *et al.* (2019), which shows that an increased content of the bacterium *Firmicutes sp.* is responsible for obesity and lipid metabolism disorders.

The relative number of the main types of bacteria did not differ between different study groups of rabbits, which were added to the main diet of an enzyme and probiotic complex based on enzymes and probiotic microorganisms. This can be explained by changes in the quantitative composition of microorganisms that make up the microbiome of the rabbit gastrointestinal tract, since they are influenced by nutritional factors, which is confirmed by Z. Wu *et al.* (2019). According to the results of the experiment, the positive effect of the enzyme and probiotic complex on haematological parameters, metabolism, microflora of the gastrointestinal tract, and productivity of rabbits.

CONCLUSIONS

Studies have established an increase in the live weight of one rabbit unit in 30 days in the experimental groups: in the first – by 4.18%, in the second – by 9.69%, in the third – by 18.72%. At the end of the experiment, the live weight of rabbits in the first experimental group was 5.47% higher, in the second – 11.0%, and in the third – 12.6%. The average daily growth by group was increased by 6.64%; 12.58%, 32.86%, respectively, compared to the control. Feed conversion compared to the control group was 90.73% in the first experimental group, 76.58% in the second group, and 82.92% in the third group.

The use of an enzyme and probiotic complex with three probiotics in rabbits contributed to a likely increase in the content of red blood cells by 68.19%, white blood cells by 72.17%, and haemoglobin by 28.44% ($P < 0.05$). The use of the enzyme and probiotic complex in rabbits showed no negative effect on metabolites. Enzyme activity, total bilirubin, creatinine, and urea within the reference level in experimental and control animals. There was an improvement in the lipid profile due to a decrease in cholesterol levels in the first experimental group by 25.3%, the second – by 36.6%, the third – by 39.4% ($P < 0.05$). Protein uptake increased in the experimental groups: in the first by 4.18%, in the second – by 17.5%, in the third – by 34.35% ($P < 0.05$) and albumin by 15.33%, 24.04%, and 28.57%, respectively. The level of calcium in the blood of rabbits in the experimental groups was correspondingly higher by 10.1%, 8.7%, and 17.9% ($P < 0.05$) compared to the control group.

It was found that the use of an enzyme and probiotic complex in rabbits does not change the composition of the microbiome, but it affects the quantitative content of various types of bacteria. Thus, the use of three probiotics in the diet significantly increases the content of species: *Coprococcus sp.*, *Ruminococcaceae sp.*, *Lachnospiraceae sp.*, *Bacteroidetes sp.*, *Proteobacteria sp.* and *Tenericutes sp.* The antagonistic properties of the enzyme and probiotic complex, which includes three probiotics, showed the maximum effect on *Firmicutes sp.*, *Clostridium sp.*, *Akkermansia sp.* The prospect of further research is to investigate the effect of the enzyme and probiotic complex on rabbits in production conditions.

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CONFLICT OF INTEREST

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Визначення впливу ферментно-пробіотичного комплексу на продуктивність тварин

Оксана Шкромада

Доктор ветеринарних наук, професор
Сумський національний аграрний університет
40021, вул. Г. Кондратьєва, 160, м. Суми, Україна
<https://orcid.org/0000-0003-1751-7009>

Юлія Супрун

Аспірат
Сумський національний аграрний університет
40021, вул. Г. Кондратьєва, 160, м. Суми, Україна
<https://orcid.org/0000-0001-8035-6282>

Олексій Фотін

Кандидат ветеринарних наук, доцент
Сумський національний аграрний університет
40021, вул. Г. Кондратьєва, 160, м. Суми, Україна
Біологічний центр академії наук Чеської республіки
370 05, вул. Бранішовська, 31, м. Чеське Будейовіце, Чеська Республіка
<https://orcid.org/0000-0002-1872-3341>

Лариса Плюта

Кандидат ветеринарних наук, доцент
Сумський національний аграрний університет
40021, вул. Г. Кондратьєва, 160, м. Суми, Україна
<https://orcid.org/0000-0001-8935-4873>

Ірина Ліфар

Аспірат
Сумський національний аграрний університет
40021, вул. Г. Кондратьєва, 160, м. Суми, Україна
<https://orcid.org/0009-0007-3878-7880>

Анотація. Під час відлучення від кролематки відбувається виробничий та кормовий стрес у кроленят, в результаті чого знижується резистентність організму. Молодняк у перехідний період часто має розлади шлунково-кишкового тракту та значну втрату ваги. Пробіотичні штами мікроорганізмів та ферменти є безпечною альтернативою для стимуляції росту та підтримки імунітету кроликів. Метою дослідження було визначити вплив добавок до основного раціону на гематологічний статус, біохімічні та продуктивні показники кролів. Використані методи: зоотехнічний, гематологічний, біохімічний, статистичний. В дослідних групах, де застосовували ферменти з пробіотиками, спостерігали збільшення живої ваги на 30 добу експерименту: у першій дослідній групі на 4,18 %, у другій – на 9,69 %, у третій – на 18,72 %. На момент досягнення забійного віку у кролів жива вага збільшилась на 5,47 %, у другій на – 11,0 %, та у третій на – 12,6 %. Середньодобовий приріст у групах, де використовували комплексну добавку, був більше відповідно на: 6,64 %, 12,58 %, 32,86 %. За весь період проведення експерименту захворювання шлунково-кишкового тракту спостерігали у трьох кролів контрольної групи, які отримали лікування. Конверсія корму була краща у першій дослідній групі на 90,73 %, у другій – на 76,58 %, у третій – на 82,92 %, порівняно до контролю. У групі, де застосовували три пробіотичні штами, зафіксовано збільшення еритроцитів на 68,19 % ($P < 0,05$), гемоглобіну на 28,44 %, лейкоцитів на 72,17 %. У кролів дослідних груп відбулось покращення ліпідного обміну на фоні зниження холестерину у першій на 25,3 %, другої – на 36,6 %, третьої – на 39,4 %. Збільшилось засвоєння білку та альбуміну у дослідних групах: у першій на 15,33 %, у другій – на 24,04 %, у третій – на 28,57 %. Покращився мінеральний обмін у тварин дослідних груп за рахунок підвищення вмісту кальцію у першій на 10,1 %, другої – на 8,7 %, третьої – на 17,9 %. Практичною цінністю роботи є збільшення продуктивності та зниження шлунково-кишкових розладів за рахунок застосування ферментів та пробіотичних штамів бактерій до основного раціону

Ключові слова: альтернативні стимулятори росту; приріст живої маси; конверсія корму; захворюваність; метаболізм кролів

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Regional epidemiology of brucellosis infection in modern conditions of animal husbandry technology in Kazakhstan (by the degree of spread and incidence)

Aspen Abutalip*

Doctor of Veterinary Sciences, Chief Scientist
Kazakh Scientific Research Veterinary Institute
050016, 223 Raiymbek Ave., Almaty, Republic of Kazakhstan
<https://orcid.org/0000-0002-2724-8220>

Alim Bizhanov

Doctor of Veterinary Sciences, Biosecurity Officer
Kazakh Scientific Research Veterinary Institute
050016, 223 Raiymbek Ave., Almaty, Republic of Kazakhstan
<https://orcid.org/0009-0004-4052-3866>

Nurali Matikhan

Doctor of Philosophy, Lecturer
Kazakh National Agrarian Research University
050010, 8 Abay Ave., Almaty, Republic of Kazakhstan
<https://orcid.org/0000-0002-3297-1907>

Aiken Karabassova

Doctor of Philosophy, Senior Researcher
Kazakh Scientific Research Veterinary Institute
050016, 223 Raiymbek Ave., Almaty, Republic of Kazakhstan
<https://orcid.org/0000-0001-6118-0576>

Bibizada Orynbayeva

Master of Science, Lecturer
Mukhtar Auezov South Kazakhstan University
160012, 5 Tauke Khan Ave., Shymkent, Republic of Kazakhstan
<https://orcid.org/0009-0008-1949-0990>

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Abstract. The research relevance is determined by the prevalence and impact of brucellosis in the developing livestock landscape of the Republic of Kazakhstan, which requires immediate assessment to understand the current state due to dynamic changes in animal breeding technologies. The study aims to implement various diagnostic programmes and compare the data obtained with information provided by other organisations. To achieve this goal, the "gold standard" research methods were used,

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*Corresponding author

a set of classical serological methods, which included the Rose-Bengal test, agglutination reaction, complement binding reaction, enzyme-linked immunosorbent assay, as well as the analysis method and graph analytical method. The results showed that the most infected with brucellosis were epizootic units in Aktobe, Kostanay, Mangistau, Atyrau, Akmola and West Kazakhstan regions, with infection rates exceeding 23.4%. At the same time, Almaty, Turkestan, and Karaganda regions were the least vulnerable, with infection rates not exceeding 3.1%. The largest number of animals with brucellosis was registered in West Kazakhstan Region and the smallest – in Zhambyl Region. This is due to the peculiarities of keeping and geographical locations of the regions of Kazakhstan. Thus, we can classify the situation in Almaty, Pavlodar, Karaganda and Zhambyl regions as class A, as having a low degree of infection. Kostanay, Akmola, Kyzylorda and Atyrau regions are considered to be zones with a medium degree of infection, belonging to class B. In turn, all other regions are characterised by a high degree of infection and are assigned to class C. The practical significance of the study is due to the contribution of valuable information to the scientific understanding of the epidemiology of brucellosis in the Republic of Kazakhstan. The findings provide a basis for the development of targeted intervention strategies and policy recommendations to mitigate the impact of brucellosis on livestock

Keywords: epidemic; regions; diagnostics; statistics; cattle; biotypes

INTRODUCTION

Brucellosis infection poses a serious threat to livestock and human health, resulting in significant economic losses in agriculture and health care costs. In the context of modern livestock production technologies, where highly organised housing systems can facilitate the rapid spread of infection, understanding the current epizootic situation becomes key to effective control and prevention.

A. Shevtsov *et al.* (2023) and A.A. Taipova *et al.* (2023) determined that in modern microbial taxonomy, *Brucella* occupies its place in the domain Bacteria, belonging to the type *Proteobacteria*, class *Alphaproteobacteria*, order *Rhizobiales*, family *Brucellaceae* and genus *Brucella*. This genus includes 12 different species, each characterised by variations in genetic, biochemical, antigenic and virulence traits. *B. suis* – represented by 5 biotypes, main host – pigs, *B. vulpis* (common fox *Vulpes vulpes*), *B. inopinata* (main host not identified), *B. ceti* (cetaceans), *B. neotomae* (desert – bush rats), *B. abortus* – 7 biotypes, main host – cattle, *B. microti* (grey vole), *B. ovis* (sheep), *B. pinnipedialis* (pinnipeds), *B. papionis* (*Papio* spp. baboons), *B. canis* (dogs), *B. meliensis* – represented by 5 biotypes, main host – goats and sheep. This diverse set of *Brucella* species demonstrates their adaptation to different hosts with different biotypes and characteristics in terms of their ecological niches and relationships with different animal species (Yespembetov *et al.*, 2019).

Some domesticated and free-living wild animals may inadvertently become hosts of *Brucella* species of epidemiological importance. As noted by N.S. Syrym *et al.* (2019), the brucellosis pathogen exhibits general resistance to environmental factors typical of non-spore-forming bacteria, persisting for long periods in various substrates. In a humid environment at 60°C, the brucellosis pathogen dies in 45 minutes; at 70°C, it dies in 25 minutes; at 75°C, in 15 minutes and instant-

ly at boiling temperature. Dry heat (90-95°C) is fatal to brucellosis after one hour. When exposed to sunlight, brucellae die within a period ranging from a few minutes to 6-9 days, depending on factors such as insolation intensity, atmospheric conditions, and other variables. This resistance to a variety of environmental conditions contributes to the ability of the pathogen to persist and poses challenges to effective eradication measures (Storozhuk *et al.*, 2022).

A. Raushan *et al.* (2023) estimate that Kazakhstan, located in Central Eurasia and a former Soviet republic is among the twenty-five countries in the world with the highest incidence of brucellosis. Despite the implementation of several brucellosis eradication programmes over the past eight decades, epidemiological data for this period are scarce. This deficit makes it difficult to draw definitive conclusions regarding the effectiveness of these measures and the dynamic changes in brucellosis prevalence in both animals and humans over time. In addition, accurate and up-to-date data on specific genotypes of circulating brucellosis strains are lacking, further complicating a comprehensive understanding of the disease situation in the region.

Effective control of brucellosis requires comprehensive planning at the national level. D. Charypkhan and S.R. Rüegg (2022) recommend the promotion of increased cooperation between the veterinary and health sectors, adequate financial resources and health education programmes for health professionals, veterinarians, and the general public. In Kazakhstan, new efforts to control animal brucellosis were initiated in 2001. These efforts were mainly based on a screening and slaughter method involving serological testing to detect asymptomatic cases in livestock, followed by culling of the animals (Korotetsky *et al.*, 2010). However, this approach proved costly and produced unsatisfactory results.

Additions by K. Turgenbayev *et al.* (2023) include the following information: “Alternatively, a transition to a mass vaccination programme for sheep and goats was implemented as of 10 March 2019. Evaluation of the effectiveness of this new programme requires additional time and data analysis”. Analysis of primary studies of other authors concludes that there is a lack of accurate data and extensive research in each region and comparison with geographical components in different content systems. Therefore, the study aims to conduct different diagnostic programmes and compare them with the data provided by other frameworks.

MATERIALS AND METHODS

The study, conducted in 2021-2023 in 14 regions of Kazakhstan to investigate the epizootic situation of bovine brucellosis, provides an overview of the number of livestock, including cattle, small cattle, pigs, and horses, in different geographical units such as districts, rural districts (RD), settlements and each epizootological unit (EU) for 2023. According to the data presented in Table 1, there are a total of 2479 rural districts in the Republic of Kazakhstan. Among them, the largest number is observed in Almaty Region with 268 rural districts, while the smallest number is observed in Mangystau Region with 52 rural districts.

Table 1. Census of cattle, pigs and horses by region, rural districts, and epizootic foci of the Republic of Kazakhstan for 2023

Regions	Overall RD number	Counts of EU	Number of animals			
			Cattle	Small cattle	Horses	Pigs
Atyrau	65	384	234,538	729,988	998	112
Akmola	231	1,398	400,106	512,332	160,365	91,819
Mangystau	52	273	23,568	431,425	81,474	64
Kostanay	257	1,199	413,142	410,057	120,477	169,201
Jambyl	155	2,402	432,741	3,000,425	124,011	15,504
Kyzylorda	139	1,786	331,289	626,681	149,551	4,679
Almaty	268	5,550	1,018,467	3,578,598	130,007	8,324
Turkestan	192	2,741	1,001,764	3,989,416	318,255	9,178
Pavlodar	131	2,268	402,342	476,316	154,433	40,652
East Kazakhstan	257	2,512	987,465	1,722,687	335,035	87,728
Aktobe	171	2,497	491,858	987,652	136,026	45,378
North Kazakhstan	201	1,347	349,657	441,842	131,713	140,327
West Kazakhstan	149	3,527	618,427	1,235,611	180,321	18,795
Karaganda	211	4,145	572,984	9,455,743	314,655	89,137
Total in Kazakhstan	2,479	32,029	7,854,528	24,407,622	2,493,193	607,237

Source: compiled by the authors based on the Ministry of Agriculture of the Republic of Kazakhstan (2023)

Identification of *Brucella* species and biovars in specific regions and foci of infection has important epidemiological significance for categorisation of foci, assessment of the status of the epizootic process and confirmation of cases of *Brucella* migration between animal species. Differentiation procedures were carried out under the conditions of the brucellosis laboratory of the Kazakh Veterinary Research Institute. The following parameters considered the “gold standard” of *Brucella* differentiation, were investigated: dependence on elevated carbon dioxide (CO₂) concentrations in the growth medium, ability to generate hydrogen sulphide (H₂S), ability to reduce the activity of dyes such as thionine and basic fuchsin, agglutination potential with monospecific brucellosis sera, including anti-abortion and anti-melitensis sera, and sensitivity to the diagnostic brucellosis bacteriophages Tb, Wb, Fi and Bk2. These criteria are fundamental for the accurate classification of brucellosis strains, allowing a thorough assessment of the epidemiological situation and an understanding

of the dynamics of brucellosis transmission among different animal species.

Classical serological methods including the Rose-Bengal test, agglutination reaction, complement binding reaction and enzyme immunoassay were used in the diagnostic study. The Rose-Bengal antigen test was used as the initial screening test, detecting antibodies against *Brucella* by agglutination with specific antigens. The agglutination test further confirmed and characterised the serological response by observing the accumulation of anti-*Brucella* antibodies in the serum of infected animals. The complement binding test quantifies antibody levels in serum, providing accurate titres and helping to quantify the immune response. The diagnostic repertoire has been enriched by enzyme-linked immunosorbent assay (ELISA), a sensitive and specific assay that uses antibody-binding enzymes to detect and quantify *Brucella*-specific antibodies. This multifaceted serological approach has provided a comprehensive assessment of *Brucella* infection, combining

traditional and advanced techniques for a detailed understanding of the immune response.

The evolution of the brucellosis epizootic situation over time has been studied by analysing the data provided and the main epizootic indicators. The risk assessment focused on the prevalence of brucellosis-infected animals in certain areas, using this information to assess the potential impact and severity of the disease in these regions. Most of the data used in this study were obtained from annual official reports that focus on brucellosis, a registered epizootic disease in the Republic of Kazakhstan. To summarise the relevant information, some data were extracted from the official statistical reports of the Veterinary Control and Surveillance Committee and the Ministry of Agriculture. These reports provided information on the absolute number of farm animals that had serological tests positive for brucellosis during the relevant period.

The graph-analytical method involves maps with smaller mapping units and annual data. These maps are vital in identifying 'hot spots' by determining areas that may serve as potential sources of disease spread, as well as 'cold spots' that require in-depth research for disease control. The analysis includes surveillance of regions

with increased incidence, assessment of their recovery and identification of new areas susceptible to the disease. This advanced research approach helps to understand the causes of animal brucellosis in the Republic of Kazakhstan, providing valuable information for the development of targeted prevention and control strategies.

RESULTS

Extensive research has established that *Brucella* species such as *B. melitensis* and *B. suis* are anaerobes. It is worth noting that the initial generations of *B. ovis* and *B. abortus* cultures can only be isolated in a 6-12% carbon dioxide environment. However, with subsequent reseeded, *B. abortus* cultures lose this requirement and feel perfectly well under normal atmospheric conditions. Furthermore, the hydrogen sulphide (H_2S) production capacity varies among *Brucella* species. Notably, *B. suis* (biotype 1) has the most pronounced ability to produce hydrogen sulphide, whereas *B. neotomae*, and *B. abortus* (biotypes 1-3, 7) show this trait to a lesser extent. These results shed light on the diverse physiological characteristics of different *Brucella* species, highlighting their ability to adapt to different environmental conditions (Table 2).

Table 2. Distinctive characteristics of different bacterial species and biological variants of brucellae

Type	Biotype	Comparison strains	CO ₂ -dependency	H ₂ S formation						
<i>B. melitensis</i>	I	14-T	-	-						
	II	3/15	-	-						
	III	Bart	-	-						
<i>B. abortus</i>	I	633	(+)	+						
	II	91/3/62	(+)	+						
	III	Theon	(+)	+						
	IV	194	(+)	+						
	V	W-4387	-	-						
	VI	957	-	(+)						
	VII	A-32	-	+						
<i>B. suis</i>	I	2,950	-	+						
	II	Virat 34	-	-						
	III	752	-	-						
	IV	39	-	-						
	V	483	-	-						
<i>B. ovis</i>			+	-						
<i>B. canis</i>			-	-						
Type	Growth on media with dyes		Agglutination reaction with sera			Sensitivity to bacteriophages				Animal carriers
	Fuchsin	Tionine	R	A	M	Wb	Tb	Bk2	Fi	
<i>B. melitensis</i>	+	+	-	-	+	(-)	-	+	-	Sheep, goats
	+	+	-	+	-	(-)	-	+	-	
	+	+	-	+	+	(-)	-	+	-	
<i>B. abortus</i>	+	-	-	+	-	+	+	+	+	Cattle
	-	-	-	+	-	+	+	+	+	
	+	+	-	+	-	+	+	+	+	
	(+)	-	-	-	+	+	+	+	+	
	+	+	-	-	+	+	+	+	+	
	+	+	-	+	-	+	+	+	+	
	+	+	-	-	+	+	+	+	+	

Table 2. Continued

Type	Growth on media with dyes		Agglutination reaction with sera			Sensitivity to bacteriophages				Animal carriers
	Fuchsin	Tionine	R	A	M	Wb	Tb	Bk2	Fi	
<i>B. suis</i>	(-)	+	-	+	-	+	-	±	+	Pigs
	-	+	-	+	-	+	-	±	+	Pigs, rabbits
	+	+	-	+	-	+	-	±	+	Pigs
	(-)	+	-	+	+	+	-	±	+	Reindeer
	-	+	-	-	+	+	-	±	+	Mice rodents
<i>B. ovis</i>	(-)	+	+	-	-	-	-	-	-	Sheep
<i>B. canis</i>	-	+	+	-	-	-	-	-	-	Dogs

Note: + – the trait is detected in all representatives; (-) – the trait is absent in most cultures; - the trait is absent in all representatives, ± – the trait is detected in some strains that are not sensitive; (+) – the majority of cultures have this trait

Source: compiled by the authors

Some strains of *B. abortus* (biotype 6) demonstrated hydrogen sulphide generation ability. At the same time, cultures of *B. abortus* (biovar 5), *B. melitensis*, *B. canis*, and *B. ovis* show notable reducing activity against dyes. In particular, cultures of *B. abortus* biotype 1 grow on media containing fuchsin but do not grow on media containing thionine. Conversely, cultures of biotype 1 *B. suis* grow on media containing thionine but show no growth on media containing fuchsin. In contrast, cultures of *B. melitensis* species show growth on media containing both dyes, demonstrating their unique dye staining characteristics.

The agglutination reaction with monospecific (R-, A-, M-) sera varies between *Brucella* cultures. In addition, agglutination of *Brucella* cultures with monospecific sera against *melitensis* (M) and against *abortus* (A) depends on the respective biotypes. In the case of cultures of *B. ovis* and *B. canis* as well as other *Brucella* species and biotypes in the R-form, monospecific antisera are used in the agglutination reaction. In addition, the sensitivity to the brucellosis diagnostic bacteriophages Wb, Tb, Bk2 and Fi varies among brucellosis species.

B. abortus is lysed by all four bacteriophages, whereas *B. melitensis* is sensitive only to bacteriophage Bk2. *B. suis* is sensitive to Bk2 and Wb. It is noteworthy that *B. Abortus* and partially *B. suis* are lysed by bacteriophage Fi. However, cultures of *B. ovis* and *B. canis* are resistant and are not lysed by these phages. These observations highlight the diverse and subtle characteristics of different *Brucella* strains in response to different diagnostic tests and conditions.

According to the data presented in Tables 3 and 4, among 2,479 rural districts, brucellosis-positive animals were detected in 1,634, which is 56.4% of the total. Brucellosis was most prevalent in West Kazakhstan Region, where out of 149 rural districts, brucellosis-positive animals were recorded in 137, or 91.9% of the total. Similarly, a significant prevalence of brucellosis infection among rural districts was observed in Akmola (83.9%), Kyzylorda (70%), East Kazakhstan (75.8%) and North Kazakhstan (75.6%) regions. The obtained data indicate that brucellosis is widespread in some regions, which requires special attention and measures to reduce the spread of the disease among livestock.

Table 3. Brucellosis incidence and animal infection rates by RD and EU in 2023

Regions	RD amount	RDs with infected animals/%	EU amount	EUs with infected animals/%
Atyrau	65	38/58.4	384	123/32
Akmola	231	194/83.9	1,398	365/26.1
Mangystau	52	28/53.8	273	67/24.5
Kostanay	257	157/61	1,199	297/24.7
Jambyl	155	102/65.8	2,402	308/12.8
Kyzylorda	139	98/70	1,786	158/8.8
Almaty	268	81/30	5,550	157/2.8
Turkistan	192	113/58.8	2,741	56/2
Pavlodar	131	89/67.9	2,268	361/15.9
East Kazakhstan	257	195/75.8	2,512	409/16.2
Aktobe	171	107/62.5	2,497	1,273/50.9
North Kazakhstan	201	152/75.6	1,347	176/13
West Kazakhstan	149	137/91.9	3,527	827/23.4
Karaganda	211	68/32.2	4,145	129/3.1
Total	2,479	1,634/56.4	32,029	4,976/17.4

Source: compiled by the authors

Table 4. Number of infected animals by species

Regions	Cattle		Small cattle		Pigs		Horses	
	Total	Infected/%	Total	Infected/%	Total	Infected/%	Total	Infected/%
Atyrau	175,905	1,327/0.7	44,453	468/0.1	34,024	312/0.9	1,196	3/0.02
Akmola	300,080	1,422/0.5	549,836	1,976/0.3	80	4/5	372	0
Mangystau	17,676	521/2.9	329,173	399/0.1	30,034	68/0.2	447	0
Kostanay	309,857	1,693/0.5	233,921	108/0.05	50	0	146	0
Jambyl	324,556	398/0.1	2,281,051	1,934/0.08	4,529	18/0.3	770	0
Kyzylorda	248,467	1,224/0.4	2,504,441	2,667/0.1	2,396	5/0.2	14,387	5/0.003
Almaty	763,850	968/0.1	566,449	201/0.03	622	0	620	0
Turkistan	751,323	10,512/1.3	3,237,266	1,097/0.03	2,461	0	1,221	2/0.1
Pavlodar	301,757	420/0.1	1,856,900	2,237/0.1	2,312	11/0.4	9,265	7/0.007
East Kazakhstan	740,599	4,381/0.6	443,273	694/0.02	22,028	23/0.1	550	0
Aktobe	368,893	3,079/0.8	770,866	1,327/0.1	5,068	0	533	0/0
North Kazakhstan	262,243	4,512/1.7	1,133,192	2,733/0.2	8,546	0	2,272	2/0.008
West Kazakhstan	463,820	8,647/1.8	1,088,723	4,502/0.4	6,133	0	671	1/0.1
Karaganda	429,738	795/0.2	390,325	204/0.005	24,996	37/0.1	552	0
Total	5,890,896	39,899/0.7	15,082,168	20,547/0.1	142,008	478/0.3	33,001	13/0.03

Source: compiled by the authors

On the territory of the Republic of Kazakhstan, 32,029 epizootological units were registered. Of these, in 4,976 epizootological units, or 17.4%, animals positive for brucellosis were detected. The spread of brucellosis is particularly pronounced in some regions. It is noteworthy that the Aktobe Region has the highest prevalence rate: 50.9% of epizootological units were affected, followed by Kostanay Region – 24.7%, Mangystau Region – 24.5%, Atyrau Region – 32%, Akmola Region – 26.1% and West Kazakhstan Region – 23.4%. In 2023, a comprehensive testing of the cattle population of the Republic of Kazakhstan was carried out. A total of 5,890,896 cattle were tested, as a result of which 39,899 cattle, representing only 0.7%, were identified as brucellosis-positive. In parallel, 15,082,168 sheep were tested, of which 20,547 (0.1%) tested positive for brucellosis. Among 142,008 pigs tested, only 478 were positive, representing 0.3%. In addition, 33,001 horses were tested and only 13 (0.03%) tested positive for brucellosis. According to Tables 3 and 4, the highest incidence of brucellosis in cattle was observed in West

Kazakhstan (8,647 heads), North Kazakhstan (4,512 heads), East Kazakhstan (4,381 heads) and Turkestan (10,512 heads) regions. On the contrary, Zhambyl (398 heads) and Pavlodar (420 heads) regions registered the smallest number of cattle with brucellosis positive status. Regional analysis of the epizootic situation places Almaty, Pavlodar, Karaganda and Zhambyl regions in class “A” (areas with a low degree of infection) in terms of bovine brucellosis incidence. Kostanay, Akmola, Kyzylorda and Atyrau regions are classified as class “B” (zones with medium degree of infection). Conversely, all other regions have the status of class “C” (zones with a high contamination degree).

According to the data presented in Table 5, the analysis of the results of diagnostic tests shows that in recent years, from 2021 to 2023, Mangystau Region has consistently had the highest level of infestation among cattle. In particular, a rate of 2.3% was recorded in 2021. Subsequently, a slight increase was noted in 2022, where 2.9% of animals had reactions indicative of brucellosis and this indicator remained stable in 2023.

Table 5. Results of diagnostics of brucellosis of cattle in Kazakhstan: analysis 2021-2023

Regions	2021			2022			2023		
	Study groups	Pos. reactions	%	Study groups	Pos. reactions	%	Study groups	Pos. reactions	%
Atyrau	204,590	1,454	0.7	188,706	1,440	0.8	175,905	1,327	0.7
Akmola	358,120	1,420	0.3	327,138	1,347	0.4	300,080	1,422	0.5
Mangystau	20,481	487	2.3	187,740	549	2.9	17,676	521	2.9
Kostanay	355,555	2,181	0.6	330,762	1,902	0.6	309,857	1,693	0.5
Jambyl	381,528	389	0.1	349,999	342	0.1	324,556	398	0.1
Kyzylorda	283,457	1,155	0.4	261,761	1,346	0.5	248,467	1,224	0.4
Almaty	886,620	1,117	0.1	808,989	1,084	0.2	763,850	968	0.1
Turkistan	878,755	9,662	1.0	820,754	9,961	1.2	751,323	10,512	1.3
Pavlodar	348,450	359	0.1	323,309	402	0.1	301,757	420	0.1
East Kazakhstan	844,161	5,274	0.6	778,610	4,829	0.6	740,599	4,381	0.6

Table 1. Continued

Regions	2021			2022			2023		
	Study groups	Pos. reactions	%	Study groups	Pos. reactions	%	Study groups	Pos. reactions	%
Aktobe	434,924	2,467	0.5	402,322	2,703	0.7	368,893	3,079	0.8
North Kazakhstan	308,263	4,605	1.4	282,691	4,833	1.7	262,243	4,512	1.7
West Kazakhstan	542,383	9,526	1.7	493,553	8,660	1.8	463,820	8,647	1.8
Karaganda	489,711	935	0.1	455,439	894	0.2	429,738	795	0.2
Total	6,841,464	41,031	0.6	6,266,917	40,292	0.5	5,890,896	39,899	0.7

Note: Pos. reactions – positive reactions

Source: compiled by the authors

In recent years, West Kazakhstan and North Kazakhstan regions experienced a high incidence of brucellosis in cattle. In West Kazakhstan, incidence rates were 1.7% in 2021, 1.8% in 2022, and 1.8% in 2023. Atyrau Region also had a relatively high incidence of brucellosis in cattle from 2021 to 2023 with relatively stable rates of 0.7%, 0.8% and 0.7%, respectively. On the contrary, in the Zhambyl Region, the situation of cattle brucellosis is more stable, nevertheless, for several years in a row there have been up to 400 positive animals. In Almaty and Pavlodar regions there are single cases, where the incidence of cattle brucellosis does not exceed 0.1% during annual routine diagnostic tests. These differences in brucellosis morbidity highlight the diverse regional dynamics and emphasise the need for targeted measures to control and treat the disease in specific regions. Comparing these data with the physical map of the Republic of Kazakhstan reveals a remarkable observation: cattle and small ruminant breeding is concentrated mainly in hilly and flat areas where arable land development is less prominent (National Atlas of..., 2023).

By studying the atlas maps illustrating the features of Kazakhstani land and Tables 1, 3 and 4, it is possible to estimate the prevalence of the disease in different regions of Kazakhstan. A marked correlation is evident when comparing the table data, which respectively represent the number of cattle and the number of infected cattle. This correlation is more obvious for small ruminants. This means that the farming approach is not strongly tied to the type of animals being farmed. However, an interesting pattern emerges when assessing the incidence of brucellosis in cattle compared to small ruminants. Geographical factors play an important role in this respect, as small ruminants are predominantly reared in mountainous and more arid areas, whereas cattle are reared in the highlands. This conclusion is supported by a similar comparison in the case of cattle and small ruminant livestock (sheep and goats), allowing an assessment of the scale of agricultural activity in the study area. Moreover, these data indicate the perceived presence of natural conditions and economic viability favouring this particular agricultural activity in different regions of Kazakhstan.

Mangystau Region is the least developed in terms of cattle production in comparison with other oblasts.

Among other less productive regions, Kyzylorda and Atyrau regions are 10 times ahead of the Mangystau Region ($p \leq 0.05$), and Kostanay and Zhambyl regions surpass it even more significantly. Karaganda, Aktobe, Akmola and West Kazakhstan regions belong to the category of medium producers. The most favourable agricultural conditions are observed in three regions – East Kazakhstan, Almaty, and Turkestan regions – where livestock production is three times higher than in North Kazakhstan oblast ($p < 0.05$). Thus, six regions of Kazakhstan can boast a medium to high level of livestock development, which exceeds the number of less favourable regions. The resulting Pearson correlation coefficients indicate significant associations within the dataset. In particular, there is a strong positive correlation of 0.71 ($p \leq 0.005$) between the total headcount and the number of cases, suggesting that as the total herd size increases, the number of reported cases also increases. In addition, there is a moderate positive correlation of 0.44 ($p < 0.01$) between the total population and the proportion of infected animals, indicating a tendency for a higher proportion of infected animals in areas with larger populations. In addition, a remarkable correlation of 0.91 ($p \leq 0.0001$) was observed between the number of animals and the proportion of infected animals. This finding emphasises that as the number of animals in a given area increases, the probability of brucellosis infection among them increases. These results are consistent with the broader patterns observed in the elevation sector and rainfall map, confirming a consistent trend in the relationship between population factors and brucellosis prevalence.

The prevalence of infected animals is often correlated with herd size. As the number of animals in a herd increases, the number of infected animals increases accordingly. Conversely, this trend may reverse, indicating a potential decrease in the number of infected animals as herd size increases, allowing more attention to be paid to animal health. To effectively capture and visualise this dynamic, it is useful to calculate the percentage of infected animals to total herd size within an administrative unit. This ratio, chosen as a cartographic indicator, indicates disease patterns. A similar analytical approach is valid when comparing data on the number of infected animals with the percentage of the total animal population. It is noteworthy that the data obtained show

a strong correlation with maps showing agricultural land, especially areas labelled as pastures. This correlation is important, especially in the Republic of Kazakhstan, where pastures dominate the landscape, emphasising their role in sustainable livestock production.

The increased prevalence of sheep and goat diseases in the south-western regions is primarily due to the proximity to the border with Kyrgyzstan, where there are similarly high levels of animal infections. Poor control at the border checkpoint, combined with shared pastures and evacuation routes, exacerbates the incidence of the disease in these areas. In contrast, addressing the data obtained for the number of hectares of pasture per sheep shows a different trend: a constant pasture size reduces the probability of contracting the disease. This suggests that management and optimisation of pasture allocation can play a key role in mitigating the spread of disease. In addition, factors such as farm size, equipment and transport accessibility can influence disease incidence. Ensuring good sanitation and hygiene, providing adequate water sources, and promoting controlled grazing are additional key elements affecting disease prevalence. The complex interplay of these factors emphasises the multifaceted nature of disease dynamics, which requires an integrated approach to effectively address and manage the associated risks.

DISCUSSION

The study results obtained show a marked correlation between geographical location and the extent of brucellosis infection. The correlation between geographical location and the extent of brucellosis infection was also important. Nevertheless, for greater objectivity and relevance of the data, it is important to compare these figures with similar works by other authors.

A study by M. Pal *et al.* (2020) a study of 131 *B. abortus* strains from animals in two specific regions of Mexico revealed limited genetic diversity, indicated by a TYND-22 genetic diversity index of 0.512. However, the discriminatory power of the study was considered insufficient for reliable epidemiological monitoring, a limitation possibly related to the limited sampling area. To address this limitation, scaling up the study would have entailed expanding both the sampling area and time frame, including samples from repositories dating as far back as 1952. To overcome these limitations, an alternative approach was adopted in Kazakhstan, where more extensive diagnostic methods and statistical analyses were used in a comprehensive study. This approach yielded accurate results in determining the genetic diversity and extent of brucellosis infection throughout the country. The comparative effectiveness of this broader methodology in Kazakhstan highlights the importance of methodological considerations and the need for a thorough approach to provide reliable epidemiological data.

The observations of D. Tulu (2022) and J.M. Blasco *et al.* (2023), show that the main factors contributing to the spread of this disease among animals are the disregard of strict veterinary and sanitary regulations, the shortage of veterinary specialists and the insufficient coverage of diagnostic tests for animals, especially breeding bulls. Other key factors were untimely isolation and transport of sick livestock to slaughter, irregularities related to prophylactic and continuous forced disinfections with inadequate quality control, and sub-optimal housing and proper feeding conditions.

The practice of feeding raw milk and skimmed calf fat to calves was also a major concern for J. Pappaskevas *et al.* (2023). These animals, which are not identified by commonly accepted standard diagnostic methods, persist in herds as vectors of brucellosis. They are hidden sources of infection, thus supporting the ongoing epizootic process. Addressing these multifaceted issues is crucial for effective control and prevention of brucellosis in animal populations. This information is also very important for the above study; as possible modes of disease transmission are not sufficiently suppressed even under current conditions of animal husbandry technology in the Republic of Kazakhstan.

The main approach to controlling sheep brucellosis in Iran until the early 1990s, as stated by M. Dadar *et al.* (2020), was to test and cull seropositive animals. However, this strategy had limitations as the coverage of the sheep population did not exceed 50%, which consequently had minimal impact on the overall economic situation in the country. Between 1991 and 2003, there was a shift towards brucellosis vaccination using the *B. abortus* R21 vaccine for sheep of all ages, combined with pre-testing and culling of seropositive cattle. This initiative resulted in a significant reduction in the incidence of brucellosis in sheep by 50%.

The additions of R. Al Jindan (2021) are equally important, noting that since 2004, young sheep received the Kov2 vaccine and adults continued to be vaccinated with the *B. abortus* R21 vaccine until 2015. Subsequently, a switch to a single immunisation of young sheep with the Kov2 vaccine was made to coincide with a complex epidemiological scenario where groups of animals of different ages were housed together. This adjustment proved ineffective, leading to a rise in brucellosis incidence between 2015 and 2022, reaching levels equivalent to those observed in 1990. Similar epidemic control methodologies have been applied in Kazakhstan but have also shown variable success in herd recovery.

According to C. Di Bari *et al.* (2022), the prevalence of brucellosis in Venezuela is due to global climate change, in particular general warming, which favours an increase in the incidence of the disease in animals and humans. This phenomenon is aggravated by intensive agricultural development and a lack of compliance with veterinary and sanitary regulations. The uncontrolled movement of infected animals, inadequate

indoor hygiene, and the use of semen from untested animals for insemination have contributed to the spread of brucellosis (Busol *et al.*, 2023). This trend is not unique to Venezuela; similar findings were reported for countries such as Brazil, Mexico, Canada, India, Peru, and various Asian countries. Although Kazakhstan is slightly north of these countries, the effects of global warming are also affecting farms in this territory.

Z.G. Liu *et al.* (2020) determined the economic standard of living that forces people to keep farm animals on individual farms unattended. Similar oversight applies to the limited differentiation of pastures where multiple species coexist, favouring cooperative grazing. The relatively modest participation of Central Asian countries in the global division of labour increases unemployment among local populations. As a result, there is a significant share of small private farms characterised by inadequate equipment and a lack of compliance with sanitary norms (Turmagambetova *et al.*, 2017).

Following L. Xu and Y. Deng (2022), these problems are compounded by the impact of unprotected borders and the increased prevalence of animal infections in neighbouring countries, further adding to the complexity of the situation. This complex interplay of economic factors, livestock management practices and regional dynamics emphasises the multifaceted nature of the challenges faced in this context. This indicates that, in addition to Kazakhstan's internal problem with brucellosis infection, this is compounded by the presence of similar situations among its neighbours.

The spread of brucellosis, as observed by K.I. Prahesti *et al.* (2020), is primarily related to economic and geographical factors, which are essentially products of human activities. Contrary to this view, physiographic factors such as climate and weather are believed to have a negligible effect on the incidence of brucellosis due to careful animal care. However, this view overlooks the potential influence of physiographic factors on the type of farming activities that ultimately determine the economic viability of stabling and grazing. This contradiction emphasises the complex interplay between environmental conditions, human habits and wider economic dynamics that influence the prevalence of brucellosis (Koroban *et al.*, 2023). These ideas further emphasise the importance of the above study of the regional epizootiology of brucellosis infection under the current conditions of livestock production technology in the Republic of Kazakhstan.

The study results obtained by A. Shehzad *et al.* (2021) and S.U. Hassan *et al.* (2023) highlighted the significant correlation between total population and number of infected animals, revealing a significant correlation of 0.66 for cows ($p \leq 0.004$) and 0.49 for sheep and goats ($p \leq 0.02$). These results emphasise that regions with a higher prevalence of infection foci have an increased probability of brucellosis. Even though Pakistan has almost twice as many regions favourable for cattle than

regions suitable for small ruminants, the correlations of the variables for cattle and small ruminants remain remarkably comparable. The findings from this study prompted S.U. Hassan *et al.* (2023) to advocate a modification of the existing methodology for epidemiological surveillance. The proposed changes include the use of spatial (geographical) analysis techniques to improve the accuracy of disease monitoring. In addition, it is proposed to adapt the cattle and small ruminant breeding process by incorporating additional health guidelines that consider geographical aspects of disease spread. This approach echoes similar observations and correlation values recorded in Kazakhstan. Thus, the recommendations of S.U. Hassan *et al.* (2023) recommendations are valuable for choosing an effective strategy to study and control brucellosis infection, given the similarity of the situations observed in both regions.

According to the statements of S.S.R. Vakamalla *et al.* (2023), established in India at the beginning of the last century, brucellosis has since been reported in almost all states. Numerous publications emphasise the widespread occurrence of brucellosis in the country, affecting various mammalian species including cattle, goats, buffaloes, yaks, camels, horses, and pigs. Five years ago, a nationwide cattle survey revealed that 4% of cattle and 2% of buffaloes in the country were infected with brucellosis. The disease is more common in organised farms (45%) compared to marginal herds (8%), which is primarily due to intensive management practices employed in large livestock enterprises. Data obtained in a study of brucellosis in Kazakhstan regionally confirm the study of colleagues.

CONCLUSIONS

Analysis of data on the prevalence of brucellosis in cattle in the regions of Kazakhstan revealed notable trends emphasising the importance of geographical, climatic, and economic factors in the dynamics of disease incidence. The following key numerical indicators are highlighted based on the information provided. The total number of epizootological units in the Republic of Kazakhstan is 32,029, of which 4,976 (17.4%) were found positive for brucellosis in cattle. In 2023, 5,890,896 cattle were tested, and 39,899 brucellosis cases (0.7%) were detected, and among sheep and goats, out of 15,082,168 tested, 20,547 (0.1%) were positive. Importantly, only 478 out of 142,008 pigs tested (0.3%) tested positive. In 33,001 horses tested, brucellosis was detected in only 13 cases (0.03%).

In the regional context, in the West-Kazakhstan region, 50.9% of epizootological units are affected, in North-Kazakhstan Region – 24.7%, in Akmola Region – 26.1%, in Atyrau Region – 32%, and in Mangistau Region – 24.5%. It is noted that in the Mangistau Region, which is a less developed agricultural region, there is a persistent infection of cattle with brucellosis. Geographical dynamics are also noticeable, with Zhambyl

Region demonstrating a stable and more favourable brucellosis situation. Correlation analyses indicate a relationship between total herd size and the number of brucellosis cases. There is also an influence of herd size on the probability of infection, emphasising the importance of effective herd management. In addition, geographical factors such as pasture availability and climatic patterns have been observed to influence the prevalence of the disease.

Based on these findings, it is reasonable to assume that the adoption of comprehensive measures, including optimisation of herd management, pasture management and sanitary and hygienic practices, could help to reduce the prevalence of brucellosis in different regions of Kazakhstan. Consideration of geographical and climatic specificities in the development of control strategies may also increase the effectiveness of the measures taken. Prospects for further research include genomic analyses for comprehensive strain

characterisation, which will provide a better understanding of strain diversity for targeted interventions. Adopting a holistic One Health (“Единое здоровье”) approach that integrates human, animal and environmental health data may provide a more complete understanding of disease dynamics, enabling the development of effective control measures.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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**Крайова епізоотологія бруцельозної інфекції
в сучасних умовах технології тваринництва в Республіці Казахстан
(за ступенем розповсюдження та рівнем захворюваності)**

Аспен Абуталіп

Доктор ветеринарних наук, головний науковий співробітник
Казахський науково-дослідний ветеринарний інститут
050016, просп. Раїмбаєка, 223, м. Алмати, Республіка Казахстан
<https://orcid.org/0000-0002-2724-8220>

Алім Біжанов

Доктор ветеринарних наук, офіцер біологічної безпеки
Казахський науково-дослідний ветеринарний інститут
050016, просп. Раїмбаєка, 223, м. Алмати, Республіка Казахстан
<https://orcid.org/0009-0004-4052-3866>

Нуралі Матіхан

Доктор філософії, викладач
Казахський національний аграрний дослідницький університет
050010, просп. Абая, 8, м. Алмати, Республіка Казахстан
<https://orcid.org/0000-0002-3297-1907>

Айкен Карабасова

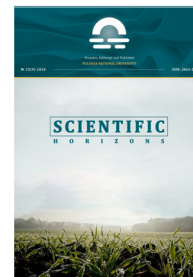
Доктор філософії, старший науковий співробітник
Казахський науково-дослідний ветеринарний інститут
050016, просп. Раїмбаєка, 223, м. Алмати, Республіка Казахстан
<https://orcid.org/0000-0001-6118-0576>

Бібізада Оринбаєва

Магістр, викладач
Південно-Казахстанський університет імені Мухтара Ауєзова
160012, просп. Тауке Хана, 5, м. Шимкент, Республіка Казахстан
<https://orcid.org/0009-0008-1949-0990>

Анотація. Актуальність статті обумовлена тим, що в тваринницькому ландшафті Республіки Казахстан, який розвивається, гостра проблема поширеності та впливу бруцельозу вимагає негайної оцінки для розуміння поточного стану, обумовленого динамічними змінами в технологіях розведення тварин. Мета цього дослідження полягає у виконанні різних діагностичних програм і зіставленні отриманих даних з інформацією, наданою іншими організаціями. Для досягнення мети було використано методи дослідження «золотого стандарту», комплекс класичних серологічних методів, до якого входили Роз-Бенгал проба, реакція аглютинації, реакція зв'язування комплекменту, імуноферментний аналіз, а також метод аналізу та графоаналітичний метод. Отримані результати продемонстрували, що найзараженішими щодо бруцельозу виявилися епізоотологічні одиниці Актюбінської, Костанайської, Мангістауської, Атирауської, Акмолинської та Західно-Казахстанської областей, показники зараженості яких перевищували 23,4 %. Водночас найменш уразливими були Алматинська, Туркестанська та Карагандинська області, показники яких не перевищували 3,1 %. Найбільша кількість хворих на бруцельоз тварин зареєстрована в Західно-Казахстанській області, а найменша – в Жамбильській. Це пов'язано з особливостями утримання та географічними положеннями регіонів Казахстану. Таким чином, можна віднести ситуацію в Алматинській, Павлодарській, Карагандинській і Жамбильській областях в клас «А», як з низьким ступенем зараження. Костанайська, Акмолинська, Кизилординська і Атирауська області розглядаються як зони із середнім ступенем зараження, відносячись до класу «Б». Своєю чергою, всі інші регіони відзначаються високим ступенем зараження і приписуються класу «С». Практична значущість обумовлюється внесенням цінної інформації в наукове розуміння епідеміології бруцельозу в Республіці Казахстан. Отримані результати слугують підґрунтям для розроблення цільових стратегій втручання та політичних рекомендацій щодо пом'якшення впливу бруцельозу на поголів'я тварин

Ключові слова: епідемія; регіони; діагностика; статистика; велика рогата худоба; біотики



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Phytocoenotic assessment of herbaceous plant communities in the organic sweet cherry orchard

Tetyana Gerasko

PhD in Agricultural Sciences, Associate Professor
Dmytro Motorny Tavria State Agrotechnological University
72310, 18 Zhukovskiy Str., Zaporizhzhia, Ukraine
<https://orcid.org/0000-0002-1331-4397>

Tetiana Tymoshchuk

PhD in Agricultural Sciences, Associate Professor
Polissia National University
10008, 7 Staryi Blvd., Zhytomyr, Ukraine
<https://orcid.org/0000-0001-8980-7334>

Vira Moisiienko

Doctor of Agriculture Science, Professor
Polissia National University
10008, 7 Staryi Blvd., Zhytomyr, Ukraine
<https://orcid.org/0000-0001-8880-9864>

Natalia Hrytsiuk

PhD in Agricultural Sciences, Associate Professor
Polissia National University
10008, 7 Staryi Blvd., Zhytomyr, Ukraine
<https://orcid.org/0000-0002-4185-7495>

Tetiana Alekseeva

PhD in Geography, Associate Professor
Regional College "Kremenchuk Anton Makarenko Humanitarian
and Technological Academy" of the Poltava Regional Council
39600, 33 Valentyny Fedko Str., Kremenchuk, Ukraine
<https://orcid.org/0000-0002-5671-7372>

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Abstract. Biodiversity loss is one of the global environmental issues facing humanity. Intensive use of natural resources has led to degradation of landscapes and reduction of the species diversity of plant communities. Therefore, finding natural solutions to overcome these challenges is an urgent issue. The purpose of the study was to investigate the dynamics of floral composition and coenotic structure of herbaceous plant communities in an organic cherry orchard for the sustainable functioning of the

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*Corresponding author

agricultural landscape. The dynamics of the coenotic composition of natural grasses of vegetation cover in the organic cherry orchard was studied during 2013–2020 in the arid conditions of the Southern Steppe of Ukraine on low-humus sandy loam soils. Morphological, ecological, and geographical methods were used to investigate the species diversity of flora in an organic garden. The composition of herbaceous plant communities was estimated using conventional geobotanic description methods. The results of the study of the species composition and coenotic structure of plant communities of grass cover in an organic sweet cherry orchard are presented. Grassing of the garden with natural grasses has led to the enrichment of agricultural landscapes with useful species that are important components of sustainable agricultural systems and can perform ecological services. Colonisation of the grass cover by invasive and quarantine species was not observed due to natural processes of demutation succession and the use of moderate four-fold mowing of plants during the growing season (to a height of 15–20 cm). As part of herbal plant communities in the 8th year of research, all species were useful, had medicinal properties, and served as a food base. The natural grasses in an organic sweet cherry orchard are a resource of biomass and biodiversity. Phytocoenotic analysis of the grass cover in the organic cherry orchard will allow substantiating and proposing principles for predicting the development of plant communities to optimise their structure, improve quality, and maintain biodiversity

Keywords: species composition; biodiversity; environmental services; grass cover; coenomorphs; secondary succession; natural restoration of agroecosystems

INTRODUCTION

The increased anthropogenic impact on natural ecosystems has led to a serious violation of the state of the environment, including a reduction in the area of territories occupied by ecosystems and being the habitat of biological species. A significant part of landscapes is rapidly degraded due to the intensive use of natural resources and economic activity. The scale of anthropogenic pollution is extremely large, so natural compensatory processes are not able to offset their harmful effect on the state and species diversity of plant communities and ecosystems in general. The international community has repeatedly stressed the need to take decisions to prevent the negative impact of human economic activity on biodiversity, which corresponds to the present.

Current trends in horticulture provide for the greening of this branch of agriculture. Greening horticulture involves the introduction of organic gardening. In order to protect the soil in organic gardens, “live mulch” is increasingly used – the soil should be covered with live plants, most often sown with cover crops (Mia *et al.*, 2021). However, the cultivation of cover crops requires additional financial investments, which may not be justified due to the low competitive ability of cultivated species against the local weed flora (Licznar-Małańczuk, 2020).

However, the use of the local weed flora itself as a live mulch can be useful for many reasons: firstly, to preserve the local authentic flora; secondly, natural grasses, due to their adaptability to local conditions, are able to form a dense cover for the soil (Oldfield *et al.*, 2019). This, in turn, helps to protect the soil surface from overheating in summer and freezing in winter, slow down the wind speed, and reduce the impact force of raindrops (protect the soil from deflation and dispersion). Grass not only slows down water erosion of the soil, but is also a nesting site for beneficial insects (Carvell *et al.*, 2022). The grass rhizosphere is a

habitat for numerous soil biota (including mycorrhizal fungi). The results of research have established that mycorrhizal fungi can enhance the adaptive properties of plants to stressors. The functioning of mycorrhizal symbioses in organic gardens improves the growth and development of plants, increases their yield, and ensures the sustainable development of agriculture and biodiversity conservation (Gerasko *et al.*, 2023).

Flowering natural grasses can attract pollinating insects to the garden (Antoine & Forrest, 2021; Mateos-Fierro *et al.*, 2021). The loss of habitat, in particular flower resources, is one of the main reasons for the decrease in the number of pollinating insects and their diversity in agricultural landscapes, and, as a result, makes entomophilic pollination of plants impossible. Pollinators can affect the stability, diversity, and functioning of plant communities. In agroecosystems, pollinators are able to provide ecosystem services, affect crop yields and product quality, which ensures sustainable development of agriculture and solving food security problems (Kowalska *et al.*, 2023). Since sweet cherries are recognised as a geographical brand in the south of Ukraine, the blooming grass cover in the organic garden of this crop can serve as a tourist magnet of the region. This will create new opportunities for the country's economic development, which is especially important for its recovery in the post-war period (Trusova *et al.*, 2020).

Despite all these advantages, using weeds as live mulch can be harmful due to the dominance of invasive, quarantine species. To install live mulch made from natural grasses, it is necessary to stop the black fallow regime. It is known that the cessation of tillage in abandoned areas (fallows) leads to secondary succession with a gradual restoration of authentic flora (Borovyk, 2020). The rate of achievement of the quasi-climatic state of the phytocoenosis depends

on many factors: soil and climatic conditions, the location of the site, anthropogenic activities (mowing, grazing), the seed bank of authentic species (Szirmai *et al.*, 2022). However, now there is practically no information about the course of succession processes of natural grasses as live mulch in the conditions of the Southern Steppe of Ukraine. In this regard, there is a need for further scientific research and comprehensive study to develop a strategy for harmonious sustainable agricultural development in the concept of biodiversity conservation.

The purpose of this study was to determine the dynamics of the coenotic composition of natural herbs in the organic cherry orchard during the eight years of live mulch existence in the Southern Steppe of Ukraine. From a practical standpoint, it was necessary to find out whether grassing the garden with natural herbs would lead to the enrichment of the phytocoenosis with useful species (capable of providing valuable environmental services), or, conversely, to colonisation by invasive, quarantine species, and whether it was possible to prevent the spread of invasive and quarantine species due to moderate mowing (to a height of 15-20 cm, 4 times during the growing season).

MATERIALS AND METHODS

The study was conducted during 2013-2020 in the Research Garden owned by the Tavria State Agrotechnological University (Zelene village, Melitopol district, Zaporizhzhia Oblast: 46°46'N, 35°17'E).

Characteristics of natural vegetation of the research area. Due to extensive ploughing, the natural authentic herbaceous and fescue vegetation remained on the slopes of the gullies, in some areas of watersheds, and near the forest edges. The most characteristic representatives of mixed grasses were the following: *Adonis vernalis* L., *Paeonia tenuifolia* L., *Filipendula vulgaris* Moench, *Fragaria viridis* Duschesne, *Plantago lanceolata* L., *Dianthus capitatus* Balb., *Salvia nutans* L., *Draba verna*, *Limonium sareptanum* (A.Becker) Gams, *Centaurea adpressa* Ledeb., etc. Of the cereals, the most common were the following: *Stipa capillata* L., *Stipa pennata* L., *Bromus erectus*, *Bromopsis inermis* (Leyss.) Holub, *Festuca*

valesiaca, *Elytrigia repens* (L.) Nevski, *Poa angustifolia* L. Of the legumes, the most common were the following: *Trifolium alpestre*, *Medicago minima* (L.) Bartalini and *Vicia angustifolia*.

Soil characteristics. According to the soil and ecological zoning of land resources of Ukraine, the territory of the research site belonged to the dry steppe zone, dry steppe subzone, winter-moderate-warm facies (frost period lasts 75-90 days, cold period precipitation is absorbed by 72%). Hydrothermal conditions of soil development were characterised by the arid first part of the growing season (hydrothermal index_{v-vi} = 0.64 - 0.73) and very dry conditions of the second part (hydrothermal index_{vii-ix} = 0.40 - 0.49) with moderate humidity during cold time (140-160 mm). The soil of the experimental site was chestnut saline, very low humus accumulation, heavy sandy loam, xeromorphic, superficially saline, lithological series – ancient alluvial. Ground water was below 3 m. The reaction of the soil solution was slightly alkaline (pH = 7.1 - 7.4). The humus content in the upper horizon of the soil of light particle size distribution was only 0.6%. No mineral nitrogen was detected, content of P₂O₅ was 5.4; K₂O – 6.5 mg/kg of soil. There was no salinity with water-soluble salts – the total content of water-soluble salts in the water extract did not exceed 0.015-0.024%. No easily soluble neutral salts (magnesium, sodium chloride, sulphates, calcium) were found in the soil in amounts that cause toxic effects on tree growth and development. A high specific gravity of sodium up to 3.5% of the total absorbed bases indicates salinity of the soil. Despite the poor soil composition, sweet cherries have been successfully grown in this region since the 19th century and have excellent fruit quality on such sandy loam soils. The light granulometric composition of the soil, due to its high thermal conductivity, contributes to the early harvesting of products compared to plantations on heavy soils.

Weather conditions. Analysing weather conditions over the years of research (Tables 1 and 2), a trend towards climate warming can be stated, since the average annual air temperature was 0.8-1.6°C higher than the normal annual average rate.

Table 1. Average air temperature in the research area, °C (according to the nearest weather station – Melitopol city)

Month	Years of research								Standard precipitation rate
	2013	2014	2015	2016	2017	2018	2019	2020	
January	63.2	55.9	42.1	60.0	45.9	53.4	52.4	11.3	44.0
February	9.8	7.3	32.1	42.1	29.0	47.8	11.1	101.8	34.4
March	45.8	10.2	80.7	25.6	13.3	70.1	37.9	6.4	35.7
April	9.2	48.6	64.3	30.7	60.7	5.5	49.4	9.9	34.4
May	32.3	65.3	23.9	84.6	12.7	22.4	96.2	78.4	46.5
June	58.1	102.3	62.2	28.2	41.8	32.4	14.4	55.2	54.0
July	23.6	27.1	52.2	34.3	60.0	80.1	42.1	48.5	44.2
August	6.4	17.0	0.9	17.8	42.4	6.1	55.1	21.1	34.8
September	22.1	104.1	0.5	61.4	51.4	80.7	13.2	19.4	39.5
October	79.4	15.5	17.3	25.4	33.7	18.1	18.7	20.5	32.5

Table 1. Continued

Month	Years of research								Standard precipitation rate
	2013	2014	2015	2016	2017	2018	2019	2020	
November	13.8	18.8	71.1	38.7	18.0	36.8	19.5	16.0	37.8
December	7.4	69.9	12.0	26.1	18.5	74.3	31.7	29.1	42.8
Per year	370.1	542.0	459.3	474.9	427.4	527.7	441.7	417.6	480.6

Source: compiled by the authors

The annual amount of precipitation did not significantly differ from the long-term average, with the exception of an abnormally dry 2013, when precipitation was 23% lower. However, 2014 was quite wet for the Melitopol district – precipitation fell by 13% more than the long-term average norm. Winter conditions for all the years of research were favourable for natural grasses, since the air temperature, for the most part, was higher than the long-term average norm. In March, when the average daily air temperature rises above +5°C, perennial and winter natural grasses resume vegetation, seeds of early spring species

germinate. During the research period, the average monthly air temperature in March was significantly higher than the long-term average norm, with the exception of 2018, when March was cold. The temperature conditions of April during all the years of research were also favourable for grass growth. The summer months during the study period were hot. Particularly severe heat and drought continued in June 2019, when the average monthly air temperature was 4.1°C higher than the annual average, while the amount of precipitation for the month was only 27% of the long-term average norm.

Table 2. Total precipitation, mm (according to the nearest weather station – Melitopol city)

Month	Years of research								Standard precipitation rate
	2013	2014	2015	2016	2017	2018	2019	2020	
January	0.4	-1.6	-1.0	-3.0	-2.8	-0.7	-0.3	0.9	-1.9
February	2.5	0.1	1.0	3.8	-0.9	-0.3	1.0	2.2	-1.4
March	3.4	6.6	5.4	6.1	6.8	1.6	3.8	7.8	3.1
April	12.3	11.2	9.5	12.9	8.9	13.4	11.4	9.4	10.4
May	20.8	18.7	17.1	16.4	16.4	19.8	18.3	15.1	16.8
June	23.1	20.7	21.9	22.6	22.1	23.4	25.3	22.8	21.2
July	24.0	25.0	23.7	24.8	23.6	24.8	23.1	25.0	23.7
August	25.2	24.8	25.2	25.8	26.4	25.8	23.6	23.4	23.2
September	14.9	18.5	21.7	17.3	20.1	18.7	17.9	20.5	17.2
October	8.8	9.5	9.1	8.5	10.7	13.3	1.8	15.0	10.4
November	6.6	2.7	6.7	3.8	5.2	2.9	6.3	4.7	4.0
December	-0.4	0.1	2.2	-2.1	5.2	0.5	3.7	0.1	-0.1
Per year	11.8	11.4	11.9	11.4	11.8	11.9	12.2	12.2	10.6

Source: compiled by the authors

In terms of precipitation in March, the most favourable conditions for the germination of early spring species and the resumption of vegetation of winter and perennial species developed in 2013 and 2015. However, the following months of the growing season in 2013 were dry. In 2015, May was dry, and the severe drought lasted from August to December of that year. March 2018 was wet (precipitation was 196% of the annual average), but, as mentioned above, very cold. After the abnormally cold March 2018 for the Melitopol district, an abnormally dry April came (the amount of precipitation was 16% of the annual average). May and June of that year were also dry, which, respectively, affected the amount of terrestrial biomass of live mulch. In addition to 2018, 2016 and 2020 were unfavourable for the development of a dense stand of grasses – due to the drought that

lasted during the two most important months for the development of grasses – March and April.

Description of the experimental site. The total area of the experimental plot of organic sweet cherries was 1.7 hectares. In 2011, the sweet cherry (*Prunus avium* L.) varieties Dilema and Valery Chkalov were planted on this territory. These two varieties are grafted on an extensive tall rootstock – mahaleb cherry (*Prunus mahaleb*). Scheme of planting cherry trees – 7×5 m. The shape of the crown of trees is a slender columnella. Since 2013, the experimental plot of the orchard with an area of 0.9 hectares was kept under plant mulch (spontaneous vegetation cover). Vegetation was mowed 4 times during the growing season, and the mown mass was left on the soil surface. The rest of the plot area was kept under black fallow, and then – under the sowing of medicinal plants. During the care

of black fallow, standard mechanical cultivation, one disking to a depth of 15 cm, and manual weeding during the growing season were carried out. Chemical protection of plants and application of mineral fertilisers were absent. On all sides, the site of organic sweet cherries was surrounded by field roads (4-6 m wide), which border the old forest belts on the east, north, and west (10-12 m wide, the trees were about 60 years old), and on the south side – with a field of grain crops.

Basic elements of accounting and observations.

Species composition of grass cover plants; ecomorphs of species; abundance and occurrence of species in the experimental site; general aboveground phytomass of plant mulch; general projective soil cover with herbaceous plant communities. The species composition of the herbaceous plant communities was determined according to the generally accepted methods of studying the flora of vascular plants using keywords, atlases and reference books (Prokudin & Dobrochaieva, 1999; Lebeda, 2009; Lebeda, 2011; Mashkovska, 2015). Latin names of species were specified according to the nomenclature list of vascular plants of Ukraine (Mosyakin & Fedorochuk, 1999). Ecological certification of plant species was carried out based on the ecomorph classification (Tarasov, 2012; Baranovskij *et al.*, 2017). The abundance of plant species in live mulch was determined by counting the number of plant specimens of each species (in rhizomatous plants – the number of shoots) on temporary accounting plots with an area of 1 m² in a 6-time repetition with a random location on the experimental site of an organic garden (Abduloieva & Solomaha, 2011).

Occurrence of species was determined by the equation (1):

$$F = S_2/S_1 \times 100, \quad (1)$$

where F – occurrence, %; S₁ – number of accounting plots (in this study S₁ = 10); S₂ – number of sections where this species is present.

Common aboveground phytomass of plant mulch was determined 3 times during the growing season (May, July, and September) using the method of mowing to the ground level. The area of the accounting plot was 1 m². The repetition was 10 times with a random location of an organic cherry orchard on the experimental plot. The mown fresh mass was weighed, after which control samples were taken (in 3-time biological repetition), which were also weighed and dried to an air-dry state in a thermostat at a temperature of 105°C. Total dry phytomass of plant mulch (g/m²) was calculated considering the moisture content in fresh phytomass. The weight for three mows was summed up and taken as the value of the total aboveground dry phytomass for the growing season (g/m²). General projective soil coverage with herbaceous plant groups was determined visually using a 1×1 m grid with a 10×10 cm window. The grid was kept at the level of the grass stand, the grass cover on the accounting plot was considered (there were 10 accounting plots in total) and the number of grid cells accounted for plants and the soil surface free of plants was determined. Then they were recalculated in % of the soil surface. Determination was carried out 3 times during the growing season (May, July, and September), after which the average value of the total projective grass cover of the soil for the growing season was calculated (Abduloieva & Solomakha, 2011). Statistical analysis was performed using a general linear model using Minitab 19 software suite (Minitab Inc., State College, PA).

RESULTS

Anthropogenic human impact on natural ecosystems leads to impoverishment of biodiversity and degradation of landscapes. Discontinuation of tillage under such circumstances leads to colonisation of sites by invasive and adventitious species, which is confirmed by the experimental data obtained (Table 3).

Table 3. Bioecological characteristics of grass cover plant species in an organic sweet cherry orchard

Plant families and species	Climamorphs	Biomorphs	Heliomorphs	Trophomorphs	Hygromorphs	Coenomorphs	Adventitious species
Amaranthaceae							
<i>Amaranthus blitoides</i> S.Wats.	T*	Ann	He	MsTr	MsX	Ru	+ I
<i>Amaranthus retroflexus</i> L.	T	Ann	He	MsTr	MsX	Ru	+ I
Apiaceae							
<i>Daucus carota</i> L.	THKr	Per	ScHe	OgMgTr	XMs	Ru	
<i>Eryngium campestre</i> L.	G	Per	He	MsTr	X	St	
Asteraceae							
<i>Achillea micrantha</i> Willd	HKr	Per	ScHe	OgTr	MsX	Sil Ps	
<i>Achillea millefolium</i> L.	HKr	Per	He	MgTr	XMs	Ru St	
<i>Ambrosia artemisifolia</i> L.	T	Ann	ScHe	OgMgTr	X	Ru	+ IQ
<i>Anthemis arvensis</i> L.	T	Ann	He	MsTr	MsX	Ru St	

Table 3. Continued

Plant families and species	Climamorphs	Biomorphs	Heliomorphs	Trophomorphs	Hygromorphs	Coenomorphs	Adventitious species
<i>Crepis tectorum</i> L.	THKr	Bien	He	OgMsTr	MsX	Ps St Ru	
<i>Hieracium umbellatum</i> L.	HKr	Per	ScHe	OgTr	MsX	St Ps	
<i>Lactuca serriola</i> Torner	THKr	Ann Bien	ScHe	MsTr	XMs	Sil Ru	+
<i>Senecio vernalis</i> Waldst. et Kit.	T	Ann	ScHe	OgMgTr	XMs	Ru	
<i>Taraxacum officinale</i>	HKr	Per	ScHe	MsTr	Ms	Ru Pr	
<i>Tragopogon dubius</i> Scop.	HKr	Bien	He	MsTr	MsX	Ru St	
Boraginaceae							
<i>Cynoglossum officinale</i> L.	HKr	Bien	He	MgMsTr	MsX	Pr Ru	+
<i>Echium vulgare</i> L.	HKr	Bien	He	MsTr	X	Ps St Ru	
<i>Lycopsis arvensis</i> L.	HKr	Per	ScHe	MsTr	MsX	Ru Pt	
Brassicaceae							
<i>Arabidopsis thaliana</i> (L.) Heynh.	HKr	Ann Bien	He	OgTr	XMs	Ps Ru	+
<i>Barbarea vulgaris</i> R.Br.	HKr	Bien Ann	ScHe	MgMsTr	Ms	Pr Ru	
<i>Capsella bursa-pastoris</i> (L.)	T	Ann	He	MsTr	XMs	Ru	+I
<i>Descurainia Sophia</i> L.	T	Ann	He	MsTr	XMs	Ru	+
<i>Lepidium campestre</i>	THKr	Ann Bien	ScHe	MsTr	XMs	Ru	
Caryophyllaceae							
<i>Melandrium album</i> (Mill.) Garcke	HKr	Bien	ScHe	MsTr	MsX	Ru SMn Pr	
Chenopodiaceae							
<i>Chenopodium album</i> L.	T	Ann	ScHe	MsTr	MsX	Ru	
<i>Chenopodium polyspermum</i> L.	T	Ann	ScHe	MsTr	MsX	Ru	
Convolvulaceae							
<i>Convolvulus arvensis</i> L.	G	Per	ScHe	MsTr	MsX	Ru	
Cuscutaceae							
<i>Cuscuta campestris</i> Junk.	T	Ann	He	Par	Ms	Pr Ru	+Q
Dipsacaceae							
<i>Scabiosa ochroleuca</i> L.	HKr	Per	ScHe	MsTr	MsX	Ps Pr St	
Euphorbiaceae							
<i>Euphorbia stepposa</i> Zoz.	HKr	Per	He	MgTr	X	Ru Cr Pt St	
Fabaceae							
<i>Lotus Ucrainicus</i> Klok.	HKr	Per	He	MgTr	XMs	St Pr	
<i>Trifolium arvense</i> L.	T	Ann	He	MsTr	MsX	Ru Ps St	
<i>Vicia villosa</i> Routh	HKr	Ann Bien	ScHe	MgTr	XMs	Ru SMn Pr	+I
Fumariaceae							
<i>Fumaria officinalis</i> L.	T	Ann	He	MsTr	XMs	Ru	+
Papaveraceae							
<i>Papaver rhoeas</i> L.	HKr	Per	ScHe	MsTr	Ms X	Pt St Ru	+
Plantaginaceae							
<i>Plantago lanceolata</i> L.	HKr	Per	He	MsTr	XMs	Pr St SMn Ru	
Poaceae							
<i>Agropyron pectinatum</i> (Bieb.) Beauv	HKr	Per	He	Ms Tr	X	St	
<i>Agrostis capillaris</i> L.	HKr	Per	ScHe	OgTr	Ms	Sil Pr	
<i>Anisantha sterilis</i> (L.)	T	Ann	ScHe	MsTr	MsX	Pr St Ru	+
<i>Anisantha tectorum</i> (L.)	T	Ann	ScHe	OgMgTr	MsX	Ps Ru	+
<i>Apera spica - venti</i> (L.) Beauv.	T	Ann	ScHe	OgTr	XMs	Ru Ps	+
<i>Avena fatua</i> L.	T	Ann	He	MsTr	MsX	Ru	+
<i>Bromopsis inermis</i> (Leys.) Holub	G	Per	He	OgMgTr	XMs	Ru Pr St	
<i>Bromus arvensis</i> L.	T	Ann	He	MsTr	XMs	Ru	+
<i>Bromus squarrosus</i> L.	T	Ann Bien	ScHe	OgMgTr	MsX	Ru Ps St	+
<i>Cynodon dactylon</i> (L.) Pers.	HKr	Per	He	MsTr	XMs	HalPr	+
<i>Elytrigia repens</i> (L.) Nevski	G	Per	ScHe	MsTr	Ms	Sil St Pr Ru	
<i>Poa angustifolia</i> L.	HKr	Per	ScHe	MgMsTr	MsX	Sil Pr St	
<i>Poa pratensis</i> L.	G	Per	He	MsTr	Ms	Pr	

Table 3. Continued

Plant families and species	Climamorphs	Biomorphs	Heliomorphs	Trophomorphs	Hygromorphs	Coenomorphs	Adventitious species
<i>Puccinella distans</i> (Jac q.) Parl.	HK r	Per	He	MsTr	XMs	Ru Hal Pr	
<i>Setaria glauca</i> (L.) Beauv.	T	Ann	He	MsTr	XMs	Ps Ru	+
Portulacaceae							
<i>Portulaca oleracea</i> L.	T	Ann	ScHe	MsTr	XMs	Ru	+
Ranunculaceae							
<i>Delphinium consolida</i>	T	Ann	ScHe	MsTr	MsX	SMn Ru	+
Scrophulariaceae							
<i>Verbascum phlomoides</i>	HKr	Bien	He	OgMsTr	MsX	St Ru	
Zygophyllaceae							
<i>Tribulus terrestris</i> L.	T	Ann	He	MsOgTr	MsX	Ps Ru	+

Note: Abbreviations for Table 3: Climamorphs: HKr – hemicryptophyte; G – geophyte; Kr – cryptophyte; T – therophyte. Biomorphs: Ann (Annuus) – annual species; Bien (Biennis) – biennial species; Per (Perennis) – perennial species. Heliomorphs: He (Heliophiton) – heliophyte; ScHe – partially demanding of light. Trophomorphs: OgTr (Oligotroph) – oligotroph; MsTr (Mesotroph) – mesotroph; MgTr (Megatroph) – megatroph. Hygromorphs: Ms (Mesophiton) – mesophyte (a plant of medium-moist habitats); X (Xerophiton) – xerophyte (plant of dry habitats). Coenomorphs: Pr (Pratensis) – pratensis (Meadow plant); Sil (Silvaticus) – silvanthus (forest landscape species); St (Stepposus) – stepanthus (steppe plant); SMn (Margosilvaticus) – silvomargoant (edge plant); Ps (Psammophyton) – psammophantus (sandy soil plant); Pt (Petrophyton) – petrant (plant of stony soils); Ru (Ruderatus) – ruderant (weed); Hal (Halophyton) – halophant (a species of saline soils and reservoirs with high mineralisation); Par (Parasitus) – parasite; I – invasive species; Q – quarantine species.

Source: compiled by the authors

It has been established that the species composition of grass cover plants in an organic sweet cherry orchard includes representatives of 21 families. The most numerous families were Poaceae (15 species) and Asteraceae (10 species). The Brassicaceae family is represented by 5 species; Boraginaceae and Fabaceae – 3 species each; Amaranthaceae, Apiaceae, and Chenopodiaceae –

2 species each. Other families – Caryophyllaceae Convolvulaceae, Cuscutaceae, Dipsacaceae, Euphorbiaceae, Euphorbiaceae, Fumariaceae, Papaveraceae, Plantaginaceae, Portulacaceae, Ranunculaceae, Scrophulariaceae, Zygophyllaceae – are represented by one species. However, the abundance of species varied both within the family and over the years of research (Table 4).

Table 4. Abundance of herbaceous plant species in an organic sweet cherry orchard

Plant families and species	Years of research							
	2013	2014	2015	2016	2017	2018	2019	2020
Amaranthaceae								
<i>Amaranthus blitoides</i> S. Wats.	Sol	Cop	Cop	Sp	Sp	Sol	Sol	Sol
<i>Amaranthus retroflexus</i> L.	Sol	Cop	Cop	Sp	Sol	-	-	-
Apiaceae								
<i>Daucus carota</i> L.	-	-	-	Sol	Sol	Sol	Sol	Sol
<i>Eryngium campestre</i> L.	-	-	-	-	Sol	Sol	Sol	Sol
Asteraceae								
<i>Achillea micrantha</i> Willd	-	-	-	-	-	Sol	Sol	Sol
<i>Achillea millefolium</i> L.	-	-	-	Sp	Cop	Cop	Sol	Sp
<i>Ambrosia artemisifolia</i> L.	Sol	Cop	Cop	Sp	Sol	-	-	-
<i>Anthemis arvensis</i> L.	-	Sp	Cop	Cop	Cop	Cop	Sp	Sp
<i>Crepis tectorum</i> L.	-	Sp	Sp	Sp	Sp	Sp	Sol	Sol
<i>Hieracium umbellatum</i> L.	-	Sp	Sp	Sp	Sp	Sp	Sol	Sol
<i>Lactuca serriola</i> Torner	Sol	Cop	Cop	Sp	Sol	-	-	-
<i>Senecio vernalis</i> Waldst. et Kit.	Sp	Sp	Cop	Cop	Cop	Cop	Sp	Sp
<i>Taraxacum officinale</i>	-	Sp	Sp	Sp	Sp	Sp	Sp	Sp
<i>Tragopogon dubius</i> Scop.	-	-	-	Sol	Sol	Sol	-	-

Table 4. Continued

Plant families and species	Years of research							
	2013	2014	2015	2016	2017	2018	2019	2020
Boraginaceae								
<i>Cynoglossum officinale</i> L.	-	-	-	Sol	Sol	Sol	Sol	Sol
<i>Echium vulgare</i> L.	-	-	Sol	Sol	Sol	Sol	Sol	Sol
<i>Lycopsis arvensis</i> L.	-	-	Sol	Sol	Sol	Sol	Sol	Sol
Brassicaceae								
<i>Arabidopsis thaliana</i> (L.) Heynh.	Sp	Sp	Sp	Sp	Sol	Sol	-	-
<i>Barbarea vulgaris</i> R.Br.	Sp	Sp	Sp	Sp	Sp	Sol	Sol	-
<i>Capsella bursa-pastoris</i> (L.)	Sp	Sp	Sp	Sp	Sp	Sp	Sp	Sp
<i>Descurainia Sophia</i> L.	-	Sp	Sp	Sp	Sp	Sp	Sp	Sp
<i>Lepidium campestre</i>	-	-	Sp	Sp	Sol	Sol	-	-
Caryophyllaceae								
<i>Melandrium album</i> (Mill.) Garcke	-	-	-	Sol	Sol	Sol	-	-
Chenopodiaceae								
<i>Chenopodium album</i> L.	Sol	Cop	Cop	Sp	Sol	-	-	-
<i>Chenopodium polyspermum</i> L.	Sol	Cop	Cop	Sp	Sp	-	-	-
Convolvulaceae								
<i>Convolvulus arvensis</i> L.	Sol	Sp	Sp	Sol	Sol	Sol	Sol	Sol
Cuscutaceae								
<i>Cuscuta campestris</i> Junk.	-	-	Sol	Sol	-	-	-	-
Dipsacaceae								
<i>Scabiosa ochroleuca</i> L.	-	-	-	Sol	Sol	Sol	Sol	Sol
Euphorbiaceae								
<i>Euphorbia stepposa</i> Zoz.	-	Sol	Sol	Sol	Sol	Sol	Sol	Sol
Fabaceae								
<i>Lotus Ucrainicus</i> Klok.	-	Sol	Sol	Sol	Sol	-	-	-
<i>Trifolium arvense</i> L.	-	Sol	Sp	Sp	Sp	Sp	Sp	Sp
<i>Vicia villosa</i> Routh	Sol	Sp	Sp	Sp	Sp	Sp	Sp	Sp
Fumariaceae								
<i>Fumaria officinalis</i> L.	-	Sol	Sol	Sol	Sol	Sol	-	-
Papaveraceae								
<i>Papaver rhoeas</i> L.	-	Sp	Sp	Sp	Sp	Sp	Sp	Sol
Plantaginaceae								
<i>Plantago lanceolata</i> L.	-	Sol	Sol	Sol	Sol	Sol	Sol	Sol
Poaceae								
<i>Agropyron pectinatum</i> (Bieb.) Beauv	-	-	-	-	-	Sol	Sol	Sp
<i>Agrostis capillaris</i> L.	-	-	-	Sp	Sp	Sp	Sp	Sp
<i>Anisantha sterilis</i> (L.)	Sp	Sp	Sp	Sp	Sp	-	-	-
<i>Anisantha tectorum</i> (L.)	-	Sp	Sp	Sp	Sp	Sp	-	-
<i>Apera spica-venti</i> (L.) Beauv.	-	Sp	Sp	Sp	Sp	Sp	Sp	Sp
<i>Avena fatua</i> L.	-	Cop	Cop	Soc	Soc	Sp	Sp	Sp
<i>Bromopsis inermis</i> (Leys.) Holub	-	-	-	Sp	Sp	Sp	Sp	Sp
<i>Bromus arvensis</i> L.	-	Sp	Sp	Sp	Sp	Sp	Sp	Sp
<i>Bromus squarrosus</i> L.	-	Sp	Sp	Sp	Sp	Sp	-	-
<i>Cynodon dactylon</i> (L.) Pers.	-	-	-	Sp	Sp	Sp	Sp	Sp
<i>Elytrigia repens</i> (L.) Nevski	Sol	Sp	Sp	Cop	Cop	Soc	Soc	Soc
<i>Poa angustifolia</i> L.	-	Sp	Sp	Sp	Sp	Sp	Sp	Sp
<i>Poa pratensis</i> L.	-	Sp	Sp	Sp	Sp	Sp	-	-
<i>Puccinella distans</i> (Jac q.) Parl.	-	-	-	Sp	Sp	Sp	Sp	Sp
<i>Setaria glauca</i> (L.) Beauv.	Sol	Sp	Sp	Sp	Sp	-	-	-
Portulacaceae								
<i>Portulaca oleracea</i> L.	Cop	Sp	Sp	Sol	-	-	-	-

Table 4. Continued

Plant families and species	Years of research							
	2013	2014	2015	2016	2017	2018	2019	2020
Ranunculaceae								
<i>Delphinium consolida</i>	-	-	Sol	Sol	Sol	Sol	Sol	-
Scrophulariaceae								
<i>Verbascum phlomoides</i>	-	-	Sol	Sol	Sol	Sol	Sol	-
Zygophyllaceae								
<i>Tribulus terrestris</i> L.	Sol	Sol	-	-	-	-	-	-

Note: Soc (*Socialis*) – number of plants 100 units/m²; Cop (*Copiosus*) – number of plants from 10 to 100 units/m²; Sp (*Sparsus*) – number of plants ≤10 units/m²; Sol (*Solitarius*) – number of plants from 10 to 100 units/ha

Source: compiled by the authors

Thus, in the first year of research, after stopping soil retention in the black fallow mode, natural grasses did not create a dense cover in the garden. The study areas were dominated by *Portulaca oleracea* L. In the 2nd year, it was replaced by such species as *Amaranthus blitoides* S. Wats., *Amaranthus retroflexus* L., *Ambrosia artemisiifolia* L., *Lactuca serriola* Torner, *Chenopodium album* L., *Chenopodium polyspermum* L., *Avena fatua* L. In the 3rd year of research, these species remained abundant at the experimental site. Two other species were also identified: *Anthemis arvensis* L. and *Senecio vernalis* Waldst. et Kit. In the 3rd year of research, the parasitic plant *Cuscuta campestris* Junk. was found in the vegetation. This species was present in grass cover also next year, despite systematic deletion (manually). In the fourth year, there was a decrease in the abundance of the following

species: *Amaranthus blitoides* S. Wats., *Amaranthus retroflexus* L., *Ambrosia artemisiifolia* L., *Lactuca serriola* Torner, *Chenopodium album* L., *Chenopodium polyspermum* L. At the same time, the abundance of *Elytrigia repens* (L.) Nevski and, especially, *Avena fatua* L. also increased. In the 5th year of research, the highest abundance rates were characterised by *Avena fatua* L., *Elytrigia repens* (L.) Nevski, *Senecio vernalis* Waldst. et Kit., *Anthemis arvensis* L., *Achillea millefolium* L. In the sixth year, abundance of *Avena fatua* L. decreased, and *Elytrigia repens* (L.) Nevski on the contrary increased. In the 7th or 8th year of research, *Elytrigia repens* (L.) Nevski was more abundant than the rest of the plant species in the experimental area. In addition to the abundance, an important indicator is also the occurrence of species at the experimental site, which is presented in Table 5.

Table 5. Occurrence of herbaceous plant species in an organic sweet cherry orchard, %

Plant species within families	Years of research							
	2013	2014	2015	2016	2017	2018	2019	2020
Amaranthaceae								
<i>Amaranthus blitoides</i> S. Wats.	20	80	70	30	20	10	10	10
<i>Amaranthus retroflexus</i> L.	30	90	80	40	20	-	-	-
Apiaceae								
<i>Daucus carota</i> L.	-	-	-	10	10	20	10	10
<i>Eryngium campestre</i> L.	-	-	-	-	10	10	10	10
Asteraceae								
<i>Achillea micrantha</i> Willd	-	-	-	-	-	10	10	10
<i>Achillea millefolium</i> L.	-	-	-	20	30	30	30	20
<i>Ambrosia artemisiifolia</i> L.	30	100	90	60	30	-	-	-
<i>Anthemis arvensis</i> L.	-	50	100	100	100	80	60	30
<i>Crepis tectorum</i> L.	-	60	70	60	50	40	20	10
<i>Hieracium umbellatum</i> L.	-	40	30	30	40	20	10	10
<i>Lactuca serriola</i> Torner	10	30	30	20	10	-	-	-
<i>Senecio vernalis</i> Waldst. et Kit.	60	40	50	60	40	40	10	10
<i>Taraxacum officinale</i>	-	10	40	50	50	50	50	40
<i>Tragopogon dubius</i> Scop.	-	-	-	10	10	10	-	-
Boraginaceae								
<i>Cynoglossum officinale</i> L.	-	-	-	10	10	10	10	10
<i>Echium vulgare</i> L.	-	-	10	10	20	10	10	10
<i>Lycopsis arvensis</i> L.	-	-	10	20	20	10	10	10
Brassicaceae								
<i>Arabidopsis thaliana</i> (L.) Heynh.	80	90	100	100	60	50	-	-

Table 5. Continued

Plant species within families	Years of research							
	2013	2014	2015	2016	2017	2018	2019	2020
<i>Barbarea vulgaris</i> R.Br.	40	30	30	30	20	10	10	-
<i>Capsella bursa-pastoris</i> (L.)	100	100	100	100	100	70	60	50
<i>Descurainia Sophia</i> L.	-	100	100	100	100	100	70	30
<i>Lepidium campestre</i>	-	-	30	30	20	20	-	-
Caryophyllaceae								
<i>Melandrium album</i> (Mill.) Garcke	-	-	-	30	30	20	-	-
Chenopodiaceae								
<i>Chenopodium album</i> L.	30	100	100	40	30	-	-	-
<i>Chenopodium polyspermum</i> L.	20	60	50	30	20	-	-	-
Convolvulaceae								
<i>Convolvulus arvensis</i> L.	100	100	100	100	100	100	100	100
Cuscutaceae								
<i>Cuscuta campestris</i> Junk.	-	-	30	30	-	-	-	-
Dipsacaceae								
<i>Scabiosa ochroleuca</i> L.	-	-	-	10	10	10	10	10
Euphorbiaceae								
<i>Euphorbia stepposa</i> Zoz.	-	30	30	30	10	10	10	10
Fabaceae								
<i>Lotus Ucrainicus</i> Klok.	-	20	20	20	20	-	-	-
<i>Trifolium arvense</i> L.	-	30	50	60	60	60	100	100
<i>Vicia villosa</i> Routh	100	100	100	100	100	100	80	60
Fumariaceae								
<i>Fumaria officinalis</i> L.	-	100	100	100	80	70	-	-
Papaveraceae								
<i>Papaver rhoeas</i> L.	-	50	100	100	100	40	20	10
Plantaginaceae								
<i>Plantago lanceolata</i> L.	-	10	10	10	10	10	10	10
Poaceae								
<i>Agropyron pectinatum</i> (Bieb.) Beauv	-	-	-	-	-	50	80	80
<i>Agrostis capillaris</i> L.	-	-	-	50	50	60	60	60
<i>Anisantha sterilis</i> (L.)	30	30	40	40	40	-	-	-
<i>Anisantha tectorum</i> (L.)	-	40	50	50	40	30	-	-
<i>Apera spica-venti</i> (L.) Beauv.	-	30	40	50	50	30	30	30
<i>Avena fatua</i> L.	-	30	60	60	60	50	30	30
<i>Bromopsis inermis</i> (Leys.) Holub	-	-	-	30	50	60	60	60
<i>Bromus arvensis</i> L.	-	60	70	40	40	30	20	10
<i>Bromus squarrosus</i> L.	-	40	40	50	30	10	-	-
<i>Cynodon dactylon</i> (L.) Pers.	-	-	-	40	50	60	70	70
<i>Elytrigia repens</i> (L.) Nevski	100	100	100	100	100	100	100	100
<i>Poa angustifolia</i> L.	-	30	50	50	60	60	60	60
<i>Poa pratensis</i> L.	-	20	40	40	50	30	-	-
<i>Puccinella distans</i> (Jac q.) Parl.	-	-	-	30	50	60	70	100
<i>Setaria glauca</i> (L.) Beauv.	100	100	80	50	50	-	-	-
Portulacaceae								
<i>Portulaca oleracea</i> L.	100	60	40	30	-	-	-	-
Ranunculaceae								
<i>Delphinium consolida</i>	-	-	10	10	10	20	10	-
Scrophulariaceae								
<i>Verbascum phlomoides</i>	-	-	10	30	30	10	10	-
Zygophyllaceae								
<i>Tribulus terrestris</i> L.	30	10	-	-	-	-	-	-

Source: compiled by the authors

As a result of studying the occurrence of plant species in the organic garden, it was established that in the 1st year of research a high value of this indicator was characteristic of *Capsella bursa-pastoris* (L.), *Convolvulus arvensis* L., *Vicia villosa* Routh, *Elytrigia repens* (L.) Nevski, *Setaria glauca* (L.) Beauv. and *Portulaca oleracea* L. In the 2nd year of research, *Ambrosia artemisifolia* L., *Descurainia Sophia* L., *Chenopodium album* L., *Fumaria officinalis* L. also had a high occurrence. It should be noted that the occurrence of *Ambrosia artemisifolia* L. reached its maximum in the 2nd year after the termination of the black fallow regime, then gradually decreased, and in the 6th year this plant disappeared from the experimental site. The occurrence of *Anthemis arvensis* L. was high (100%) in years 3-5 of the study, and decreased in subsequent years. *Capsella bursa-pastoris* (L.) had a high (100%) occurrence in the first five years, and in subsequent years it decreased. *Descurainia Sophia* L. was 100% encountered from the 2nd to 6th year of research. *Chenopodium album* L. had a high occurrence (100%) only in the 2nd and 3rd years of research, and from the 6th year this plant disappeared from the experimental site. *Vicia villosa* Routh had a high occurrence (100%) in the first 6 years. *Fumaria officinalis* L. had the highest incidence within 2-4 years. *Papaver rhoeas* L. had a high occurrence value during 3-5 years of research. *Convolvulus arvensis* L. and *Elytrigia repens* (L.) Nevski had the highest occurrence during all the years of research.

Thus, as of the 8th year of the grass cover's existence on the experimental site in the organic cherry orchard (2020), it was possible to state the stage of segetal and ruderal species. The number of species was dominated by families *Poaceae* (10 species) and *Asteraceae* (7 species). Family *Boraginaceae* was represented by 3 species, *Apiaceae*, *Brassicaceae*, and *Fabaceae* – 2 types each, *Amaranthaceae*, *Convolvulaceae*, *Dipsacaceae*, *Euphorbiaceae*, *Papaveraceae* and *Plantaginaceae* – 1 type each. Control of invasive species in the herbal plant communities was achieved due to moderate application of mowing (4 times during the growing season). Due to this event, it was possible to get rid of the presence of such species as *Amaranthus retroflexus* L., *Ambrosia artemisifolia* L., *Lactuca serriola* Torner, *Tragopogon dubius* Scop., *Arabidopsis thaliana* (L.) Heynh., *Barbarea vulgaris* R.Br., *Lepidium campestre*, *Melandrium album* (Mill.) Garcke, *Chenopodium album* L., *Chenopodium polyspermum* L. Parasitic species *Cuscuta campestris* Junk. during the growing seasons of 2014 and 2015, was removed from the site by hand and burned outside the site, which helped to get rid of this quarantine plant.

As part of herbaceous plant communities, the total number of plant species that were determined in the course of research was 55 species (Tables 3, 4, and 5). However, the number of species present at the experimental site varied over the years (Fig. 1).

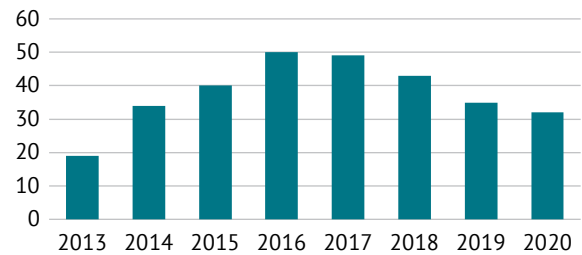


Figure 1. Number of plant species in the composition of grass cover in the organic cherry orchard

Source: compiled by the authors

In the first year of research, only 19 plant species were identified, in the next three years the number of species increased and in 2016 it was 50 species. In the future, the number of species tended to decrease and in 2020 amounted to 32 species. That is, starting from the 5th year of research, the species composition of plants of herbaceous plant communities gradually simplified. In the 1st year of research, the composition of herbaceous plant communities was dominated by therophytes, i.e., annuals that are restored from seed (Tables 4 and 5, Fig. 2 and 3).

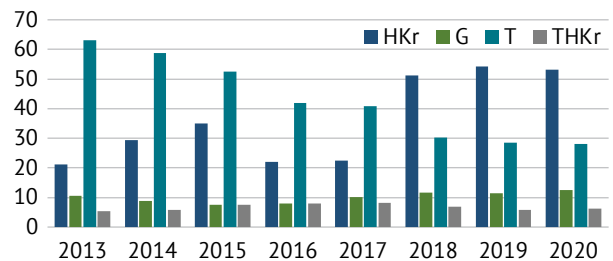


Figure 2. Climamorphs of species in the composition of grass cover in the organic cherry orchard, % of the total number of species

Note: *HKr – hemicryptophyte; Kr – cryptophyte; G – geophyte; T – therophyte

Source: compiled by the authors

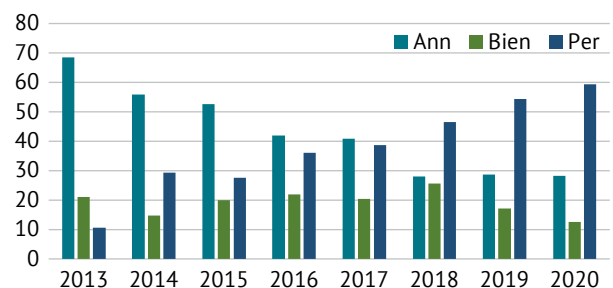


Figure 3. Biomorphs of species in the composition grass cover in the organic cherry orchard, % of the total number of species

Note: *Ann (Annuus) – annual plant; Bien (Biennis) – biennial plant; Per (Perennis) – perennial plant

Source: compiled by the authors

In the following years, the number of therophytes steadily decreased (from 68 to 28%), and the number of hemicryptophytes (herbaceous perennials) – gradually increased. In 2020 (on the 8th year of research), the number of herbaceous perennials became 59% of the total number of plant species on the experimental site. This

indicates that in the biocoenosis of the cherry orchard, a secondary succession of plants occurred as part of grass cover. Plant heliomorphs as part of herbaceous plant communities (Fig. 4) during the study period were represented by sciogeliophytes and heliophytes (approximately equally, with a small predominance of sciogeliophytes).

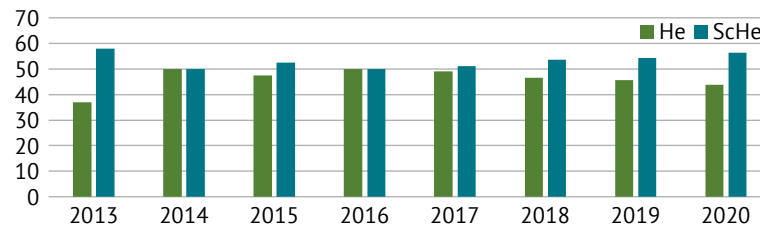


Figure 4. Heliomorphs of species in the composition of grass cover in an organic orchard, % of the total number of species

Note: *Heliomorphs: He (Heliophiton) – heliophyte; ScHe – partially demanding of light

Source: compiled by the authors

Such properties of plants are logically related to the features of their place of growth, because this cherry orchard has quite wide row spacing (7 m) and a fairly large distance between trees in a row (5 m), which

creates fairly good lighting conditions for natural grasses. In terms of nutrient requirements in the soil, the herbaceous plants in the organic sweet cherry orchard were mainly mesotrophs in all years of the study (Fig. 5).

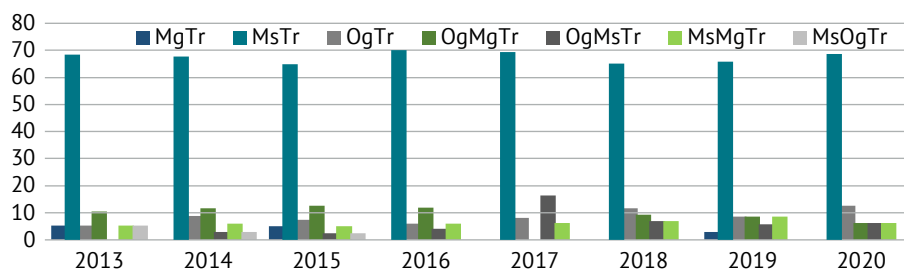


Figure 5. Trophomorphs of species in the composition of grass cover in the organic cherry orchard, % of the total number of species

Note: *OgTr (Oligotroph) – oligotroph; MsTr (Mesotroph) – mesotroph; MgTr (Megatroph) – megatroph

Source: compiled by the authors

The percentage of mesotrophs ranged from 65 to 69% of the total number of species. In the 2nd, 3rd, and 4th years of research, 12-13% of plant species belonged to oligomegatrophs. In the 5th year of research, a significant share (16%) was made up of oligomesotrophs,

in the 6th and 8th years – oligotrophs (12-13%). In the 7th year, none of the trophomorphs (except mesotrophs) reached the limit of 10% of the total number of species. Xeromesophytes and mesocerophytes were the most numerous in terms of moisture demand (Fig. 6).

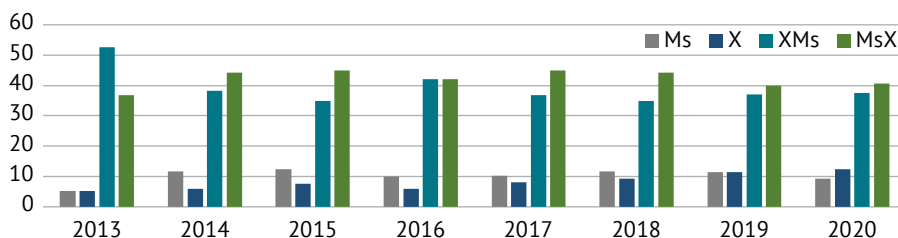


Figure 6. Hygromorphs of species in the composition of grass cover in an organic garden, % of the total number of species

Note: *Hygromorphs: Ms (Mesophiton) – mesophyte (a plant of medium-moist habitats); X (Xerophiton) – xerophyte (a plant of dry habitats)

Source: compiled by the authors

Moreover, in the first year of research, xeromesophytes prevailed (53% of the total number of species). In subsequent years, mesoxerophytes prevailed (except in 2016, when the number of xeromesophytes and mesoxerophytes was the same). In 2020 (in the 8th year of research), the number of mesoxerophytes was 41%. However, the number of xerophytes has significantly increased – up to 12% of the total number

of species. This indicates the competitive advantages of more drought-tolerant species in arid climates, regardless of the seed stock of other species accumulated during the wetter weather conditions of past decades. By changing the ratio of representations of various coenomorphs at the experimental site (Fig. 7) it is possible to judge the restoration of quasi-climatic vegetation.

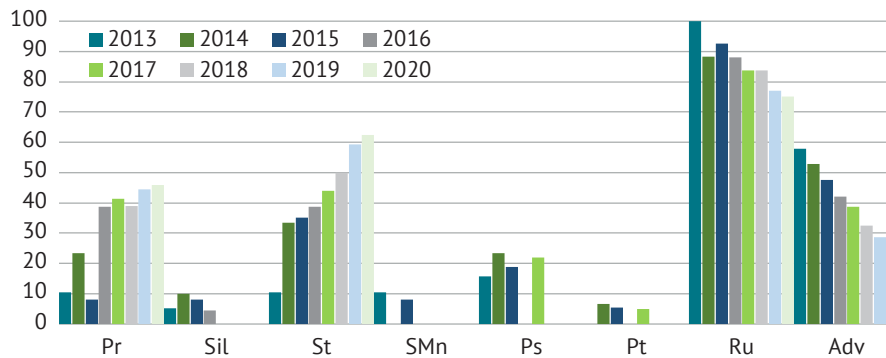


Figure 7. Coenomorphs of species in the composition of grass cover in an organic orchard, % of the total number of species

Note: *Pr (*Pratensis*) – pratant (meadow); Sil (*Silvaticus*) – silvant (forest); St (*Stepposus*) – stepant (steppe); SMn (*Margosilvaticus*) – silvomargoant (edge species); Ps (*Rsamphyton*) – psammophant (sandy soil species); Pt (*Petrophyton*) – petrant (stony soil species); Ru (*Ruderatus*) – ruderanthus (weed); Adv – adventitious species

Source: compiled by the authors

Thus, the number of pratants increased over eight years of research from 11 to 46% of the species, stepants – from 11 to 64% of the total number of species that grew at the experimental site. At the same time, the number of adventitious species decreased from 58% to 28% of the total number of species. The number of ruderants, although it decreased over the years of research from 100 to 75%, remained large. This can be explained by the relatively short period of existence of the grass cover in an organic cherry orchard – only 8 years. Recovery succession is slow. The accumulation of biomass is an important indicator of

ecosystem productivity, as the equivalent of the efficiency of using solar energy for the accumulation of organic matter, which will then be used to feed (and, accordingly, enrich the number and number of species) various participants in the biocoenosis, and to enrich the soil. Total aboveground biomass of plant mulch in the organic garden accumulated most intensively in the 3rd year of research, when the site was dominated by *Ambrosia artemisifolia* L., *Amaranthus retroflexus* L., *Lactuca serriola* Torner, *Chenopodium album* L. which can build up large biomass. This suggests the positive ecological role of these weeds (Table 6).

Table 6. Total aboveground dry phytomass of plant mulch for the growing season, g/m²

Years of research							
2013	2014	2015	2016	2017	2018	2019	2020
215 ± 18	507 ± 43	865 ± 74	399 ± 37	463 ± 37	448 ± 38	566 ± 42	575 ± 59

Source: compiled by the authors

In subsequent years of research, the value of the total aboveground phytomass of plant mulch experienced fluctuations, depending on weather conditions and the composition of plants in the experimental site. However, in the 7th or 8th year of research, this indicator stabilised and was 2.7 times higher than the total aboveground phytomass of plant mulch at the beginning of research in 2013. The overall projective

coverage of the soil with grassy vegetation affects its ecological function of protecting the soil from overheating, freezing, over-drying, deflation, and water erosion. According to the data obtained (Table 7), the total projective coverage of the soil over the years of research was subject to fluctuations depending on climatic conditions, but it steadily increased over 8 years, and at the 7th-8th years it was 100%.

Table 7. Total projective coverage of the soil with plant mulch (average value for the growing season), %

Years of research							
2013	2013	2013	2013	2013	2013	2013	2013
65±9	72±8	78±7	82±9	85±5	93±9	100±9	100±7

Source: compiled by the authors

Dense soil coverage became possible due to the development of such purely steppe species as *Elytrigia repens* (L.) Nevski, *Bromopsis inermis* (Leys.) Holub., *Poa angustifolia* L. That is, it can be stated that for 8 years the authentic flora was partially restored at the experimental site, judging by the presence of stepants (*Eryngium campestre* L., *Achillea millefolium* L., *Crepis*

tectorum L., *Anthemis arvensis* L., *Echium vulgare* L., *Scabiosa ochroleuca* L., *Hieracium umbellatum* L., *Euphorbia stepposa* Zoz., *Trifolium arvense* L., *Papaver rhoeas* L., *Elytrigia repens* (L.) Nevski, *Plantago lanceolata* L., *Agropyron pectinatum* (Bieb.) Beauv., *Bromopsis inermis* (Leys.) Holub., *Poa angustifolia* L.), which formed a dense and beautiful soil cover in the cherry orchard (Fig. 8).



Figure 8. Variety of grass cover in the organic cherry orchard, June 2017

Source: compiled by the authors

Many of these species are classified as ruderal, as their presence in arable fields can significantly reduce the yield of cultivated plants. However, their presence in the garden can be useful for providing numerous environmental services, in particular: enriching the soil with organic matter, protecting against erosion, promoting the development of soil biota, attracting beneficial insects and pollinators. For example, *Taraxacum officinale* is classified as ruderal. However, it is this species, due to its early flowering (when the sweet cherry is not yet blooming), that plays a major role in the nutrition of pollinators, and *Osmia spp* itself. Such species as *Trifolium arvense* L. and *Vicia villosa* Routh are also considered ruderal. However, at the same time – these are very useful legumes for the soil, which, surprisingly, can grow on sandy soil without watering in hot and arid conditions.

From a practical (utilitarian) standpoint, all types of grass cover plants that were present at the experimental site in the 8th year of research have practical applications. Firstly, all of them have medicinal properties, even such species as *Achillea millefolium* L., *Elytrigia repens* L., *Papaver rhoeas* L., *Capsella bursa-pastoris* L. are officially recognised medicinal plants. Secondly, *Amaranthus blitoides* S.Wats., *Taraxacum officinale*, *Senecio vernalis* Waldst. et Kit., *Descurainia Sophia* L., *Capsella bursa-pastoris*, *Vicia villosa* Routh, *Agropyron pectinatum* (Bieb.) Beauv., *Trifolium arvense* L., *Agrostis capillaris* L., *Apera spica-venti* (L.) Beauv., *Bromopsis inermis* (Leys.) Holub., *Plantago lanceolata* L., *Puccinella distans* (Jacq.) Parl., *Elytrigia repens* (L.) Nevski, *Poa angustifolia* L., *Cynodon dactylon* (L.) Pers. are fodder plants. In addition, *Scabiosa ochroleuca* L., *Echium vulgare* L., *Lycopsis arvensis* L., *Taraxacum officinale*, *Descurainia Sophia* L.,

Senecio vernalis Waldst. et Kit., *Vicia villosa* Routh are honey plants. That is, the absolute majority of plant species in the composition of grass plant communities, as of the 8th year of research, in addition to environmental significance, had major practical importance. Unfortunately, in Ukraine, such species as *Vicia villosa* Routh, *Apera spica-venti* (L.) Beauv. and *Amaranthus blitoides* S. Wats. are recognised as invasive. However, further application of mowing may lead to the removal of these species from the biotope and their replacement with steppe species.

DISCUSSION

Researchers from different countries are engaged in research on key challenges related to the loss of biodiversity due to human economic activity and ways to solve them (Abuhasel, 2023). According to A. Kotelnyska *et al.* (2021), the priority area of the agricultural sector is not only to increase the volume of crop production, but also to maintain the stability of agroecosystems. This can be achieved by changing the way we farm and switching to organic production, which will contribute to achieving policy goals under the Kunming-Montreal Global Biodiversity System and the EU's Farm to Fork strategy (Sharma *et al.*, 2019; Wang *et al.*, 2023).

Human impact on Ukraine's steppe ecosystems has caused irreversible loss of biodiversity, and today the fragmented remnants of steppe vegetation in Ukraine account for less than 20% of the vegetation (Dubyna *et al.*, 2021). Ya.V. Kopylyk (2022) confirmed a high degree of anthropogenic transformation of steppe biotopes on the territory of Ukraine. According to the researcher, for the normal functioning of ecosystems, it is a priority to study the dynamics of steppe vegetation as a result of anthropogenic transformation, climate changes, and load regimes. The impoverishment of the diversity of grass cover in the organic cherry orchard on experimental plots can be explained by the following reasons: firstly, due to competition of grasses with cherry trees; secondly, due to mowing. However, mowing in an industrial garden is necessary to make it easier for workers to take care of the garden. As for the competition of herbs with cherry trees, this issue was previously addressed in publications. The sweet cherry trees were suppressed by coexistence with grasses in the first 3 years after the grassing in the orchard. A significant decrease in the annual growth of the trunk diameter, the number and length of annual shoots was recorded. However, in subsequent years, the annual growth of shoots and leaf area was significantly larger in grassing conditions, compared to black fallow. In other words, the trees intensively created shading to suppress competitive vegetation. At the same time, the analysis of physiological and biochemical parameters of cherry leaves and fruits showed successful overcoming of stress from competition with herbs (Ivanova *et al.*, 2021).

Studies confirm the significant influence of soil fertility on plant growth and development, the species composition and diversity of plant communities (Tian *et al.*, 2023). In the studies conducted, the herbaceous plants in the organic sweet cherry orchard were mainly mesotrophs (65-69% of the total number of species). The high level of ruderal species in plant communities at the experimental sites can be explained by the short period of existence of the grass cover (8 years) in the organic cherry orchard, since the recovery succession is slow. According to J. Zhang *et al.* (2023), the early stage of recovery succession lasts from 5 to 14 years. Restoration of phytocoenosis to quasi-climax (stable) state can last for several decades (Sărățeanu *et al.*, 2020). D.V. Dubyna *et al.* (2021) reported an increase in the level of coenotic diversity of ruderal vegetation in Ukraine over the past 30 years. Researchers explain this phenomenon by increasing the intensity and various types of anthropogenic loads on natural ecosystems.

Since invasive species are resistant components of the synanthropic fraction of flora in Ukraine, controlling their spread, monitoring, and studying bioecological features is an important task for the scientific community (Protopopova & Shevera, 2019). Mowing is recognised as an effective means of controlling invasive species (Minuto *et al.*, 2020). The lack of colonisation of the grass cover by invasive and quarantine species in the experimental areas of the cherry orchard can be explained by moderate mowing (4 times during the growing season). Control over invasive species is considered active recovery (Grašič *et al.*, 2023), and moderate mowing (or moderate grazing) as reported (Yang *et al.*, 2022; Kun *et al.*, 2024) accelerate recovery processes in the phytocoenoses of meadows and pastures (the so-called "moderate concern hypothesis"). In a global ecological sense, ruderal species provide invaluable ecosystem services, namely, a dense cover of natural grasses mitigates the effects of climate warming, binds carbon and thereby reduces CO₂ emissions in the atmosphere (Berlinches de Gea *et al.*, 2023). The obtained findings are consistent with the data of other researchers regarding the attraction of natural pollinators – *Osmia* – by plant species of the grass cover. These species are considered the main pollinators of sweet cherries (Osterman *et al.*, 2023). The efforts of the international community are aimed at developing measures that promote pollinator conservation and crop pollination.

In the future, it is advisable to continuously carry out phytocoenotic monitoring of the species composition of plant communities under the influence of various stressors to fully understand the relationship between biodiversity and the stability of the agroecosystem.

CONCLUSIONS

In the arid conditions of the Southern Steppe of Ukraine on low-humus sandy loam soils, an organic cherry orchard is formed within 5 to 8 years and significantly

depends on the species diversity and the state of populations of herbaceous perennials and annuals in row spacing. The species composition of herbaceous vegetation over the years of research was 55 plants belonging to different botanical families. The number of species in live mulch varied over the years, peaking in the 4th year of research – 50 species. In the future, the species composition of grass cover plants gradually simplified and in the 8th year numbered 32 species.

The most common floral composition of the grass cover and phytocoenotic activity of species in row spacing were found in families **Asteraceae** (*Achillea micrantha* Willd., *Achillea millefolium* L., *Ambrosia artemisifolia* L., *Anthemis arvensis* L., *Hieracium umbellatum* L., *Crepis tectorum* L., *Lactuca serriola* Torner, *Senecio vernalis* Waldst. et Kit., *Taraxacum officinale*, *Tragopogon dubius* Scop.); **Poaceae** (*Agropyron pectinatum* (Bieb.) Beauv., *Agrostis capillaris* L., *Anisantha sterilis* (L.), *Anisantha tectorum* (L.), *Apera spica-venti* (L.) Beauv., *Avena fatua* L., *Bromopsis inermis* (Leys.) Holub, *Bromus arvensis* L., *Cynodon dactylon* (L.) Pers., *Bromus squarrosus* L., *Elytrigia repens* (L.) Nevski, *Poa angustifolia* L., *Poa pratensis* L., *Puccinella distans* (Jac q.) Parl., *Setaria glauca* (L.); **Boraginaceae** (*Cynoglossum officinale* L., *Echium vulgare* L., *Lycopsis arvensis* L.); **Brassicaceae** (*Arabidopsis thaliana* (L.) Heynh., *Capsella bursa-pastoris* (L.), *Barbarea vulgaris* R.Br., *Descurainia Sophia* L., *Lepidium campestre*); **Fabaceae** (*Lotus Ucrainicus* Klok., *Trifolium arvense* L., *Vicia villosa* Routh); **Chenopodiaceae** (*Chenopodium album* L., *Chenopodium poly spermum* L.). The composition of plant mulch in the first year of research was dominated by therophytes (annuals that are restored from seed). In subsequent years, the number of therophytes steadily decreased due to mowing of the herbage before the development of generative organs (from 68 to 28%), and the number of hemicryptophytes (herbaceous perennials) – gradually grew and in the 8th year of research accounted for 59% of the total number of plant species on the experimental site.

In relation to light, it was revealed that during the research period, plant heliomorphs in the herbaceous plant communities of the cherry orchard were represented by scyogeliophytes and heliophytes with a slight predominance of scyogeliophytes, that is, shade-tolerant plants. According to the requirements of plants for moisture, the most numerous were xeromesophytes and mesoxerophytes, the development of the aboveground mass of which depended on the hydrothermal conditions of the vegetation period. In terms of nutrient content in the soil, grass cover plants were mainly mesotrophs (65-69% of the total number of species) during all years of research. The change in the ratio of representations of various coenomorphs at the experimental site indicates the restoration of quasi-climax vegetation: the number of meadow plants increased over 8 years of research from 11 to 46% of species, steppe plants – from 11 to 64%, the number of adventitious or alien plant species decreased from 58 to 28% of the total number of species. The total aboveground phytomass of herbaceous vegetation fluctuated depending on weather conditions and species composition in the experimental area (from 215 to 865 g/m² of dry matter), but in the 8th year of research it was 2.7 times higher compared to the 1st year of research. The total projected soil coverage by populations of herbaceous annuals and perennials varied depending on climatic conditions, but gradually increased and reached 100% by the 7th-8th year. The findings of this study can be useful for establishing strategies for the natural restoration of agroecosystems of the Southern Steppe of Ukraine.

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CONFLICT OF INTEREST

None.

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Фітоценотична оцінка трав'яних рослинних угруповань органічного саду черешні

Тетяна Герасько

Кандидат сільськогосподарських наук, доцент
Таврійський державний агротехнологічний університет імені Дмитра Моторного
72310, вул. Жуковського, 66, м. Запоріжжя, Україна
<https://orcid.org/0000-0002-1331-4397>

Тетяна Тимошук

Кандидат сільськогосподарських наук, доцент
Поліський національний університет
10008, бульв. Старий, 7, м. Житомир, Україна
<https://orcid.org/0000-0001-8980-7334>

Віра Мойсієнко

Доктор сільськогосподарських наук, професор
Поліський національний університет
10008, бульв. Старий, 7, м. Житомир, Україна
<https://orcid.org/0000-0001-8880-9864>

Наталя Грицюк

Кандидат сільськогосподарських наук, доцент
Поліський національний університет
10008, бульв. Старий, 7, м. Житомир, Україна
<https://orcid.org/0000-0002-4185-7495>

Тетяна Алексєєва

Кандидат географічних наук, доцент
Обласний коледж «Кременчуцька гуманітарно-технологічна академія імені А. С. Макаренка»
Полтавської обласної ради
39600, вул. Валентини Федько, 33, м. Кременчук, Україна
<https://orcid.org/0000-0002-5671-7372>

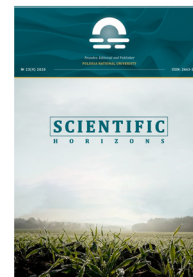
Анотація. Втрата біорізноманіття є однією з глобальних екологічних проблем, з якими стикається людство. Інтенсивне використання природних ресурсів призвело до деградації ландшафтів і скорочення видового різноманіття рослинних угруповань. Тому пошук природних рішень для подолання цих викликів є актуальним питанням. Метою роботи було дослідження динаміки флористичного складу і ценотичної структури трав'яних рослинних угруповань природних трав у органічному саду черешні для стійкого функціонування агроландшафту. Динаміку ценотичного складу природних трав рослинного покриву у органічному саду черешні досліджували упродовж 2013-2020 рр. у посушливих умовах Південного Степу України на малогумусних супіщаних ґрунтах. Для вивчення видової різноманітності флори в органічному саду застосовували морфолого-еколого-географічні методи. Оцінку складу трав'яних рослинних угруповань здійснювали за допомогою традиційних методик геоботанічних описів. Наведено результати дослідження видового складу і ценотичної структури рослинних угруповань трав'яного покриву в органічному саду черешні. Задерніння саду природними травами привело до збагачення агроландшафтів корисними видами, які є важливими компонентами стійких сільськогосподарських систем і можуть виконувати екологічні послуги. Колонізації трав'яного покриву інвазійними і карантинними видами не спостерігали завдяки природним процесам демураційної сукцесії і застосуванню помірного чотириразового скошування рослин за вегетацію (на висоту 15-20 см). У складі трав'яних рослинних угруповань на восьмий рік досліджень усі види були корисними, мали лікувальні властивості і слугували кормовою базою. Природні трави в органічному саду черешні є ресурсом біомаси і біорізноманіття. Фітоценотичний аналіз трав'яного покриву в органічному саду черешні дасть змогу обґрунтувати і запропонувати принципи прогнозування розвитку рослинних угруповань для оптимізації їх структури, поліпшення якості і підтримки біорізноманіття

Ключові слова: видовий склад; біорізноманіття; екологічні послуги; трав'яний покрив; ценоморфи; вторинна сукцесія; природне відновлення агроecosystem

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Stochastic predetermination of bioproductivity component by the growth features of winter wheat upper leaf blades

Anhelina Dubytska

PhD in Agricultural Sciences, Leading Researcher
Institute of Agriculture of the Carpathian Region of the National Academy of Sciences
81115, 5 Hrushevskiy Str., Obroshyne Village, Ukraine
<https://orcid.org/0000-0002-5685-0237>

Oksana Kachmar*

PhD in Agricultural Sciences, Senior Researcher
Institute of Agriculture of the Carpathian Region of the National Academy of Sciences
81115, 5 Hrushevskiy Str., Obroshyne Village, Ukraine
<https://orcid.org/0000-00020382-6030>

Oleksandr Dubytskyi

PhD in Biological Sciences, Senior Researcher
Institute of Agriculture of the Carpathian Region of the National Academy of Sciences
81115, 5 Hrushevskiy Str., Obroshyne Village, Ukraine
<https://orcid.org/0000-0002-8293-4119>

Oksana Vavrynovych

PhD in Agricultural Sciences, Senior Researcher
Institute of Agriculture of the Carpathian Region of the National Academy of Sciences
81115, 5 Hrushevskiy Str., Obroshyne Village, Ukraine
<https://orcid.org/0000-0003-3466-1432>

Zynoviy Kotyk

PhD in Technical Sciences, Associate Professor of the Department
Lviv Polytechnic National University
79013, 12 Bandery Str., Lviv, Ukraine
<https://orcid.org/0000-0002-7725-0791>

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Abstract. The relative and absolute importance of a number of traits, in particular, agrophysiological, morpho-functional, at the level of individual organs and parts of an integral plant, and/or sowing for the development of features of biological traits, and other agroecologically significant components of the crop production process, has been discussed in research papers for a long time. The purpose of the study was to search for agroecologically significant signs of growth of the upper leaf blades (ULB), which can empirically and potentially determine the development of the grain

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*Corresponding author

dry mass (GDM) of winter wheat under “model” conditions of biological agrotechnical influences designated as biological fertiliser systems. Methods used in the research: methodological approaches of field experiments, gravimetric, convective drying, and stochastic methods. The development of GDM was largely driven by potentially scalable integral growth traits of ULB – leaf area duration, biomass duration (LAD_{ULB} , BMD_{ULB} , respectfully) or their combinations with potentially non-scalable features of the average growth rate ULB – net assimilation rate, relative growth rate (NAR_{ULB} , RGR_{ULB} , respectfully). It is also highly probable that LAD_{ULB} may play a central role in the development of RGR_{ULB} or BMD_{ULB} (but not NAR_{ULB}). The coordination of RGR_{ULB} with NAR_{ULB} was not excluded, although it was overly complicated. The construction of such and similar studies in the line of an exhaustive explanation of consistent systemic and mechanistic predeterminations of the production process with signs of ULB growth under various agrotechnical and biological influences will improve discursive and mathematical simulation constructs that can characterise and integrate the differential effects of plant components on photosynthesis of leaf cover, crown, and ultimately on the processes of development of components of the final biological and economic yield of winter wheat

Keywords: signs or features of growth of upper leaf blades; leaf area and biomass durations; net assimilation and relative growth rates; winter wheat; “model” biologically improved agronomic conditions – biologically improved fertilisation systems

INTRODUCTION

To improve the final results of the production process, among the world’s theoretical and applied aspects of biological, agronomic, and related sciences, various alternative ways to control and increase the efficiency of photosynthesis of agricultural leaves were proposed. The lack of proper success up to the day is mainly conditioned by the fact that the biological and economic productivity of agricultural plants is largely determined by photosynthetic capacity indices (PI) and related terms (size, duration, and architecture of green leaf cover, amount of captured radiation, RUE – radiation use efficiency of the crown, distribution of photoassimilates, size sinks strengths in the source-sink system of plants). PI of green organs and related terms are capable of being translated into growth indices (GI) and bioproductivity of plants. However, during the grain production of cereals, only two upper leaves produce more than 80% of the photoassimilates of the entire plant. Therefore, it is important to formulate scientific questions in the areas of clarifying the measure and methods of determining the components of bioproductivity by the GI of individual upper leaf blades (ULB) of winter wheat, developing a deeper understanding of the (mutual) subordination between the first and second in the “scaling down” coordinates under various agrotechnical influences. The results of such studies will become a meaningful basis for correcting theoretical, applied, and generalising constructs for the development of the “scaling up” yield components under various technologies for growing winter wheat.

Consistent with the classical analysis of plant growth outlined several decades ago, total dry matter (TDM) is directly proportional to the product of GI – net assimilation rate (NAR), leaf area duration (LAD); at the same time, crop growth rate (CGR) is directly proportional to the product of NAR, leaf area index (LAI) (theoretical and analytical equations (Eqs.) – TAE category

1 for plant growth analysis). It is also legitimate to predetermine TDM by the product of two other GI – relative growth rate (RGR), biomass duration (BMD), and the coordination of CGR with the product of RGR, biomass index (BMI) (TAE category 2). Modern definitions and formalisations of NAR and CGR are given by A. Khan *et al.* (2023); for LAD, LAI – by N. Mehboob *et al.* (2022); BMD, BMI in TAE category 2 – biomass-GI, similar to LAD, LAI.

Formalisation of the RGR, submitted by M. Tripathi (2020), can be supplemented by considerations of F.F.M. Oliveira *et al.* (2019), and interpreted as the rate at which a given amount of existing biomass can produce new biomass. Since RGR is the key to analytical understanding of growth, it is often presented as a product of NAR, LAR (LAR – product of LMF, SLA, or $1/LMA$) (Yano *et al.*, 2018). In this TAE category 3 LAR, LMF, SLA, LMA – leaf area ratio, leaf mass fraction, specific leaf area, leaf mass per area ratio (specific leaf weight, SLW). In consistency with S. Tripathi *et al.* (2018), the latter TAE is important for intra- and interspecific variability of plant growth rates depending on environmental factors, availability of sources of alimentary reserves. As noted by M. Khirkehah *et al.* (2019), crop bioproductivity of GI components may be affected by insufficient or excessive intake of any of the main alimentary components.

I.C. Dodd and E.D. Elphinstone (2021) showed that N-supplements caused an increase in LAI, leaf longevity (LL), LAD, leading to an improvement in plant biological and/or economic productivity. Ukrainian researchers D.A. Kirizii and I.M. Sheheda (2019) proposed predicting the ability to photosynthesise (individual plants, seeding) by LNC (Area), LDMC (Area) (N-leaf content/area, leaf dry matter content/area, respectfully), SLW, which characterise interspecific differences in N-allocation to proteins (Rubisco), cell walls, mesophyll conductivity, CO_2 - partial pressure (leaf structure), etc. An increase in

N-concentration caused a decrease in LMF, RGR *Hordeum vulgare* L. (hydroponics); at higher N-concentration, the increase in LMF was offset by a decrease in NAR, without changes in SLA (Ge et al. 2019). M. Khirkhah et al. (2019) found that max-gain LAI, CGR, NAR, RGR of alfalfa (a two-year field experiment) was induced by P-biofertilisers + extracellular boron-supplements, extracellular or “intra-soil” manganese-supplements.

According to H. Tiwari et al. (2023), highest CGR, NAR, RGR *Triticum aestivum* L. 100%-recommended N-rate+farmyard manage + “Azatobacter” (biofertiliser) (comparison with other integrated crop cultivation systems) were determined. J.L. Miglioli et al. (2020) demonstrated that a decrease in RGR, NAR, an increase in DM of *Brassica oleracea* var. *gemmifera* was caused by treatment with 6-benzylaminopurine, while the opposite changes were caused by dopamine. An increase in LAI, NAR, %-light interception in rice was caused by the use of green manure crops with different N-dosage or N₆₀-only (Islam et al. 2019). L.S. Yermko et al. (2019) showed that an increase in the rate of mineral fertilisers (using plant root feeding) caused an increase in photosynthetic potential = LAD, net photosynthesis productivity of pea crops, both without inoculation with Rhizohumin, and with inoculation, compared with control (without fertilisers, without inoculation) or non-inoculated plants, respectively.

The analysed scientific sources show that the study of aspects of GI coordination, components of bioproductivity, functional and ecological relations is expedient in hydroponics, agricultural systems of plant cultivation, and supplementation of the latter with biological factors. Thus, the biologised fertiliser systems used in this work (BFS, complex agrotechnical and biological fertilisers) can be a full-fledged model agroecosystem for elucidating the patterns of (inter-) subordination between the indicators of bioproductivity and growth of winter wheat. Over the past decade, a wide range of researchers have formed a consensus, highlighted in particular by J.L. Araus et al. (2021), according to which it is advisable to consider the most significant factors of increasing bio-productivity and economic grain yield in conjunction with changes in growth and development processes in the source-sink system of plants. However, there are no clear answers to questions about the aspects of predetermined results of the production process (the final sink) by the ULB-GI, i.e., by the important attributes of growth and primary sources of photosynthate, which characterise the accumulation, preserva-

tion, and outflow of assimilates from the ULB to sinks in terms of “scaling down”.

The structure of such considerations should be supplemented by the predestination of the RGR_{ULB} by the product of NAR_{ULB}, SLA_{ULB} (TAE category 4), similar to T. Inoue et al. (2022). The latter suggests the existence of growth-TAE that regulate TDM_{ULB} coordination on the one hand, and NAR_{ULB}, LAD_{ULB}, RGR_{ULB}, BMD_{ULB}, on the other. The assumption that sink size, e.g. grain dry mass (GDM), can be empirically coordinated with NAR_{ULB} and/or LAD_{ULB}, RGR_{ULB} and/or BMD_{ULB} (TAE categories 1, 2); RGR_{ULB} can be stochastically determined by NAR_{ULB} (TAE category 4) is logical. Given the importance of LAD for the development of NAR (TAE category 1), the subordination of NAR to the value of RGR (TAE category 3), the need for BMD for RGR (TAE category 2), and the scientific sources cited above, the authors of this paper suggested that within the framework of this experiment, NAR_{ULB}, RGR_{ULB}, BMD_{ULB} can be predefined by LAD_{ULB}.

Research objective: to establish whether NAR_{ULB}, LAD_{ULB}, RGR_{ULB}, BMD_{ULB}, empirically and statistically determine, and how exactly, the development of GDM of winter wheat under the conditions of biologised fertilisation systems (BFS); to find out functionally and ecologically feasible stochastic subordination between the described signs of ULB growth.

MATERIALS AND METHODS

The study was carried out in 2017-2018 on grey forest surface gleyed light loamy soil in the conditions of a stationary experiment to investigate the scientific foundations of productivity management of short-rotation crop rotations in the Carpathian region (Institute of Agriculture of the Carpathian region of the National Academy of Agrarian Sciences of Ukraine). Plants of winter wheat (*Triticum aestivum* L.) of the Benefis variety (predecessor – peas, *Pisum sativum* L.) were used for the research within a 4-field crop rotation with the following crop rotation: oats, corn (for grain), peas, winter wheat. The area of the experimental microplot was 1 m²; replication of plots was 3-fold; the arrangement of the plots – systemic. Physical and agrochemical parameters of the soil (substrate thickness 0-30 cm) were tested in 2016 before the field stationary experiment. For the sake of space, the authors of this paper consider it appropriate to mention that the values of the measured soil characteristics were presented in the previous paper. The content of research variants (technologies) for groups 1 and 2 is presented in Table 1.

Table 1. Content of research variants (Group 1 and 2 technologies)

DRV(T)	Content of option (Group 1)	DRV(T)	Content of option (Group 2)
C.0	Control (no fertilisers or biologisation factors)		
1.1	PSS ¹⁾	2.1	MF(FD) ⁷⁾
1.2	PSS ¹⁾ + MF(HD) ²⁾	2.2	MF(FD) ⁷⁾ + BS(TS) ³⁾

Table 1. Continued

DRV(T)	Content of option (Group 1)	DRV(T)	Content of option (Group 2)
1.3	PSS ¹⁾ + MF(HD) ²⁾ + BS(TS) ³⁾	2.3	MF(FD) ⁷⁾ + BS(TS) ³⁾ + CM(AE) ⁸⁾
1.4	PSS ¹⁾ + MF(HD) ²⁾ + BS(TS) ³⁾ + HF(EI) ⁵⁾	2.4	MF(FD) ⁷⁾ + BS(TS) ³⁾ + HF(EI) ⁵⁾
1.5	PSS ¹⁾ + MF(HD) ²⁾ + BS(TS) ³⁾ + MF(ES) ⁶⁾	2.5	MF(FD) ⁷⁾ + BS(TS) ³⁾ + MF(ES) ⁶⁾
1.6	PSS ¹⁾ + MF(HD) ²⁾ + CF(RS) ⁴⁾	2.6	MF(FD) ⁷⁾ + CF(RS) ⁴⁾

Note: DRV(T) – designation of research variant (technology); upper numerical indices ^{1), 2), 3), 4), 5), 6), 7), 8)} – *Pisum sativum* straw; mineral fertiliser (half of the dose); biostimulant Tera-Sorb; chelated fertiliser Rose-Salt 18-18-18+125+ME; humus-containing fertiliser Eco-Impuls; microbiological fertiliser Eco-Soil; mineral fertiliser (full dose – N₆₀P₉₀K₉₀); cattle manure (after-effect), respectively. The supplements, marked with indexes ^{1)–6), 8)} are biologisation factors of the corresponding biologised fertiliser systems (BFS)

Source: compiled by the authors

Brief characteristics and methods of application of biologisation factors represented by commercial preparations (indices ^{2)–6)} in Table 1) were contained in the previous paper already cited above (Dubytzkyi *et al.*, 2020). Supplements PSS, CM(AE) (see note to the same table) represented non-commercial agricultural biologisation factors. N, P, K were added to the soil in the form of ammonium nitrate (34% of the active substance), superphosphate (18% of the active substance), and potassium salt (40% of the active substance), respectively, in doses of 30, 45, 45, or 60, 90, 90 kg/ha⁻¹ (variants of Group 1 or Group 2 – MF(HD) or MF(FD), respectively), immediately after sowing winter wheat; PSS was applied for autumn ploughing (2.2 t/ha⁻¹); CM – for autumn ploughing (40 t/ha⁻¹) before spring corn sowing.

Fluctuations in typical climate characteristics during the growing seasons of 2016-2017 and 2017-2018 had a number of features. Among other things, the beginning of this interval of winter wheat growth in 2016 was marked by an oversaturation of precipitation and relatively low average ten-day temperatures; however, overwintering of plants was satisfactory. During the tubing–earring phase of 2017, weather conditions were acceptable. During the flowering-waxy ripeness period, there was a partial lack of moisture in the soil, and an increase in air temperatures by 1.0-1.9°C above the long-term average norms (LAN). In the interval of the initial stages of winter wheat ontogenesis in 2017-2018, the distributions of the sums of active temperatures and precipitation were uniform. During the 3rd-4th months of the specified interval of years, there was a lack of precipitation (95 mm against 52.7 LAN) and an increased temperature background. During the tubing-earring period of 2018, excessive soil moisture occurred. On the contrary, during flowering – waxy ripeness that year, there was a partial lack of moisture and an increase in air temperatures by 3.8°C, compared with the LAN. Summarising the properties of the climatic background of winter wheat vegetation during

2017-2018, it was clear that the ontogenesis of these plants, taking place against the background of changes in precipitation intensity and temperature, still typically contributed to the optimal growth of this crop.

The upper leaf blades (ULB; one the flag FLB and one the pre-flag PFLB – 1st and 2nd leaves of the upper tiers, respectively) from productive shoots of winter wheat were selected in the range of 8.00-11.30 h until noon under the conditions of the onset of the ontogenesis phases of tubing, earing, flowering, milk ripeness (T, E, F, MR, respectively; ~ 75% of plants in the proper phase), as previously noted (Dubytzkyi *et al.*, 2020). ULB was separated from 3 productive shoots in one field repetition (diagonally across the field plot) and on 3 field repetitions (total number n FLB + PFLB = 18). These operations were performed using scissors, ULB was placed in labelled open moistened plastic ice bags, which were placed in a moistened plastic ice container, and transported to the laboratory in this form. In the laboratory, the leaves were rinsed with tap water, dried with filter paper, and the length and maximum width of each ULB was measured using a ruler (in such a sequence as the leaves were placed in a plastic bag – important for subsequent calculations). 2 discs were cut out of each ULB using a cork drill, placed in glass buckets and fixed in a drying cabinet 2B-151 (USSR) at 105°C. During the next 2 days, the leaf discs were dried in a drying cabinet at 105°C to a constant mass (~ 8-14 hours) to determine the dry mass of ULB (Dubytzkyi *et al.*, 2020). The dry matter mass of ULB disks was measured on Radwag AS 220/R2 analytical scales, Poland (± 0.0001 g). Specific leaf weight $SLW = \text{leaf disc weight} / \text{leaf disc area}$; found the average for each research variant i – $SLW_{av(i)}$. The area of ULB was calculated from the ratio represented by K. Liu *et al.*, (2019): $A_{ULB} = 0.75 \cdot LBL \cdot LBW \cdot 10^{-2}$, where LBL , LBW , 10^{-2} – leaf blade length, leaf blade width, conversion factor mm² in cm². Mass of dry matter of i -th leaf blades found as a product of $SLW_{av(i)}$ and $LA_{i(j)}$: $LDM_i = LA_i \cdot SLW_{av(i)}$

With the onset of the full grain ripeness phase (for ~ 75% of plants), wheat ears were cut from every 3 productive shoots in one field repetition (diagonally), and on 3 field repetitions ($n = 18$), and were transported to the laboratory in “dry” form. Grain from the ears was ground, the grain dry mass (GDM) was determined from the grinding part in the same way as described for upper leaf blades. The values of this attribute were recalculated on grain dry weight per plant (GDM_{pl} , g plant⁻¹). The bio-productivity of winter wheat was estimated as GDM based on the area under cultivation (g/m² of the area of sowing; biologically and agro-ecologically important “dry” or net result of the production process); this plant trait was calculated as a product of GDM_{pl} and S (average number of productive shoots in the waxy ripeness phase, pieces m⁻²).

Average values of RGR and NAR attributes for each i -th ULB pair ($n = 18$) of winter wheat between the phases of ontogenesis $(j+1) - j = k$ ($RGR_{ULBk(i)}$, $NAR_{ULBk(i)}$; T – E, E – F, F – M) were calculated based on general approaches presented by S. Liu *et al.* (2019), considering the source (Dubytka *et al.*, 2020):

$$RGR_{ULBk(i)} \cdot 10^2 = 10^2 \cdot \log_e(DMI_{ULBj+1(i)} / DMI_{ULBj(i)}) / \Delta t_k, \quad (1)$$

$$NAR_{ULBk(i)} = \Delta DMI_{ULBk(i)} / \Delta AI_{ULBk(i)} \cdot \log_e(AI_{ULBj+1(i)} / AI_{ULBj(i)}) / \Delta t_k, \quad (2)$$

$$\Delta DMI_{ULBk(i)} = 10^{-3} \cdot S \cdot (DM_{ULBj+1(i)} - DM_{ULBj(i)}), \quad (3)$$

$$\Delta AI_{ULBk(i)} = 10^{-4} \cdot S \cdot (A_{ULBj+1(i)} - A_{ULBj(i)}), \quad (4)$$

$$\Delta t_k = t_{j+1} - t_j, \quad (5)$$

where the marking $DMI_{ULBk(i)}$, $AI_{ULBk(i)}$ – the indexes of dry weight and area of i -th ULB (flag or pre-flag), $DM_{ULBj(i)}$, $DM_{ULBj+1(i)}$, $A_{ULBj(i)}$, $A_{ULBj+1(i)}$, S , Δt_k – dry weight and area of i -th ULB on the stages $j, j+1$ (mg, cm²), the number of productive shoots (m⁻²), the duration of the period between phases $(j+1) - j = k$ (day), respectively; 10^2 , 10^{-3} , 10^{-4} – coefficients for easy reading of numbers, for converting mg to g, for converting cm² to m², respectively, indicators of i -th ULB pair between the T – M ontogenesis phases – considered growing season ($RGR_{ULB(i)} \cdot 10^2$, $NAR_{ULB(i)}$ – $G_{ULB(i)}$) were calculated as averages for the periods T – E, E – F, F – M; average RGR_{ULB} , NAR_{ULB} (10² day⁻¹, g/m² day) between ULB $n = 18$ – by dividing $G_{ULB(i)}$ by n :

$$G_{ULB(i)} = \sum_{k=1}^{k=K} (RGR_{ULBk(i)} \cdot 10^2 \text{ or } NAR_{ULBk(i)}) / K; \quad (6)$$

$$RGR_{ULB} \cdot 10^2 \text{ or } NAR_{ULB} = \sum_{i=1}^{i=n} G_{ULB(i)} / n, \quad (7)$$

where $G_{ULB(i)} = RGR_{ULBk(i)}$, $NAR_{ULBk(i)}$; $k = (j+1) - j$ – just like the previous Eqs.; $K = N - 1 = 3$ – number of interfacial periods.

Average LAD, BMD for each i -th ULB pair ($n = 18$) winter wheat between the phases of ontogenesis $(j+1) - j = k$ ($LAD_{ULBk(i)}$, $BMD_{ULBk(i)}$; T – E, E – F, F – M) were calculated based on the general approaches presented by W. Saeed *et al.* (2021), using numerical integration by the trapezoid method:

$$LAD_{ULB(i)} \text{ or } BMD_{ULB(i)} = Z \cdot S \cdot \sum_{j=1}^{j=N} 0.5(D_{ULBj(i)} + D_{ULBj+1(i)})(t_{j+1} - t_j), \quad (8)$$

where $D_{ULBj(i)} = A_{ULBj(i)}$, $D_{ULBj+1(i)} = A_{ULBj+1(i)}$ for $LAD_{ULBk(i)}$ or $D_{ULBj(i)} = DM_{ULBj(i)}$, $D_{ULBj+1(i)} = DM_{ULBj+1(i)}$ for $BMD_{ULBk(i)}$, $N = 4$ – number of ontogenesis phases (T, E, F, M); Z – conversion factor cm² in m² (10⁻⁴) or mg in kg (10⁻⁶), S – see previous Eqs. Calculating average $n = 18$ (LAD_{ULB} , BMD_{ULB} ; m² m⁻²/day, kg/m² day) is similar to Eqs. (6), (7).

Average values of each trait $T_{ULB(i), IA}$ (interannual trait) for the i -th pair of ULB (T – M) between 2017–2018:

$$T_{ULB(i), IA} = 1/2 \cdot (T_{ULB(i), 2017} + T_{ULB(i), 2018}), \quad (9)$$

where $T_{ULB, IA}$ – similar to Eq. (7).

Statistical reliability α of differences between numerical quantities of the data in groups (combinations) of research variants (technologies) C.0-2.6, 1.1-1.6, 2.1-2.6 were analysed using univariate analysis of variance (Libre Office Calc Version 5), while t -statistics was used for pairwise comparison (similar to O. Stasiv *et al.* (2023)); the last of these parameters was calculated as previously indicated by S. Brown *et al.* (2020) (the software mentioned above). 2D and part-relation coefficients (tr , pr , respectively), their α was found in the Statistica Version 10 package (StatSoft Inc). Standard stochastic OLS-dependencies (OLD; spatial data) were constructed and generated in the GNU Regression, Econometrics, and Time-Series Library (the GNU Unix operating system) (all the last specified statistical procedures were previously described by O. Stasiv *et al.* (2023)). The analytical achievement indicators and the autocorrelation (denoted as AC) were tested in the same way as in the previous paper (Stasiv *et al.*, 2023). Eqs. for evaluating D -criterion and the concept of weighing the presence or absence of AC were drawn from P. Das (2019).

The authors adhered to the standards of the Convention for the Protection of Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS

The study demonstrated that field technologies 1.1-2.6 caused a statistically significant increase in GDM of winter wheat by 31.7–298.6%, compared with C.0 (Fig. 1). Under the conditions of pre-existing technologies 1.2-1.6, 2.2-2.6, this trait of biological productivity of plants increased by 10.0–94.7%, compared to 1.1, 2.1.

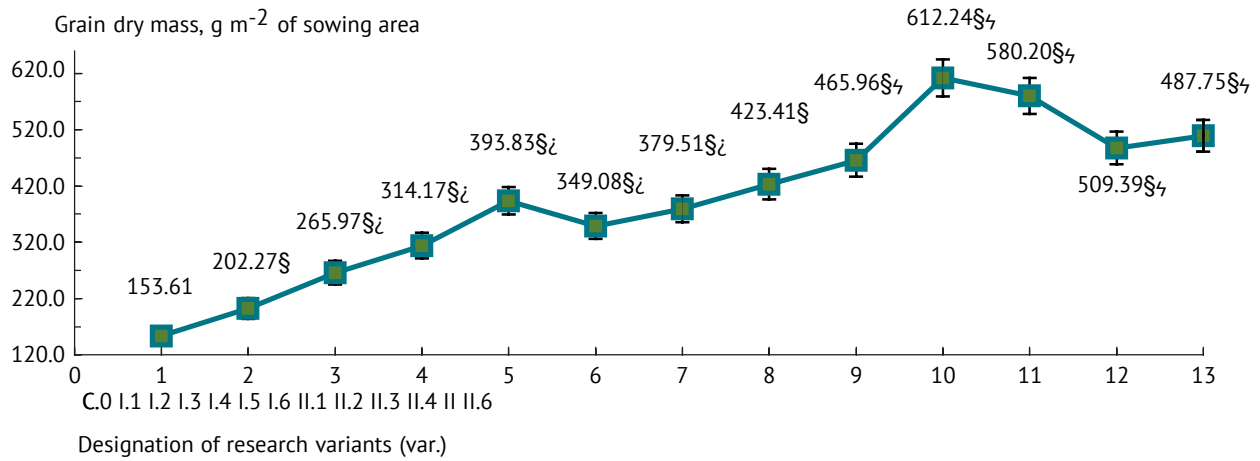


Figure 1. GDM of winter wheat depending on the applied field technologies (1.1-1.6, 2.1-2.6) and under control conditions (C.0) (full grain ripeness, 2017-2018)

Note: statistical reliability of differences between one-factor analysis of variance data for C.0 – 2.6, 1.1 – 1.6, 2.1 – 2.6 – $\alpha < 0.001$; §, ζ, ζ – probability of differences from C.0, 1.1, 2.1 according to the t-criterion – $\alpha < 0.001$

Source: compiled by the authors

Highly significant decline in NAR_{ULB} , RGR_{ULB} 42.1-61.0% was observed in winter wheat on research variants 1.1, 1.2 with typical comparisons with C.0 (Fig. 2). Simultaneously, there was a decrease in these indices of ULB plant growth rate in the case of field technologies 1.5-2.6 by 45.1-125.6% (vs. C.0). In winter wheat under 1.4 conditions, a significant decrease in RGR_{ULB} by 40.3% was observed and, at the same time, only downward trends in NAR_{ULB} (-36.6%, $\alpha < 0.1$), in the case of comparison with C.0. There were no statistically significant changes in NAR_{ULB} , RGR_{ULB} in plants under 1.3 conditions ($\alpha > 0.1$, matching with C.0). However, in 1.3 there was an increase in NAR_{ULB} , RGR_{ULB}

of winter wheat by 65.8-103.1% compared to 1.1; in plants under 1.2, 1.4 there was only a tendency to increase NAR_{ULB} by 43.8-62.5%, and no statistically valid changes in RGR_{ULB} , when compared to 1.1. Similarly, there were no statistically reliable changes in the ULB growth rate indices of winter wheat under the conditions of research technologies 1.5, 1.6 (vs. 1.1). In the case of field technologies 2.2, 2.3, 2.5, 2.6, a significant decrease in NAR_{ULB} , RGR_{ULB} plants by 75.0-187.5% was noted, while in conditions 2.4 – only a downward trend in NAR_{ULB} (-120.8, $\alpha < 0.1$), and in addition – a decrease in RGR_{ULB} by 123.5% (all recent comparisons – from 2.1).

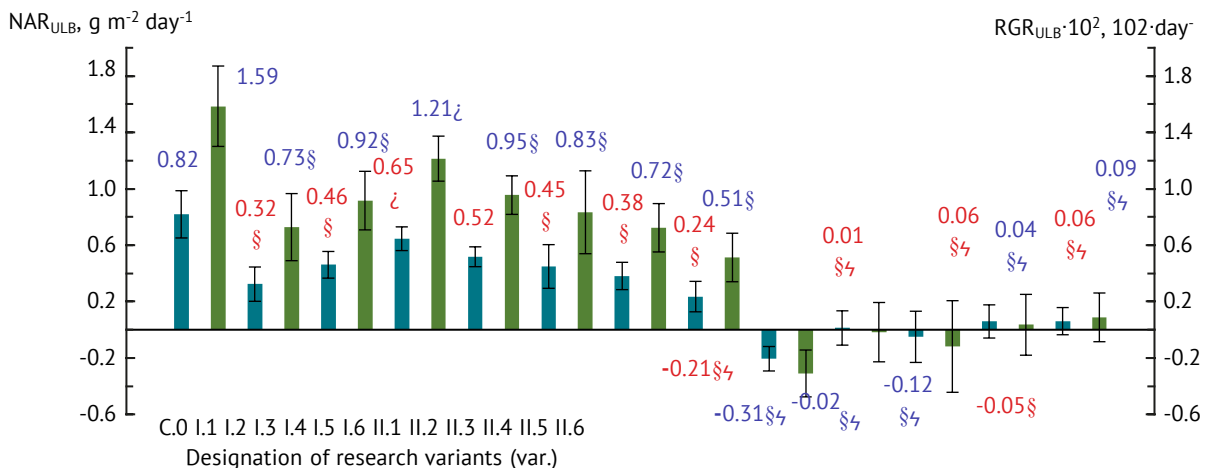


Figure 2. Average net assimilation rate NAR_{ULB} and relative growth rate RGR_{ULB} of the upper leaf blades (flag leaves and pre-flag leaves) of winter wheat under the conditions of BFS (research variants using of the biologisation factors: 1.1 – 1.6, 2.2 – 2.6), MF(FD) (2.1) and without fertilisers and biologisation factors (C.0) (tubing-milk ripeness, 2017-2018)

Note: Statistical validity of differences between features based on one-factor analysis of variance for C.0 – 2.6 $\alpha < 0.001$, for 1.1 – 1.6 – $\alpha = 0.069$, $\alpha = 0.080$, 2.1 – 2.6 – $\alpha < 0.001$; §, ζ, ζ – reliability of differences from C.0, 1.1, 2.1 according to the T-criterion – $\alpha < 0.001-0.05$

Source: compiled by the authors

Briefly summarising the above-mentioned variations in the growth rate of winter wheat ULB alone, it is clear that all fertilisation systems (field technologies 1.1-2.6) caused a decrease in NAR_{ULB} , RGR_{ULB} of winter wheat during the evaluated phases of ontogenesis, compared with C.0. The nuance in this pattern is described under conditions 1.3, 1.4, respectively, or statistically unreliable changes in NAR_{ULB} , RGR_{ULB} plants, or just a tendency to decrease NAR_{ULB} fluently with a reliable decrease in RGR_{ULB} of these organisms (vs. C.0). The negative values of NAR_{ULB} and RGR_{ULB} for winter wheat presented here are not unique or incorrect (among other things, an artefact). S. Mohammadi

Alagoz et al. (2023) reported, respectively, negative RGR, NAR values of triticale variety Giannillo-92 86-93 days after sowing under conditions of 3 levels of salinity and 4 levels of drought, in saffron (*Crocus sativus*), negative growth of leaves of macrophytes *Vallisneria natans* (depending on nitrogen load, fish abundance).

The combined effects in 1.1 – 2.6 caused a significant and statistically reliable increase in the integral growth indicators of ULB in winter wheat LAD_{ULB} , BMD_{ULB} by 9.1-233.5% (compared to C.0; Fig. 3). Similarly, in the case of 1.2-1.6, 2.2-2.6, these plant ULB growth indices increased by 12.9-133.3% compared to 1.1, 2.1.

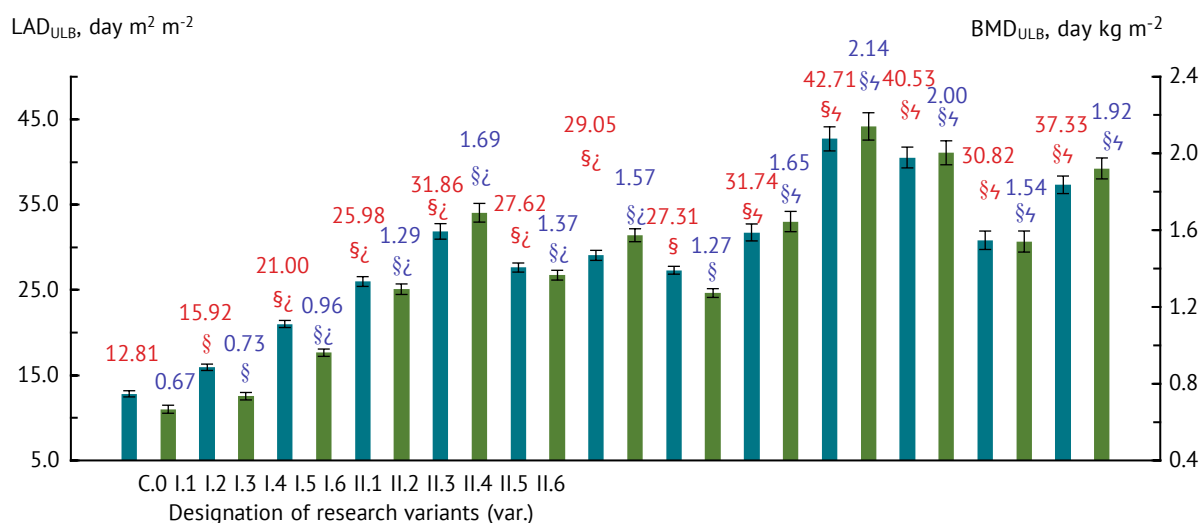


Figure 3. Average leaf area duration LAD_{ULB} , biomass duration BMD_{ULB} of the upper leaf blades (flag leaves and pre-flag leaves) for the actions of applied field technologies (1.1-1.6, 2.1-2.6), and under conditions without fertilisation and biologisation factors (C.0); tubing – milk ripeness, 2017-2018)

Note: statistical reliability of differences between one-factor analysis of variance data for C.0 – 2.6, 1.1 – 1.6, 2.1 – 2.6 – $\alpha < 0.001$; §, ζ, ♀ – probability of differences from C.0, 1.1, 2.1 according to the t-criterion – $\alpha < 0.001-0.05$

Source: compiled by the authors

The tendencies to mostly statistically reliable decrements of NAR_{ULB} , RGR_{ULB} , in conjunction with highly reliable increments LAD_{ULB} , BMD_{ULB} , indicate the opposite response of the Indicated categories of ULB growth signs of winter wheat to agrotechnical influences in the research technology groups both 1 and 2, compared with C.0. Significant increases in LAD_{ULB} , BMD_{ULB} of plants and much less statistically defined variations in their NAR_{ULB} , RGR_{ULB} in the case of 1.2-1.6, 2.2-2.6, create opportunities for identifying different responses of these two categories of ULB growth traits of these organisms to technologies of groups 1 and 2, also in comparison with 1.1, 2.1. Higher values and higher increments of LAD_{ULB} , BMD_{ULB} of winter wheat on 2.1-2.6, 2.2-2.6 (comparison with C.0, 2.1), than on 1.1-1.6, 1.2-2.6 (comparison with C.0, 1.1), at the same time lower values and larger decrements of NAR_{ULB} , RGR_{ULB} of plants on 2.1-2.6, 2.2-2.6 (comparison with C.0, 2.1), than on 1.1-1.6, 1.2-1.6 (comparison with

C.0, 1.1) may indicate different sensitivity of the two categories of ULB growth traits of these organisms to experimental groups 1 or 2.

However, questions about the detailed reasons for these inventions are beyond the scope of this section and, in general, this study. Other important findings are that the patterns of variation of LAD_{ULB} , BMD_{ULB} but not NAR_{ULB} , RGR_{ULB} , were, in general, similar to those for GDM. The presented statements highlight a certain intrigue around the subordination between the classical “interval” signs of ULB growth and the ecological and physiological features of the production process of winter wheat under the conditions of the studied agrotechnical influence (P.0, 1.1-1.6, 2.1-2.6). This provides quite natural grounds for elucidating the (mutually) predestination of GDM by the ULB growth traits presented here, and the (mutually) subordination of the latter to each other using typical tr analysis approaches. The comparisons of GDM with

NAR_{ULB} or RGR_{ULB} revealed statistically significant negative correlations between them (Table 2). On the contrary, there are highly probable but positive tr between GDM and LAD_{ULB} , BMD_{ULB} . In this case, all empiric

correspondences between independent variables (Vrb.; IV) for the discussed correlation matrix (NAR_{ULB} , LAD_{ULB} , RGR_{ULB} , BMD_{ULB}) were high in absolute value and statistically significant.

Table 2. Values of tr for the winter wheat indicators under study

Trait	M	N	L	R
N	-0.8098 ^x	–	-0.7121 [‡]	0.9955 ^x
L	0.9726 ^x	-0.7121 [‡]	–	-0.7608 [‡]
R	-0.8519 ^x	0.9955 ^x	-0.7608 [‡]	–
B	0.9503 ^x	-0.6786 [†]	0.9906 ^x	-0.7297 [‡]

Note: N, L, R, B, M – $NAR_{(ULB)}$, $RGR_{(ULB)}$, $LAD_{(ULB)}$, $BMD_{(ULB)}$, GDM; ^x, [‡], [†] – $\alpha < 0.001$, $\alpha < 0.01$, $\alpha < 0.05$, respectively

Source: developed by the authors based on O. Stasiv et al. (2023)

To better understand the internal configuration of interdependencies, the detection of collinearity (denoted as the MC) or statistical elimination (SE), an analysis pr was performed between considered Vrb.

(Table 3) and comparison of this criterion with tr , similarly to (Stasiv et al., 2023). Only 3 statistically reliable differences were found ($\alpha < 0.001-0.05$) pr for M-L, N-R, L-B (control Vrb., respectively, N, R, B; M, L, B; M, N, R).

Table 3. Values of pr between the winter wheat indicators under study

Index	M	N	L	R
N	0.4049	–	-0.2346	0.9927 ^x
L	0.7226 [†]	-0.2346	–	0.2689
R	-0.4810	0.9927 ^x	0.2689	–
B	-0.3966	0.2597	0.8955 ^x	-0.2648

Note: N, L, R, B, M – $NAR_{(ULB)}$, $RGR_{(ULB)}$, $LAD_{(ULB)}$, $BMD_{(ULB)}$, GDM; pr for any 2 indexes are presented considering that the remaining 3 belong to the control Vrb.; ^x, [†] – $\alpha < 0.001$, $\alpha < 0.05$, respectively

Source: developed by the authors based on O. Stasiv et al. (2023)

Comparative assessments of tr , pr in Table 2 and Table 3 provided the following results: 1) between IV N, L, R, B there is an MC (by absolute values tr and comparison tr with pr , according to A. Kalnins (2018) and P. Das (2019)); 2) SE of the Vrb. (Martinez Gutierrez & Cribbie, 2021) between the considered traits is absent. Nevertheless, the analysis of tr , pr does not allow predicting exactly how GDM can be determined by NAR_{ULB} , LAD_{ULB} , RGR_{ULB} , BMD_{ULB} separately or in combinations according to TAE categories 1, 2 in the “INTRODUCTION” section, and what is the probable form of consistency between RGR_{ULB} and NAR_{ULB} (TAE categories 3, 4; “INTRODUCTION” section) or NAR_{ULB} , RGR_{ULB} , BMD_{ULB} on the one hand and LAD_{ULB} – on the other hand (hypotheses of the authors of this paper). Within the outlined framework and considering TAE categories 1, 2, it is clear that $\log_e TDM$ is an allomeric function $\log_e NAR$ and $\log_e LAD$, or $\log_e RGR$ and $\log_e BMD$. However, $\log_e GDM$ is not identical to $\log_e TDM$ plants, nor $\log_e DM$ of the ULB and therefore cannot be immediately represented in a list of terms containing $\log_e NAR_{ULB}$ and $\log_e LAD_{ULB}$, or $\log_e RGR_{ULB}$ and $\log_e BMD_{ULB}$.

(Since among the NAR_{ULB} , RGR_{ULB} if there are values less than 0, then instead of $\log_e N$, $\log_e R$ in the future, the logarithms of the squares corresponding to Vrb. were used.)

Such considerations are valid for $R = f(N)$ (TAE categories 3, 4, and for assumed predestinations N, R, B with index L. In connection with the above, the authors of this paper found conceptually characterised coordinates as OLD with the use of an untransformed criterion variable and IV, using making a linear path (MLP) exponential-power (LE), semi-log (SL), log (LG) and modified logit or log-normal (ML) Eqs., power-univariate polynomial (PP) functions; selected the best and at the same time the simplest OLD; for each univariate Eq. or multivariate multinomials Eq. sequential IV exclusion based on two-way values was performed $\alpha = 0.01-0.1$ (typical approach in GNU Regression, Econometrics and Time-Series Library) (all this is similar to the previous post (Stasiv et al., 2023)). Depending on “single-” or “multi-regression”, the type of criterion Vrb. (M, or N, or N, R, B), and compliance with TAE classical analysis of plant growth (TAE categories 1,

2, 3, 4), or to the consistency of N, R, B with the L trait assumed by the authors of this paper, the obtained OLD were divided into 4 categories. This classification of OLD certainly differs from the one previously presented by O. Stasiv et al. (2023), but to a certain extent consistent with the principles of the conditional process analysis and, among other things, contains components of moderation and mediation of the Vrb. (Hayes & Rockwood, 2020; Igartua & Hayes, 2021).

Category 1. 2-regressor polynomial predestination $\log_e M$ signs N, L (LE-function – (10A-1), (10b-1)), $\log_e M$ by IV $\log_e R^2, \log_e B$ (LG-function, or “logarithm dependence” of the LE – (11-1) type), and $\log_e (M_m \cdot 10^4/M) = b_0 + b_2L + b_3R + b_6L^2$ as a result of sequential exclusion of IV from the OLD type $\log_e (M_m \cdot 10^4/M) = b_0 + b_1N + b_2L + b_3R + b_4B + b_5N^2 + b_6L^2 + b_7R^2 + b_8B^2 + b_9N \cdot L + b_{10}R \cdot B$ (multinomial ML-function – (12-1)).

$$\log_e M = 4.001 + 0.311 \cdot L - 0.010 \cdot L^2 - 0.030 \cdot N \cdot L$$

$$\alpha < 0.01 \quad \alpha < 0.01 \quad \alpha < 0.01 \quad \alpha < 0.01, \quad (10a-1)$$

$$\log_e M = 4.272 - 0.282 \cdot N + 0.262 \cdot L - 0.008 \cdot L^2$$

$$\alpha < 0.01 \quad \alpha < 0.01 \quad \alpha < 0.01 \quad \alpha < 0.01, \quad (10b-1)$$

$$\log_e M = 6.109 - 0.096 \cdot \ln R^2 - 0.428 \cdot \ln^2 B - 0.007 \cdot \ln^2 R^2$$

$$\alpha < 0.01 \quad \alpha < 0.01 \quad \alpha < 0.01 \quad \alpha < 0.05, \quad (11-1)$$

$$\log_e (615 \cdot 10^4/M) = 11.314 - 0.258 \cdot L + 0.162 \cdot R + 0.008 \cdot L^2$$

$$\alpha < 0.01 \quad \alpha < 0.01 \quad \alpha < 0.01 \quad \alpha < 0.05, \quad (12-1)$$

where $\alpha < 0.1, \alpha < 0.05, \alpha < 0.01$ under OLD – corresponding statistical reliability of OLD coefficients.)

Category 2. Linear and power polynomial coordinates $\log_e M$ separately from IV N, L, R, B (LE functions – (13A-2) – (16-2)).

$$\log_e M = 6.216 - 1.070 \cdot N$$

$$\alpha < 0.01 \quad \alpha < 0.01, \quad (13a-2)$$

$$\log_e M = 6.362 - 1.902 \cdot N - 7.231 \cdot N^2 + 30.586 \cdot N^3 - 26.084 \cdot N^4$$

$$\alpha < 0.01 \quad \alpha < 0.01 \quad \alpha < 0.1 \quad \alpha < 0.05 \quad \alpha < 0.05, \quad (13b-2)$$

$$\log_e M = 4.004 + 0.281 \cdot L - 0.008 \cdot L^2,$$

$$\alpha < 0.01 \quad \alpha < 0.01 \quad \alpha < 0.05, \quad (14-2)$$

$$\log_e M = 6.234 + 0.587 \cdot R,$$

$$\alpha < 0.01 \quad \alpha < 0.01, \quad (15a-2)$$

$$\log_e M = 6.290 - 10.588 \cdot R^4 + 40.002 \cdot R^6 - 42.034 \cdot R^7 + 12.242 \cdot R^8$$

$$\alpha < 0.01 \quad \alpha < 0.05 \quad \alpha < 0.1 \quad \alpha < 0.1 \quad \alpha < 0.1, \quad (15b-2)$$

$$\log_e M = 4.134 + 5.271 \cdot B - 3.007 \cdot B^2$$

$$\alpha < 0.01 \quad \alpha < 0.01 \quad \alpha < 0.1, \quad (16-2)$$

where $\alpha < 0.1, \alpha < 0.05, \alpha < 0.01$ under OLD – corresponding statistical reliability of OLD coefficients.)

Category 3. ML-predestination R by N .

$$\log_e ((1.65/R + 4 \cdot 10^2) \cdot 10^5) = 17.765 + 0.357 \cdot \log_e N^2 +$$

$$+ 0.210 \cdot \log_e \log_e^2 N^2 +$$

$$\alpha < 0.01 \quad \alpha < 0.01 \quad \alpha < 0.01,$$

$$+ 0.098 \cdot \log_e^2 \log_e N^2 - 0.049 \cdot \log_e \log_e^2 \log_e N^2$$

$$\alpha < 0.01 \quad \alpha < 0.1 \quad (17-3)$$

where $\alpha < 0.1, \alpha < 0.05, \alpha < 0.01$ under OLD – corresponding statistical reliability of OLD coefficients.)

Category 4. Coordinations N, R, B with a trait L (ML-multinomials – (18-4), (19-4), PP-functions – (20-4)).

$$\log_e (-0.395 \cdot 10^5 / \log_e N^2) = 11.103 - 0.051 \log_e L^4$$

$$\alpha < 0.01 \quad \alpha < 0.01, \quad (18-4)$$

$$\log_e ((1.65/R + 4 \cdot 10^2) \cdot 10^5) = 17.590 - 0.002 \cdot L^3 +$$

$$+ 0.332 \cdot 10^{-3} \cdot L^4 - 1.427 \cdot 10^{-5} \cdot L^5$$

$$\alpha < 0.01 \quad \alpha < 0.05 \quad \alpha < 0.05 \quad \alpha < 0.05, \quad (19-4)$$

$$B = 0.105 + 0.648 \cdot 10^{-2} \cdot L^2 - 0.024 \cdot 10^{-2} \cdot L^3$$

$$\alpha < 0.01 \quad \alpha < 0.01 \quad \alpha < 0.1, \quad (20-4)$$

where $\alpha < 0.1, \alpha < 0.05, \alpha < 0.01$ under OLD – corresponding statistical reliability of OLD coefficients.)

(Accompanying descriptions: 615, 1.65, -0.395 represent the theoretical (expected) maximum values of the criterion Vrb.; $10^2, 10^4, 10^5$ – a posteriori values for “fitting” OLD; M, N, L, R, B – GDM, $NAR_{ULB}, LAD_{ULB}, RGR_{ULB}, BMD_{ULB}$, respectively). Of course, the fact of suboptimal complexity for Eq. interpretations (21-3) is an additional reason and substantiation for the search for alternative predestinations N, R, B by L (OLD category 4). However, all the OLD presented above were marked with statistically suitable characteristics in the plans for checking linearity (squares, cubes, squares + cubes, logarithms), heteroskedasticity (White, Breusch-Pagan), normal distribution of residuals, and structural stability of the data sample (See O. Stasiv et al. (2023)).

To evaluate the analytical achievement indicators generated by OLD, the study used “standard” highly professional measures, in particular for the field of “Econometrics”, built into the GNU Regression, Econometrics and Time-Series Library: 1) standard sampling error (SSE); 2) Fisher’s coefficient (Φ); 3) adjusted coefficient of determination (ACD); 4) mean absolute %-error ($E_{MA\%}$); 5) logarithm of the likelihood (LL), Akaike, Bayesian, Hannan-Quinn information measures – AIM, BIM, HQM; 6) Theil U decomposition criterion; 7) AC-criterion; 8) MC-criterion - fractions of variances (ϕ), variance-inflation coefficients (v), predestination numbers (η) (similar to the previous study by O. Stasiv et al. (2023)). All generated Eqs. described $\Phi \subset \alpha \leq 0.001-0.01$ (Table 4). Least satisfactory $SSE, ACD, E_{MA\%}$ were inherent to Eqs. (13a-2), (18-4); most suitable $SSE, ACD, E_{MA\%}$ – in (10a-1)-(12-1), (14-2), (16-2), (20-4); intermediate $ACD, SSE, E_{MA\%}$ – in Eqs. (13b-2), (15a-2), (15b-2), (17-3), (19-4).

Table 4. Key analytics dashboard of the generated OLD (of the individual and by category)

# and category of OLD	General criteria of statistical reliability				LL	Highly specific information measures		
	$E_{MA\%}$	Φ	ACD	SSE		AIM	BIM	HQM
Category 1								
10a-1	0.612	176.592 ^f	0.9777	0.061	20.361	-32.723	-30.463	-33.187
10b-1	0.652	178.814 ^f	0.9780	0.060	20.441	-32.882	-30.623	-33.347
11-1	0.637	153.864 ^f	0.9745	0.065	19.482	-30.964	-28.704	-31.428
12-1	0.388	188.456 ^f	0.9791	0.059	20.777	-33.554	-31.294	-34.019
Category 2								
13a-2	3.492	17.657 ^{ff}	0.5813	0.263	-0.013	4.027	5.157	3.795
13b-2	2.125	8.910 ^{ff}	0.7250	0.213	4.790	0.420	3.244	-0.161
14-2	1.008	128.278 ^f	0.9550	0.086	15.102	-24.201	-22.510	-24.553
15a-2	3.154	23.769 ^f	0.6549	0.239	1.243	1.514	2.644	1.281
15b-2	2.212	9.650 ^f	0.7425	0.207	5.217	-0.434	2.391	-1.014
16-2	1.637	56.966 ^f	0.9032	0.127	10.124	-14.249	-12.554	-14.597
Category 3								
17-3	0.164	8.013 ^{ff}	0.7004	0.047	24.342	-38.685	-35.860	-39.266
Category 4								
18-4	4.106	18.946 ^{ff}	0.5993	0.550	-9.594	23.188	24.318	22.956
19-4	0.155	14.245 ^f	0.7680	0.042	25.241	-42.481	-40.221	-42.946
20-4	3.321	357.598 ^f	0.9834	0.020	34.259	-62.518	-60.8234	-62.867

Note: ^f, ^{ff} – $\alpha \leq 0.001$, $\alpha \leq 0.01$; $E_{MA\%}$, Φ , ACD, SSE, LL, AIM, BIM, HQM – mean absolute %-error, Fisher's statistics, adjusted coefficient of determination, standard sampling error, logarithm of the likelihood, Akaike, Bayesian, Hennen-Quinn information measures, respectively

Source: developed by the authors based on O. Stasiv et al. (2023)

Mostly, clear correspondences between SSE, ACD, $E_{MA\%}$ on the one hand and LL, and AIM, BIM, HQM – on the other hand, detected for the groups of Eqs. (10a-1)-(12-1), (14-2), (16-2), (20-4), and for Eqs. (17-3), (19-4) (Table 4; comparison with O. Stasiv et al. (2023)). Low LL (among other things $LL < 0$), significant AIM, BIM, HQM (among other things > 0) confirm the low probability of analytical forms of predestination M sign N , or N trait L in Eqs. (13a-2), (18-4), M by Vrb. N or R in Eqs. (13b-2), (15a-2), (15b-2).

Value of Theil ($U1$) inequality coefficients for all subordinates were $<< 1$ (0.00099-0.02596) and > 0 , certifying their total forecast accuracy and quality (Fang et al., 2020). Other relevant measures of Theil U decomposition of the mean error MSE – the disturbance proportion (UD – is a result from source of the random error), the regression proportion and the bias proportion (UR, UM, respectfully; they are the result from sources of systemic errors in model parameters) had optimal values for each OLD, i.e., 1, 0, 0, respectively, thus confirming the totals in the previous sentence (Ferrentino & Vota, 2020).

None of the AC were found in the list of generated Eqs. However, unlike the previous notice (Stasiv et al., 2023) Eqs. (10a-1), (10b-1), (12-1) – (15b-2), (17-3), (19-4), (20-4) had unknown zones for AC (Table 5). It is worth noting that the Vrb. M , N , L , R , B are estimates of ecological and physiological processes in winter wheat crops. A number of researchers, in particular J. Martínez-Minaya et al. (2018), G. Gaspard et al. (2019),

formulated the idea that the structure of the development of ecological or biological processes is developed under the conditions of interaction of "spatial" and "temporal" abiotic and biotic factors, causing spatial autocorrelation (SAC), rSAC (residual SAC), and temporal correlation. In addition, the researchers emphasise that the potential source of AC, rSAC, may be some features that arise in the course of obtaining and processing environmental data, for example, failure to take into account of the contagious biotic processes (growth, mortality, etc.), scales and distances, inability to choose the appropriate localised and Vrb. with SAC (omitted Vrb), sample design, hypotheses and methodological approaches, etc. The authors of this paper are inclined to assume that the uncertain zones for AC in the above-mentioned OLD (this paper) are at least partly conditioned by the failure to take into account the not yet established aspects of (inter-) coordination between ULB growth traits, an insufficiently perfect analytical form, and/or omitted Vrb. Optimal ways out of this situation could be to change the analytical forms of the corresponding OLD using basic functions, including Moran I (Pedersen et al., 2019), and in the directions of the generalised additive model (GAM), the hierarchical generalised linear models (HGLM) (Pedersen et al., 2019), the generalised additive mixed models (GAMM) (Baayen et al., 2018). A well-known alternative to such approaches – consideration of AC in OLD – can be done by looking for AC coefficients and data lags, and constructing AR, MA, ARMA and ARIMA, as mentioned by P. Das (2019).

Table 5. The most important benchmarks of the AC and MC for the OLD (of the individual and by category)

# and category of OLD	AC-criteria			MC-criteria		
	D-criterion	$\rho > 0$ or $\rho < 0$	Uncertainty zone	η (max)	ϕ (total interval)	ν (total interval)
Category 1						
10a-1	3.03861	None	Yes ^b	47.525	0.885-1.000	1.433-37.027
10b-1	2.86054	None	Yes ^b	46.460	0.861-1.000	2.030-33.490
11-1	1.83745	None	None	10.629	0.915-0.988	1.769-14.533
12-1	2.85631	None	Yes ^b	10.074-46.673 ^c	0.767-1.000 ^d	2.375-33.859
Category 2						
13a-2	1.10258	None	Yes ^a	– ^e	– ^e	– ^e
13b-2	1.13358	None	Yes ^a	18.927-87.332 ^c	0.693-1.000 ^d	12.580-862.448
14-2	1.47929	None	Yes ^a	43.006	0.942-1.000	32.683-32.683 ^f
15a-2	1.16510	None	Yes ^a	– ^e	– ^e	– ^e
15b-2	1.12215	None	Yes ^a	12.134-6438.357 ^c	0.567-1.000 ^d	14429.852-5710158.011
16-2	1.83822	None	None	44.468	0.944-1.000	38.110-38.110 ^f
Category 3						
17-3	1.81374	None	Yes ^a	64.594	0.598-1.000	7.536-223.971
Category 4						
18-4	1.66049	None	None	– ^e	– ^e	– ^e
19-4	1.40682	None	Yes ^a	19.945-409.846 ^c	0.678-1.000	2834.572-14396.170
20-4	2.81928	None	Yes ^b	31.429	0.815-1.000	46.188-46.188 ^f

Note: ρ – AC-coefficient; ^{a, b} – zones of uncertainty AC at intervals $dL < D < dU$, $4-dU < D < 4-dL$, respectively; n, ϕ, ν – predetermination numbers, fractions of variances, variance-inflation coefficients, respectively; ^{c, d} – intervals for N (max) and ϕ in the presence of $N \geq 10 - N \geq 30$; ^e – MC-criteria are missing because Eq. contains only one variable; ^f – ν is the same in the case of the 1st and 2nd Vrb

Source: developed by the authors based on O. Stasiv et al. (2023)

Similarly, to the report by O. Stasiv et al. (2023), in multi-step polynomial and single-step multi-step multi-step Eqs. generated in this paper, ((10a-1) – (12-1), (13B-2), (14-2), (15b-2) – (17-3), (19-4), (20-4)), a significant MC in terms of ϕ, ν, η was observed (Das, 2019; Kim, 2019) (Table 5). According to A. Kalnins (2018), MC can often be driven by a common cause with IV (a common source of measurement error or a statistically robust unobserved Vrb.) and a significant but idiosyncratic term. This phenomenon can cause type 1 errors (false positive results) – an overestimation of the β of the OLD, their statistical validity, and a change in the sign to the opposite. Therefore, MC, like AC or uncertainty zones for AC, can be caused by the influence of the omitted reasons on the behaviour of IV; however, the nature of such reasons and their effect on IV is different in each case.

Additionally, attention should be paid to the fact that Eqs. (10a-1)-(12-1), (14-2), (16-2) are mostly non-hierarchical (with the exception of (14-2), (16-2)) polynomial predestinations of the criterion Vrb. by the IV, it is clear that such properties of analytical forms will lead to overfitting OLD (Montgomery, 2021). However, D. C. Montgomery (2021) noted that the use of multilingual OLD is appropriate for approximating functions with unknown and possibly very complex nonlinear dependencies, i.e., similar to those found in this paper. Interesting in this sense is, in particular, that polynomial

regression can be both an “essential” process in artificial neural networks and an alternative to the latter (Cheng et al. 2018). Therefore, polynomial regression can be considered as, to some extent, an alternative to machine learning algorithms, and as a means for solving complex nonlinear problems.

The authors of this study suggest that Eqs. (10a-1)-(12-1), (14-2), (16-2) for predestination M by the IV N, L, R, B , and also R, B by the IV L (OLD (19-4), (20-4)) empirically and stochastically satisfactorily describe the conditionality and subordination between the evaluated ecological and physiological characteristics of winter wheat under the studied agrotechnical influences. Naturally, the presence of omitted Vrb., that affect such coherence is an objective condition for the existence of the latter. Eqs. (17-3), which characterises predestination of R by the N unfortunately, cannot be considered properly due to the excessive complexity of its interpretations.

DISCUSSION

Decrease to positive values or immutability of NAR_{ULB} , RGR_{ULB} in research variants vs. C.0, 1.1, 2.1, at least to some extent, were conditioned by the balance between (i) increase or stabilisation of DM, DMI_{ULB} , $LDMC_{ULB}$ (explained by J.L. Miglioli et al. (2020), at defoliation – K.E. Mueller et al. (2024)), respectively, with unidirectional AI_{ULB} changes, and probably LAR, LNC, LPC (under defoliation – R. Bhadouria et al. (2023)), a decrease in

the intensity of photosynthesis (Rezvani-Moghaddam, 2020) (tubing – flowering; early leaf ageing), (ii) a subsequent decrease in photosynthetic activity, typical increases in the rate of respiration (Rezvani-Moghaddam, 2020), outflow of photoassimilates and remobilisation of ULB resources, accompanied by a decrease in DMI_{ULB} , $LDMC_{ULB}$, AI_{ULB} (earring – milky ripeness). The changes in DMB_{ULB} , AI_{ULB} specified in (ii) can lead to RGR_{ULB} , $NAR_{ULB} \leq 0$ (Lamont *et al.*, 2023). Since, according to J. Gu *et al.* (2018), negative leaf growth is accompanied by a decrease in plant RGR, then winter wheat with RGR_{ULB} , $NAR_{ULB} < 0$ reached full ripeness the fastest. Simultaneously, LAD_{ULB} , BMD_{ULB} changed reciprocally, relative to NAR_{ULB} , RGR_{ULB} . Such trade-offs can be scaled to the level of plants, leaf cover, and mediate the development of optimal eco-resistant results of the winter wheat production process.

A. Bilal *et al.* (2019) demonstrated that for TDM-seed Bt. cotton yield $tr = 0.94$, $\alpha \leq 0.05$. Therefore, the components of bioproductivity can be significantly determined by GI – NAR, LAD, RGR, BMD. For example, after exposure to biological agrotechnical factors on alfalfa, both NAR, RGR, and CGR grew, parts of which are components of biological products (Khirkhah *et al.* 2019). Confirming this, H. Tiwari *et al.* (2023) documented unidirectional increase of RGR, NAR, CGR, bio-productivity components, wheat harvest index (HI), whereas P. Kumar and S.K. Brar (2021) cited studies in which there were simultaneous increases in LAD, NAR, CGR, and HI. Simultaneous increases in LAI, CGR, and yield structure indicators in wheat (Khan *et al.*, 2023), LAI, NAR, dry matter volumes and economic productivity of rice (Islam *et al.* 2019). It is well known that FLB (“functional leaves”) is important for providing 45-58% of wheat’s photosynthetic activity at the grain completion stage (Liu *et al.*, 2019), the contribution of more than 80% of the top three leaves of cereals to photosynthesis of the entire plant at the grain maturation stages (Du *et al.* 2019). However, the authors of this paper did not find scientific reports with a comprehensive analysis of the (inter-) conditions of the classical interval GI of the upper leaves (in particular, FLB, PFLB) and a bioproductivity of winter wheat (*Triticum aestivum* L.) due to the influence of agrotechnical and technological factors on it.

This paper documents the presence of stochastic essential 2D GDM– LAD_{ULB} co-subordination of, low-expressive 2D GDM– BMD_{ULB} co-ordinations, and the absence of statistically clear subordination of GDM– NAR_{ULB} , GDM– BMD_{ULB} . The presentation of the determinants of the GDM growth trait ULB, and then the individual GI analytical forms of OLD among themselves, allowed a deeper and more diverse understanding of the complex principles of development of the final bioproductivity of winter wheat (primarily in terms of $\pm \Delta DMI_{ULB}$, $\pm \Delta AI_{ULB}$) under “model” conditions of BFS. Among the generated OLD that characterise the development of GDM depending on GI of the ULB, Eqs. (10a-1)–(12-1),

(14-2), (16-2) is completely statistically satisfied. It follows from them that not M , but $\log_e M$ are non-linearly determined by 2-regressor conjugations N, L or R, B ((10a-1), (10b-1)), whereas MLP ML function M – combinations of L and R (12-1) (multinomials). In (10a-1), (10b-1) $\log_e M$ is positively coordinated with L , but negative – with $L^2, N, N \cdot L$, at the same time, in (12-1) the MLP ML function M is negatively predetermined L , but positive – L^2, R . In (11-1), $\log_e M$ is effectively coordinated with $\log_e R^2, \log_e B$ but not with R, B .

Considering TAE category 3 (“INTRODUCTION”), the basis of the relevant ideas published by S. Tripathi *et al.*, (2018), it is clear that (i) light intensity, (ii) reach, capture of alimentary resources from the soil and/or atmosphere, (iii) their interactive effects affect RGR, and each of the growth components: an increase in (ii) causes an increase in LAR by increasing LMF, RMF (root mass fraction), a decrease in LMA; an increase in (i) causes an increase in NAR, LMA, and a decrease in LAR; multivariate studies are important for understanding (iii) (Tripathi *et al.*, 2018). Typically, NAR variations lead to RGR changes if NAR does not have a negative covariance with LMF or SLA (Gómez-Fernández *et al.*, 2022). In accordance with the presented ideas, plant biomass allocation (BA) takes place in line with the “theory of optimal biomass allocation”: for optimal growth, plants will distribute biomass to the organ that captures the most growth-limiting resources. Differences in ontogenetic drifts of GI and BA also lead to trade-offs, in particular between NAR and LAI, or RGR, and investment in structural components, tissue renewal, and self-shading (Islam *et al.*, 2019). The trade-offs (NAR_{ULB}, RGR_{ULB}) – (LAD_{ULB}, BMD_{ULB}) found in this paper, statistically reliable negative values tr for LAD_{ULB} – NAR_{ULB} , BMD_{ULB} – RGR_{ULB} resemble the constructs of plant GI ratios outlined in this paragraph; significant tr , pr for RGR_{ULB} – NAR_{ULB} allow predicting $RGR_{ULB} \sim NAR_{ULB}$ (as confirmation – TAE category 4 (“INTRODUCTION”). Through nonlinear coordination of the ML function R with $\log_e N^2$ (Eq. (17-3), interpretive suboptimality) a likely alternative would be $RGR_{ULB} \sim SLA_{ULB}$ or the involvement of the nearest morphological Vrb. – LAD_{ULB} : this is consistent with significant positive and negative values tr for LAD_{ULB} – BMD_{ULB} , LAD_{ULB} – NAR_{ULB} , LAD_{ULB} – RGR_{ULB} , statistically reliable positive pr for LAD_{ULB} – BMD_{ULB} ; mathematically $SLA \sim LAI$ (LAD component) and $SLA \sim 1/LDM$ (Bosi *et al.* 2020). Therefore, non-hierarchical polynomial OLD was generated between ML functions N^2, R, B and L , among which the second (19-4) and third (20-4) are statistically satisfied; these Eqs. are less difficult than (17-3).

According to K. Kikuzawa *et al.* (2018), and according to TAE category 3, the larger the RGR, the smaller the LMA and is directly proportional to it by LL. According to this, leaf economic spectrum (LES) is considered: long-lived plant species with structurally valuable leaves (high LL, LMA), low instantaneous net photosynthetic

rate Aarea, NAR – fast-growing species with short-lived leaves, high RGR, Aarea (NAR), low LL, LMA. Both in the case of TAE categories 1, 2 and in terms of functional ecology, the increase in carbon over plant life (net production) is proportional to the products of (i) functional LL or biomass duration, respectively, and (ii) of the average instantaneous rate of photosynthesis normalised by weight. This implies a close or identical essence of LAD, BMD, and LL. The influence of LAI on LL was previously noted by I.C. Dodd and E.D. Elphinstone (2021). Consequently, LAD, BMD play a central role in classical plant growth analysis, whereas LAD_{ULB} , BMD_{ULB} – significantly determine the remaining signs of ULB growth and probably GDM. This opinion corresponds to the correlation matrices presented in this paper (the value and statistical reliability of mutual agreements with L , B). The contribution of L is significant and statistically reliable in the development of $\log_e M$ in (10a-1), (10b-1), (12-1), (14-2), ML functions R (19-4), in deployment B (20-4); it is important that $\log_e M \sim \log_e^2 B$ (11-1).

Since OLD $\log_e M$ from N or R in (13A-2), (13B-2), (15A-2), (15B-2) are characterised by unsatisfactory LL , and AIM, BIM, HQM, then GDM should not depend on NAR_{ULB} or RGR_{ULB} , either depend on them weakly, or non-linearly. This corresponds to the basic concepts proposed by J.L. Araus et al. (2021): the result of the production process of agricultural crops is not determined or insufficiently, or is not directly determined by the efficiency of leaf photosynthesis, but source-sink relations, RUE, architecture and duration of the (green) leaf cover play a crucial role in its development. The latter type of traits will be determined by the functional LL, LAD size of the culture population. This makes it fundamentally possible to scale to the level of leaf cover of LAD_{ULB} , BMD_{ULB} – the most important GI of the ULB for GDM development. Thus, in the “successful” OLD (10A-1) – (12-1), except L or B , also present N or R . Since NAR_{ULB} , RGR_{ULB} characterise the average rate of BA in the area or ULB biomass, then it is reasonable to assume that GDM can be caused by BA, both at the level of ULB and at the level of parts of the whole plant, in particular the structures of reproductive organs.

Thus, the statistically reliable (inter-) dependence of winter wheat GDM (full maturity) on LAD_{ULB} and BMD_{ULB} (tubing – milky ripeness), i.e., on ULB growth traits that can be scaled to the level of crop leaf cover, is fundamentally explainable. These subordinates do not contradict, but rather correspond to, (mutually) coordinated ULB-growth terms, similar to multipliers in TAE category 3 (“INTRODUCTION”), with the LAD_{ULB} trait.

The authors of this study consider a middle way between the approaches proposed by M. Weemstra et al. (2023) to consider plant functional traits (PFT) of the whole plant (underground + aboveground parts) and, for example, the findings of N. An et al. (2021), which attest to the influence of agroclimatic conditions on resource capture and leaf construction costs (SLA,

LMA, LDMC, LNC), and, in particular, the findings of J.L. Araus et al. (2021) in terms of prioritisation of plant traits that scale to leaf cover, crown, and seeding. It is clear that in subsequent studies, it is advisable to search for similar allometric Eqs. (10A-1)-(16-2) GDM predeterminations not only by the GI of the ULB, but also by features similar to BA (DM investment in the ULB – LMA_{ULB} area, area reinvestment in DM of $ULB-SLA_{ULB}$, average leaf area, leaf DM – dimensions of source), of the reproductive allocation (RA, see G. Li et al. (2019); average volumes of ULB biomass outflow on leaf DM, or GDM, or GDM/leaf DM), among other things, for the purpose of “embedding” the GI of classical growth analysis of even ULB itself in broader, but still compact systems of causal relationships woven into the processes of formation of potential, relevant bio-, eco-important and economically valuable features under various agrotechnical and technological influences. The development of appropriate networks and/or groups of plant traits can help solve a number of inconsistencies in the scientific area.

CONCLUSIONS

The potential possibilities and significance of empirical and statistical (mutually) predeterminations of the levels of an agroecologically important component of the production process of winter wheat (grain dry mass, single-character designation – M) potentially scalable integral growth traits of the upper leaves blades (ULB), which characterise the development power of their photosynthetic apparatus – leaf area duration or biomass duration (L , B , respectively), under the conditions of “model” biological and agrotechnical influences (biologised fertilisation systems – BFS). For the development of M , the consolidated additive effects of one of the above-mentioned ULB growth traits and non-scaled features of the average ULB growth rate (net assimilation rate, relative growth rate – N , R), for example, combinations N and L , or R and B , or L and R . Statistically reliable unidirectional changes of L , B , on the one hand, and M – on the other hand, and simultaneous inversely directed variations N , R , found obvious trade-offs (in terms of reciprocity of changes in the indices under consideration) between potentially scalable and non-scalable ULB growth traits (L , B vs. N , R , respectively).

In passing with the expected statistically reliable empirical (mutually) consistency between R and N in the direction of well-established regularities of functional ecology and classical analysis of plant growth, the analytical form of predestination of the first of these features of the second was too complex for semantic and abstract-logical interpretations. Analytical forms of predetermination of criteria can be quite appropriate partial alternatives to such subordination between the specified ULB growth traits of winter wheat R or B sign L . However, N , most likely, did not

depend, or was difficult to coordinate with *L*. The identification of semantic and statistical weights of growth traits, the distribution of biomass in the components of the plant and/or sowing within existing and/or newly found networks and groups of such indices can be important for deepening ideas about the patterns of development of the final biological results of the pro-

duction process in winter wheat.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Стохастичні зумовленості складника біопродуктивності рисами росту пластинок верхніх листків пшениці озимої

Ангеліна Дубицька

Кандидат сільськогосподарських наук, провідний науковий співробітник
Інститут сільського господарства Карпатського регіону Національної Академії Аграрних Наук
81115, вул. Грушевського, 5, с. Оброшине, Україна
<https://orcid.org/0000-0002-5685-0237>

Оксана Качмар

Кандидат сільськогосподарських наук, старший науковий співробітник
Інститут сільського господарства Карпатського регіону Національної Академії Аграрних Наук
81115, вул. Грушевського, 5, с. Оброшине, Україна
<https://orcid.org/0000-00020382-6030>

Олександр Дубицький

Кандидат біологічних наук, старший науковий співробітник
Інститут сільського господарства Карпатського регіону Національної Академії Аграрних Наук
81115, вул. Грушевського, 5, с. Оброшине, Україна
<https://orcid.org/0000-0002-8293-4119>

Оксана Вавринович

Кандидат сільськогосподарських наук, старший науковий співробітник
Інститут сільського господарства Карпатського регіону Національної Академії Аграрних Наук
81115, вул. Грушевського, 5, с. Оброшине, Україна
<https://orcid.org/0000-0003-3466-1432>

Зиновій Котик

Кандидат технічних наук, доцент кафедри
Національний університет «Львівська політехніка»
79013, вул. Бандери, 12, м. Львів, Україна
<https://orcid.org/0000-0002-7725-0791>

Анотація. Відносна та абсолютна важливість низки ознак, зокрема, агрофізіологічних, морфофункціональних, на рівні окремих органів і частин цілісної рослини та/або посіву для розвитку особливостей біологічних ознак та інших агроекологічно значущих складових продукційного процесу рослинництва, обговорюється в наукових працях вже тривалий час. Метою роботи був пошук агроекологічно значущих ознак росту верхніх листових пластинок (GDM), які можуть емпірично та потенційно визначати розвиток сухої маси зерна (ULB) пшениці озимої за «модельних» умов біологічних агротехнічних впливів, позначених як системи біологічного удобрення. Методи дослідження: методичні підходи польового досліду, гравіметричний, конвективного сушіння та стохастичні методи. Розвиток GDM значною мірою визначався потенційно масштабованими інтегральними ростовими ознаками ULB – тривалістю листової поверхні, тривалістю біомаси (LAD_{ULB} , BMD_{ULB} , відповідно) або їх комбінаціями з потенційно немасштабованими характеристиками середньої швидкості росту ULB – чистою асиміляційною швидкістю, відносною швидкістю росту (NAR_{ULB} , RGR_{ULB} , відповідно). Також дуже ймовірно, що LAD_{ULB} може відігравати центральну роль у розвитку RGR_{ULB} або BMD_{ULB} (але не NAR_{ULB}). Координація RGR_{ULB} з NAR_{ULB} не була виключена, хоча вона була надто складною. Побудова таких і подібних досліджень у руслі вичерпного пояснення послідовних системно-механістичних зумовленостей продукційного процесу з ознаками зростання ULB за різних агротехнічних і біологічних впливів сприятиме вдосконаленню дискурсивних і математичних імітаційних конструкцій, здатних характеризувати та інтегрувати диференційовані впливи рослинних компонентів на фотосинтез листового покриву, крони і, зрештою, на процеси розвитку складових кінцевого біологічного та економічного врожаю озимої пшениці

Ключові слова: ознаки або особливості росту верхніх листових пластинок; тривалість періоду формування листової поверхні та біомаси; чиста асиміляція та відносна швидкість росту; озима пшениця; «модельні» біологічно покращені агрономічні умови – біологічно покращені системи удобрення

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Ecological stability, plasticity, and adaptability of cowpea varieties (*Vigna unguiculata* (L.) Walp. *subsp. sesquipedalis* (L.) Verdc.)

Iryna Bobos

PhD in Agricultural Sciences, Associate Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
<https://orcid.org/0000-0001-5193-7192>

Oleksandr Komar*

PhD in Agricultural Sciences
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
<https://orcid.org/0000-0001-7511-4190>

Ivanna Havrys

PhD in Agricultural Sciences, Associate Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
<https://orcid.org/0000-0001-5965-9916>

Oleksandr Shemetun

PhD in Agricultural Sciences, Associate Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
<https://orcid.org/0000-0001-7129-9108>

Vasyl Kokoiko

PhD in Agricultural Sciences, Senior Research Fellow
Institute of Climate-Smart Agriculture of the National Academy of Agrarian Sciences
67667, 24 Mayatska Doroga Str., Khlybodarske Village, Ukraine
<https://orcid.org/0000-0002-2528-7920>

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Abstract. Determining the ecological plasticity and stability of varieties and hybrids of agricultural crops helps to comprehensively assess them, considering the productivity potential, qualitative technological indicators, and the level of resistance to stressful conditions. The purpose of this study was to investigate the development of the yield of beans of cowpea varieties with high ecological stability, plasticity, and adaptability. The leading methods of studying this problem are field-based – to determine the

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*Corresponding author

interaction of the research object with biotic and abiotic factors; statistical – to evaluate the results to determine the parameters of cowpea adaptability. Within the studied varieties, a direct and inverse correlation was established between the yield of cowpea and the sum of effective temperatures. For Groik ($r = 0.36$) and Kafedralna (Control) ($R = 0.36$), U-Cha-Kontou ($r = -0.64$) varieties, the correlation was average, while for Gasson ($r = 0.96$) and American improved ($r = -0.98$) varieties, it was strong. Based on the regression equations, an increase in the amount of precipitation by 1 mm can increase the yield of cowpeas by 3.4 kg/ha in the American improved variety and by 20.8 kg/ha – U-Cha-Kontou, and for the Gasson, Kafedralna (control), Groik varieties, there will be a decrease in yield by 6.4 kg/ha, 10.8 kg/ha, and 20.7 kg/ha, respectively. Varieties with high overall adaptive capacity, defined as the ability of genotypes to maximise the manifestation of traits under all environmental conditions, are valuable. High indicators of total adaptive capacity for plant yield were observed in the varieties Gasson (TAC = 5.16) and Groik (SAC = 2.16). The lowest value of this indicator was observed in the U-Cha-Kontou variety (TAC = -3.44). Varieties that produce high but unstable yields are not able to guarantee maximum yields in conditions of improper farming and difficult climatic conditions. The genotype breeding value is a complex indicator that determines the totality of productivity and stability of varieties. Studies have obtained such fluctuations in this indicator from 0.84 to 13.63. The best varieties in terms of genotype breeding value were Gasson (GBVi = 13.63) and Kafedralna (GBVi = 8.06). There is a relatively low yield stability and the ability to respond to improved growing conditions in the U-Cha-Kontou variety (GBVi = 0.84)

Keywords: legumes; seedpods; technical ripeness; yield, stability; adaptability; plasticity

INTRODUCTION

The population of the whole world, as in Ukraine, is changing approaches to nutrition, which consists in increasing the consumption of products from less common crops. More and more Ukrainians, along with traditional vegetables, require less well-known ones, which are valued for their medicinal properties and are safe for human health. Supermarkets and wholesale markets offer a small number of sparsely distributed vegetable crops. The main reason in Ukraine is the insufficient supply of new products. Over the past decades, the world's food system has experienced several crises, including climate change and the COVID-19 pandemic, war that has disrupted markets and supply chains, and raised concerns about food security. The military conflict between Russia and Ukraine also undermines important principles of food security, as Ukraine has long been known as the breadbasket of Europe (Rabbi *et al.*, 2023).

In this context, sparsely distributed vegetable legumes are a significant factor in meeting the needs of the population in a balanced diet. Vegetable legumes are a valuable source of carbohydrates, vitamins and minerals, and biologically active substances that promote health. Due to the growing awareness of consumers about a balanced diet, there is a constant increase in demand for fresh and processed legumes and vegetables. With this in mind, maintaining optimal yields of vegetable legumes is extremely important (Dhaliwal *et al.*, 2020; Fedosiy *et al.*, 2022).

Despite the significant impact of legumes on global food and food security, solving the problem of restoring and preserving soil fertility, there is also an opinion that their production volumes are still unsatisfactory, compared to the need for them, due to biotic and abiotic factors (Ojiewo *et al.*, 2019; Tanchyk *et al.*, 2021; Hnatiuk *et al.*, 2023). Among legumes, representatives

of the genus *Vigna unguiculata* are becoming increasingly socio-economic, especially in countries where the local population cannot afford animal proteins. According to M. Guney *et al.* (2021), cowpea is a low-calorie source of protein, which makes it worth adding to the diet, especially for those who are vegetarian or prone to obesity. B. Abebe and M. Mulugeta (2022) and A. Quamruzzaman *et al.* (2022) noted that cowpea contains dietary fibre, a number of vitamins and minerals, and is also characterised by a high content of phytochemical antioxidants. It belongs to the category of healthy and high-quality food products.

The value of the crop is its high heat, drought and salt resistance, and the ability to grow it for vegetables, seeds, green manure, and feed. However, annual warming and rising air temperatures accelerate the growth and development of the crop, reducing the duration of phenological phases. Under stressful conditions, plants change their metabolism for optimal development, which is conditioned by increased respiration (Dehodyuk *et al.*, 2021). J. Barros (2021) pointed out that the crop reacts negatively to increased water scarcity and rising temperatures. It is the study of the ecological stability, plasticity, and adaptability of cowpea plants that can help producers change growing technologies to maintain sustainable crop production.

In 2008-2010, for the first time in the northern Forest-Steppe, cowpea varieties were studied and evaluated for early maturity, morphological characteristics, productivity, yield of seedpods and ripe seeds at the Department of Vegetable Crops and Indoor Greenhouse at the National University of Life and Environmental Sciences of Ukraine (Bobos *et al.*, 2022). The selected source material of varietal samples of cowpea was used in breeding work as parent forms. As a result

of breeding, the first Kafedralna variety of cowpea was created, which in 2024 was listed in the State register of plant varieties (2024).

Nowadays, there is a growing interest in the consumption of cowpea, but it remains sparsely distributed. Given the climatic conditions that change every year, there is a need for a comparative assessment of cowpea varieties by phenological, morphological, and economically valuable characteristics. With this in mind, comprehensive research on introduction, creation, and replenishment of the Ukrainian gene pool, and selection of promising samples for further breeding work will significantly expand the range of economically valuable plants aimed at developing the agricultural sector and ensuring a high quality of life for the population. That is why the purpose of this study was to investigate the development of the yield of seedpods of cowpea varieties with high ecological stability, plasticity, and adaptability.

MATERIALS AND METHODS

During 2014-2016, the following cowpea varieties were studied: Groik (Israel), Kafedralna (Ukraine), Gasson (Vietnam), American improved (USA), U-Cha-Kontou (China). Variety samples were obtained from the National Centre for Plant Genetic Resources of Ukraine (n.d.). The research was conducted in the training laboratory "Fruit and vegetable garden" at the collection plots of the Department of Vegetable Crops of the National University of Life and Environmental Sciences of Ukraine. The plot was located on soddy-medium podzolic soils in the northern part of the Forest-Steppe region of Ukraine. The field study was conducted according to the methodology of one-factor experiments (Bondarenko & Yakovenko, 2001). Repeatability – three times with randomisation. The accounting area – 5 m². The control was the Kafedralna variety, which has been approved for use in Ukraine since 2014. The variety was created by the staff of the Department of Vegetable Crops of NUBIP of Ukraine (authors: I.M. Bobos, Z.D. Sych, I.O. Fedosiy, O.O. Komar).

Research continued in 2022-2023 within the framework of the state programme "Development of innovative technologies for growing sparsely distributed vegetable crops" (state registration number: 0122U001637). An examination of the new variety was carried out for the purpose of state registration of the variety for distribution in Ukraine and state registration of rights to it. In 2023, Certificate No. 230516 on state registration and Patent No. 230332 for the Kafedralna cowpea variety (*Vigna unguiculata* (L.) Walp. subsp. *sesquipedalis* (L.) Verdc.) were obtained.

Technology of growing cowpea varieties, adopted in production conditions. Sowing scheme – 70×25 cm. Seed embedding depth – 2-3 cm. Seeds of varieties together with the control were sown simultaneously on May 13 in all years of the study. Plant care consisted of

mulching, systematic loosening, protection from weeds, diseases, and pests. During the field method, phenological phases were noted: full shoots, the beginning and full flowering, the beginning of harvesting ripeness of pods, and economic ripeness of pods. The beginning of maturation was noted for the maturation of the predominant number of pods (more than 75%). The duration of the growing season was determined from sowing to the date of economic ripeness. The period from sowing to germination in varieties ranged from 12 to 17 days and passed with an average sum of effective temperatures of 70.2-105.7°C and precipitation of 42.8-56.8 mm.

Harvesting of pods in technical ripeness was carried out weekly on all variants of the experiment simultaneously. Before harvesting, biometric measurements were made, namely, the length of the central stem was measured and the number of side shoots on the plants was counted. During harvesting, the length of the pod was measured and the number, weight of pods on the plant, and the number of seeds in one pod were determined. The response of a variety to growing conditions characterises the total adaptive capacity (TAC) – the average value of the trait in different environmental conditions, specific adaptive capacity (SAC) – a deviation from the total in a particular environment. Stability is characterised by the ability of a genotype to maintain a specific phenotype under various growing conditions as a result of regulatory mechanisms. Plasticity (bi-regression coefficient for the environment) is the response of a genotype primarily to changes in environmental conditions, expressed in phenotypic variability (Tyshchenko *et al.*, 2023).

A population study with n genotypes in m environments was used for the determination of TAC and SAC. The number of repetitions in this case is c :

$$x_{ikr} = U + V_i + d_k + (Vd)_{ik} + e_{ikr}, \quad (1)$$

where x_{ikr} – phenotypic value (i) of genotype grown in (k) environment in (r) repetition; U – total average of the entire set of phenotypes; V_i – effect of (i) genotype; d_k – effect of (k) environment; $(Vd)_{ik}$ – effect of interaction of (i) genotype with (k) environment; e_{ikr} – effect caused by random causes and attributed to (ikr) phenotype.

Model elements have a set of the following restrictions:

$$\sum_i V_i = \sum_k d_k = \sum_k (vd)_{ik} = \sum_k (vd)_{ik} = \sum_{ik} e_{ik} = 0. \quad (2)$$

At the first stage of evaluating the parameters of TAC and the stability of varieties, a two-factor analysis of variance was performed. The second stage of evaluation included the establishment of TAC, SAC, and stability of varieties. According to the definition, the effect of the total adaptive capacity of the TAC_{*i*} variety is V_i . Deviation from the sum of $U + V_i$ is the effect of the specific adaptive capacity of the variety in the R medium – SAC_{ikr} . This effect combines a linear (R medium effect) and a nonlinear part (interaction effect $(Vd)_{ikr}$).

The SAC parameters of cowpea are defined as follows:

$$\sigma^2 SAC_i = \frac{1}{m-1} * \sum_R (d_R + Vd_{iR})^2 - \frac{m-1}{m} * \sigma^2. \quad (3)$$

$$\sigma SAC_i = \sqrt{\sigma^2 CA3_i}. \quad (4)$$

The values of relative stability S_{gi} used to compare the variability of different characteristics of varieties:

$$S_{gi} = \frac{\sigma_{CA3_i}}{U+3A3} * 100 \%. \quad (5)$$

Regression coefficient b_i was defined:

$$b_i = \frac{\sum X_{iR} * d_R}{\sum d_R^2}. \quad (6)$$

The genotype breeding value (GBVi) was used to identify cowpea varieties that combine productivity and stability:

$$GBV_i = U + 3A3_i - p\sigma_{CA3_i}. \quad (7)$$

The sum of effective air temperatures was calculated by the formula:

$$\sum t_{ef} = (t_{avg} - B) * n, \quad (8)$$

where $\sum t_{ef}$ – sum of effective air temperatures for the period, °C; t_{avg} – average active air temperature for the period, °C; b – biological minimum, which in this study was taken as 10°C; n – number of days in the period.

Variance (ANOVA) and correlation analysis were performed using the XLSTAT add-in in MS Excel software suite. The differences were considered significant for the validity of $\alpha=0.95$ (Rao, 2018). The authors adhered to the standards of the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS

As a result of a study of the yield of commercial seedpods in 5 cowpea varieties with 3 replications of the experiment and 3 replications in time (2014, 2015, 2016) with a sample size $n=45$. The approximate number of groups was $\sqrt{45}$, so 7 groups were selected. In this case, the interval value will be 1.7. A visual representation of the frequency distribution is shown in Figure 1. A step graph (histogram) in the form of columns has a height proportional to the frequencies, and its width, equal to the class intervals, the distribution curve connects the average values of groups with a line.

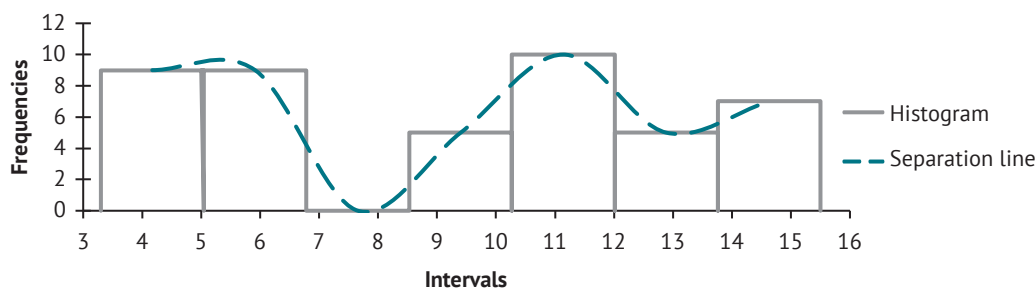


Figure 1. Histogram and yield distribution curve of commercial seedpods of cowpea varieties (2014-2016)

Source: developed by the authors based on the conducted research

Based on the obtained data of the variance analysis $F_{fact.} > F_{crit} = 459.684 > 3.47804$, which indicates

the reliability of these differences at the level of $P_{0.95}$ (Table 1).

Table 1. Results of one-factor analysis of variance (2014-2016)

Source of Variation	SS	df	MS	F	P-value	F crit
Bethwein Groups	209.616	4	52.404	459.684	2.76576 E-11	3.47804
Winter Groups	1.14	10	0.114			
Total	210.756	14				

Source: developed by the authors based on the conducted research

Judging by the coefficient of determination ($R^2 = 0.13-0.95$), approximately 2% in the Groik variety, 17% – U-Cha-Kontou, 43% – Kafedralna (control), 84% – Gasson, and 91% – American improved) of changes in the yield of seedpods were conditioned by changes in the sum of effective air temperatures and only, respectively, by 98%, 83%, 57%, 16%, and 9% of the changes

were conditioned by other factors. Within the variants under study, a direct and inverse correlation was established between the yield of cowpeas and the sum of effective temperatures. For Groik ($r=0.36$) and Kafedralna (Control) ($R=0.36$), U-Cha-Kontou ($r=-0.64$) varieties, the correlation was average, while for Gasson ($r=0.96$) and American improved ($r=v-0.98$) varieties, it was strong.

Based on the regression equations presented in Figure 2, it can be assumed that an increase in the sum of effective temperatures by 1°C corresponds to both an increase in the yield of seedpods for the varieties Groik (2 kg/ha), Kafedralna (control) (2.5 kg/ha), Gasson (2.2 kg/ha), and a decrease – for the varieties American improved (2.0 kg/ha), U-Cha-Kontou (2.4 kg/ha).

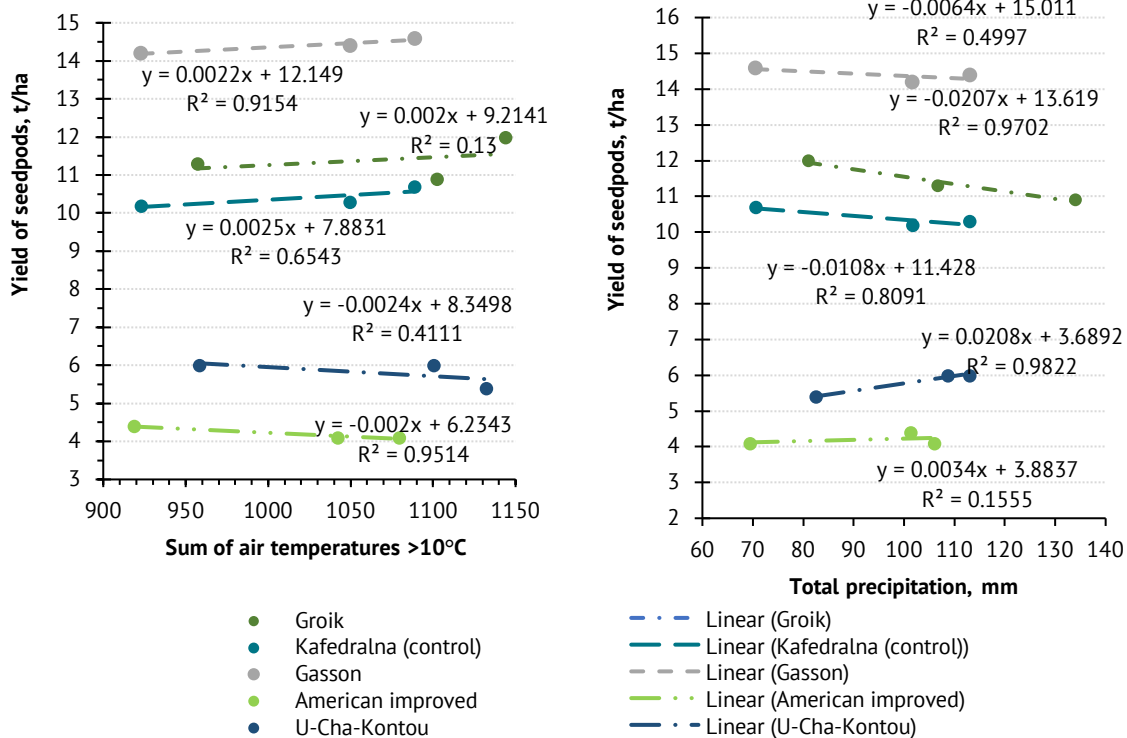


Figure 2. Dependence of the yield of cowpea seedpods between the sum of effective air temperature (left) and precipitation (right) (2014-2016)

Source: developed by the authors based on the conducted research

It turned out that among the varieties under study, the yield directly and inversely depended on the amount of precipitation. The correlation was average for the American improved variety ($r = 0.39$), and strong for the Gasson ($r = 0.71$), Kafedralna (control) ($r = -0.90$), Groik ($r = -0.98$), and U-Cha-Kontou ($r = 0.99$) varieties. Based on the regression equations, an increase in the amount of precipitation by 1 mm can increase the yield of cowpeas by 3.4 kg/ha in the American improved variety and by 20.8 kg/ha – U-Cha-Kontou, and for the Gasson, Kafedralna (control), Groik varieties, there will be a decrease in yield by 6.4 kg/ha, 10.8 kg/ha, and 20.7 kg/ha, respectively.

The range of feature variability allows assessing a certain influence of the environment on the expression of quantitative parameters. A higher scope means a greater environmental impact. Samples that have a low range of variations, regardless of the growing environment, are more stable. This means that the degree of influence of the genotype on the severity of the trait in

them is greater than the influence of the environment. According to the coefficients of determination ($R^2 = 0.02 - 0.96$), about 2% of the yield variation in the varieties American improved, 25% – Gasson, 65% – Cathedral (control), 94% – Groik, and 96% – U-Cha-Kontou was due to a change in the amount of precipitation, but the rest 98%, 75%, 35%, 6%, and 4% of the variation, respectively, was due to the influence of other factors.

The smallest yield range of seedpods was found in the varieties American improved (0.3 t/ha) and Gasson (0.4 t/ha). This indicates that the boundaries in which the value of the trait changes narrow when the growing conditions of these varieties worsen. The largest range of variation of this trait was observed in the Groik variety (1.1 t/ha) (Fig. 3). Varieties with high overall adaptive capacity, defined as the ability of genotypes to maximise the manifestation of traits under all environmental conditions, are valuable. High indicators of total adaptive capacity according to plant yield was observed in the varieties Gasson (TAC = 5.16) and Groik (TAC = 2.16). The lowest value of this indicator was observed in the U-Cha-Kontou variety (TAC = -3.44) (Fig. 4). The specific adaptive capacity allows assessing the level of stability of varieties – the lower the value of this indicator, the more stable the variety. The Gasson (SAC = 0.015) and American improved (SAC = 0.005) varieties were the most stable in the study.

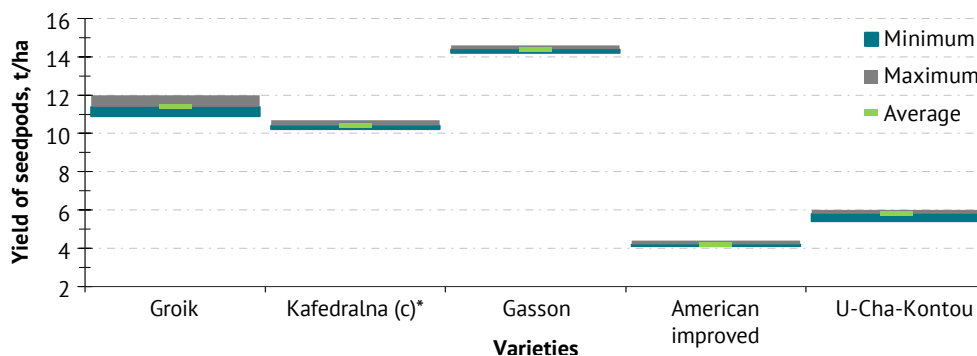


Figure 3. Yield of seedpods of cowpea varieties, t/ha (2014-2016)

Note: (c)* – control

Source: developed by the authors based on the conducted research

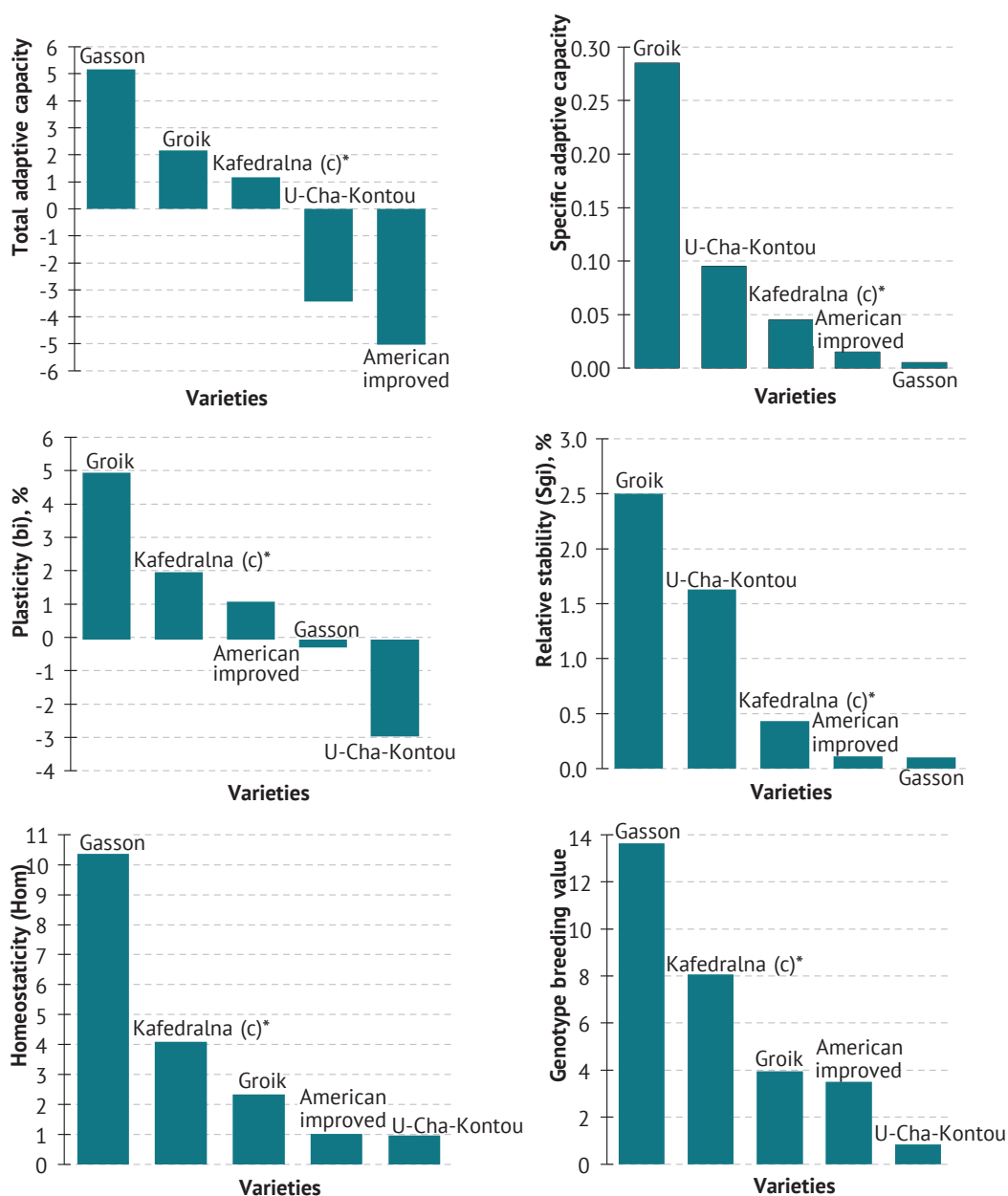


Figure 4. Parameters of adaptive capacity and stability of cowpea varieties: (2014-2016)

Note: A) total adaptive capacity; B) specific adaptive capacity; C) relative stability (Sgi); D) plasticity (bi); E) homeostasis (Hom); F) genotype breeding value (GBV); (c)* – control

Source: developed by the authors based on the conducted research

When assessing relative stability (S_{gi}), it was found that all the varieties have a high stability in the range of 0.10 to 2.50 %. The plasticity coefficient is a measure of adaptive ability. The higher the coefficient, the more sensitive the variety is to improved growing conditions, and this may indicate its ability to make the best use of favourable environmental conditions. At the same time, it is less stable in the event of deterioration of growing conditions. A coefficient value of less than 1 indicates both greater stability of the variety and a worse ability to respond to better growing conditions with an increase in the quantitative trait. The variety does not respond to changes in environmental conditions when $b_i = 0$. The Groik variety had the highest regression coefficient (5.0), therefore, it has a high sensitivity to growing conditions. A value close to 1 was observed in the Gasson variety ($b_i = 1.13$). Varieties American improved and U-Cha-Kontou had a b_i coefficient in the range from -0.24 to -0.29, therefore, they have a low level of sensitivity to any changes in the environment (stable). Such a variety provides a guaranteed high yield in any growing conditions.

A higher homeostatic index, compared to the control, was observed in the Gasson variety ($Hom = 10.37$). Varieties that produce high but unstable yields are not able to guarantee maximum yields in conditions of improper farming and difficult climatic conditions. The genotype breeding value is a complex indicator that determines the totality of productivity and stability of varieties. In this study, this indicator ranged from 0.84 to 13.63. The best varieties in terms of genotype breeding value were Gasson ($GBVi = 13.63$) and Kafedralna ($GBVi = 8.06$). There is a relatively low yield stability and the ability to respond to improved growing conditions in the U-Cha-Kontou variety ($GBV_i = 0.84$).

Using the correlation calculation, a direct strong relationship was established between the average yield and genotype breeding value ($GBVi$) ($r = 0.77$), homeostasis (Hom) ($r = 0.84$), total adaptive capacity (TAC) ($r = 0.99$); between the range of variation and relative stability (S_{gi}) ($r = 0.94$), specific adaptive capacity (SAC) ($r = 0.99$); between the coefficient of variation and relative stability (S_{gi}) ($r = 0.71$); between total adaptive capacity (TAC) and homeostasis (Hom) ($r = 0.84$), genotype breeding value ($GBVi$) ($r = 0.77$); between specific adaptive capacity (SAC) and relative stability (S_{gi}) ($r = 0.94$); between homeostasis (Hom) and genotype breeding value ($GBVi$) ($r = 0.96$).

An inverse strong correlation was found between the average yield and the coefficient of variation ($r = -0.68$); between the coefficient of variation and total adaptive capacity (TAC) ($r = -0.68$), homeostaticity (Hom) ($r = -0.87$), and the genotype breeding value ($GBVi$) ($r = -0.97$). The presence of a direct average relationship was established: between the average yield and plasticity (b_i) ($r = 0.62$); between the range of variation and the coefficient of variation ($r = 0.46$), plasticity (b_i) ($r = 0.62$); between the coefficient of variation and

specific adaptive capacity (SAC) ($r = 0.51$); between total adaptive capacity (TAC) and plasticity (b_i) ($r = 0.62$); between specific adaptive capacity (TAC) and plasticity (b_i) ($r = 0.62$); between specific adaptive capacity (SAC) and plasticity (b_i) ($r = 0.61$).

An inverse average correlation was found: between the range of variation and the genotype breeding value ($GBVi$) ($r = -0.38$); between specific adaptive capacity (SAC) and the genotype breeding value ($GBVi$) ($r = -0.44$); between relative stability (S_{gi}) and homeostaticity (Hom) ($r = -0.46$), and the genotype breeding value ($GBVi$) ($r = -0.62$).

DISCUSSION

Cowpeas perform well in semi-arid tropics, where other legumes cannot thrive. Due to its ability to grow in extreme conditions, cowpea is a suitable choice in the face of climate change (Ayalew & Tarek, 2022). Q. Cui *et al.* (2023) reported that 4 drought-tolerant samples were identified among 36 Arkansas cowpea lines. O. Olorunwa *et al.* (2022) confirmed that the UCR 369 genotype can develop adventitious roots and provide biomass accumulation during waterlogging. The photosynthetic response to waterlogging varied between tolerant and sensitive cowpea genotypes. According to the study, excessive precipitation was observed in May 2016, where the difference between the average long-term precipitation was 102 mm. Waterlogging led to an increase in the concentration of CO_2 in the root zone of plants, and to a decrease in hydraulic conductivity, which as a result, caused rapid closure of stomata.

The study of the effect of temperature stress on pollen is extremely important, as the viability of pollen grains is one of the key indicators for assessing plant tolerance to temperature stress (Havryliuk *et al.*, 2022). In San Francisco, the cowpea variety BRS Gurguéia has proven itself well, which under conditions of temperature stress maintained greater pollen viability with a lower level of flower abortivity and, as a result, provided a higher yield (Barros *et al.*, 2024). Our research also confirms that high temperatures affected the metabolism of cowpea plants, causing changes in plant growth. However, the varieties had different physiological responses due to each variety's different need for thermal energy.

Soil salinity is one of the key abiotic factors limiting the productivity of cowpea plants. For the most part, salinity negatively affects growth processes, reproductive characteristics such as the number of flowers, bean development, seed yield and size, thus affecting the final yield (Le *et al.*, 2021). W. Ravelombola *et al.* (2019) found that PI582438 variety had a lower percentage of dead plants, increased chlorophyll content, and a lower rate of leaf damage.

In recent years, heavy metal toxicity has become one of the most serious threats to agricultural production, which may become even more urgent in the coming decades (Tonkha *et al.*, 2020). In particular, the effect of heavy metal toxicity on cowpea is evident in

almost all plant tissues and at all stages from seed germination to ageing, although these effects are strongest during seed germination and root system growth (Riyazuddin *et al.*, 2021). A. Ahmad *et al.* (2023) proved that the use of rhizobacteria is an effective tool for improving the growth and physiological parameters of cowpea in conditions of lead contamination. Some of the most serious bacterial infections of cowpea are *Xanthomonas axonopodis* pv. *vignicola* (Xav) and *Xanthomonas citri* pv. *glycines* (Xcg), causing serious damage to crops (Mahmoud, 2021). Depending on the time and intensity of infection, viral diseases can cause crop losses from 10% to 100% (Mekonnen *et al.*, 2022). In August, a summer drought was observed, and intense dews at the end of August led to the development of diseases (bacteriosis, anthracnose), which reduced the marketability of products.

Cowpea is damaged by insects at all stages of growth and development. Aphids are the first major pest to settle in the early stages of development (Mofokeng & Gerrano, 2021). According to the study, dry weather was often observed in May, which led to intensive infestation of plants by bean aphids. Plants inhabited by aphids were distinguished by the presence of sticky honeydew, which is a favourable environment for the development of mould. In such plants, a decrease in the effective leaf area was observed, which significantly reduced the level of photosynthesis.

Cowpea is one of the most valuable leguminous crops that ensures food and food safety. Due to its nutritional value, it is in demand all over the world. Although the climatic conditions prevailing in Ukraine are not so difficult in terms of drought and high temperatures, in contrast to the tropical climate, in which cowpea is mainly grown, it is exposed to numerous abiotic and biotic influences, and other factors that reduce its yield. However, the genetic resources of cowpea in most cases remain unexploited. Therefore, to further unlock its

potential, it is necessary to create highly productive varieties with a variety of purposes, high nutritional value and adapted to the climatic and soil conditions of the region.

CONCLUSIONS

According to the results of studies on cowpea in the conditions of the northern forest-steppe of Ukraine, it was established that the maximum level of yield of seed-pods was provided by the Gasson variety (14.4 t/ha), the minimum – by the American improved variety (4.2 t/ha). The maximum range of yield variation (Max-Min) ranged from 0.3 to 1.1 t/ha. A low value of linear yield regression ($b_i < 1$) was found only in the varieties American improved and U-Cha-Kontou, therefore, such varieties respond less to changes in environmental conditions than on average the entire set of varieties under study. The Groik variety was the most responsive to changes in environmental conditions for this feature ($b_i > 1$).

The relative stability index of the varieties under study ranged from 0.1 to 2.5. Thus, all the studied varieties belong to a highly stable group. However, the American improved and U-Cha-Kontou varieties do not have high productivity (average yield 4.2-5.8 t/ha), so they are not economically valuable. Kafedralna and Gasson varieties are distinguished, which are characterised by a combination of high yield parameters (10.4-14.4 t/ha), adaptability, and genotype breeding value (8.06-13.63). Marketing of little-known legumes is complicated by the fact that they are mostly less well-known to consumers, so a promising area of further research is to investigate the mechanisms of popularisation and widespread inclusion of them in the human diet.

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None.

CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Екологічна стабільність, пластичність та адаптивність сортів вігні спаржевої (*Vigna unguiculata* (L.) Walp. *subsp.* *sesquipedalis* (L.) Verdc.)

Ірина Бобось

Кандидат сільськогосподарських наук, доцент
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
<https://orcid.org/0000-0001-5193-7192>

Олександр Комар

Кандидат сільськогосподарських наук
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
<https://orcid.org/0000-0001-7511-4190>

Іванна Гаврись

Кандидат сільськогосподарських наук, доцент
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
<https://orcid.org/0000-0001-5965-9916>

Олександр Шеметун

Кандидат сільськогосподарських наук, доцент
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
<https://orcid.org/0000-0001-7129-9108>

Василь Кокойко

Кандидат сільськогосподарських наук, старший науковий співробітник
Інститут кліматично орієнтованого сільського господарства
Національної Академії Аграрних Наук України
67667, вул. Маяцька дорога, 24, смт. Хлібодарське, Україна
<https://orcid.org/0000-0002-2528-7920>

Анотація. Визначення екологічної пластичності та стабільності сортів і гібридів с/г культур дає можливість комплексно оцінити їх з урахуванням потенціалу продуктивності, якісних технологічних показників та рівня стійкості до стресових умов. Метою даного дослідження було вивчення формування врожаю бобів-лопаток сортів вігні спаржевої з високою екологічною стабільністю, пластичністю та адаптивністю. Провідними методами дослідження даної проблеми є польовий – для визначення взаємодії об'єкта дослідження з біотичними та абіотичними факторами, статистичний – для оцінки результатів досліджень з метою визначення параметрів адаптивності вігні. В межах досліджуваних варіантів встановлено пряму та зворотню кореляцію між урожайністю вігні та сумою ефективних температур. Для сортів Гроік ($r = 0,36$) і Кафедральна (контроль) ($r = 0,36$), У-Тя-Контоу ($r = -0,64$) кореляція була середньою, а для сортів Гассон ($r = 0,96$), Американська поліпшена ($r = -0,98$) – сильною. Виходячи з рівнянь регресії підвищення суми опадів на 1 мм може збільшувати урожайність бобів-лопаток вігні спаржевої на 3,4 кг/га у сорту Американська покращена та на 20,8 кг/га – У-Тя-Контоу, а для сортів Гассон, Кафедральна (контроль), Гроік спостерігатиметься зменшення врожайності на 6,4 кг/га, 10,8 кг/га та 20,7 кг/га відповідно. Сорти з високою загальною адаптивною здатністю, яка визначається як здатність генотипів до максимального прояву ознак за будь-яких умов навколишнього середовища, є цінними. Високі показники загальної адаптивної здатності за урожайністю рослини спостерігалися у сортів Гассон (ЗАЗ = 5,16) та Гроік (ЗАЗ = 2,16). Найменше значення даного показника спостерігали у сорту У-Тя-Контоу (ЗАЗ = -3,44). Сорти, які дають високі, але нестабільні врожаї, не здатні гарантувати отримання максимальної врожайності за умов неналежного землеробства та складних кліматичних умов. Селекційна цінність генотипу – це комплексний показник, який визначає сукупність продуктивності та стабільності сортів. У дослідженнях отримано такі коливання цього показника від 0,84 до 13,63. Кращими за показниками селекційної цінності виявилися сорти Гассон (СЦГі = 13,63) і Кафедральна (СЦГі = 8,06). Спостерігається відносно низька стабільність врожайності та здатність реагувати на покращення умов вирощування у сорту У-Тя-Контоу (СЦГі = 0,84)

Ключові слова: бобові культури; боби-лопатки; технічна стиглість; урожайність; стабільність; адаптивність; пластичність

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Productivity of common flax varieties depending on fertiliser

Lyubov Tkachenko*

PhD in Agricultural Sciences

Institute of Agriculture of the Carpathian Region of the National Academy
of Agrarian Sciences of Ukraine

81115, 5 Hrushevskiy Str., Obroshyno Village, Ukraine

<https://orcid.org/0009-0000-3780-0368>

Nataliia Rudavska

PhD in Agricultural Sciences

Institute of Agriculture of the Carpathian Region of the National Academy
of Agrarian Sciences of Ukraine

81115, 5 Hrushevskiy Str., Obroshyno Village, Ukraine

<https://orcid.org/0000-0002-4443-5319>

Oksana Tymchyshyn

PhD in Agricultural Sciences

Institute of Agriculture of the Carpathian Region of the National Academy
of Agrarian Sciences of Ukraine

81115, 5 Hrushevskiy Str., Obroshyno Village, Ukraine

<https://orcid.org/0000-0002-2147-8818>

Oleh Stasiv

Doctor of Agricultural Sciences, Corresponding Member of the National Academy of Sciences

Institute of Agriculture of the Carpathian Region of the National Academy
of Agrarian Sciences of Ukraine

81115, 5 Hrushevskiy Str., Obroshyno Village, Ukraine

<https://orcid.org/0000-0003-3737-739X>

Hryhorii Konyk

Doctor of Agricultural Sciences, Professor, Corresponding Member
of the National Academy of Sciences

Institute of Agriculture of the Carpathian Region of the National Academy
of Agrarian Sciences of Ukraine

81115, 5 Hrushevskiy Str., Obroshyno Village, Ukraine

<https://orcid.org/0000-0003-2841-2982>

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Abstract. Modern flax varieties have a high genetic potential for productivity, which can be realised by improving the elements of cultivation technology, in particular, the fertilisation system, which is why the study is relevant. The purpose of the study was

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*Corresponding author

to investigate the regularities of the development of productivity of common flax plants and determine changes in quality indicators depending on the application of improved agrotechnological techniques in the soil and climatic conditions of the Western Forest-Steppe. The following methods were used: field, laboratory (to determine qualitative indicators), and statistical (to assess the reliability of data). Field studies were conducted during 2021-2023 on grey forest surface-gleyed soils. The features of growth and development of common flax varieties Miandr, Oberih, Usivskiy and Ivanivskiy were studied using the following fertiliser rates: $N_{20}P_{40}K_{60}$; $N_{30}P_{60}K_{90}$; $N_{45}P_{90}K_{135}$. It was found that the productivity of common flax varied depending on the dose of mineral fertilisers and varietal characteristics. On average, in 2021-2023, the growing season of common flax lasted 91-94 days (depending on the variety and mineral nutrition of plants). The highest yield of flax straw (4.37 t/ha) was obtained on average for 2021-2023 in the Oberih variety, subject to the application of a dose of mineral fertilisers $N_{30}P_{60}K_{90}$. The increase over control was 0.52 t/ha (13.51%). The yield of straw in the Miandr variety varied from 3.59 t/ha (in the control) to 4.31 t/ha (with the application of $N_{45}P_{90}K_{135}$), for the Usivskiy variety – 3.97-4.17 t/ha, for the Ivanivskiy variety – 3.12-3.81 t/ha. In terms of seed yield, the highest indicators on average for 2021-2023 were obtained from the Miandr variety, provided that a dose of mineral fertilisers $N_{45}P_{90}K_{135}$ was used – 1.26 t/ha. The control yield was 0.88 t/ha. A similar trend was observed in the Oberih variety with seed yield indicators of 0.93 t/ha and 0.58 t/ha in the control. The seed yield of the Miandr variety exceeded the indicator of the Oberih variety by 0.33 t/ha against the background of fertiliser $N_{45}P_{90}K_{135}$. Against this background, fertilisation resulted in the highest seed yields in the varieties Usivskiy (0.99 t/ha) and Ivanivskiy (0.91 t/ha), which was 0.17 t/ha (20.73%) and 0.07 t/ha (8.33%) higher than the control variant, respectively. The results of these studies can be used to adjust the elements of the technology of growing common flax in production conditions to increase the yield and quality of fibre

Keywords: common flax; varieties; mineral fertilisers; productivity; cultivation technologies

INTRODUCTION

In modern conditions, the improvement of existing cultivation technologies and the selection of new adaptive varieties is relevant in the cultivation of flax. Since climate change is currently taking place, improving technologies and adapting varieties to appropriate conditions without losing the yield and quality of fibre and seeds is an important aspect of research. The average annual air temperature has increased by 2.0 degrees Celsius since the beginning of the 20th century, according to L. Wilson *et al.* (2021). O. Tarariko *et al.* (2022) note that recent climate changes are encouraging researchers to improve technologies for growing all crops.

Meteorological factors and their role in the development of flax productivity were investigated by Y. Trach (2020). The weather conditions and their changes were analysed during 2000-2020 in relation to long-term average indicators and the criterion of the coefficient of materiality of deviations of elements of agrometeorological data. According to these observations and analyses, climate change is still occurring in the Western Forest-Steppe and Polissia, namely: an increase in the average daily air temperature, a change in the duration and onset of the growing season of flax, and an increase in the number and intensity of adverse weather events.

The application of mineral fertiliser doses was studied by A. Shuvar *et al.* (2021). According to these data, the combined application of organic and mineral fertilisers is an alternative to the use of moderate doses of mineral fertilisers. Fertilisation, as an agrotechnical method of regulating the potential capabilities of common flax varieties, was considered by O. Melnyk *et al.* (2022), O. Petrova (2020), I. Vereshchagin *et al.* (2022). The researchers highlighted the state of the

problem and developments in the field of flax growing and the impact of fertilisers on product quality. Improvement of the technology of growing long-stemmed flax in the Western region of Ukraine was studied by V. Dumych (2020). His study highlights the systems of minimising tillage, which are used to increase the yield of straw and seeds. Another important aspect of flax research is the evaluation of breeding material for the main economic indicators, which was carried out by H. Dorota *et al.* (2020).

Yu. Berezovsky *et al.* (2021), S.V. Yahelyuk and V.F. Didukh (2020), A. Seleznyov and N. Danilova (2020), in their papers covering the development of the flax industry in Ukraine, analysed the current state and main trends in its development. V. Petrychenko and V. Lykhochvor (2020) substantiated the strategy for the development and improvement of the efficiency of this industry, proposals for its development. A. Limont and Z. Limont (2021) in their study on the development of productivity of common flax and stem, considering the density of plants before harvesting, note the influence of these factors on the change in the number of stalk bolls, the proportion of unproductive stems, and the coefficient of variation in the height and diameter of stems. According to data, the highest yield of seeds and straw was obtained at the maximum density values, namely: 2,500 pcs./m².

The study of the features of the elements of common flax technology under certain soil and climatic conditions with different fertiliser rates is an important aspect of obtaining a high-yield fibre and seed crop. The purpose of this study was to determine the influence of these factors on the development of yield indicators.

MATERIALS AND METHODS

The research was conducted on the experimental field of the Institute of Agriculture of the Carpathian Region of NAAS in 2021-2023 according to generally accepted methods. The soil of the experimental field was grey forest is superficially gleyed with the following agrochemical indicators (before the experiment)

at a 0-20 cm layer: humus (by Tyurin) – 1.7-2.1%; pH (salt extract) – 5.1-5.4; easily hydrolysable nitrogen (by Cornfield) according to DSTU 7863:2015 (2015), – 85.4-88.2 mg/kg of soil; mobile forms of phosphorus – 67.4-99.0 mg/kg of soil and potassium (by Kirsanov) according to DSTU 4405:2005 (2005) – 84.4-86.2.0 mg/kg of soil. The predecessor of flax was winter cereals.

Table 1. Experiment scheme

No.	Factor A (variety)	Factor B (fertiliser)
1	Miandr	Without fertilisers (control)
2		$N_{20}P_{40}K_{60}$
3		$N_{30}P_{60}K_{90}$
4		$N_{45}P_{90}K_{135}$
5	Oberih	Without fertilisers (control)
6		$N_{20}P_{40}K_{60}$
7		$N_{30}P_{60}K_{90}$
8		$N_{45}P_{90}K_{135}$
9	Usivskiy	Without fertilisers (control)
10		$N_{20}P_{40}K_{60}$
11		$N_{30}P_{60}K_{90}$
12		$N_{45}P_{90}K_{135}$
13	Ivanivskiy	Without fertilisers (control)
14		$N_{20}P_{40}K_{60}$
15		$N_{30}P_{60}K_{90}$
16		$N_{45}P_{90}K_{135}$

Source: developed by the authors

Ploughing was carried out to a depth of 22-26 cm, followed by harrowing, application of mineral fertilisers, pre-sowing cultivation, and rolling. The crops were sown at the optimum time, at a soil temperature of 7-8°C at a depth of 10 cm, as soon as weather conditions allowed (second ten days of April) with a SL-16 seeder using a narrow-row method (7.5 cm) in a four-fold replication with a seeding rate of 22 million germinated seeds per hectare in accordance with the methodological recommendations. Plot area: sown area – 36 m²; accounting area – 25 m². The repetition of the experiment was fourfold. The seeding rate was 22 million germinated seeds per 1 ha. The following mineral fertilisers were used: ammonium nitrate, granular superphosphate, potassium salt, or potassium magnesium. To control weeds in the phase of leaf development, a tank mixture of herbicides Grodil (0.1 l/ha) and Oreol maxi (1.25 l/ha) was introduced on all variants of the experiment. To control the flax flea beetle (*Aphthona euphorbiae* Schrk) in the presence of economic threshold of harmfulness (ETH) (pest population density exceeds 10 beetles per 1m²) – the entire field is treated using Fury insecticide (0.10 l/ha) during the onset of the full germination phase.

Collection and accounting of seeds and straw was carried out separately. The weight of 1,000 seeds, its

germination rate, and germination energy were determined. Fibre quality was determined by the following indicators of technological analysis: fibre content in straw, in flax stock, fibre yield, its strength and flexibility. Sampling for structural and technological analysis was carried out in the yellow ripeness phase of flax plants. Morphophysiological studies in dynamics by stages of organogenesis of common flax was determined according to procedures (Molotskyi et al., 2006). Statistical processing of the results was carried out using the programmes Statistica 6.0 and Excel 2003.

Experimental studies of plants (both cultivated and wild), including the collection of plant material, were in accordance with institutional, national or international guidelines. The authors adhered to the standards of the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS AND DISCUSSION

The effectiveness of the fertiliser application was primarily assessed based on the yields of flax straw and flax seeds. It is from them that conclusions can be drawn about the influence of growing conditions on the processes of plant growth and development. The choice of variety and the application of appropriate

fertiliser affects the course of plant vegetation and productivity.

The results of the study showed that the use of fertiliser significantly affected the productivity of common flax (Table 2). The yield of straw in 2021 of the Miandr variety ranged from 5.8 t/ha (in the control) to 6.11 t/ha (with the application of $N_{30}P_{60}K_{90}$). A similar pattern of straw yield formation under the influence of fertiliser was recorded in the Oberih variety from 6.0 t/ha (in the control), up to 6.21 t/ha (for applying a dose of mineral fertilisers $N_{30}P_{60}K_{90}$). On average, the increase in flax straw yield was 0.20-0.31 t/ha (3.45-5.34%) for the Miandr variety, 0.12-0.21 t/ha (2.00-3.50%) for the

Oberih variety, and for the Usivskyi variety, the average increase in flax straw yield was 0.21-0.42 t/ha (3.32-6.65%), for the Ivanivskyi variety – 0.19-0.47 t/ha (3.37-8.33%). The highest yield of flax straw (6.74 t/ha) was obtained from the new variety Usivskyi, subject to the application of $N_{30}P_{60}K_{90}$. The increase over control was 0.42 t/ha (6.65%). The yield of straw in 2022 of the Miandr variety ranged from 1.58 t/ha (in the control) to 2.20 t/ha (with the application of $N_{45}P_{90}K_{135}$). A similar pattern of straw yield generation under the influence of fertiliser was recorded in the Oberih variety from 1.17 t/ha (in the control) to 2.13 t/ha (when applying a dose of mineral fertilisers $N_{45}P_{90}K_{135}$).

Table 2. Productivity of flax straw of common flax varieties depending on the elements of cultivation technology in 2021-2023, (t/ha)

Variety	Fertilisation background	Flax straw yield, t/ha			Deviation from control, t/ha		
		2021	2022	2023	2021	2022	2023
Miandr	Control	5.80	1.58	3.38	–	–	–
	$N_{20}P_{40}K_{60}$	6.00	1.95	3.59	0.20	0.37	0.21
	$N_{30}P_{60}K_{90}$	6.11	2.07	4.33	0.31	0.49	0.95
	$N_{45}P_{90}K_{135}$	6.09	2.20	4.65	0.29	0.62	1.27
Oberih	Control	6.00	1.17	4.38	–	–	–
	$N_{20}P_{40}K_{60}$	6.10	1.30	4.74	0.10	0.13	0.36
	$N_{30}P_{60}K_{90}$	6.21	1.92	4.97	0.21	0.75	0.59
	$N_{45}P_{90}K_{135}$	6.13	2.13	4.76	0.13	0.96	0.38
Usivskyi	Control	6.32	1.13	2.64	–	–	–
	$N_{20}P_{40}K_{60}$	6.53	1.18	3.01	0.21	0.05	0.37
	$N_{30}P_{60}K_{90}$	6.74	1.38	3.33	0.42	0.25	0.69
	$N_{45}P_{90}K_{135}$	6.67	1.40	4.43	0.35	0.27	1.79
Ivanivskyi	Control	5.64	1.45	2.29	–	–	–
	$N_{20}P_{40}K_{60}$	5.83	1.90	2.79	0.19	0.45	0.50
	$N_{30}P_{60}K_{90}$	6.11	2.05	3.12	0.47	0.6	0.83
	$N_{45}P_{90}K_{135}$	5.95	2.18	3.31	0.31	0.73	1.02

Source: compiled by the authors

The increase in the yield of flax straw in 2022 was 0.37-0.62 t/ha for the Miandr variety (23.42-39.24%), for the Oberih variety – 0.13-0.96 t/ha (11.11-82.05%), for the Usivskyi variety, the average increase in the yield of flax straw was 0.05-0.27 t/ha (4.42-23.89%), for the Ivanivskyi variety – 0.45-0.73 t/ha (31.03-50.34%). The highest yield of flax straw in 2022 (2.20 t/ha) was obtained in the Miandr variety, subject to the application of $N_{45}P_{90}K_{135}$, the increase over the control was 0.62 t/ha (39.24%), and the Ivanivskyi variety (2.18 t/ha), subject to the application of a dose of $N_{45}P_{90}K_{135}$, the increase over the control was 0.73 t/ha (50.34%).

The yield of flax straw in 2023 mainly depended on the varietal characteristics and fertilisation background, namely: Miander – 3.38-4.65 t/ha; Oberih – 4.38-4.97 t/ha; Usivskyi – 2.64-4.63 t/ha; and Ivanivskyi –

2.29-3.31 t/ha. The increase over control (without fertilisers): Miandr – 0.21-1.27 t/ha (6.21-37.57%); Oberih – 0.36-0.59 t/ha (8.22-13.47%); Usivskyi – 0.37-1.79 t/ha (14.01-67.80%) and Ivanivskyi – 0.50-1.02 t/ha (21.83-44.54%). The highest straw yield in 2023 was in the Oberih variety with the applicatoin of $N_{45}P_{90}K_{135}$ – 4.97 t/ha. Other varieties were also characterised by high indicators – Miandr – 4.65 t/ha, Usivskyi – 4.63 t/ha. Slightly lower straw yield indicators were obtained with the Ivanivskyi variety – 3.31 t/ha.

Regarding the seed yield indicator in 2021 (Table 3), it was obtained from the Miandr variety under the condition of using a dose of mineral fertilisers $N_{45}P_{90}K_{135}$ – 0.99 t/ha. With this, the yield of the control was 0.91 t/ha. A similar trend was observed in the Oberih variety with seed yield indicators of 0.90 t/ha and

0.83 t/ha in the control. The seed yield of the Miandr variety exceeded the indicator of the Oberih variety by 0.09 t/ha against the background of $N_{45}P_{90}K_{135}$ application. Against this background, fertilisation resulted

in the highest seed yields in the varieties Usivskiy (1.02 t/ha) and Ivanivskiy (1.05 t/ha), which is 0.08 t/ha (8.51%) and 0.06 t/ha (6.06%) higher than the control variant, respectively.

Table 3. Productivity of seeds of common flax varieties depending on the elements of cultivation technology in 2021-2023, (t/ha)

Variety	Fertilisation background	Seed yield, t/ha			Deviation from control, t/ha		
		2021	2022	2023	2021	2022	2023
Miandr	Control	0.91	0.77	0.97	–	–	–
	$N_{20}P_{40}K_{60}$	0.94	0.86	1.00	0.03	0.09	0.03
	$N_{30}P_{60}K_{90}$	0.96	0.98	1.23	0.05	0.21	0.26
	$N_{45}P_{90}K_{135}$	0.99	1.43	1.37	0.08	0.66	0.40
Oberih	Control	0.83	0.45	0.47	–	–	–
	$N_{20}P_{40}K_{60}$	0.86	0.65	0.69	0.03	0.2	0.22
	$N_{30}P_{60}K_{90}$	0.89	0.87	0.90	0.06	0.42	0.43
	$N_{45}P_{90}K_{135}$	0.90	0.98	0.92	0.07	0.53	0.45
Usivskiy	Control	0.94	0.55	0.97	–	–	–
	$N_{20}P_{40}K_{60}$	0.98	0.68	1.01	0.04	0.13	0.04
	$N_{30}P_{60}K_{90}$	1.01	0.77	1.07	0.07	0.22	0.10
	$N_{45}P_{90}K_{135}$	1.02	0.8	1.16	0.08	0.25	0.19
Ivanivskiy	Control	0.99	0.55	0.97	–	–	–
	$N_{20}P_{40}K_{60}$	1.02	0.57	1.00	0.03	0.02	0.03
	$N_{30}P_{60}K_{90}$	1.03	0.58	1.03	0.04	0.03	0.06
	$N_{45}P_{90}K_{135}$	1.05	0.58	1.09	0.06	0.03	0.12

Source: compiled by the authors

The use of a dose of mineral fertiliser $N_{45}P_{90}K_{135}$ for the new variety Ivanivskiy in 2021 resulted in an increase in seed yield of 0.06 t/ha (6.06%) compared to the control variant (without fertiliser), with the highest seed yield of 1.05 t/ha. The highest seed yield in 2022 was obtained from the Miandr variety – 1.43 t/ha. The yield of the control was 0.77 t/ha. A similar trend was observed in the Oberih variety with seed yield indicators of 0.98 t/ha and 0.45 t/ha in the control.

The seed yield of the Miandr variety exceeded the indicator of the Oberih variety by 0.45 t/ha against the background of $N_{45}P_{90}K_{135}$ application. Against the same background, fertilisation provided the highest seed yields in the Usivskiy (0.80 t/ha) and Ivanivskiy (0.58 t/ha) varieties, which were 0.25 t/ha (45.45%) and 0.03 t/ha (5.45%), respectively. The use of a dose of mineral fertiliser $N_{45}P_{90}K_{135}$ for the Miandr variety in 2022 resulted in an increase in seed yield of 0.66 t/ha (85.71%) compared to the control variant (without fertiliser), Oberih variety – 0.53 t/ha (117.78%) compared to the control variant (without fertiliser), respectively, with the highest seed yield of 1.43 t/ha.

Analysing the yield indicators of flax seeds that were received in 2023, it is worth noting that the Miandr variety had the highest result, namely 1.37 t/ha

against the background of $N_{45}P_{90}K_{135}$ application, an increase over the control (without fertilisers) – 0.40 t/ha (41.23%). The second in terms of yield was the Usivskiy variety, with a yield in the range of 0.97-1.16 t/ha, an increase over control (without fertilisers) – 0.04-0.19 t/ha (4.12-19.59%). Slightly lower indicators of seed yield were noted in the Ivanivskiy varieties – 0.97-1.09 t/ha, an increase of 0.03-0.12 t/ha (3.09-12.37%) and Oberih – 0.47-0.92 t/ha, an increase of 0.22-0.45 t/ha (46.81-95.74%). According to the data presented in Table 2, it can be concluded that the yield of flax seeds during 2021-2023 depended on varietal characteristics and the level of mineral nutrition, and hydrothermal conditions that accompanied the plant during the growing season.

The analysis of the productivity of common flax varieties on average for 2021-2023 is shown in Table 3. The highest yield of flax straw (4.37 t/ha) was obtained on average for 2021-2023 (Table 4) in the Oberih variety, subject to the application of a dose of $N_{30}P_{60}K_{90}$. The increase over control was 0.52 t/ha (13.51%). The average straw yield for 2021-2023 in the Miandr variety ranged from 3.59 t/ha (in the control) to 4.31 t/ha (with the application of $N_{45}P_{90}K_{135}$), in the Usivskiy variety – 3.97-4.17 t/ha, in the Ivanivskiy variety – 3.12-3.81 t/ha.

Table 4. Productivity of common flax varieties depending on the elements of cultivation technology, on average for 2021-2023 (t/ha)

No.	Fertilisation background	Flax straw yield, t/ha	Deviation from control, t/ha	Deviation to control, %	Seed yield, t/ha	Deviation from control, t/ha	Deviation to control, %
Miandr							
1	Control	3.59	–	–	0.88	–	–
2	N ₂₀ P ₄₀ K ₆₀	3.85	0.26	7.24	0.93	0.05	5.68
3	N ₃₀ P ₆₀ K ₉₀	4.17	0.58	16.16	1.06	0.18	20.45
4	N ₄₅ P ₉₀ K ₁₃₅	4.31	0.72	20.01	1.26	0.38	43.18
Oberih							
5	Control	3.85	–	–	0.58	–	–
6	N ₂₀ P ₄₀ K ₆₀	4.05	0.20	5.19	0.73	0.15	25.86
7	N ₃₀ P ₆₀ K ₉₀	4.37	0.52	13.51	0.89	0.31	53.45
8	N ₄₅ P ₉₀ K ₁₃₅	4.34	0.49	12.73	0.93	0.35	60.31
Usivskiy							
9	Control	3.36	–	–	0.82	–	–
10	N ₂₀ P ₄₀ K ₆₀	3.57	0.21	6.25	0.89	0.07	8.54
11	N ₃₀ P ₆₀ K ₉₀	3.82	0.46	13.69	0.95	0.13	15.85
12	N ₄₅ P ₉₀ K ₁₃₅	4.17	0.81	24.11	0.99	0.17	20.73
Ivanivskiy							
13	Control	3.12	–	–	0.84	–	–
14	N ₂₀ P ₄₀ K ₆₀	3.17	0.05	1.60	0.86	0.02	2.38
15	N ₃₀ P ₆₀ K ₉₀	3.76	0.64	20.51	0.88	0.04	4.76
16	N ₄₅ P ₉₀ K ₁₃₅	3.81	0.69	22.11	0.91	0.07	8.33

Note: LSD_{0.05} t/ha: flax straw yield A (varieties) – 0.5; B (fertilisers) – 0.11; AB (interaction) 0.010; LSD_{0.05} t/ha: seed yield A (varieties) – 0.47; B (fertilisers) – 0.03; AB (interaction) – 0.09

Source: compiled by the authors

On average, the increase in flax straw yield was 0.26-0.72 t/ha (7.24-20.01%) for the Miandr variety; 0.20-0.52 t/ha (5.19-13.51%) for the Oberih variety; 0.21-0.81 t/ha (6.25-24.11%) for the Ivanivskiy variety; 0.05-0.69 t/ha (1.6-22.11 %) depending on the fertiliser. The average seed yield for 2021-2023 was 1.26 t/ha in the Miandr variety, subject to the application of N₄₅P₉₀K₁₃₅. The control yield was 0.88 t/ha. A similar trend was observed in the Oberih variety with seed yield indicators of 0.93 t/ha (against the application of N₄₅P₉₀K₁₃₅) and 0.58 t/ha (in control). The yield of seeds of the Miandr variety exceeded the indicator of the Oberih variety by 0.33 t/ha against the application of N₄₅P₉₀K₁₃₅. Against this background, fertilisation resulted in the highest seed yields in the varieties Usivskiy (0.99 t/ha) and Ivanivskiy (0.91 t/ha), which was 0.17 t/ha (20.73%) and 0.07 t/ha (8.33%) higher than the control variant, respectively.

The results of current studies indicate that the productivity and growing conditions of common flax directly depend on the varietal characteristics and mineral nutrition of plants. Analysing the significance of the

research factor, fertilisers had a greater impact on productivity than varieties. When applying different fertiliser rates, the productivity of straw and flax seeds of all the varieties under study increases. These findings were consistent with the data of other scientists. H. Dorota and O. Voloshchuk (2023) investigated that the highest straw yield was developed by applying mineral fertilisers N₃₀P₆₀K₉₀. When increasing the rates of mineral nutrition from N₂₀P₄₀K₆₀ to N₄₅P₉₀K₁₃₅, the straw yield increased. According to the findings, the influence on straw yield was established. The highest results in the Western Forest-Steppe were obtained with N₄₅P₉₀K₁₃₅ in the Miandr variety, while the yield of flax straw was 4.15 t/ha and seeds – 1.21 t/ha. The increase in relation to the non-fertilised version (control) was 0.46 and 0.37 t/ha, respectively.

Ye. Zaika *et al.* (2021) found that in seed crops of common flax varieties, the highest yield was obtained with the application of N₄₈P₄₈K₄₈, namely: 0.69 t/ha (Rushnichok variety) and 0.66 t/ha (Vruchiy variety). The researchers recommend using the results of these studies to accelerate the introduction of new varieties

of common flax in various parts of seed production in the Forest-Steppe zone and note that it is characterised by a good reaction to the use of fertilisers, and low sensitivity to condensed crops. Comparing these studies, the application of fertiliser also had a positive effect on these indicators, the increase in relation to non-fertilised variants (control) was: 0.05-0.38 t/ha (Miandr variety), 0.15-0.35 t/ha (Oberih variety), 0.07-0.17 t/ha (Usivskiyi variety) and 0.02-0.07 t/ha (Ivanivskiyi variety).

One of the main measures to increase the productivity of common flax and improve the quality of fibre is the use of mineral fertilisers. Indicators of its quality may vary depending on the doses and ratio of micro- and macro- elements, the timing and methods of their introduction. According to current research, the amount and quality of fibre also improved with the movement of fertiliser application. The highest flexibility indicators were observed in the Oberih variety – 56.3-63.7 mm; Miandr – 55.0-62.7 mm, Usivskiyi – 52.0-52.4 mm, Ivanivskiyi – 53.7-57.6 mm. Improvement of cultivation technology should be carried out depending on zonal features, using new achievements in agrochemistry and ecology. The solution of this problem involves the use of microelements and biologics that are important for growth and development on flax, depending on the availability of mobile forms of elements in soils. This information is consistent with the data set out by O. Rudik and R. Vozhegova (2018), A. Chuhlib (2020).

Summing up the above data, it can be noted that given the changes in the environment, it is important to revise some elements of the technology of growing common flax depending on the zone and varietal characteristics.

CONCLUSIONS

The results of three years of research show that in the soil and climatic conditions of the Western Forest-Steppe, the maximum yield of flax straw was

ensured by the rates of mineral fertilisers $N_{30}P_{60}K_{90}$ and $N_{45}P_{90}K_{135}$. According to these fertilisation rates, the varieties under study formed an average yield of 4.17-4.31 t/ha (Miandr), 4.37-4.34 t/ha (Oberih), 3.82-4.17 t/ha (Usivskiyi) and 3.76-3.81 t/ha (Ivanivskiyi). A decrease in the fertilisation rate and non-fertiliser options resulted in lower coenosis yields. The deviation of these indicators in relation to the control (without fertilisation) was: in the Miandr variety – 0.58-0.72 t/ha; Oberih – 0.52-0.49 t/ha; Usivskiyi – 0.46-0.81 t/ha; Ivanivskiyi – 0.64-0.69 t/ha.

Application of mineral fertilisers at the rate of $N_{20}P_{40}K_{60}$, $N_{30}P_{60}K_{90}$, $N_{45}P_{90}K_{135}$ contributed to an increase in the yield of flax seeds of all the varieties under study. Depending on the variety and mineral nutrition, the increase ranged from 0.02 to 0.38 t/ha. Based on the results of the research, the influence of the studied factors on the yield and fibre content in straw was established. The highest indicators were obtained in the Oberih variety – 1.24 t/ha and 28.3% with the application of $N_{30}P_{60}K_{90}$. Slightly lower indicators of fibre yield and its content in straw against the same background were found in the Miandr variety – 1.04 t/ha and 25.1%; Usivskiyi – 0.97 t/ha and 25.1%; Ivanivskiyi – 1.02 t/ha and 24.1%, respectively. The increase over control ranged from 0.08 to 0.22 t/ha, depending on the variety and mineral nutrition.

Prospects for further research will be related to the study of seeding rates of common flax in the Carpathian region in order to prevent lodging of plants, increase productivity and fibre quality. It is crucial to investigate the impact of biological methods on the effectiveness of growing common flax.

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CONFLICT OF INTEREST

None.

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Продуктивність сортів льону-довгунця залежно від удобрення

Любов Ткаченко

Кандидат сільськогосподарських наук
Інститут сільського господарства Карпатського регіону
Національної академії аграрних наук України
81115, вул. Грушевського, 5, с. Оброшине, Україна
<https://orcid.org/0009-0000-3780-0368>

Наталія Рудавська

Кандидат сільськогосподарських наук
Інститут сільського господарства Карпатського регіону
Національної академії аграрних наук України
81115, вул. Грушевського, 5, с. Оброшине, Україна
<https://orcid.org/0000-0002-4443-5319>

Оксана Тимчишин

Кандидат сільськогосподарських наук
Інститут сільського господарства Карпатського регіону
Національної академії аграрних наук України
81115, вул. Грушевського, 5, с. Оброшине, Україна
<https://orcid.org/0000-0002-2147-8818>

Олег Стасів

Доктор сільськогосподарських наук, член-кореспондент
Національної академії аграрних наук
Інститут сільського господарства Карпатського регіону
Національної академії аграрних наук України
81115, вул. Грушевського, 5, с. Оброшине, Україна
<https://orcid.org/0000-0003-3737-739X>

Григорій Коник

Доктор сільськогосподарських наук, професор, член-кореспондент
Національної академії аграрних наук
Інститут сільського господарства Карпатського регіону
Національної академії аграрних наук України
81115, вул. Грушевського, 5, с. Оброшине, Україна
<https://orcid.org/0000-0003-2841-2982>

Анотація. Сучасні сорти льону-довгунця мають високий генетичний потенціал продуктивності, реалізувати його можна за допомогою удосконалення елементів технології вирощування, зокрема, системи удобрення, що й зумовлює актуальність дослідження. Метою роботи було дослідити закономірності формування продуктивності рослин льону-довгунця та визначити зміни якісних показників залежно від застосування удосконалених агротехнологічних прийомів в ґрунтово-кліматичних умовах Лісостепу Західного. У процесі виконання роботи використовували наступні методи: польовий, лабораторний (для визначення якісних показників), та статистичний (для оцінки достовірності даних). Польові дослідження проводили впродовж 2021-2023 рр. на сірих лісових поверхнево-оглеєних ґрунтах. Досліджували особливості росту і розвитку сортів льону-довгунцю Міандр, Оберіг, Усівський та Іванівський із застосуванням таких норм удобрення, як $N_{20}P_{40}K_{60}$, $N_{30}P_{60}K_{90}$, $N_{45}P_{90}K_{135}$. Встановлено, що продуктивність льону-довгунця змінювалися залежно від дози мінеральних добрив та сортових особливостей. В середньому за 2021-2023 рр. вегетаційний період у льону-довгунця тривав 91-94 доби (залежно від сорту та мінерального живлення рослин). Найвищу врожайність льоносоломи (4,37 т/га) отримано в середньому за 2021-2023 рр. у сорту Оберіг за умови внесення дози мінеральних добрив $N_{30}P_{60}K_{90}$. Приріст до контролю становив – 0,52 т/га (13,51 %). Врожайність соломи у сорту Міандр, варіювала від 3,59 т/га (на контрольному варіанті) до 4,31 т/га (за внесення дози мінеральних добрив $N_{45}P_{90}K_{135}$), у сорту Усівський – 3,97-4,17 т/га, у сорту Іванівський – 3,12-3,81 т/га. Щодо врожайності насіння, то найвищі показники в середньому за 2021-2023 рр. отримано у сорту Міандр за умови використання дози мінеральних добрив $N_{45}P_{90}K_{135}$ – 1,26 т/га. При цьому врожайність на контролі становила 0,88 т/га. Аналогічну тенденцію спостерігали у сорту Оберіг з показниками врожайності насіння – 0,93 т/га та 0,58 т/га на контролі. Врожайність насіння у сорту Міандр перевищувала показник сорту Оберіг на 0,33 т/га при фоні удобрення $N_{45}P_{90}K_{135}$. На цьому ж фоні удобрення отримали найвищі показники врожайності насіння у сортів Усівський (0,99 т/га) та Іванівський (0,91 т/га), що вище контрольного варіанту на 0,17 т/га (20,73 %), та 0,07 т/га (8,33 %) відповідно. Результати цих досліджень можуть бути використані для корегування елементів технології вирощування льону-довгунця у виробничих умовах для підвищення врожайності та якості волокна

Ключові слова: льон-довгунець; сорти; мінеральні добрива; продуктивність; технології вирощування

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Selection of perennial grasses for an extended pasture in the autumn period

Volodymyr Kurhak*

Doctor of Agricultural Sciences, Professor, Corresponding Member
of the National Academy of Agrarian Sciences of Ukraine
National Research Centre "Institute of Agriculture of the National Academy
of Agrarian Sciences of Ukraine"

08162, 2-b Mashynobudivnykiv Str., Chabany Village, Ukraine
<https://orcid.org/0000-0003-2309-0128>

Larysa Kolomiets

PhD in Agricultural Sciences, Senior Research Fellow
National Research Centre "Institute of Agriculture of the National Academy
of Agrarian Sciences of Ukraine"

08162, 2-b Mashynobudivnykiv Str., Chabany Village, Ukraine
<https://orcid.org/0000-0003-3408-8541>

Anton Tkachenko

PhD in Economic Sciences
National Research Centre "Institute of Agriculture of the National Academy
of Agrarian Sciences of Ukraine"

08162, 2-b Mashynobudivnykiv Str., Chabany Village, Ukraine
<https://orcid.org/0000-0001-9145-7003>

Ivan Senyk

Doctor of Agricultural Sciences, Senior Research Fellow
Western Ukrainian National University
46009, 11 Lvivska Str., Ternopil, Ukraine
<https://orcid.org/0000-0003-3249-2065>

Svitlana Stotska

PhD in Agricultural Sciences, Associate Professor
Polissia National University
10008, 7 Stary Blvd., Zhytomyr, Ukraine
<https://orcid.org/0000-0003-0751-7996>

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Abstract. The relevance of the study lies in the fact that until recently the reaction of various types of perennial grasses to the terms of alienation of herbage in the last cycle of use has not been clarified, which hinders the development and implementation of technology for creating perennial agrophytocoenoses in the continuous pasture

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*Corresponding author

system with an extended grazing period for meat livestock in the late autumn period. The purpose of the study was to select the best perennial grasses for late autumn alienation of herbage in the system of an extended continuous pasture for meat breeds of cattle in the Right-Bank Forest-Steppe. The results of long-term research on the features of the development of the yield of aboveground biomass, the chemical composition of feed, the stability of certain types of grasses depending on the time of alienation of aboveground biomass in total for all cycles of use and in the last cycle in the autumn period are presented. The highest productivity (at the level of 0.60-0.95 t/ha of dry weight) of all types of grasses in the last (autumn) cycle of use is provided when the green mass is alienated on October 1. When alienated at a later date, the collection of dry mass from 1 ha decreases, while the quality of feed worsens due to a decrease in the content of crude protein and an increase in the concentration of crude fibre to the limits that do not meet the zootechnical norm of feeding cattle and the requirements of DSTU for green feed. Studies have identified the best single-species agrophytocoenoses of grasses, which include smooth brome, cocksfoot grass, and intermediate wheatgrass. On average, for 2008-2015, in the sum of all three cycles of use, they provide a productivity of 6.52-7.19 t/ha of dry weight when applying N_{120} . The results of these studies can be used in the development of recommendations for the creation of continuous pasture with an extended period of grazing grass with meat livestock in the autumn period, which reduces the cost and increases the competitiveness of livestock products

Keywords: fertilisers; green feed; productivity; pasture; mode of use; reserve paddock; chemical composition of feed; cycle of use

INTRODUCTION

Increasing the production of competitive livestock products, in particular cattle breeding products, is impossible without developing a high-quality feed base. In the structure of feeding beef cattle, green fodder should account for at least 60-70% in the summer and autumn period. The cheapest are grass feeds, in particular pasture ones, developed based on perennial grasses, which, along with feed-producing ones, are of great environmental importance (Crews *et al.*, 2018; Reynolds *et al.*, 2021; Kurhak, 2023).

Such agrophytocoenoses are the basis for profitable production of meat cattle products. In this regard, it is extremely important for beef cattle, which are the least demanding in terms of feed and maintenance, to extend the grazing period. Previous studies by V. Kurhak and U. Karbivska (2019), U. Karbivska (2020a), S. Panasiuk (2023) suggest that the grazing period in late autumn can be extended by 60 days, and under favourable weather conditions up to 90 days, until snow falls.

The presence of several optimal dates for the beginning of regrowth of autumn aftergrass in combination with grass stands of different types in ripeness ensure the continuous supply of pasture feed in reserve pens. Especially promising is the use of reserve pens in pasture, where a supply of grass is formed for grazing beef cattle or sheep in the late autumn period. For this purpose, meadow lands can be used, which are reproduced on former arable land in the erosion-hazardous zone of agricultural landscapes, including by their spontaneous overgrowth with grassy vegetation. As evidenced by V. Picasso *et al.* (2019), S. Culman *et al.* (2023), for this purpose, hayfields and seed beds of perennial grasses can also be used, or the cultivation of perennial grasses for grain, the aftergrass of which can be used for grazing livestock in the late autumn period. The maintenance of meat livestock extended to 200 or

more days is possible not only on cultivated pastures, but also on uncultivated pastures and even on unequipped sites or summer camps. This allows feeding live weight of animals on cheap grass feeds in the late autumn period. All this, combined with the subsequent intensive fattening of animals in stable conditions, will significantly reduce the cost of beef and accelerate the achievement of high weight conditions of meat cattle (Favre *et al.*, 2019; Hunter *et al.*, 2020)

Such an alternative possibility of extending the pasture period in the late autumn period due to perennial grasses, which causes the late alienation of the grass stand during this period, which is not recommended until now, becomes a reality due to new theoretical prerequisites for preserving the species composition and productive longevity of meadow coenoses under certain conditions. Such prerequisites, according to the authors' experience and previous research, may include the use of reserve paddocks in the system of haylage or pasture rotation, selection of appropriate components that can withstand late autumn alienation (Panasiuk, 2023).

However, until recently, there are still many unexplored issues in the use of pastures, which negatively affects the development of scientific foundations and technologies for creating reserve pens for grazing cattle in the late autumn period. That is why the purpose of the study was to select the best perennial grasses for late autumn grass alienation in the system of extended continuous pasture for beef cattle breeds with green fodder supply for 200-220 days in the Right-Bank Forest-Steppe.

MATERIALS AND METHODS

Research on the selection of perennial grasses for late autumn alienation of grass stand in the system of extended continuous pasture was conducted during 2008-2015 at the National Research Centre Institute of

Agriculture of the National Academy of Agrarian Sciences in Fastiv district, of Kyiv Oblast. The experiment was established in the spring of 2007 and conducted on dry meadows of normal moisture with grey forest light loamy soil. In a 0-20 cm layer, this dry soil contained 1.7% humus, 83 mg/kg – alkaline hydrolysed nitrogen, 175 mg – P_2O_5 , and 98 mg – K_2O . The salt pH – 5.5. The terrain of the research site was flat. The size of the sown area is 21 m², accounting – 15 m². The experiment was repeated four times. The number of variants – 32, and the number of land plots – 128.

The alkalinisation of experimental areas was carried out in early spring without cover. For this purpose, zoned varieties of cereals were used, in particular: cocksfoot grass *Muravka*, smooth brome *Vyshhorodskyi*, meadow fescue *Siverianka*, tall fescue *Dominika*, meadow timothy *Vyshhorodska*, intermediate wheatgrass *Vitas*, red fescue *Manchul*, smooth meadow-grass *Alex*. A two-factor field experiment to investigate the reaction of perennial grasses to late autumn use of herbage was carried out according to the scheme shown in Table 1.

Table 1. Experiment scheme

Factor A Cereals (types and norms of sowing seeds, kg/ha at 100% economic capacity)	Factor B Mode of use with different dates of the last grazing cycle
1. Smooth meadow-grass (<i>Poa pratensis</i> L.) – 20	1. September 1
2. Smooth brome (<i>Bromopsis inermis</i> (Leyss.) Holub) – 28	2. October 1
3. Meadow fescue (<i>Festuca pratensis</i> Huds) – 25	3. November 1
4. Tall fescue (<i>Festuca orientalis</i> (Hack.) – 25	4. December 1
5. Meadow timothy (<i>Phleum pratense</i> L.) – 15	
6. Intermediate wheatgrass (<i>Elytrigia intermedia</i> (Host) Nevski – 22	
7. Red fescue (<i>Festuca rubra</i> L.) – 22	
8. Smooth meadow-grass (<i>Poa pratensis</i> L.) – 15	

Source: developed by the authors

The experiment was conducted against the background of the introduction of $N_{120(40+40+40)}P_{45}K_{90}$. Nitrogen fertilisers (ammonium nitrate) were applied separately in equal parts in three terms: N_{40} in early spring for the 1st cycle, N_{40} for the 2nd cycle, and N_{40} for the 3rd (last) cycle of use. Phosphorous (simple granular superphosphate) and potash (potassium chloride) were applied early in spring in the same period. The weather conditions for the vegetation of grass plants were generally satisfactory in the spring-summer period and often not favourable, mainly in August and September, when there were long rainless periods, which negatively affected the regrowth of grasses.

Phenological observations of the growth and development phases of perennial grasses were carried out in accordance with DSTU 4674:2006 (2008). The dry weight content was determined by the thermo-static-weight method at a temperature of 105°C according to DSTU 4674:2006 (2008). Accounting of the green mass yield was carried out by weighing and then calculating the yield per 1 ha of dry weight according to DSTU 8044:2015 (2018). In dry vegetable mass, the content of crude protein and protein was determined according to DSTU ISO 5983-2003 (2003); crude fat – according to DSTU ISO 6492-2003 (2005); crude fibre, crude ash – according to DSTU ISO 5984:2004 (2005); nitrogen, phosphorus, potassium – by infrared spectroscopy according to DSTU 4117:2007 (2007); the content of nitrogen-free extractives (NFE) – according to DSTU 4674:2006 (2008).

Agrochemical parameters of the soil were determined in a 0-20 cm layer of soil according to gen-

erally accepted methods, namely: humus – by Tyurin according to DSTU 4289:2004 (2006), nitrogen, which is easily hydrolysed by alkali – by Cornfield according to DSTU 7863:2015 (2018), mobile phosphorus and potassium – by Chirikov according to DSTU 4115:2002 (2003), pH (salt) – using the potentiometric method by V.F. Moiseichenko, V.O. Eshchenko according to DSTU ISO 10390:2001 (2008).

Experimental studies of plants (both cultivated and wild), including the collection of plant material, were in accordance with institutional, national or international guidelines. The authors adhered to the standards of the Convention for the Protection of Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS AND DISCUSSION

The dynamics of the content of sown cereals in single-species cereal agrocoenoses by year during 2008-2015, depending on the duration of the last cycle of use, is shown in Table 2. According to average indicators, the duration of the last cycle of use in terms of the share of sown crop did not significantly affect the smooth brome, tall fescue, meadow timothy, red fescue, and smooth meadow-grass. At the latest period of the last alienation, namely 1.12 compared to the earliest (1.09), the share of sown crops in single-species agrophytocoenoses of cocksfoot grass, meadow fescue, and medium wheatgrass decreased by 5-7%. Analysis of the findings showed that the species characteristics of grasses had a greater impact on their stability over the years of use. According to average indicators, the

highest proportion of sown crops (76-89%) was best kept in agrophytocoenoses with the highest proportion of sown crops (76-89%), cocksfoot grass and smooth

brome, and the worst – meadow fescue with the proportion of sown crops of 41-48%. Other species occupied an intermediate position.

Table 2. Content of sown cereals depending on the period of the last cycle of use of herbage by year, %, 2008-2015

Duration of the last cycle	Years of use								Average for these years
	2008, 1 st	2009, 2 nd	2010, 3 rd	2011, 4 th	2012, 5 th	2013, 6 th	2014, 7 th	2015, 8 th	
Cat grass – <i>Dactylis glomerata</i> L., Muravka variety									
1.09	91	96	94	89	88	82	84	81	88
1.10	92	95	95	88	90	83	82	84	89
1.11	90	93	92	84	85	84	81	80	86
1.12	89	90	92	83	83	80	76	72	83
Smooth brome <i>Bromopsis inermis</i> (Leys. Holub – Vyshhorodskyyi									
1.09	88	89	92	86	82	74	69	59	79
1.10	87	90	93	87	81	76	70	54	80
1.11	85	87	88	84	80	76	73	54	77
1.12	86	87	81	82	79	73	71	52	76
Meadow fescue – <i>Festuca pratensis</i> Huds – Siverianka									
1.09	96	81	66	49	35	19	18	14	47
1.10	95	83	67	48	34	22	20	13	48
1.11	91	78	58	41	28	25	21	12	44
1.12	88	76	55	38	27	20	16	10	41
Tall fescue – <i>Festuca orientalis</i> (Hack.) – Dominika									
1.09	82	83	87	75	71	66	70	62	74
1.10	81	84	86	74	73	67	74	63	75
1.11	80	82	83	71	70	69	77	63	74
1.12	81	80	84	70	66	65	76	61	72
Meadow timothy – <i>Phleum pratense</i> L. – Vyshhorodska									
1.09	92	87	71	59	52	49	41	26	60
1.10	93	88	72	58	57	54	42	25	61
1.11	90	85	70	58	55	56	44	23	60
1.12	90	80	70	57	54	55	38	21	58
Intermediate wheatgrass – <i>Elytrigia intermedia</i> (Host) Nevski – Vitas									
1.09	97	85	81	77	72	58	52	41	70
1.10	94	86	80	78	73	66	56	40	72
1.11	93	80	78	64	66	65	58	35	67
1.12	91	77	74	63	61	59	51	32	63
Red fescue – <i>Festuca rubra</i> L. – Manchulska									
1.09	83	79	72	68	66	57	52	48	67
1.10	84	80	71	69	67	81	61	50	70
1.11	82	80	72	71	65	80	74	56	72
1.12	81	76	70	65	63	72	72	57	69
Smooth meadow-grass – <i>Poa pratensis</i> L. – Alex									
1.09	96	90	78	64	61	49	49	41	66
1.10	94	91	77	65	59	53	53	43	67
1.11	92	89	74	66	62	58	58	38	67
1.12	92	88	72	63	58	60	48	38	65

Note: the experiment was conducted against the background of $N_{120(40+40+40)} P_{45} K_{90}$

Source: compiled by the authors

This pattern was more clearly manifested in the years of life and use of herbage. Notably, in the first three years, all types of grasses were well preserved in agrophytocoenoses with a seeding rate of 55-97%. In the following years, up to the 8th year of use, the cocksfoot grass with a high proportion of sown crops was best preserved. The fastest rate of decline in sown crops occurred in the agrophytocoenosis from meadow fescue,

which almost completely fell out of the grass stand, starting from 2013 to 2015 with a share of 10-25%, which negatively affected the productivity of this species.

Meadow timothy was also characterised by a strong liquefaction of the herbage over the years of use, which almost fell out of the herbage in the 8th year of life and use, when the content of the main crop in the variants did not exceed 21-26%. Other species (smooth brome,

tall fescue, intermediate wheatgrass, red fescue, smooth meadow-grass), except for cocksfoot grass, which was well preserved in all years, are better preserved in herbage. Their number gradually decreased over the years, but still was at a sufficient level and in the 8th year ranged from 32-62%. Among these species, at the last year of use in 2015, the best preserved are smooth brome, tall fescue, and red fescue.

Studies have established that the productivity of single-species crops of cereals was determined not only by the share of the sown species, but also by weather conditions during the years of study (Table 3). With the

application of a total dose of nitrogen N_{120} , the productivity of different types of these grasses in total for all mowing ranged from 5.08-7.19 t/ha of dry weight on average in 2008-2015. Regardless of the timing of the last cycle of use, the most productive were herbage, which was formed based on single-species crops of cocksfoot grass, smooth brome, and medium wheatgrass, and the least productive – agrophytocoenosis from meadow fescue, where the share of sown crop was the smallest in the yield. Other species, namely tall fescue, meadow timothy, red fescue, smooth meadow-grass, occupied an intermediate position.

Table 3. Dynamics of productivity of cereals depending on the period of the last cycle of use by year, t/ha of dry weight, 2008-2015

Duration of last cycle	Years of use								Average for 2008-2015
	2008, 1 st	2009, 2 nd	2010, 3 rd	2011, 4 th	2012, 5 th	2013, 6 th	2014, 7 th	2015, 8 th	
Cocksfoot grass									
1.09	8.90	7.18	5.74	5.24	5.12	5.65	9.64	5.11	6.52
1.10	9.32	7.23	5.82	5.32	5.20	5.96	9.72	5.29	6.73
1.11	9.24	6.93	5.68	5.18	5.06	5.72	9.80	5.17	6.60
1.12	8.53	6.60	5.39	4.89	4.77	5.43	9.69	5.05	6.25
Smooth brome									
1.09	11.90	7.70	5.62	5.12	5.00	5.17	8.81	5.36	6.81
1.10	12.34	7.71	5.67	5.17	5.05	5.49	8.96	5.55	6.96
1.11	12.23	7.39	5.55	5.05	4.93	5.23	9.03	5.39	6.87
1.12	11.64	7.08	5.32	4.82	4.70	4.92	8.93	5.30	6.62
Meadow fescue									
1.09	11.95	7.80	3.40	2.90	2.78	3.84	6.12	3.25	5.22
1.10	12.03	7.81	3.49	2.99	2.87	4.19	6.19	3.29	5.33
1.11	11.72	7.55	3.40	2.90	2.78	4.10	6.16	3.27	5.25
1.12	10.98	7.23	3.32	2.82	2.70	3.77	6.14	3.23	5.08
Tall fescue									
1.09	11.91	8.11	4.04	3.54	3.42	5.05	7.48	3.99	5.92
1.10	12.00	8.13	4.05	3.55	3.43	5.29	7.61	4.15	6.04
1.11	11.55	7.84	3.88	3.38	3.26	5.07	7.69	4.17	5.81
1.12	11.06	7.51	3.73	3.23	3.11	4.61	7.62	3.96	5.66
Meadow timothy									
1.09	10.85	8.06	4.82	4.32	4.20	4.11	7.01	3.44	5.85
1.10	11.01	8.09	4.84	4.34	4.22	4.40	7.06	3.49	5.93
1.11	10.61	7.82	4.74	4.24	4.12	4.35	7.09	3.47	5.81
1.12	10.17	7.54	4.63	4.13	4.01	3.88	7.04	3.45	5.60
Intermediate wheatgrass									
1.09	11.71	8.33	7.48	6.98	6.86	4.72	7.22	3.77	7.13
1.10	11.81	8.35	7.49	6.99	6.87	4.86	7.27	3.88	7.19
1.11	11.34	8.14	7.28	6.78	6.66	4.51	7.30	3.79	6.97
1.12	11.06	7.78	7.00	6.50	6.38	4.29	7.26	3.71	6.70
Red fescue									
1.09	11.05	6.80	4.85	4.35	4.23	4.60	7.61	3.82	5.76
1.10	11.18	6.88	4.86	4.35	4.23	5.03	7.70	3.86	5.83
1.11	10.68	6.77	4.64	4.14	4.02	4.75	7.77	3.99	5.64
1.12	10.20	6.48	4.32	3.82	3.70	4.21	7.73	3.94	5.52
Smooth meadow-grass									
1.09	11.44	7.36	5.62	5.12	5.00	4.36	6.56	3.70	6.22
1.10	11.57	7.39	5.71	5.21	5.09	4.58	6.62	3.83	6.25
1.11	11.16	7.10	5.62	5.12	5.00	4.32	6.64	3.75	6.05
1.12	10.73	6.82	5.54	5.04	4.92	4.06	6.53	3.67	5.92
LSD ₀₅ , t/ha	0.41	0.22	0.19	0.27	0.17	0.19	0.37	0.07	0.13

Note: productivity in total for three cycles of use against the background of N_{120} ($40 + 40 + 40$) P_{45} K_{90}

Source: compiled by the authors

According to the average indicators, the duration of the last cycle of use had a different effect on the total productivity of the species under study. The highest productivity of all species was obtained for the alienation of aboveground biomass 01.10, which ranged from 5.33 (meadow fescue) to 7.19 (intermediate wheatgrass) t/ha. This mowing period slightly reduced the total productivity for all mowing periods at alienation 1.09 and 1.11. And only with the last alienation of 1.12, the total productivity compared to the last alienation of 1.10 significantly decreased by 0.31-0.48 t/ha. This decrease was slightly greater in the cocksfoot grass and less in the red fescue and smooth meadow-grass.

Productivity significantly changed in the sum for all mowing and for the years of use of the stands of grass types under study. The highest productivity was obtained in the 1st year of use, which was in the range of 10.20-12.34 t/ha of dry weight. The exception was the cocksfoot grass, whose productivity, due to favourable conditions, was greatest in the 7th year of use. The productivity of the cocksfoot grass that year from other species was less by 2.20-3.05 t/ha, which naturally differed little in productivity.

Over the years, the productivity of all species gradually decreased, with the exception of 2014, when due to the favourable conditions of moistening and overwintering of perennial grasses, the spread of unseeded (wild) species and groups of mixed grasses and cereals, and the good development of sown species, their productivity level was in second place after the first year of use. The exceptions were meadow fescue and tall fescue, whose productivity level in the last year ranked third after the first year. These species took the second place in terms of productivity in the 2nd year of use. In general, the smallest decrease in productivity over the years was observed in the cocksfoot grass and smooth

brome, whose performance was more or less stable during all 8 years of use. The productivity of intermediate wheatgrass and smooth meadow-grass was maintained at a relatively stable level for the first 5 years. In the 6th and 8th years, they sharply reduced their productivity. Other species, namely meadow fescue, tall fescue, meadow timothy, red fescue, sharply reduced their productivity, starting from the 3rd, with the exception of the 7th year of use of agrophytocoenoses.

The analysis of literature sources shows that reserve pens on pastures for grazing meat cattle in the autumn period are created based on the development of a reserve of grass feed from the last mowing or cycle of use of perennial grasses or natural meadow phytocoenoses (Kurhak & Karbivska, 2019; Karbivska, 2020b; Panasiuk, 2023). Results of evaluation of the feed productivity of various types of perennial grasses in the last cycle of use at different times of its implementation against the background of the introduction of N₄₀ is shown in Table 4. The productivity of the last cycle of use of the studied types of herbs with different terms of its implementation in terms of yield from 1 ha of dry weight ranged from 0.29-0.86 tonnes, fodder units – 0.15-0.53 tonnes, and crude protein – 0.04-0.16 tonnes. It was the largest in intermediate wheatgrass and red fescue, and the smallest in meadow fescue and smooth meadow-grass. Analysis of the results of productivity studies for different periods of alienation of the aboveground mass in the last cycle of use shows that its increase occurred only up to 1.10, after which it gradually decreased and it was the smallest at the alienation of 1.12. The highest productivity of the last cycle of all species obtained on 01.10 ranged from 0.60 (smooth meadow-grass) to 0.95 (red fescue) t/ha, and the lowest productivity on 01.12 – in the range of 0.29-0.51 t/ha.

Table 4. Productivity and quality of the last cycle of use of perennial grasses, depending on the duration of its implementation, average for 2008-2015

Date of the last mowing	Dry weight, t/ha	Fodder units, t/ha	Crude protein, t/ha	Provision of the fodder unit with digestible protein, g	Dry weight content, %
Cocksfoot grass					
1.09	0.73	0.44	0.12	122	31.9
1.10	0.85	0.54	0.11	120	31.3
1.11	0.69	0.43	0.10	118	30.8
1.12	0.40	0.39	0.08	115	34.8
Smooth brome					
1.09	0.69	0.40	0.11	121	33.4
1.10	0.83	0.51	0.14	117	33.2
1.11	0.63	0.38	0.10	114	32.7
1.12	0.39	0.25	0.06	108	35.2
Meadow fescue					
1.09	0.56	0.39	0.09	119	32.0
1.10	0.66	0.42	0.11	115	33.6
1.11	0.52	0.32	0.08	113	31.9
1.12	0.31	0.17	0.05	110	35.1
Tall fescue					
1.09	0.72	0.42	0.10	112	32.4

Table 4. Continued

Date of the last mowing	Dry weight, t/ha	Fodder units, t/ha	Crude protein, t/ha	Provision of the fodder unit with digestible protein, g	Dry weight content, %
Tall fescue					
1.10	0.81	0.50	0.14	109	31.8
1.11	0.68	0.41	0.12	106	33.1
1.12	0.35	0.23	0.05	103	34.2
Meadow timothy					
1.09	0.57	0.31	0.08	118	33.0
1.10	0.65	0.40	0.11	113	33.4
1.11	0.50	0.31	0.08	109	32.9
1.12	0.30	0.17	0.04	102	35.3
Intermediate wheatgrass					
1.09	0.82	0.51	0.13	110	33.7
1.10	0.88	0.56	0.15	114	34.2
1.11	0.67	0.42	0.11	105	34.1
1.12	0.39	0.24	0.05	103	36.2
Red fescue					
1.09	0.86	0.53	0.14	121	34.3
1.10	0.95	0.60	0.16	118	34.5
1.11	0.85	0.52	0.14	116	33.6
1.12	0.51	0.33	0.06	115	34.1
Smooth meadow-grass					
1.09	0.51	0.28	0.06	113	33.5
1.10	0.60	0.37	0.09	112	32.8
1.11	0.45	0.27	0.06	110	34.1
1.12	0.29	0.15	0.05	109	36.7
LSD ₀₅ , t/ha	0.04				

Note: the dose of nitrogen fertiliser for this mowing is N_{40}

Source: compiled by the authors

Analysis of the quality indicators of grass feed obtained in the last cycle of use at different times of its implementation showed that the provision of the feed unit with digestible protein ranged from 102 to 122 g, and the content of dry weight in the green mass of feed – from 31.9 to 36.7%. With the shift of the last usage cycle from 1.09 to 1.12, the parameters of these indicators worsened. In particular, the supply of digestible protein to the fodder unit during this period decreased by 4-16 g, and the dry weight content in the green mass of feed increased by 1.8-3.2%. Slightly better availability of one fodder unit in the last cycle of use was characterised by single-species agrophytocoenoses of the cocksfoot grass, smooth brome, and red fescue. Analysis of feed chemical composition indicators on average for 2008-2015 (Table 5) showed

a deterioration in the quality of feed in the last cycle of use due to alienation at a later date. In particular, with the monthly shift of the last cycle of use of grass stands from 1.09 to 1.12, the content of crude protein in the dry matter of grass stands decreased by 2.9-3.9%, and crude fibre, as the least valuable (ballast) indicator of feed quality, increased by only 5.2-7.5%. However, the content of protein, crude fat, and mineral elements, in particular, phosphorus, potassium, and calcium, decreased. The worst indicators of the chemical composition of the feed were for the alienation of the last cycle of use at the latest, namely 1.12. According to the content of crude protein, the chemical composition of the feed in the last cycle of use was slightly better: cocksfoot grass, smooth brome, red fescue.

Table 5. Chemical composition of the fodder of the last cycle of use of cereals, depending on the period of its implementation, % in dry weight (average for 2008-2015)

Duration of the last cycle	Crude protein	Crude protein	Crude fat	Crude fibre	NFE	P	K	Ca
Cocksfoot grass								
1.09	14.5	13.4	3.16	28.2	44.6	0.37	2.36	0.77
1.10	15.3	13.8	3.29	29.6	42.1	0.35	2.10	0.41

Table 5. Continued

Duration of the last cycle	Crude protein	Crude protein	Crude fat	Crude fibre	NFE	P	K	Ca
Cocksfoot grass								
1.11	12.4	11.0	3.02	32.5	43.0	0.29	2.08	0.47
1.12	11.9	11.0	2.58	35.7	38.6	0.28	2.01	0.50
Smooth brome								
1.09	14.7	13.6	2.92	29.8	42.5	0.37	1.34	0.69
1.10	15.1	13.7	3.15	29.7	43.1	0.39	2.08	0.56
1.11	12.8	11.6	3.11	33.2	41.6	0.40	2.14	0.51
1.12	11.2	10.2	2.29	36.5	38.7	0.32	2.04	0.49
Meadow fescue								
1.09	13.1	12.2	2.89	30.5	43.6	0.37	1.52	0.74
1.10	13.4	12.4	3.01	31.4	42.3	0.37	2.09	0.48
1.11	12.1	11.4	2.96	33.1	41.4	0.37	2.13	0.43
1.12	9.8	9.1	2.36	38.3	38.1	0.31	1.88	0.36
Tall fescue								
1.09	14.5	13.3	3.12	29.6	42.7	0.36	1.75	0.67
1.10	14.2	12.7	3.31	30.3	42.1	0.38	2.07	0.45
1.11	13.1	11.5	2.93	32.9	40.6	0.36	2.18	0.54
1.12	10.7	9.8	2.35	36.3	39.2	0.31	2.07	0.46
Meadow timothy								
1.09	13.6	12.5	3.17	29.1	43.2	0.36	1.70	0.59
1.10	12.9	11.8	2.74	31.8	43.0	0.38	2.10	0.41
1.11	12.4	11.3	2.49	33.9	42.2	0.37	2.12	0.48
1.12	10.2	9.6	2.38	38.3	37.5	0.29	1.66	0.38
Intermediate wheatgrass								
1.09	14.1	13.0	3.13	29.5	43.6	0.37	1.96	0.70
1.10	13.3	12.1	3.02	31.1	42.6	0.37	2.05	0.48
1.11	12.6	11.7	2.92	33.4	40.8	0.36	2.19	0.40
1.12	10.6	9.8	2.19	37.2	38.5	0.26	1.61	0.29
Red fescue								
1.09	14.8	13.5	2.73	30.6	42.7	0.35	1.80	0.51
1.10	14.7	13.5	3.35	27.7	44.6	0.36	2.11	0.50
1.11	13.3	12.3	3.22	32.5	41.0	0.36	2.13	0.49
1.12	11.9	10.9	2.18	35.4	39.2	0.33	1.80	0.38
Smooth meadow-grass								
1.09	14.1	12.8	3.46	29.5	43.3	0.35	1.83	0.74
1.10	13.9	12.6	3.19	31.4	42.0	0.38	2.11	0.47
1.11	12.2	11.4	2.83	33.7	40.6	0.40	2.17	0.48
1.12	10.2	9.6	2.45	36.8	38.9	0.29	1.66	0.35
LSD ₀₅ , t/ha	0.5	0.4	0.1	1.0	1.9	0.02	0.13	0.03
Zootechnical norm	14	–	3-5	25-30	–	0.2-0.4	1.0-3.0	0.3-0.6

Source: compiled by the authors

However, the forage of agroecosystems of grasses, even after the last cycle of use 1.12, was quite suitable for grazing less demanding beef cattle. The obtained data on the chemical composition of the feed showed that the biomass of grass stands was more or less balanced in terms of the content of organic and mineral elements and, in general, met the zootechnical standards for feeding cattle.

The study by V. Kurhak *et al* (2023) shows that the creation of intensive-type sown grasslands with multi-mowing has an important role in increasing the production of cheap grass fodder. They are a reliable

measure to increase the productivity of meadow land and significantly improve the quality of fodder compared to traditional single- or double- mowing. Multi-mown grass stands are created using economically feasible and environmentally sound doses of nitrogen mineral fertilisers at the level of N₉₀₋₁₅₀ in combination with the application of phosphorous and potash fertilisers. These fertilisers increase the productivity of floodplain, lowland, normal dry and irrigated grasslands by 2-3 times, the productive longevity of sown cereal components, and the share of valuable forage grass species in natural grass stands.

In single-species coenoses, they react well to nitrogen and are among the more productive perennial grasses: smooth brome, cocksfoot grass, red fescue, smooth meadow-grass, perennial ryegrass (Kurhak & Karbivska, 2019). One of the most important areas of grassland farming is the creation of multi-seasonal sown high-yield grasslands. On high agricultural backgrounds, subject to the recommended regimes of use, multi-season grass stands provide not only high productive longevity of meadow coenosis and proper fodder quality, but also, due to the wide range of species and varieties, allow organising continuous fodder production based on them. Such intensive grass stands should be created during the application of full mineral fertiliser in meadows with sufficient moisture (low-lying, floodplain small rivers, dry land with normal moisture).

Along with increasing the yield of sown meadow lands by selecting the most productive species and varieties, creating optimal growing conditions for them, obtaining high-quality feed is important for feeding livestock. It is known that under certain conditions, good quality of grass feed is also provided by grass stands. First of all, this is ensured by applying sufficient doses of nitrogen fertilisers. With increasing doses of nitrogen fertilisers, the content of crude protein and protein in grasses increases and the content of nitrogen-free extractives and, in particular, their component part – hydrocarbons, including water-soluble or sugars – decreases (Karbivska, 2020a; 2020b).

The mode of use also significantly affects the productivity and quality of feed. As the frequency of grass alienation increases, the possibilities of using solar energy decrease, since most of the growing season is used to grow them when they do not yet have the optimal leaf surface for maximum photosynthesis. With frequent mowing, the roots are more depleted and less “spare substances” are deposited in the reserve organs. In many herbs, these substances begin to accumulate intensively only in the phases of stemming, earing, budding, and even flowering. Therefore, frequent alienation is particularly dangerous for them, they grow weaker, overwinter worse, and provide lower yields (Kurak, 2023).

The timing of harvesting perennial herbs has a decisive influence on the content of protein, fibre, mineral elements, vitamins, and other substances in plants. The best quality fodder is obtained when mowing grasses in the early phases of vegetation, when plants use the main nutrients, including spare and re-synthesised ones, to increase the vegetative mass. As plants age, especially during the flowering period and seed formation, when growth processes slow down and nutrients are deposited in the storage organs, the quality of grass biomass deteriorates greatly. All this is accompanied by a decrease in valuable nutrients (protein, carotene, minerals) and an increase in the content of the least nutritious part of the feed in grass biomass – fibre (Favre *et al.*, 2019).

Thus, the analysis of literature sources has shown that one of the conditions for obtaining sufficient productivity of cereal herbage and good feed quality is the introduction of environmentally and economically justified doses of mineral fertilisers, and mowing grasses in optimal terms. This is of particular importance when alienating grass stands in the late autumn period, which is confirmed by current research.

CONCLUSIONS

Against the background of $N_{120}P_{45}K_{90}$ application on grey forest soils, perennial grasses are suitable for late autumn use in the continuous pasture system for grazing beef cattle in reserve pens, which, with long-term use (on average, 8 years), provide 5.33-7.19 t/ha of dry weight. Perennial grasses are characterised by various productive longevity. In single-species agrophytocoenoses, it is best to preserve the cocksfoot grass, smooth brome, tall fescue, and red fescue with a 50-97% share of sown culture for 8 years, and the highest productivity is the cocksfoot grass, smooth brome, and intermediate wheatgrass. It is well kept in single-species agrophytocoenoses at the level of 55-96% and provides high productivity only during the first three years of meadow fescue and meadow timothy. Tall fescue, red fescue, and smooth meadow-grass occupy an intermediate position in these indicators.

All types of perennial grasses provide the highest productivity in the total for three cycles of use due to the alienation of aboveground biomass in the last cycle of use 01.10. With the last alienation of 1.12 compared to alienation of 1.10, the total productivity decreases by 0.31-0.48 t/ha. The productivity of the last cycle of use of the grass species under study with different periods of its implementation in terms of dry weight per 1 ha ranges from 0.29-0.86 t, fodder units – 0.15-0.53 t, and crude protein – 0.04-0.16 t. The most productive are intermediate wheatgrass and red fescue, and the least – meadow fescue and smooth meadow-grass. In the last cycle of use, at different times of its implementation, the supply of the fodder unit with digestible protein ranges from 102 to 122 g, and the dry weight content in the green mass of feed ranges from 31.9 to 36.7%. With the shift of the last cycle of use from 1.09 to 1.12, the quality of feed worsens: the supply of digestible protein to the fodder unit decreases, and the content of dry weight in the green mass of feed increases. At the same time, the crude protein content in dry weight decreases by 2.9-3.9%, and protein, crude fat, and the mineral macronutrients phosphorus, potassium and calcium, while the crude fibre content increases by 5.2-7.5%.

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CONFLICT OF INTEREST

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Володимир Кургак

Доктор сільськогосподарських наук, професор, член-кореспондент
Національної академії аграрних наук України
Національний науковий центр «Інститут землеробства
Національної академії аграрних наук України»
08162, вул. Машинобудівників, 2-б, смт. Чабани, Україна
<https://orcid.org/0000-0003-2309-0128>

Лариса Коломієць

Кандидат сільськогосподарських наук, старший науковий співробітник
Національний науковий центр «Інститут землеробства
Національної академії аграрних наук України»
08162, вул. Машинобудівників, 2-б, смт. Чабани, Україна
<https://orcid.org/0000-0003-3408-8541>

Антон Ткаченко

Кандидат економічних наук
Національний науковий центр «Інститут землеробства
Національної академії аграрних наук України»
08162, вул. Машинобудівників, 2-б, смт. Чабани, Україна
<https://orcid.org/0000-0001-9145-7003>

Іван Сенік

Доктор сільськогосподарських наук, старший науковий співробітник
Західноукраїнський національний університет
46009, вул. Львівська, 11, м. Тернопіль, Україна
<https://orcid.org/0000-0003-3249-2065>

Світлана Стоцька

Кандидат сільськогосподарських наук, доцент
Поліський національний університет
10008, бульв. Старий, 7, м. Житомир, Україна
<https://orcid.org/0000-0003-0751-7996>

Анотація. Актуальність наведених результатів досліджень полягає в тому, що до останнього часу не з'ясовано реакцію різних видів багаторічних злакових трав на строки відчуження травостоїв в останньому циклі використання, що стримує розроблення і впровадження технології створення багаторічних агрофітоценозів у системі зеленого пасовищного конвеєра з подовженим терміном випасання м'ясного поголів'я худоби в пізньоосінній період. Мета досліджень полягала в доборі кращих багаторічних злакових трав для пізньоосіннього відчуження травостою у системі подовженого пасовищного конвеєра для м'ясних порід великої рогатої худоби в Правобережному Лісостепу. Наведено результати багаторічних досліджень з вивчення особливостей формування урожаю надземної біомаси, хімічного складу корму, стійкості окремих видів злакових трав залежно від строків відчуження надземної біомаси в сумі за всі цикли використання та в останньому циклі в осінній період. Найбільшу продуктивність (на рівні 0,60-0,95 т/га сухої маси) всі види злакових трав в останньому (осінньому) циклі використання забезпечують при відчуженні зеленої маси 1-го жовтня. При відчуженні у пізніші строки збір сухої маси з 1 га зменшується, одночасно погіршується якість корму через зменшення вмісту сирого протеїну та збільшення концентрації сирого клітковини до меж, що не відповідають зоотехнічній нормі годівлі великої рогатої худоби та вимогам ДСТУ на зелені корми. Дослідженнями виявлено кращі одновидові агрофітоценози злакових трав, якими є стоколос безостий, грястиця збірна, пирій середній. Вони в середньому за 2008-2015 роки у сумі за всі три цикли використання при внесенні N_{120} забезпечують продуктивність на рівні 6,52-7,19 т/га сухої маси. Результати цих досліджень можуть бути використані при розробленні рекомендацій щодо формування пасовищних конвеєрів з подовженим в осінній період терміном випасання травостою м'ясним поголів'ям худоби, що дозволяє знизити собівартість і підвищити конкурентноздатність тваринницької продукції

Ключові слова: добрива; зелені корми; продуктивність; пасовище; режим використання; резервний загін; хімічний склад корму; цикл використання



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Determination of milk quality indicators and first streams depending on the stage of lactation and daily milk yield

Iryna Tkachova*

Doctor of Agricultural Sciences, Chief Researcher
Institute of Animal Science of the National Academy of Agrarian Sciences of Ukraine
61026, 1-A Tvarynnykiv Str., Kharkiv, Ukraine
<https://orcid.org/0000-0002-4235-7257>

Galina Prusova

PhD in Agricultural Sciences, Senior Researcher
Institute of Animal Science of the National Academy of Agrarian Sciences of Ukraine
61026, 1-A Tvarynnykiv Str., Kharkiv, Ukraine
<https://orcid.org/0000-0002-2604-5720>

Victoria Petrash

PhD in Agricultural Sciences, Senior Researcher
Institute of Animal Science of the National Academy of Agrarian Sciences of Ukraine
61026, 1-A Tvarynnykiv Str., Kharkiv, Ukraine
<https://orcid.org/0000-0001-9114-6117>

Anatoliy Tkachov

Junior Researcher
Institute of Animal Science of the National Academy of Agrarian Sciences of Ukraine
61026, 1-A Tvarynnykiv Str., Kharkiv, Ukraine
<https://orcid.org/0000-0002-6325-4724>

Vitaliy Petrash

Postgraduate Student
Institute of Animal Science of the National Academy of Agrarian Sciences of Ukraine
61026, 1-A Tvarynnykiv Str., Kharkiv, Ukraine
<https://orcid.org/0009-0002-2024-0127>

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Abstract. The relevance of the study is to solve the problem of cow's milk quality and the influence of factors of lactation stage and daily milk yield on milk parameters, and to establish links between the content of somatic cells in milk and other milk parameters. The purpose of the study was to determine the influence of the lactation stage and daily milk yield on the quality indicators of milk and its first streams, and to establish links between the content of somatic cells and other indicators of the

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*Corresponding author

quality of milk and its first streams. Research methods – zootechnical (selection of groups, organisation of the experiment, determination of milk productivity, assessment of the stage of lactation, the level of milk yields, control milking), biochemical (determination of the main indicators of milk quality), statistical, mathematical. A significant difference between milk quality indicators in the daily milk yield and in the first three streams of milk ($p \geq 0.95$) was established, therefore, the need to separate the first streams of milk from the main milk yield was experimentally proved. It was found that the indicators of the quantity and quality of milk and its first streams in various degrees correlate with the stage of lactation, the highest daily milk yield was established in cows that were in the first trimester of lactation. Fluctuations in the quality indicators of milk and its first streams depending on the level of daily milk yield were established. It was found that the content of somatic cells in milk is quite significantly negatively associated with the indicators of lactose content and freezing point of milk, to a lesser extent – with daily milk yield, and positively – with the duration of lactation, protein and whey+casein content. In the first streams of milk, the correlation coefficients for milk productivity and quality did not exceed 0.250. The highest somatic cell content was positively correlated with the MSNF index, protein and whey+casein content, freezing point, urea content, and negatively correlated with daily milk yield and fat content. The findings can be used in milk production farms and when planning breeding work to improve the quality characteristics of milk by selection

Keywords: dairy cows; milk quality parameters; lactation stage; daily milk yield; somatic cell content

INTRODUCTION

Food safety is the foundation of the health of any nation in the world, and the population of developed countries is paying more and more attention to healthy nutrition. In most countries, laws set minimum requirements for milk components and standards that provide value added if they are satisfactory. Therefore, producers need to implement strategies that ensure the best quality of milk in the production process and, thus, receive economic benefits. High standards of quality and safety of dairy raw materials, which are the norm for the world's leading producers, should be integrated into domestic production as soon as possible. The issue of milk quality is of particular relevance in connection with the signing of the EU-Ukraine Association Agreement in 2014, under which Ukraine had to harmonise its legislation with EU provisions, in particular, Regulation (EC) No. 853/2004 (2004) laying down specific hygiene rules for food, including milk and milk products.

The need to approach European standards has contributed to the introduction of new requirements for raw materials for the production of dairy products, so the task of Ukraine, which seeks the fastest accession to the EU, is to introduce these standards. For this purpose, on March 12, 2019, the Order of the Ministry of Agrarian Policy and Food of Ukraine No. 118 (2019) was issued. This order has been repeatedly amended to improve the requirements for milk quality in the conditions of Ukraine. The new requirements set criteria for exceeding which milk cannot be sold.

In addition to food safety, milk quality is an important factor with significant weight in the marketing and industrial sectors. In most countries, laws set minimum requirements for milk components and standards that provide value added if they are satisfactory. Therefore, producers need to implement strategies that ensure the best quality of milk in the production process and, thus, receive economic benefits. High standards of quality and safety of dairy raw materials, which are

the norm for the world's leading producers, should be integrated into domestic production as soon as possible. On the other hand, consumers are becoming more aware of food safety issues as the population's income increases.

Much attention is paid to milk quality research all over the world, and high quality requirements are set for milk and dairy products. Thus, one of the important tasks is to search for factors influencing milk quality indicators. P.L. Ruegg (2022), M. Cassandro (2020), L.M. Piddubna *et al.* (2021) highlight genetic factors as the main impact factors, whereas R. Feliciano *et al.* (2020), E. Jeon *et al.* (2023) distinguish climatic factors.

S. Quiédeville *et al.* (2022), J. Nzeyimana *et al.* (2023) prove a significant impact on cow productivity and milk quality of weather conditions and the heat stress caused by them. However, many researchers focus on technological factors. Thus, A. Correa-Calderón *et al.* (2022), E. Hayes *et al.* (2023) prove the importance of feeding rations in obtaining high milk yields and high-quality milk. M. Lutsenko *et al.* (2021), R. Vieira *et al.* (2022) note the special importance of keeping livestock conditions for obtaining high-quality milk. Among the main factors influencing the quality of milk, V. Tančin *et al.* (2020) distinguish the indicator of the number and stage of lactation. In the context of international standards for milk quality, T. Chernyavska (2023) and D. Giannuzzi *et al.* (2023) identify the particular importance of studying the somatic cell content in milk as a key indicator of milk and dairy product safety. Thus, the study of factors affecting the quality of milk requires testing in various conditions.

Given the relevance of the issue, the purpose of the study was to determine the factors that affect the quality indicators of milk and its first streams: the timing and stages of lactation, the level of daily milk yield, and the relationship between milk quality indicators. Special attention is paid to the study of the indicator of

the content of somatic cells in milk and the establishment of relationships of this trait with other indicators of milk quality.

MATERIALS AND METHODS

The scientific and economic experiment was conducted in June 2023 on high-yielding cows of the Ukrainian Black-and-White dairy breed, taking into account productivity and lactation stage, at Gagarin Agrofirma LLC in Kharkiv Oblast. Control ($n = 160$) and experimental ($n = 56$) groups of analogue cows were established in terms of productivity and lactation stages under the conditions of one typical four-row cowshed with a tethered keeping. The conditions of keeping, feeding and drinking regimes, and microclimate parameters during studies between groups of experimental animals were the same. Cows were fed with complete feed mixtures twice a day. Control milking was performed twice a day – in the morning and in the evening using portable buckets. Sanitary and hygienic treatment of udders and teats in cows of all groups was carried out in the same way. In the experimental group, the first three streams of milk from each quarter of the udder were taken in a separate container, in the control group – an average sample from a bucket. Milk samples from each cow were taken using a probe in proportion to morning and evening milk yields in accordance with the requirements of the instructions for sampling milk and dairy products (DSTU ISO 707:2002, 2003). Samples were delivered to the laboratory with a preservative (MicroTabs broad-spectrum tablets, USA).

Biochemical parameters of milk were determined in a certified laboratory for assessing the quality of livestock products. Determination of the mass fraction of fat, protein, casein+whey proteins, lactose, dry matter was carried out by express infrared spectrometry (DSTU 8396:2015, 2017). The freezing point of milk was determined by the conductometric express method

(DSTU 7671:2014, 2015), the content of somatic cells – by express flow cytometry (DSTU 7672:2014, 2015).

The influence of lactation on milk quality indicators was determined by dividing cows of the control and experimental groups into gradations: ≤ 100 ; 101-200; 201-300; $300 \geq$ differences between groups by gradation were determined, and correlation coefficients between lactation duration and milk quality indicators were established. Accordingly, the influence of lactation duration on the quality indicators of the first streams of milk in cows of the experimental group was determined. The influence of daily milk yield on milk quality indicators was determined by dividing cows of the control and experimental groups into gradations: ≤ 25 , 26-30, 31-35, $36 \geq$ kg and determined differences between groups by gradation, and established correlation coefficients between daily milk yield and milk quality indicators. Accordingly, the influence of daily milk yield on the quality indicators of the first streams of milk in cows of the experimental group was determined.

All experimental studies were conducted in accordance with modern methodological approaches, requirements and standards (DSTU ISO/IEC 17025:2019, 2021), Directive 2010/63/EC (2010) and the Procedure for conducting animal testing in research institutions (Law of Ukraine No. 249, 2012). The experiments were performed in accordance with the provisions of the European Convention for the Protection of Vertebrate Animals used for Experimental and other Scientific Purposes (1986).

RESULTS AND DISCUSSION

At the first stage of the experiment, a comparative analysis of milk quality indicators of cows of the control and experimental groups was carried out (Table 1). Milk quality indicators of cows in the control group corresponded to the state of mature milk in accordance with Table 1.

Table 1. Milk quality indicators of experimental cows

Milk quality indicators	Control (n = 160)	Experimental (n = 56)
Fat, %	3.913 ± 0.041	1.404 ± 0.063
Protein, %	3.287 ± 0.029	3.351 ± 0.030
Whey+casein, %	3.481 ± 0.026	3.580 ± 0.030
Ratio (fat/protein)	1.197 ± 0.012	0.418 ± 0.017
Lactose, %	4.958 ± 0.013	4.839 ± 0.044
Dry matter, %	12.430 ± 0.055	10.212 ± 0.077
MSNF, %	8.516 ± 0.027	8.808 ± 0.059
Urea, %	23.031 ± 0.138	22.929 ± 0.225
Freezing point, °C	0.559 ± 0.001	0.529 ± 0.003
Somatic cell content (thous/ cm ³)	469.09 ± 64.286	1,223.643 ± 37.114

Source: compiled by the authors

Analysis of the obtained data proved the probable difference between the milk quality indicators of the control and experimental groups of cows ($p \geq 0.95$).

Thus, the fat content in the first streams of milk was almost three times lower than in the average samples – by an average of 2.509%. The protein content in the

control and experimental groups did not significantly differ, and therefore, the fat/protein ratio significantly differed in favour of the experimental group – by 0.779. The dry matter content was higher in the milk of cows in the control group by 2.218%. The indicator of the content of somatic cells in the first streams of milk in cows of the experimental group exceeded the control by more than 2.5 times – by 754,553 thous/cm³

with a probability ($p \geq 0.99$). Other indicators of milk quality did not significantly differ from those of the control group. At the second stage of the experiment, all control animals and experimental cows were divided into groups on gradations according to lactation terms to determine the effect of the lactation stage on milk quality indicators. The results are shown in Tables 2-3.

Table 4. The Contribution of agroforestry practice to pesanggem household income

Milk quality indicators	Lactation periods, days			
	≤ 100 (n=28)	101-200 (n=56)	201-300 (n=46)	300 ≥ (n=30)
Daily milk yield, kg	33.107 ± 0.916	28.107 ± 0.849	25.804 ± 0.983	28.700 ± 1.361
Fat, %	3.692 ± 0.064	3.889 ± 0.070	4.002 ± 0.075	4.030 ± 0.106
Protein, %	2.900 ± 0.040	3.253 ± 0.042	3.495 ± 0.046	3.389 ± 0.063
Whey+casein, %	3.130 ± 0.041	3.450 ± 0.038	3.659 ± 0.041	3.596 ± 0.060
Ratio (fat/protein)	1.276 ± 0.023	1.201 ± 0.022	1.147 ± 0.018	1.193 ± 0.027
Lactose, %	5.039 ± 0.021	4.968 ± 0.019	4.933 ± 0.025	4.900 ± 0.038
Dry matter, %	11.889 ± 0.091	12.391 ± 0.088	12.705 ± 0.096	12.587 ± 0.127
MSNF, %	8.197 ± 0.050	8.501 ± 0.038	8.702 ± 0.044	8.557 ± 0.065
Urea, %	22.964 ± 0.315	22.804 ± 0.224	23.152 ± 0.262	23.333 ± 0.350
Freezing point, °C	-0.560 ± 0.002	-0.560 ± 0.002	-0.560 ± 0.002	-0.557 ± 0.003
Somatic cell content (thous/cm ³)	157,750 ± 15,600	524,482 ± 109,051	488,913 ± 118,921	625,900 ± 197,748

Source: compiled by the authors

It was found that the milk quality indicators of cows of the control group fluctuated according to the lactation period. The influence of lactation duration on milk quality indicators is confirmed by indicators of the correlation coefficient. The highest daily milk yield was found in cows that were in the first trimester of lactation (33.107 ± 0.916 kg), the lowest – from 201 to 300 days (25.804 ± 0.983). This fact is confirmed by a fairly high negative association between the duration of lactation and daily milk yield ($r = -0.622$). The fat content of milk, on the contrary, increased with every 100 days of lactation, and a low positive correlation coefficient was observed between the lactation period and the fat content in milk ($r = 0.293$).

The lowest protein content in milk was observed in cows in the first trimester of lactation (2,900 ± 0.040%), the highest – from 201 to 300 days (3,495 ± 0.046%), the protein content in milk significantly correlated with the duration of lactation ($r = 0.747$). The correlation coefficient between fat and protein content in the milk of cows in the control group was quite significant ($r = 0.497$). The ratio of fat and protein content in the milk of cows in the control group was the lowest from 101 to 200 days of lactation, and the highest – at the end of lactation. Similarly to protein, the whey+casein content index varied, and the protein content in milk significantly correlated with the duration of lactation ($r = 0.687$). Lactose levels, on the contrary, were higher in cows in the first trimester of lactation (5.039 ± 0.021%), however, there was no significant

difference in this indicator in cows at different lactation periods. A negative correlation coefficient of average strength was found between the day of lactation and the lactose content ($r = -0.403$). The dry matter content, MSNF index, and urea content in the milk of control cows increased with the duration of lactation. However, the correlation coefficient was quite significant between the day of lactation and MSNF ($r = 0.601$) and between the day of lactation and the dry matter content ($r = 0.514$), and the urea content in milk did not actually correlate with the day of lactation ($r = 0.075$).

The freezing point of milk of cows in the control group exceeded the minimum requirements (-0.520°C) and was on average the same throughout lactation with limits of -0.494-0.585°C and negatively and slightly correlated with the duration of lactation ($r = -0.108$). The content of somatic cells was significantly lower in the first trimester of lactation (157,750 ± 15,600 thous/cm³), and the highest – at the end of lactation. The content of somatic cells was slightly positively associated with the day of lactation ($r = 0.130$).

Indicators of the quality of the first streams of milk of cows of the experimental group also fluctuated according to the lactation time (Table 3). The highest daily milk yield was found in cows that were in the first trimester of lactation (33,500 ± 4,252 kg), the lowest – at the end of lactation (28,000 ± 3,000). A negative relationship was established between the duration of lactation and the daily milk yield of cows of the experimental group ($r = -0.356$).

Table 3. Indicators of the quality of the first streams of cow's milk at different stages of lactation

Milk quality indicators	Lactation periods, days			
	≤ 100 (n=4)	101-200 (n=37)	201-300 (n=13)	300 ≥ (n=2)
Daily milk yield, kg	33,500±4,252	32,784±0,703	30,000±1,160	28,000±3,000
Fat,%	1.213±0.145	1.341±0.079	1.575±0.122	1.830±0.210
Protein,%	3.233±0.107	3.294±0.034	3.523±0.057	3.505±0.145
Whey+casein,%	3.458±0.110	3.525±0.034	3.753±0.057	3.720±0.150
Ratio (fat/protein)	0.379±0.056	0.406±0.022	0.449±0.035	0.521±0.038
Lactose,%	4.828±0.281	4.886±0.043	4.756±0.115	4.525±0.175
Dry matter,%	9.910±0.212	10.151±0.086	10.450±0.194	10.390±0.540
MSNF,%	8.698±0.297	8.809±0.057	8.875±0.173	8.555±0.325
Urea,%	22.500±0.289	23.027±0.304	23.000±0.408	21.500±0.500
Freezing point, °C	-0.525±0.021	-0.532±0.003	-0.523±0.009	-0.509±0.017
Somatic cell content (thous/cm ³)	1,055,500±81,974	1,227,270±51,182	1,283,385±54,164	1,104,500±115,500

Source: compiled by the authors

The indicator of fat content in the first streams of milk increased with the duration of lactation, these indicators positively correlate with each other to an average degree ($r = 0.403$). The correlation coefficient between fat and protein content in the first streams of milk of cows of the experimental group was at the level of $r = 0.306$. The lowest protein content in the first streams of milk was observed in cows in the first trimester of lactation ($3,233 \pm 0.107\%$), the highest – from 201 to 300 days ($3,523 \pm 0.057\%$). Similarly to the protein content, the whey+casein content index varied, it was the highest from 201 to 300 days ($3.753 \pm 0.057\%$). The effect of lactation duration on protein and whey+casein content in the first streams of milk is confirmed by positive indicators of the correlation coefficient ($r = 0.517$ and $r = 0.509$, respectively). The ratio of fat and protein content in the milk of cows in the control group was lowest at the beginning of lactation and increased with the duration of lactation. The lactose level was higher in cows lactating for 101-200 days ($4.828 \pm 0.281\%$), and the lowest at the end of lactation. According to the indicator of lactose content, a negative association was observed with the day of lactation ($r = -0.334$).

The content of dry matter and urea in the first streams of milk of cows of the experimental group increased unexpectedly with the duration of lactation, the correlation coefficients were insignificant, respectively $r = 0.284$ and $r = -0.137$. The freezing point of milk of cows in the control group exceeded the minimum requirements (-0.520°C) and was on average the same throughout lactation with limits of 0.494 - 0.585°C . The freezing point index was negatively correlated with the duration of lactation ($r = -0.269$). The somatic cell content was significantly lower in the first trimester of lactation ($157,750 \pm 15,600$ thous/cm³), and the highest – at the end of lactation. The MSNF index and the content of somatic cells in the first streams of milk practically did not depend on the day of lactation ($r = -0.058$ and $r = 0.080$, respectively).

At the next stage, milk quality indicators were studied depending on the level of milk productivity. 160 milk samples from cows of the control group were examined, the average daily productivity of which was 28.431 ± 0.540 kg of milk with limits $\text{lim} = 12$ - 41 kg. The largest proportion of cows had a daily milk yield of 31-35 kg (30.6%). The results of the experiment are shown in Table 4.

Table 4. Milk quality indicators of cows of the control group with different levels of daily milk yield

Milk quality indicators	Daily milk yield, kg			
	≤ 25 (n=54)	26-30 (n=32)	31-35 (n=49)	36 ≥ (n=25)
Fat,%	4.002±0.077	3.988±0.068	3.818±0.060	3.786±0.116
Protein,%	3.551±0.041	3.365±0.053	3.088±0.037	2.978±0.050
Whey+casein,%	3.699±0.041	3.605±0.052	3.317±0.038	3.207±0.051
Ratio (fat/protein)	1.126±0.016	1.192±0.023	1.240±0.018	1.274±0.037
Lactose,%	4.904±0.025	4.994±0.017	5.015±0.018	4.987±0.024
Dry matter,%	12.734±0.100	12.610±0.095	12.188±0.080	12.045±0.134
MSNF,%	8.734±0.043	8.621±0.053	8.368±0.041	8.258±0.052
Urea,%	23.149±0.295	23.063±0.284	22.878±0.210	22.880±0.367
Freezing point, °C	0.558±0.002	0.564±0.001	0.561±0.002	0.557±0.002
Somatic cell content (thous/cm ³)	570,128±141,494	338,563±108,565	337,592±84,863	419,600±127,863

Source: compiled by the authors

Fluctuations in milk quality indicators of cows of the control group depending on the level of daily milk yield were established. Thus, the fat content in milk was highest in cows with the lowest daily milk yield, and the lowest in cows with the highest daily milk yield ($p \geq 0.95$). The correlation coefficient between these indicators was respectively negative and amounted to $r = -0.240$. The protein and whey+casein content in the milk of cows in the control group varied with a similar trend, but with a significantly higher negative correlation coefficient ($r = -0.673$ and $r = -0.573$, respectively). The ratio of fat to protein was highest in cows with a daily milk yield of 26-30 kg of milk, and the lowest in cows with the lowest daily milk yield (≤ 25 kg).

The lactose content in milk increased with an increase in daily milk yields, it was highest in cows with a milk yield of 31-35 kg per day. Calculation of the correlation coefficient established a positive level of association between daily milk yield and lactose content ($r = 0.435$). The dry matter content in milk was unex-

pectedly higher in cows with the lowest daily milk yield, although signs with average bond strength were negatively correlated with each other ($r = -0.423$). It is logical that the MSNF index also varied with a similar trend, it was highest in cows with the lowest daily milk yield and negatively correlated with it at the level of $r = -0.496$.

The urea content was not significantly different in cows with different levels of daily milk yield, the correlation coefficient was negative and insignificant ($r = -0.112$). The freezing point index did not change much in cows with different levels of daily milk yield and positively slightly correlated with this trait ($r = 0.174$). The highest content of somatic cells was observed in cows with a minimum daily milk yield (852.087 ± 232.773 thous/cm³), the lowest – in cows with a daily milk yield of 26-35 kg. The correlation coefficient was correspondingly negative, although low ($r = -0.195$). Indicators of the quality of the first streams of milk were studied in cows of the experimental group with different levels of milk productivity (Table 5).

Table 5. Quality indicators of the first streams of milk from cows of the experimental group with different levels of daily milk yield

Milk quality indicators	Daily milk yield, kg			
	≤ 25 (n=5)	26-30 (n=9)	31-35 (n=28)	$36 \geq$ (n=14)
Fat, %	1.554 ± 0.134	1.561 ± 0.172	1.368 ± 0.072	1.322 ± 0.168
Protein, %	3.446 ± 0.077	3.434 ± 0.078	3.399 ± 0.038	3.166 ± 0.054
Whey+casein, %	3.666 ± 0.075	3.668 ± 0.076	3.625 ± 0.039	3.401 ± 0.055
Ratio (fat/protein)	0.449 ± 0.030	0.454 ± 0.048	0.402 ± 0.021	0.416 ± 0.048
Lactose, %	4.488 ± 0.178	4.834 ± 0.102	4.851 ± 0.065	4.943 ± 0.055
Dry matter, %	10.042 ± 0.310	10.433 ± 0.202	10.246 ± 0.096	10.060 ± 0.171
MSNF, %	8.790 ± 0.230	8.872 ± 0.148	8.879 ± 0.088	8.738 ± 0.087
Urea, %	22.000 ± 0.447	23.333 ± 0.601	22.679 ± 0.313	23.500 ± 0.466
Freezing point, °C	0.503 ± 0.015	0.531 ± 0.008	0.530 ± 0.005	0.534 ± 0.004
Somatic cell content (thous/cm ³)	1,345,600 ± 103,982	1,289,667 ± 98,660	1,219,179 ± 49,270	1,146,571 ± 84,289

Source: compiled by the authors

It was found that in the first streams of milk there are also fluctuations in quality indicators, depending on the daily milk yield. Thus, the fat content in the first streams of milk is highest in cows with a milk yield of ≥ 30 kg. The correlation coefficient between daily milk yield and fat content in the first streams of milk was negative and low ($r = -0.117$). The protein and whey+casein content in the first streams of milk were highest in cows with a daily productivity of up to 30 kg inclusive. Accordingly, these indicators were negatively correlated with daily milk yield with the same correlation coefficient ($r = -0.385$). The ratio (fat/protein) was highest in the first streams of milk of cows with a daily milk yield of up to 30 kg inclusive.

The lactose content in the first streams of milk increased with an increase in daily milk yields, it was highest in cows with a daily milk yield of 36 kg or more. Calculation of the correlation coefficient established a positive level of association between daily milk

yield and lactose content in the first streams of milk ($r = 0.260$). The dry matter content in the first streams of milk was incredibly high in cows with a daily milk yield of 26-30 kg, the signs did not actually correlate with each other ($r = -0.078$). The MSNF index in the first streams of milk was almost the same in cows of all gradations, these indicators did not actually correlate with each other ($r = -0.023$).

The urea content in the first streams of milk of experimental cows did not significantly differ in cows with different levels of daily milk yield, the signs are not actually related ($r = 0.016$). The freezing point of the first streams of milk did not change much in cows with different levels of daily milk yield and positively slightly correlated with this feature ($r = 0.205$). The highest content of somatic cells in the first streams of milk was observed in cows with a minimum daily milk yield ($1345,600 \pm 103,982$ thous/cm³), the lowest – in cows with the highest daily milk yield. The

correlation coefficient was respectively negative and low, although higher than that of cows in the control group ($r = -0.238$). The indicator of somatic cell content requires special attention when assessing milk quality,

so the correlation coefficients of this feature with other indicators of milk quality of the control and experimental groups of cows were calculated to establish the patterns of influence (Table 6).

Table 6. Correlation coefficients (r) between the content of somatic cells (thous/cm³) with milk productivity and quality traits

Relationship of the somatic cell content indicator with signs of milk productivity and quality	Correlation coefficient (r)	
	cow groups	
	control (n = 160)	experimental (n = 56)
Duration of lactation, days	0.130	0.080
Daily milk yield, kg	-0.195	-0.238
Fat, %	-0.044	-0.141
Protein, %	0.155	0.188
Whey+casein, %	0.145	0.200
Lactose, %	-0.481	0.137
Dry matter, %	-0.068	0.071
MSNF, %	-0.072	0.244
Urea, %	-0.063	0.153
Freezing point, °C	-0.489	0.158

Source: compiled by the authors

It was found that the content of somatic cells in milk is quite significantly negatively associated with the indicators of lactose content and freezing point of milk, to a lesser extent – with daily milk yield, and positively – with the duration of lactation, protein and whey+casein content. In the first streams of milk, the correlation coefficients for milk productivity and quality did not exceed 0.250. The highest somatic cell content was positively correlated with the MSNF index, protein and whey+casein content, freezing point, urea content, and negatively correlated with daily milk yield and fat content.

Thus, it can be argued that the latest data on the quality of milk and its first streams have been obtained, depending on the duration of lactation and the amount of daily milk yield. Positive and negative relationships between traits were established, including correlations of somatic cell content with other indicators of milk productivity and quality. The need to separate the first streams of milk from the main milk yield has been experimentally proved, which helps to reduce the content of somatic cells in milk by three times and improve some quality indicators.

The study of milk quality is a topic of interest to many researchers and consumers of dairy products. The main criteria for milk quality that the EU pays attention to are total bacterial count, somatic cell count, freezing point, fat and protein content. Thus, using the multi-platform approach, C. Connolly *et al.* (2023) found that the metabolomic profile of cow milk at the beginning of lactation is markedly different from that in the middle and end of lactation. R. Feliciano *et al.* (2023) established seasonal patterns of milk quality indicators (fat and protein content) in different weather conditions throughout the year. However, A. Palii *et al.* (2020), J. Magan *et al.* (2021) link seasonal changes in milk quality

primarily to the cow's diet. J. Cole *et al.* (2023) investigated the effect of the season and stage of lactation on milk quality parameters and found that fat, protein, and lactose content vary depending on the development of lactation. G. Huculak (2019) proved that lactation affects the fat content of milk. P. Lacková *et al.* (2023) proved the seasonality of milk quality indicators. C. Hurtaud *et al.* (2020) proved changes in milk quality during milking – from the beginning to the end, lactose and protein content decreased, while fat content increased. This fact is confirmed by studies of the first streams of milk, in which the fat content is lower, and the protein content is higher.

The probable difference between the indicators of milk quality and the quality of milk of the first streams is proved. Thus, the fat content in the first streams of milk was almost three times lower than in the average samples, and the dry matter content was 2.218% higher in the milk of cows in the control group. The indicator of the content of somatic cells in the first streams of milk in cows of the experimental group exceeded the control almost three times – by 754,553 thous/cm³ with probability. A significant effect of the lactation day on the content of protein, lactose, dry matter, MSNF was experimentally proven, and the fat content of milk increased with every 100 days of lactation. The freezing point index was negatively correlated with the duration of lactation. The somatic cell content was significantly lower in the first trimester of lactation and highest at the end of lactation. The duration of lactation was negatively correlated with the indicator of daily milk yield. The freezing point indicator was slightly negative, and the content of somatic cells is slightly positively associated with the day of lactation. The data obtained were consistent with research (Connolly *et al.*, 2023) on

the influence of the lactation stage on the level of milk yield and milk quality indicators.

In studies of the parameters of the first streams of milk, the indicator of fat, protein, and whey+casein content increased with the duration of lactation, and the lactose content decreased with the development of lactation. The MSNF index and the content of somatic cells in the first streams of milk practically did not depend on the day of lactation. Fluctuations in milk quality indicators of cows of the control group depending on the level of daily milk yield were established. Thus, the content of fat, protein, whey+casein, dry matter, MSNF, urea, somatic cells in milk was highest in cows with the lowest daily milk yield. The lactose content, on the contrary, was higher in cows with a high level of daily milk yield. The freezing point indicator did not change much in cows with different levels of daily milk yield. In the first streams of milk, fluctuations in quality indicators are also established, depending on the daily milk yield.

Somatic milk cells are a mixture of milk-producing cells and immune cells. Somatic cells enter milk during the milking process, and their number is used all over the world to determine the quality of milk and the health of cows. It is known that the content of somatic cells in milk depends on many factors: environmental conditions, content, productivity level, duration and stage of lactation, etc. (Gerun *et al.*, 2020; Toghdory *et al.*, 2022). Regular monitoring of the content of somatic cells in milk is especially important in the subclinical course of mastitis. The lower the content of somatic cells in milk, the higher its quality and shelf life. In EU member states, the average actual somatic cell count has not exceeded 200,000/ml for more than twenty years. The level of dependence of the indicator of the content of somatic cells in milk and the first streams of milk on the indicators of productivity and quality of milk is established. A negative relationship was determined between the content of somatic cells in milk with the lactose content, freezing point and daily milk yield, and a positive relationship with the duration of lactation, protein and whey+casein content. In the first streams of milk, the content of somatic cells to a low degree positively correlated with the MSNF index, protein, whey+casein, freezing point, urea content, and negatively – with daily milk yield and fat content.

Thus, it has been experimentally proven that milk quality and first milk streams depend to varying degrees on the stage of lactation and daily milk yield. Positive and negative relationships between traits were established, including correlations of somatic cell content with other indicators of milk productivity and quality. The necessity of separating the first streams of milk from the main milk yield has been proved, which allows reducing the content of somatic cells in milk by three times and improving some quality indicators.

CONCLUSIONS

The probable difference between the milk quality indicators of the control and experimental group of cows is proved ($p \geq 0.95$). The fat content in the first streams of milk was 2.509% lower than in the average samples. The fat/protein ratio varied significantly in favour of the experimental group – by 0.779. The dry matter content was higher in the milk of cows in the control group by 2.218%. The indicator of the content of somatic cells in the first streams of milk in cows of the experimental group exceeded the control by more than 2.5 times – by 754,553 thous/cm³ with a probability ($p \geq 0.99$).

It was found that the indicators of the quantity and quality of milk and its first streams in different degrees correlate with the stage of lactation: daily milk yield ($r = -0.622$), fat content ($r = 0.293$), protein ($r = 0.747$), lactose ($r = -0.403$), dry matter ($r = 0.514$), MSNF ($r = 0.601$). The correlation coefficient between fat and protein content in the milk of cows in the control group was quite significant ($r = 0.497$), the ratio of fat and protein content was the lowest from 101 to 200 days of lactation, and the highest – at the end of lactation. The freezing point index exceeded the minimum requirements (-0.520°C) throughout lactation, negatively and slightly correlated with the duration of lactation ($r = -0.108$). The content of somatic cells was significantly lower in the first trimester of lactation ($157,750 \pm 15,600$ thous/cm³), and the highest – at the end of lactation.

The relationship between the duration of lactation and milk quality indicators in the first milk flows was proved: fat content ($r = 0.403$), protein ($r = 0.517$), whey+casein ($r = 0.509$), lactose ($r = -0.334$) freezing point ($r = -0.269$). The somatic cell content was significantly lower in the first trimester of lactation ($157,750 \pm 15,600$ thous/cm³), and the highest – at the end of lactation. The relationship of milk quality indicators depending on the level of daily milk yield was established: fat content ($r = -0.240$), protein ($r = -0.673$), whey+casein ($r = -0.573$), lactose ($r = 0.435$), dry matter ($r = -0.423$), MSNF ($r = -0.496$), freezing point ($r = 0.174$), somatic cells ($r = -0.195$). The level of association with the level of daily milk yield with the quality of milk of the first streams was slightly different: with the content of fat ($r = -0.117$), protein ($r = -0.385$), whey+casein ($r = -0.385$), lactose ($r = 0.260$), dry matter ($r = -0.078$), MSNF ($r = -0.023$), freezing point ($r = 0.205$), somatic cell content ($r = -0.238$).

It was found that the content of somatic cells in milk is quite significantly negatively associated with the indicators of lactose content and freezing point of milk, to a lesser extent – with daily milk yield, and positively – with the duration of lactation, protein and whey+casein content. In the first streams of milk, the correlation coefficients for milk productivity and quality did not exceed 0.250. The highest somatic cell content was positively

correlated with the MSNF index, protein and whey+casein content, freezing point, urea content, and negatively correlated with daily milk yield and fat content. The prospect of further studies is to identify a wider range of factors affecting milk quality, especially genetic, technological, and environmental factors that affect the content of somatic cells in milk of different conditions.

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CONFLICT OF INTEREST

None.

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Ірина Ткачова

Доктор сільськогосподарських наук, головний науковий співробітник
Інститут тваринництва Національної академії аграрних наук України
61026, вул. Тваринників, 1-А, м. Харків, Україна
<https://orcid.org/0000-0002-4235-7257>

Галина Прусова

Кандидат сільськогосподарських наук, старший науковий співробітник
Інститут тваринництва Національної академії аграрних наук України
61026, вул. Тваринників, 1-А, м. Харків, Україна
<https://orcid.org/0000-0002-2604-5720>

Вікторія Петраш

Кандидат сільськогосподарських наук, провідний науковий співробітник
Інститут тваринництва Національної академії аграрних наук України
61026, вул. Тваринників, 1-А, м. Харків, Україна
<https://orcid.org/0000-0001-9114-6117>

Анатолій Ткачов

Молодший науковий співробітник
Інститут тваринництва Національної академії аграрних наук України
61026, вул. Тваринників, 1-А, м. Харків, Україна
<https://orcid.org/0000-0002-6325-4724>

Віталій Петраш

Аспірант
Інститут тваринництва Національної академії аграрних наук України
61026, вул. Тваринників, 1-А, м. Харків, Україна
<https://orcid.org/0009-0002-2024-0127>

Анотація. Актуальність досліджень полягає у вирішенні проблеми якості молока корів і впливу на параметри молока факторів стадії лактації і добового надою, а також встановлення зв'язків між вмістом соматичних клітин у молоці та іншими параметрами молока. Мета роботи – визначення впливу стадії лактації і добового надою на показники якості молока і його перших цівок, а також встановлення зв'язків вмісту соматичних клітин з іншими показниками якості молока і його перших цівок. Методи дослідження – зоотехнічні (підбір груп, організація досліду, визначення молочної продуктивності, оцінювання стадії лактації, рівня надоїв, контрольні доїння), біохімічні (визначення основних показників якості молока), статистичні, математичні. Встановлено вірогідну різницю між показниками якості молока у добовому надої молока та у перших трьох цівках молока ($p \geq 0,95$), отже експериментально доведено необхідність відокремлення перших цівок молока від основного надою. Встановлено, що показники кількості і якості молока і його перших цівок у різних ступенях корелюють із стадією лактації, найбільший добовий надій молока встановлено у корів, що перебували на першому триместрі лактації. Встановлено коливання показників якості молока і його перших цівок залежно від рівня добового надою. Встановлено, що вміст соматичних клітин у молоці досить значно негативно пов'язаний з показниками вмісту лактози і точки замерзання молока, у меншій мірі – з добовим надоєм, і позитивно – із тривалістю лактації, вмістом білку і протеїну. У перших цівках молока коефіцієнти кореляції із продуктивності та якості молока не перевищував 0,250. Найбільше вміст соматичних клітин позитивно корелював з показником СОМО, вмістом протеїну, білка, точкою замерзання, вмістом сечовини, негативно – із добовим надоєм і вмістом жиру. Результати роботи можна використовувати у господарствах з виробництва молока та при плануванні племінної роботи з метою поліпшення якісних характеристик молока селекційним шляхом

Ключові слова: молочні корови; параметри якості молока; стадія лактації; добовий надій; вміст соматичних клітин

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Optimisation of water use in Kyrgyzstan agriculture: Analysis of modern and traditional irrigation methods to minimise losses and increase efficiency

Ainura Batykova*

PhD in Technical Sciences, Associate Professor
Kyrgyz National Agrarian University named after K.I. Skryabin
720000, 68 Mederov Str., Bishkek, Kyrgyz Republic
<https://orcid.org/0000-0001-9173-3151>

Kasiet Musabayeva

PhD in History, Associate Professor
Kyrgyz National Agrarian University named after K.I. Skryabin
720000, 68 Mederov Str., Bishkek, Kyrgyz Republic
<https://orcid.org/0000-0002-9145-9866>

Victoria Sultanbaeva

PhD in Agriculture, Acting Associate Professor
Kyrgyz National Agrarian University named after K.I. Skryabin
720000, 68 Mederov Str., Bishkek, Kyrgyz Republic
<https://orcid.org/0000-0002-8914-8778>

Oskon Osmonov

Doctor of History, Professor
Kyrgyz National Agrarian University named after K.I. Skryabin
720000, 68 Mederov Str., Bishkek, Kyrgyz Republic
<https://orcid.org/0000-0003-0782-1584>

Gulmira Shabikova

PhD in Technical Sciences, Associate Professor
Kyrgyz National Agrarian University named after K.I. Skryabin
720000, 68 Mederov Str., Bishkek, Kyrgyz Republic
<https://orcid.org/0009-0005-3016-393X>

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Abstract. The study conducted on analysing the characteristics of wastewater composition before and after re-treatment is relevant in the context of environmental protection. The study aims to investigate the characteristics of wastewater before and after re-treatment using a pressure sorption filter. The results of the analysis of quantitative indicators of wastewater revealed that before treatment it was characterised by a wide range of indicators exceeding the normative levels. The greatest

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*Corresponding author

excess was observed in the content of suspended solids in sample No. 10, where their concentration reached 1,000 mg/l, which exceeded the normative values by 1.43 times. A pressure sorption filter was installed to improve the quality of treatment. The analysis showed that after its implementation, the wastewater indicators improved significantly: the content of suspended solids decreased by 6.67 times, which indicated the effectiveness of this treatment method. After treatment, the content of pollutants decreased to the levels corresponding to the norms. Economic calculation showed low costs for the installation and operation of the pressure sorption filter, which amounted to 22,570 KGS. It should be concluded that in the end, the results showed that the use of a drip irrigation system was cost-effective to implement because the investment amount of 2,765.2 thousand KGS paid off with additional profit in the period of 1.3 years. The results of the study can be used in practice by hydrologists, hydraulic engineers, resource scientists, environmental engineers, ecologists, ecologists-hydrobiologists, specialists in water management and environmental monitoring, as well as decision-makers in the field of ecology and environmental management to develop and implement measures for the implementation of environmental programmes and projects aimed at improving the environmental situation in the region

Keywords: wastewater treatment plant; drip irrigation; sprinkler irrigation; drought; glacier; Lake Issyk-Kul

INTRODUCTION

The research relevance is determined by the shortage of fresh water being the major ecological problem, which leads to the reduction of crop yields and disturbance of ecosystem sustainability. In the study area, there is a problem of insufficient fresh water due to the presence of various anthropogenic and natural factors such as climate change, irrational use of water resources and pollution of water bodies.

G. Issanova *et al.* (2017) revealed that increased mineralisation and predominance of Ca^{2+} , SO_4^{2-} , Na^+ and Mg^{2+} were detected in the river waters of the Issyk-Kul Lake basin. It is necessary to further investigate the ecological consequences of changes in the chemical composition of water for local fauna and flora, as well as for human health, especially considering the alkaline reaction of water and changes in its pH. P. Chevallier *et al.* (2023) found that the climate projection for the period 2020-2060 shows a possible 8.9% decrease in precipitation and, a 0.4°C-1.8°C increase in air temperature. The study can be complemented by the development of recommendations or strategies for climate change adaptation based on the identified trends and modelling results.

R.A. Usabaliev (2022) determined that in the conditions of modern atmospheric warming due to the disintegration of large glaciers into smaller ones, the number of glaciers increased by 46. The study does not sufficiently investigate the modern dynamics and evolution of glaciation processes leading to the reduction of glaciers located in the Ak-Baura and Aravan River basins, as well as their physical changes such as melting, displacement and crevasse formation.

Ch.K. Amanturova (2020) developed economic models to assess the use of water resources of transboundary rivers in Central Asia. The shortcomings of the study include the limited scope of the study, as the study focuses exclusively on water resources in Central Asia, ignoring or omitting other regions, which may make the generalisation of the results incomplete. According to the findings of J.B. Maatkulova and N. Mirbek kyzy (2019), 75% of sewerage engineering structures

in Kyrgyzstan for wastewater treatment and disinfection required modernisation or repair works. The gap requiring research was the lack of data on the impact of wastewater pollution on the environment and human health.

M. Mambetaliev (2022) proposed the development of a set of measures for the introduction of modern systems of local treatment facilities for enterprises. The analysis of the issues of ensuring efficient operation and modernisation of local treatment facilities required additional research and development of appropriate strategies for the sustainable development of regional environmental infrastructure. J.P. Chaudhary and P. Jhaharia (2024) while conducting a study on technologies in the field of wastewater treatment concluded that the use of adsorbents based on nanomaterials such as iron, copper and titanium, carbon nanotubes, graphene and polymer-based nanoadsorbents are effective for the wastewater treatment process. The environmental and human health impacts of nanomaterials in the long term have not been sufficiently studied.

The need to improve the wastewater treatment sector is identified. S. Chaouali *et al.* (2024) presented data showing that sludge drying, and biogas production are potentially effective methods to reduce environmental impacts in wastewater treatment. A gap in the presented scientific research is the lack of research to account for potential variables such as climate change and technological innovation. E.D. Ugwuanyi *et al.* (2024) investigated promising technologies in integrating advanced treatment methods such as active sludge systems, membrane technologies and advanced oxidation processes. Additionally, the use of natural wastewater treatment methods such as phytoremediation and aquatic plants including wetlands and greenbelts should be explored.

The study aims to assess the quantitative composition of wastewater before and after a set of measures to remove pollutants contained in domestic and industrial wastewater before its release into water bodies.

MATERIALS AND METHODS

The study employed methods of wastewater analysis, as established by the following regulatory and legal documents: Constitution of the Kyrgyz Republic (2021) (Art. 16), Water Code of the Kyrgyz Republic (2005) (Art. 18), Law of the Kyrgyz Republic No. 53 "On Environmental Protection" (1999). The study applied the spectrophotometric method to determine the chemical oxygen demand (COD). Nephelometric method of analysis to measure the intensity of light flux scattered by solid particles suspended in solution (usually at an angle of 90°). The gravimetric method with residue calcination to measure sulphur dioxide (SO_4^{-2}).

The research was conducted in 2023 in the wastewater management laboratory of Cholpon-Ata city of Issyk-Kul region, in the limited liability company of the agro-industrial complex "El-Dan-Atalyk" of Issyk-Ata district, as well as in the agronomic enterprise "Green Valley" in Issyk-Ata district of Chui region. Figure 1 shows the treatment facilities of the "Vodokanal" enterprise in Cholpon-Ata city.



Figure 1. Wastewater treatment facilities of the "Vodokanal" enterprise in Cholpon-Ata city

Source: P. Chevallier et al. (2023)

The wastewater was treated only mechanically, without biological treatment. This is determined by the fact that at the treatment plant aerotanks, sand traps, and chlorinator room were in non-operational condition, and the building of the compressor unit was in an emergency condition. The area of the pressure filter was calculated according to the formula:

$$F = \frac{Q_{\text{days}}}{T v_{\text{e.f.}} - 3.6n(w_1 t_1 + w_2 t_2 + w_3 t_3) - n t_4 v_{\text{e.f.}}}, \quad (1)$$

where Q_{days} – filter capacity in m^3/day , T – daily operating time, assume 24 hours; $v_{\text{e.f.}}$ – design filtering speed; 1.1 m/h, n – number of filter washes per day; $w_1 t_1$ – intensity in $\text{l}/\text{sec}\cdot\text{m}^3$ (assume $2 \text{ l}/\text{sec}\cdot\text{m}^3$) and the duration in hours of initial loosening of the load; 0.017 hours, $w_2 t_2$ – water supply intensity in $\text{l}/\text{sec}\cdot\text{m}^2$ ($3 \text{ l}/\text{sec}\cdot\text{m}^2$, so-called coal charge) and duration in hours of water-air washing 0.083 h; $w_3 t_3$ – intensity in $\text{l}/\text{sec}\cdot\text{m}^2$ ($2 \text{ l}/\text{sec}\cdot\text{m}^2$) and washing time in hours, 0.034 hours; t_4 – filter downtime due to washing in hours, 0.33 hours.

For a given useful capacity of a plant with pressure filters $Q_{\text{days}} = 18.75 \text{ m}^3/\text{days}$. The number of pressure filters with the area of one filter 0.4 m^2 , should be (2):

$$N = F/f = 1.78/0.4 = 4. \quad (2)$$

Equipment and instruments were used to detect the contaminant content of the samples:

- for measuring acidity (pH) Philips-pw 9421 (Netherlands);
- to measure biological oxygen consumption (BOC) – test unit laboratory oxygen meter Anion 4140 (China);
- to measure chemical oxygen demand (COD) – test unit analyser CD200 (USA);
- to measure suspended solids (SS) test – using BD Phoenix Spec Nephelometer microbiological nephelometer system (USA) depending on the sample permeability;
- for measuring sulphate (SO_4^{-2}) SO_4^{-2} testing unit (USA);
- for phosphate determination and tin chloride estimation (PO_4^{-2}) PYE UHICAM spectrometer Sp 8-100 UV/VIS (Great Britain);
- for measuring nitrite concentrations and estimating content using indole ($\text{C}_8\text{H}_7\text{N}$) molarity of 0.05 and hydrochloride molarity of 5 Rikka test unit NO_2 (Ukraine);
- for measuring nitrate concentration and assessing the reduction of nitrate to nitrite in acidic media, through the interaction of nitrite with indole ($\text{C}_8\text{H}_7\text{N}$) Rikka test unit NO_3 (Ukraine);
- for chloride determination and evaluation by titration of potassium chromate (as an indicator) with silver nitrate (as titrant) Rikka test unit Cl^{-1} (Ukraine).

RESULTS

The abnormal drought experienced in Kyrgyzstan in 2023, caused by climatic changes (including a 20-year average temperature increase (2002-2023) from 4.8°C to 6°C) and weak glacier melt, was a serious problem with negative impacts on agriculture, water supply and ecosystems (Kyrgyzstan and water scarcity, 2023). Figure 2 shows an example of the degradation of the Petrov Glacier, located in the Ak-Shyirak mountain range, Issyk-Kul region.

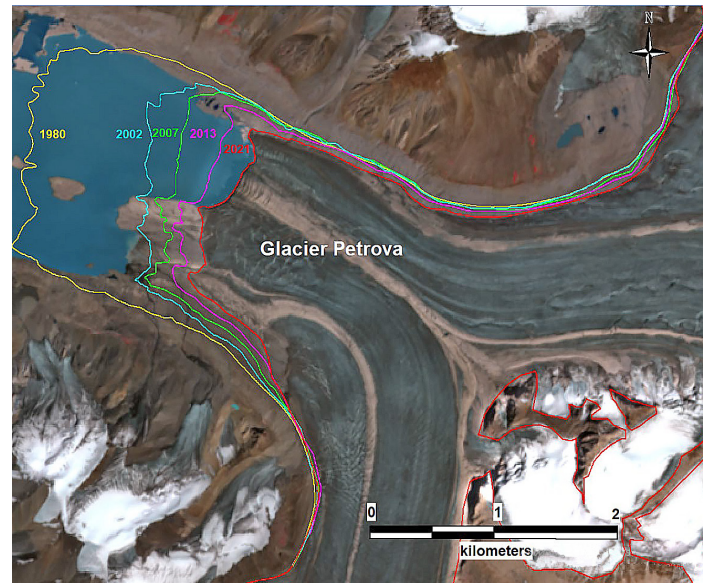


Figure 2. Reduction in the Petrov Glacier

Source: More hot days, melting glaciers and droughts: What's driving climate change in Kyrgyzstan (2023)

The data revealed shows that the area of Petrov Glacier in 1980 was 64 km². For 41 years, a gradual reduction of the glacier area was recorded at a rate of 0.084 km²/year, which resulted in the total area of the glacier being 60.5 km² in 2021. The Issyk-Ata district of the Chui region suffered the most from drought and lack of drinking and irrigation water in all regions. In this district, reduction and death of crops, deterioration of soil quality and reduction of freshwater reserves were recorded. The National Statistical Committee of the Kyrgyz Republic (Natsstatcom) reported that in summer 2023, due to drought, the gross yield of wheat decreased by 25.7% (19.1 hwt/ha was harvested) and barley by 29.2% (15.8 hwt/ha was harvested) (National Statistical Committee of the Kyrgyz Republic, 2024a, 2024b).

To combat drought and its consequences, water management measures are important, including organising the efficient use of water resources, introducing irrigation methods, improving the efficiency of agricultural production and rational use of land resources. It is also important to develop infrastructure for water harvesting and storage, as well as to improve warning and response systems for drought emergencies. Following the data presented in Decree of the President of the Kyrgyz Republic No. 23 "On the National Water Strategy of the Kyrgyz Republic until 2040" (2023) Issyk-Kul Lake level decreased by 0.95 m between 2011

and 2021 due to both climatic and anthropogenic factors. In 2023, due to water withdrawal for irrigation, Lake Issyk-Kul was fed only by water from 30 rivers.

There are many advantages of wastewater re-treatment, among them the improvement of the ecological condition of aquatic ecosystems and the reduction of pollutants (Trus *et al.*, 2020). In Kyrgyzstan, this method of wastewater treatment was not widespread. In the Wastewater Management Laboratory of Cholpon-Ata city, Issyk-Kul region, water samples taken from water bodies were analysed. The wastewater considered in this study included domestic, industrial, agricultural and stormwater runoff. As a result of decreasing water resources in the Kyrgyz Republic, a National Water Strategy was developed, which envisaged the future introduction of wastewater recycling and reuse (Decree of the President of the Kyrgyz Republic No. 23, 2023).

The data obtained in the process of characterisation studies corresponding to wastewater before and after re-treatment were reviewed. Table 1 presents the results of pre-treatment wastewater analyses conducted in the environmental laboratory, during which 12 samples were collected from the shallow water of one of the urban beaches of Cholpon-Ata, located between private guesthouses and the pumping station of "Vodokanal", containing pollutants.

Table 1. Results of quantitative tests of wastewater received before treatment from 02.02.2023 to 29.07.2023

No.	Sample date	pH	BOC, mg/l	COD, mg/l	SS, mg/l	SO ₄ ⁻² , mg/l	PO ₄ ⁻² , mg/l	NO ₂ , mg/l	NO ₃ , mg/l	Cl ⁻¹ , mg/l
1	02.02.23	6.6	64	89	92	242.4	1.11	0.00	0.00	67
2	18.02.23	6.6	112	142	346	270	0.6	7.20	0.36	57
3	03.03.23	6.6	45	74	41	126.8	1.3	2.32	0.0	74.6
4	16.03.23	6.5	72	126	98	180.3	1.10	0.0	0.0	49.8

Table 1. Continued

No.	Sample date	pH	BOC, mg/l	COD, mg/l	SS, mg/l	SO ₄ ⁻² , mg/l	PO ₄ ⁻² , mg/l	NO ₂ , mg/l	NO ₃ , mg/l	Cl ⁻¹ , mg/l
5	16.04.23	6.6	107	162	144	185.4	0.3	2.3	0.3	56
6	24.04.23	6.5	96	122	88	145.8	1.6	9	0.4	42
7	08.05.23	6.3	171	210	248	142	1.7	2.6	0.06	61
8	23.05.23	6.6	171	218	416	234	1.7	5.7	0.3	49.8
9	08.06.23	6.6	112	122	640	288.6	2.4	13.5	0.34	67
10	21.06.23	6.7	72	94	1000	79.5	2.8	0.9	0.011	29.9
11	17.07.23	6.4	146	178	388	201.3	0.11	0.0	0.09	24.10
12	29.07.23	6	76	106	134	176.6	0.10	4.9	0.0	34.9

Source: compiled by the authors

Based on the results of the 12 test samples, it is shown that the pH varied from 6 to 6.7, BOC – from 45 to 171 mg/l, COD – from 74 to 218 mg/l, SS – from 41 to 1000 mg/l, SO₄⁻² – from 79.5 to 288.6 mg/l, PO₄⁻² – from 0.3 to 2.8 mg/l, NO₂ – from 0.0 to 13.5 mg/l, NO₃ – from 0.0 to 0.36 mg/l, Cl⁻¹ – from 24.10 to 74.6 mg/l.

According to the requirements of Cholpon-Ata Municipal Enterprise “Vodokanal”, the content of suspended solids discharged into the city sewerage system in wastewater should not exceed 700 mg/l. When measuring suspended solids (SS), it was found that the concentration of these pollutants in wastewater at sampling No. 10 was 1000 mg/l and, therefore, exceeded the normative values by 1.43 times. The presence of the exceedance indicates insufficient efficiency of wastewater treatment discharged into Lake Issyk-Kul. To remove suspended solids from wastewater to the requirements of the city Vodokanal, a proposal to improve the treatment facilities of the enterprise “Vodokanal”

was developed. The selection of equipment for wastewater treatment from increased content of suspended solids was carried out and a pressure sorption filter was installed.

Selection of the carbon filter was carried out according to the indicator of water quality at the outlet – suspended solids – less than 1 mg/l. Analysis of different types of carbon filters allowed to stop on vertical pressure carbon filter, using absorbent carbon as a loading (internal pore volume 50-110 m²/g). Using formula (1), the area of the pressure filter was calculated:

$$F = \frac{18.75}{24 \cdot 1.1 - 3.6 \cdot 1(2 \cdot 0.017 + 3 \cdot 0.083 + 2 \cdot 0.034) - 1 \cdot 0.3 \cdot 1.1} = 1.78 \text{ m}^2 \quad (3)$$

The results show that the area is equal to 1.78 m², which easily allowed to place this filter on the territory of the treatment plant workshop. Table 2 shows the calculation of the cost of installation and operation of the pressure sorption filter.

Table 2. Costs for installation of pressure absorption filter

Costs, KGS/year	
The electricity consumption of the pump is 2,190 kW per year. Cost of 1kW=3.00 KGS. Electricity costs: C _e = 2,190×3.0 = 6.570 KGS/year	65,70 thousand KGS
Current maintenance and repair costs	8,000 thousand KGS
Charges for dumping	2,000 thousands KGS
Amortisation	6,000 thousand KGS
Total	22,570 thousand KGS

Source: compiled by the authors

According to the results of the calculation of costs for installation of treatment equipment, it is shown that the amount of spent costs, which amounted

to 22,570 thousand KGS, is quite low. Table 3 shows the composition of wastewater after treatment from 02.02.2023 to 29.07.2023.

Table 3. Results of quantitative tests of wastewater obtained after its treatment at the pressure sorption filter unit from 02.02.2023 to 29.07.2023

No.	Sample date	pH	BOC, mg/l	COD, mg/l	SS, mg/l	SO ₄ ⁻² , mg/l	PO ₄ ⁻² , mg/l	NO ₂ , mg/l	NO ₃ , mg/l	Cl ⁻¹ , mg/l
1	02.02.23	6.7	29	43	37	175.4	0.2	0.4	26	49
2	18.02.23	6.5	24	51	105	194	0.06	0.47	11.31	58
3	03.03.23	6.8	17	19	29	121.5	0.4	0.2	11.8	49
4	16.03.23	6.8	5	11	33	159	0.4	0.30	0.00	53.5
5	16.04.23	6.7	13	49	39	132.6	0.2	0.3	1.8	48
6	24.04.23	6.7	28	59	47	130	2.5	0.2	3.1	48

Table 3. Continued

No.	Sample date	pH	BOC, mg/l	COD, mg/l	SS, mg/l	SO ₄ ⁻² , mg/l	PO ₄ ⁻² , mg/l	NO ₂ , mg/l	NO ₃ , mg/l	Cl ⁻¹ , mg/l
7	08.05.23	6.5	26	107	49	150	0.8	0.34	4.6	53
8	23.05.23	6.6	95	132	47	319	1.2	0.00	3	58.4
9	08.06.23	6.7	26	39	49	248.7	1.8	0.33	11.2	54
10	21.06.23	6.5	40	57	43	138	0.3	0.1	3	48.5
11	17.07.23	6.8	13	51	37	138.8	0.2	1.2	12.4	48.5
12	29.07.23	6.7	15	23	81	153.2	0.2	1.00	19	38.6

Source: compiled by the authors

The data shows that after the samples were analysed, the pH values changed from 6.5 to 6.8, BOC – from 5 to 95 mg/l, COD – from 11 to 132 mg/l, SS – from 29 to 105 mg/l, SO₄⁻² – from 121.5 to 248.7 mg/l, PO₄⁻² – from 0.06 to 2.5 mg/l, NO₂ – from 0.0 to 1.2 mg/l, NO₃ – from 0.0 to 26 mg/l, Cl⁻¹ – from 38.6 to 58.4 mg/l.

A comparison of the obtained results of analyses before treatment and after treatment showed the reduction of quantitative indicators. Thus, the use of a pressure sorption filter unit for the treatment of wastewater containing synthetic surfactants allowed to reduction of the content of suspended solids in treated wastewater – by 6.67 times. Wastewater treatment was a necessary procedure, as the reused water could be used in agriculture for additional irrigation of fields requiring large amounts of water in areas where natural rainfall is insufficient.

Kyrgyzstan was a favourable region for growing maize hybrids of different maturity groups, as the sums of active and effective temperatures provide an opportunity to grow maize with a conditional index of maturity (FAO) up to 500. Annual precipitation during the spring-summer period ranged from 180 mm in the east of Kyrgyzstan to 600 mm in the south-western regions, indicating a lack of moisture for growing crops (Horticultural Crops and Wild Fruit Species in Central Asia, n.d.). In this regard, drip irrigation is appropriate for maize crops in Kyrgyzstan, which allows efficient water consumption and fertigation (irrigation with fertiliser application) during the period necessary for vegetation. This technology is significant as it achieves water savings from 30 to 50% compared to sprinkling irrigation.

Limited Liability Company (LLC) agro-industrial complex “El-Dan-Atalyk” (in Issyk-Ata district) analysed crop breeding and seed production efficiency of using drip irrigation in growing maize hybrids in southern Kyrgyzstan. The study was conducted in the fields of the agronomic enterprise “Green Valley” in the Issyk-Ata district of Chui province. Maize hybrids with FAO 300-400 were grown on this site: KRABAS FAO 300, KERBEROS FAO 310, KAIFUS FAO 330, KVS 6471 FAO 340, KINEMAS FAO 350, KVS 381 FAO 350, CARIFOLS FAO 380. Sowing was carried out on 30.04.2023 using a Kverneland Optima pneumatic precision air seeder with tube confinement (16 mm diameter). The sowing rate of

all maize hybrids was 90 thousand/ha, 24 rows of each hybrid were sown.

A starter micro granular fertiliser Agristart – 40 kg/ha and Regent – 4 kg/ha were applied to the crops. The application of post-emergence herbicide MaysTer Power for weed control in maize crops was also provided (the rate was 1.25 l/ha). This field was irrigated with water at a rate of 3800 m³ of water (corresponding to 380 mm of precipitation). During the spring-summer period in the study area, rainfall of 462 mm/ha was recorded. Figure 3 shows the results of the study of the yield of maize hybrids grown on drip irrigation technology.

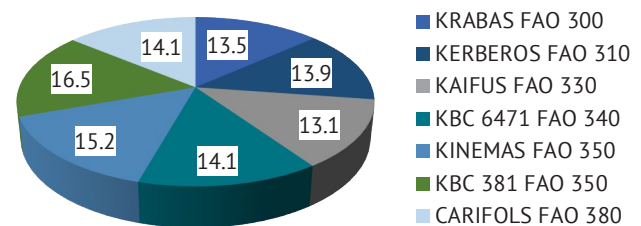


Figure 3. The yield of KWS maize hybrids at the application of drip irrigation technology, tonnes/ha

Source: compiled by the authors

In the experimental field, the yield in terms of basic moisture content of 14% varied in the range from 13.1 to 16.5 t/ha. The maximum yield level of 16.5 t/ha was reached by hybrid KVS 381 FAO 350 and KINEMAS FAO 350 – 15.2 t/ha. Figure 4 demonstrates the current harvest moisture levels.

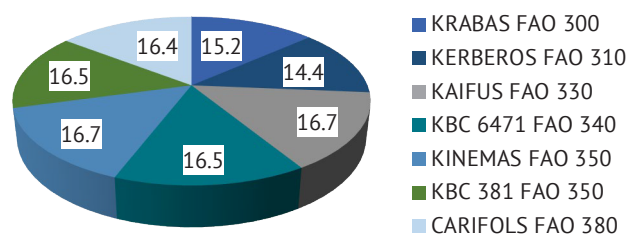


Figure 3. Harvest moisture level, %

Source: compiled by the authors

The moisture content at the time of harvest varied between 14.4-16.7%. The lowest harvest moisture content was found in hybrid KERBEROS FAO 310 – 14.4%

and KRABAS FAO 300 – 15.2%. Therefore, it is possible to assert, that when growing properly selected hybrids with increased heat and drought tolerance with FAO 350, it is possible to achieve higher yields at lower

harvest moisture. Table 4 demonstrates a comparison of approximate costs and economic indicators of the efficiency of growing maize hybrids on drip and sprinkler irrigation.

Table 4. Comparative economic indicators of maize cultivation efficiency on irrigation

Values	Rain irrigation	Drip irrigation	Deviation	
			+/-	%
Sown area, ha	125	125	-	125
Yield, hwt/ha	125	150	25	125
Gross yield, tonnes	1,025	1275	250	125
Production costs per 1 ha of area, KGS	34,426	3,2524	-1902	94.5
Production costs for growing products, thousand KGS	3,465.1	3,274.9	-190.2	94.5
The sales price of 1 tonne, KGS	7,925	7925	-	100
Revenue from sales, thousand KGS	7,925	9,900	1,975	125
The production cost of 1 hwt, KGS	369.01	284.99	-84	75.6
including irrigation expenses per 1 hwt of production	80.26	50.68	-29.6	46.5
Profit from sales, total, thousand KGS	4,484.9	6,650.1	2,165.2	148.5
including per 1 ha of sowing, thousand KGS	69.6	91.25	21.7	148.5
per 1 hwt, KGS	471	555	84	118.8
Profitability of production, %	154.644	228.86	74.2	-
The volume of investments, thousand KGS	-	2,790.5	-	-
Payback period, years	-	1.3	-	-

Source: compiled by the authors

Maize yield increased by 25 hwt/ha, which made it possible to obtain an additional yield of 250 tonnes. At saving of water and electricity, the level of production costs decreased by 1,902 KGS/ha, or 190.2 thousand KGS (based on the whole area of maize sowing). The cost of 1 hwt of production decreased to 24.4%, and the cost of irrigation itself per 1 hwt decreased by 29.6 KGS, which is 53.5%. The growth of gross production made it possible to get additional revenue from sales in the amount of 1,975 thousand KGS. At the same time, according to calculations, the amount of profit from sales was 6,625.1 thousand KGS, which is 48.5% more than under sprinkling. So, the use of a drip irrigation system was cost-effective to implement: the efficiency level reached the value of 203.8%, which is 74.2% higher than the alternative method, and the investment amount of KGS 2765.2 thousand paid off with additional profit in the period of 1.3 years.

DISCUSSION

Analysing the obtained results of the study, it is possible to conclude that further monitoring of wastewater quality and efficiency of the installed pressure sorption filter should be conducted. The study determined that the Petrov Glacier degradation was caused by a change in the precipitation regime and insufficient precipitation. A similar question was raised by S.A.G. Leroy *et al.* (2021). They obtained results according to which it was found that glaciers of the Tien Shan respond primarily to changes in precipitation rather than temperature. It is difficult to unequivocally agree with

this statement, as changes in glaciers in different geographical areas can be caused by a combination of both factors. In some regions, glaciers may respond primarily to changes in precipitation. Increased precipitation can lead to increased snow accumulation on mountaintops, which can favour glacier growth (Skarbøvik *et al.*, 2014). In warmer climates, temperature changes can have a more significant impact on glaciers. Rising temperatures can lead to the melting of ice on mountaintops, leading to a decrease in glacier size (Dzyba & Kyriienko, 2024).

The study that climate change and anthropogenic activity were the reasons for the flow fluctuation of Lake Issyk-Kul. The study of such a problem was carried out by Y. Alifujiang *et al.* (2021). They revealed that climate change was the main cause of runoff fluctuations in the Issyk-Kul Lake basin. The statement of the researchers is valid, as climate change can affect precipitation, snowfall and glacier melt, which directly affects the water level in the lake. However, it is also worth noting other factors such as human activities including the use of water for agriculture and industry. The study determined that climate change can increase or decrease precipitation concentrations in Kyrgyzstan. This was addressed by P. Yang *et al.* (2020). The results of their study indicated a significant increase in interpolated precipitation between 2000 and 2010. This statement is noteworthy, as the results of the reviewed study revealed an insufficient level of precipitation in Kyrgyzstan, which led to a decrease in crop yields.

The study determined that the removal of pollutants from secondary sedimentation tanks of wastewater treatment plants was carried out by mechanical means. A similar scientific study was conducted by A.W. Ahmadi and S. Dursun (2024). Their study determined that the use of cassava in the secondary sedimentation tanks of biological wastewater treatment plants showed complete removal of chemical contaminants. This statement is noteworthy, but it should be noted that to maximise efficiency, a combination of mechanical, biological and chemical wastewater treatment methods should be used to ensure complete removal of contaminants (Bondarev & Gheorghe, 2022). The high efficiency of irrigation methods and their economic benefits were determined. This issue was studied by A. Alamanos and Q. Zeng (2021). Their study investigated the measures of steam use in farming aimed at maintaining agriculture in arid areas. The results obtained from the work carried out do not agree with the findings of the researchers, this study present the results of the efficiency of irrigation methods and evaluate their economic benefits. As such, the efficiency level of drip irrigation reached a value of 203.8%, which is 74.2% higher than that of the rainfed irrigation method.

A similar issue was studied by C. Li *et al.* (2024). They proposed a method based on using a camera system to measure the daily carbon dioxide (CO₂) exchange at different growth stages of maize under drip and flood irrigation methods. According to the results of a study by the researchers found that in the maize ecosystem, drip irrigation showed greater average daily CO₂ uptake by maize plants compared to flood irrigation. This statement can be agreed with, as drip irrigation can indeed increase water use efficiency and improve plant conditions, which in turn can increase photosynthesis and CO₂ uptake (Shevchenko & Nikonchuk, 2022). The study determined that drip irrigation contributed to the increase in crop yields. The study of this issue was carried out by P.H. Rank and B. Vishnu (2019). The study results revealed that the developed sensor-based automated pulse drip irrigation system for irrigating agricultural plants showed high efficiency, as the presented development contributed to maintaining sufficient soil aeration, which helped to improve oxygen penetration into the deep soil layers, stimulating plant root growth and increasing plant productivity. It is worth noting the similarity of this study with that of the researchers as it was confirmed from their findings that drip irrigation helped in improving crop yield.

The results of the calculation show data on the reduction of production cost per 1 hwt of production to 24.4%, as well as information indicating the reduction of maize irrigation costs per 1 hwt by 29.6 KGS (53.5%). A similar issue was studied by M. Şahin (2023). According to the results of his study, it was shown that underground drip irrigation systems were found to be advantageous in terms of saving water, irrigation labour and

maintenance. The results obtained in this paper coincide with the findings of the researcher as the efficiency and cost-effectiveness of subsurface drip irrigation was confirmed compared to conventional irrigation methods. To remove suspended solids from wastewater, a solution to install a pressure absorption filter was undertaken. The study of such an issue was carried out by V. Cossich *et al.* (2024). According to the results of their work, a high level of efficiency of drip irrigation system with an emitter tube was revealed, which allows for preventing clogging and increasing the efficiency of water utilisation. The study results of the researchers are noteworthy, as emitters with inbuilt mechanisms to prevent clogging can significantly reduce the likelihood of clogging and maintain a more stable water flow.

Increase of maize yield by 2.5 tonnes/ha when using subsurface drip irrigation has been demonstrated. This was studied by J. Conde *et al.* (2023). During their study, it was revealed that subsurface drip irrigation to a depth of 20 cm had a water productivity of 8.23 kg/m³, which was the best compared to furrow irrigation and surface drip irrigation and achieved a high olive yield of 9.3 t/ha. This statement should be agreed upon because according to the results of the presented study, subsurface drip irrigation contributed to obtaining an additional yield of 250 tonnes.

The study determined that the application of drip irrigation contributed to increasing crop yields and saving water resources. A.R. Bawa *et al.* (2023). In their scientific paper, they presented a review of the principles of operation of solar photovoltaic pumping systems (SPVPS) used for drip irrigation in agriculture. The similarity of this work with the results of the study of the researchers, according to which it was determined that the use of SPVPS technology reduced greenhouse gas emissions, as well as achieved water savings in agriculture. The study determined that maize yield on the irrigated field plot increased by 25 kg/ha. A. Toffanin *et al.* (2024) studied a similar issue. It is necessary to note the similarity of their work with the results of the presented study, as the results show that soybean yield in the irrigated field increased by 157% in 2022 compared to the non-irrigated control plot. An increase in yield and economic efficiency by using pulse drip irrigation was found. A similar issue was studied by S.M. de Menezes *et al.* (2024). According to the results of their work, the use of pulse drip irrigation provided a reduction in water consumption, increased growth as well as yield of plant stems by 9%. It is possible to note that the conclusions of the experiment of the researchers coincide with the current study regarding the increase in yield and economic efficiency when using drip irrigation for growing maize.

The study demonstrated that economic performance has improved with the use of drip irrigation. This has been studied by U.B. Ntesat *et al.* (2023). Their proposed drip system for intermittent water supply was able to cover an area of 0.000071 m² (out of a total area

of 0.00119 ha) with spinach crops. From their results, it is shown that the use of a drip system for intermittent water supply helped to increase the off-season production of spinach. Similar results were obtained in this study, showing that improved economic performance resulted in lower production costs and increased financial returns. The study determined that when drip irrigation was applied, maize hybrid KVS 381 FAO 350 and KINEMAS FAO 350 reached a maximum yield of 16.5 tonnes/ha and 15.2 tonnes/ha. A similar issue was studied by A. Tilaye Robi *et al.* (2023). Their study showed that 100% drip irrigation gave the highest yield of 34.31 t/ha compared to 75% and 50%, while the amount of water saved at 75% irrigation was 25% and at 50% reached 50% (comparing drip irrigation with 75% irrigation level, 50% and full 100%). This statement is noteworthy, as the amount of water saved at 75% irrigation can compensate for the yield reduction due to the use of saved water.

The study determined that the lowest level of harvest moisture was found in maize hybrid KERBEROS FAO 310 – 14.4% and KRABAS FAO 300 – 15.2%. A similar issue was studied by Y. Wang *et al.* (2023). According to the results of their study, the duration of crop irrigation exceeding 8 hours was found to exceed the irrigation rate. This statement can be agreed with because under prolonged irrigation the topsoil can dry out, which reduces water absorption and irrigation efficiency (Semenko *et al.*, 2022). The decision was made to use drip irrigation to increase maize yields under conditions when rainfall rates could not always meet the plants' water needs. A similar issue was studied by D.T. Mitku (2022). His study in several regions of Ethiopia confirmed that drip irrigation can be more effective than traditional irrigation methods for vegetable crops when irrigation water is insufficient. The results of the researcher are noteworthy as drip irrigation ensures that water is delivered directly to the plant roots, which minimises water loss through evaporation and runoff. This results in significant water savings compared to irrigation methods such as surface irrigation or spray irrigation.

The superiority of the subsurface method of drip irrigation over surface irrigation has been revealed. F.A.O. Al-Obaidi and S.M.H. Al-Mehmdy (2023) studied this issue. Their study revealed that the subsurface drip irrigation method is significantly more efficient than surface drip irrigation in terms of water consumption. The efficiency of the subsurface drip irrigation method was confirmed by applying the amount of perlite with values of 252.28 kg/m³ which resulted in a high yield of potatoes. The statement of the researchers that subsurface irrigation can minimise water evaporation and reduce water losses through direct delivery of moisture to plant roots is noteworthy. An increase in profitability of agricultural production was obtained when using a drip irrigation system and it was shown that the investment of 2765.2 thousand KGS was recouped by additional profit in 1.3 years. The study of a similar issue

was carried out by I. Cartika *et al.* (2023). Their results revealed that the drip irrigation method can increase yields by 8.39%, reduce costs of chilli pepper production by 13.04% and increase farmers' income by 9.25% compared to manual irrigation. The statement of the researchers is noteworthy as with increased yields and reduced water and fertiliser costs, farmers can indeed achieve increased profits.

CONCLUSIONS

The study analyses included quantitative parameters such as pH, content of organic and inorganic pollutants, and assessment of water quality in terms of its suitability for agricultural reuse. The study provides important conclusions regarding the evaluation of wastewater treatment efficiency of wastewater collected from the beach of Cholpon-Ata before and after the application of the pressure sorption filter.

The results of the analysis revealed that there was a significant reduction in pollutant content after the filter application, indicating the effectiveness of the treatment. Irrigation with water at a rate of 3800 m³ corresponding to 380 mm of rainfall and with a rainfall of 462 mm/ha resulted in maize yields ranging from 13.1 to 16.5 t/ha. Hybrids with FAO 350, such as KVS 381 and KINEMAS, showed the highest yield levels, reaching up to 16.5 t/ha. At the same time, harvest moisture content ranged from 14.4% to 16.7%, indicating that high yields can be obtained with the right choice of hybrids with increased heat and drought tolerance. According to the results of comparing the efficiency of growing maize hybrids on drip and rainwater irrigation methods, it is shown that when using drip irrigation, the yield increased by 25 hwt/ha, which led to an additional yield of 250 tonnes. The saving of water and electricity reduced production costs by 1902 KGS/ha. The cost of production decreased by 24.4%, and the cost of irrigation of 1 hwt decreased by 29.6 KGS, amounting to 53.5%. An increase in gross production allowed us to get additional revenue from sales – 1975 thousand KGS. Profit from sales increased by 48.5% compared to the method of sprinkling. As a result, drip irrigation turned out to be more profitable: its efficiency reached 203.8%, which exceeded the alternative method by 74.2%. The investment amount was recouped by additional profit in 1.3 years.

In the review of hydrochemical studies of the Issyk-Kul Lake basin, it is necessary to note the extreme insufficiency and limitations of the previous works in this direction. A direction for further research could be the study of the impact of the wastewater treatment process on biodiversity in Issyk-Kul Lake and its vicinity.

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CONFLICT OF INTEREST

None.

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Оптимізація використання води в сільському господарстві Киргизстану: аналіз сучасних і традиційних методів іригації для мінімізації втрат і підвищення ефективності

Айнура Батикова

Кандидат технічних наук, доцент
Киргизький національний аграрний університет імені К.І. Скрябіна
720000, вул. Медерова, 68, м. Бішкек, Киргизька Республіка
<https://orcid.org/0000-0001-9173-3151>

Касіет Мусабаєва

Кандидат історичних наук, доцент
Киргизький національний аграрний університет імені К.І. Скрябіна
720000, вул. Медерова, 68, м. Бішкек, Киргизька Республіка
<https://orcid.org/0000-0002-9145-9866>

Вікторія Султанбаєва

Кандидат сільськогосподарських наук, в.о. доцента
Киргизький національний аграрний університет імені К.І. Скрябіна
720000, вул. Медерова, 68, м. Бішкек, Киргизька Республіка
<https://orcid.org/0000-0002-8914-8778>

Оскон Осмонов

Доктор історичних наук, професор
Киргизький національний аграрний університет імені К.І. Скрябіна
720000, вул. Медерова, 68, м. Бішкек, Киргизька Республіка
<https://orcid.org/0000-0003-0782-1584>

Гульміра Шабікова

Кандидат технічних наук, доцент
Киргизький національний аграрний університет імені К.І. Скрябіна
720000, вул. Медерова, 68, м. Бішкек, Киргизька Республіка
<https://orcid.org/0009-0005-3016-393X>

Анотація. Дослідження, проведене з аналізу характеристик складу стоків до та після повторного очищення, є актуальним у контексті охорони навколишнього середовища. Мета дослідження – вивчення характеристик стічних вод до та після повторного очищення з використанням напірного сорбційного фільтра. За результатами аналізу кількісних показників стічних вод виявлено, що до очищення вони характеризувалися широким діапазоном показників, що перевищують нормативні рівні. Найбільше перевищення спостерігалось у вмісті завислих твердих речовин у пробі № 10, де їхня концентрація сягала 1,000 мг/л, що перевищувало нормативні значення в 1,43 рази. Для поліпшення якості очищення було встановлено напірний сорбційний фільтр. Проведений аналіз показав, що після його впровадження показники стічних вод істотно покращилися: вміст завислих твердих речовин скоротився в 6,67 разів, що свідчило про ефективність цього методу очищення. Після очищення вміст забруднювачів знизився до рівнів, що відповідають нормативам. Економічний розрахунок показав невисокі витрати на встановлення та експлуатацію напірного сорбційного фільтра, що склали 22,570 сом. Слід зробити висновок, що в підсумку отримано результати, які засвідчили, що використання системи крапельної іригації було рентабельним для впровадження, оскільки сума інвестицій у розмірі 2,765,2 тисяч сом окупилася додатковим прибутком у період 1,3 року. Результати дослідження можуть бути використані на практиці гідрологами, гідротехніками, ресурсознавцями, інженерами-екологами, екологами-гідробіологами, фахівцями з водогосподарування та екологічного моніторингу, а також керівниками, що ухвалюють рішення у сфері екології та природокористування, з метою розроблення та впровадження заходів із реалізації екологічних програм і проектів, спрямованих на поліпшення екологічної ситуації в регіоні

Ключові слова: очисні споруди; крапельний полив; дощовий спосіб зрошення; посуха; льодовик; озеро Іссик-Куль

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Data envelopment analysis on efficiency of shallot production in Tra Vinh, Vietnam

Le Truc Linh

PhD in Agricultural Economics
Tra Vinh University
940000, 126 Nguyen Thien Thanh Str., Tra Vinh, Vietnam
<https://orcid.org/0009-0001-6515-0152>

Diep Thanh Tung*

PhD in Economics, Associate Professor
Tra Vinh University
940000, 126 Nguyen Thien Thanh Str., Tra Vinh, Vietnam
<https://orcid.org/0000-0001-9384-3776>

Luu Thi Thuy Hai

PhD in Microbiology
Tra Vinh University
940000, 126 Nguyen Thien Thanh Str., Tra Vinh, Vietnam
<https://orcid.org/0000-0003-2380-5349>

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Abstract. Shallot is a perennial crop that is grown as an annual to harvest bulb seeds and produced widely in Vietnam. This is an easy-to-grow crop, suitable for land conditions in the local area and brings high economic efficiency. Although shallot is a relatively new crop to the farmers in Tra Vinh province, it is considered one of the key crops in the agricultural development strategy of the province. This study was conducted to assess the efficiency of shallot farming in Tra Vinh province using data envelopment analysis (DEA) approach. The findings revealed that the average cost efficiency was 0.770 and only five farms (2.5%) were fully cost-efficient. The score for average allocative efficiency was slightly superior to that for technical efficiency (0.917 and 0.838); thus, inefficient shallot farms could reach higher cost efficiency by increasing technical efficiency. Accordingly, factors influencing technical and cost efficiency in shallot production were determined in this study. Household size and cultivation experience of the farmers demonstrated negative effects on the levels of technical and cost efficiency. The analysis further revealed that those shallot farmers who had larger shallot farm sizes and those who had better access to technical training tended to be more technical and cost-efficient. Consequently, this study suggests that research to improve shallot-farming techniques should be prioritised support and the quality of technical training programmes for local farmers needs to be raised to increase the technical and cost efficiency in shallot production

Keywords: Mekong Delta; Tra Vinh; data envelopment analysis; cost efficiency; shallot production

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*Corresponding author

INTRODUCTION

Tra Vinh is one of the poor coastal provinces in the Mekong River Delta of Vietnam and 60% of land area of the province is used for agricultural production. Regarding the economic structure in the financial year 2022, three main sectors of agriculture, forestry and fishery contributed 30.29% to the province's GDP (TVPPC, 2022). It therefore indicates that agriculture has been playing a vital part not only for farmers but also for the economic development of the province. Importantly, shallot production grown on coastal sand soil in Duyen Hai district and Duyen Hai town for more than 10 years has brought high economic efficiency for the farmers.

Shallot is currently considered to be an easy-to-grow crop, suitable for land conditions in the local area. Shallot-producing areas tend to increase in recent years. Results of SNV's survey (2022) showed that the total shallot production area of Duyen Hai town is estimated to be about 462 hectares in 2021 and the average yield was about 20-25 t/ha. However, shallot producers have been facing difficulties in production, including small and fragmented production models, limited farming technical competencies, high production costs, over-use of agricultural chemicals, and unpredictable and unfavourable weather leading to unstable production efficiency and profits for growers. W. Huang *et al.* (2020) demonstrated that improving technical efficiency in agricultural production and overcoming shortcomings in agricultural production efficiency is very important, contributing to poverty reduction and building comprehensively moderately prosperous rural areas. In Indonesia, technical efficiency is a main factor in maintaining shallot production (Astuti *et al.*, 2020). In addition, T. Triyono *et al.* (2021) stated that the performance of a farm can be benchmarked by production and efficiency. Therefore, efficiency analysis on shallot production and affecting factors of shallot production have been carried out in many previous studies such as K. Mamary *et al.* (2018), L. Astuti *et al.* (2019), K. Prakoso (2021). This clearly indicates that studies on efficiency of shallot farming have been concerned by researchers to help the producers increase their income.

In Vietnam, although shallot is considered a crop that brings high economic efficiency to farmers, studies on the analysis of the efficiency of shallot production are still few. There was only one study of Q. Nhut *et al.* (2013) estimating technical and cost efficiency for shallot-growing households in Soc Trang province, Vietnam. So far, no research has been conducted in Tra Vinh province to analyse the efficiency of shallot production. In addition, technical efficiency analysis of agricultural production models has received more research attention than cost efficiency analysis while the latter also makes an important and valuable contribution to enhancing farmers' profits through adjustments in production costs. Thus, the purpose of this study was to determine the technical and cost efficiency of shallot

farms in Tra Vinh province, Vietnam, and to identify factors that impact the efficiency differential among those farms. The findings of this study may be useful for the government in proposing to appropriate shallot development strategies and for shallot producers in order to improve productivity and profitability.

MATERIALS AND METHODS

Study area. Tra Vinh province is located in the Mekong Delta area of Vietnam and was purposely selected for conducting this study. The area of shallot production in the province has been increasing since 2014. The primary data were collected from Duyen Hai district and Duyen Hai town since they are main areas of shallot production. As stated by SNV (2022), the total area under shallot cultivation was about 462 ha in Duyen Hai town where shallot is mainly produced on sandy coastal areas. This crop is now a strategic commodity of the province.

Procedures. The data comprised 202 shallot farmers using a structured questionnaire. The information of the investigated shallot producers was for the crop season of 2022 (from November 2022 to January 2023) and collected from March to June 2023. The information of shallot cultivated area, yield, cost of farming inputs, and characteristics of shallot farmers were gathered and analysed in this study. The authors have conducted interviews to gather shallot farmers's information. All personal information about the farmers was collected with their agreement. This study was approved by the Science and Education Council of Tra Vinh University before conducting the survey under grant contract No. 218/2022/HĐ. HĐKH&ĐT-ĐHTV.

In the DEA model, the output was shallot yield and expressed in kilogrammes. The quantities and respective prices of three input variables were considered in the study analysis regarding shallot bulb seeds, labour (hired labour and family labour), and chemical fertilisers. Whilst the quantities of shallot bulb seeds and chemical fertiliser were expressed in kilogrammes, labour was measured by annual work units (man-days). The input variables of seeds, fertiliser, and labour, which were previously employed by T. Le *et al.* (2019), were used in the current study. Concerning the factors that contribute to the efficiency of shallot production, the characteristics of shallot farmers including the size of the households (persons), the size of the farms (hectares), the level of education, age, cultivation experience (years), membership in the cooperative, credit access and technical training (dummy variables) were investigated.

Data analysis. In this study, DEA was utilised to assess both technical and cost efficiency for shallot farms, and then these farms' efficiency levels were determined by using regression models. In agricultural production, technical efficiency refers to the quantity of agricultural products that can be achieved when using inputs such

as seeds, fertilisers, pesticides, and labour resources. Therefore, technical efficiency is a common approach to assessing the efficiency of specific resources. In the DEA approach, the technical efficiency of the shallot farms differed due to the type of return scale chosen. The Charnes, Cooper, and Rhodes (CCR) models result in gross technical efficiency when constant returns to scale are assumed while the Banker, Charnes, and Cooper (BCC) models provide a purely technical efficiency estimate (Ramanathan, 2003). This study relied on the VRS assumption to estimate the technical efficiency of shallot producers, which was widely used in previous studies. (Le *et al.*, 2019; Hassan, 2021). The DEA model that measures technical efficiency is based on the following specifications:

$$\begin{aligned} \text{Subject to} \quad & TE_{VRS} = \min_{\theta, \lambda} \theta, \\ & Y\lambda - Y_i \geq 0, \\ & \theta X_i - X\lambda \geq 0, \\ & N1'\lambda = 1, \\ & \lambda \geq 0, \end{aligned} \quad (1)$$

where Y – output vector; X – input vector; θ – scalar; λ – vector of constants that is $n \times 1$. The technical efficiency for the i -th farm was displayed by the estimated θ value, which ranges between 0 and 1. Farms were considered technically efficient when their efficiency score was equal to one. In contrast, the efficiency scores were lower than those showing technically inefficient farms.

The Scale Efficiency (SE) is the ratio between TE score under CRS that was achieved by removing the convexity constraint ($N1'\lambda = 1$) in equation (1) to TE score under VRS and expressed as in (2)

$$SE = TE_{CRS} / TE_{VRS}. \quad (2)$$

The DEA cost minimisation was adopted to estimate cost and allocative efficiencies of farms and expressed as in equation (3)

$$\begin{aligned} \text{Subject to} \quad & \min_{\lambda, x_i^*} w_i' x_i^*, \\ & Y\lambda - Y_i \geq 0, \\ & x_i^* - X\lambda \geq 0, \\ & N1'\lambda = 1, \\ & \lambda \geq 0, \end{aligned} \quad (3)$$

where w_i and x_i^* – input price and quantity for the i -th farm; Y_i – output levels. The cost efficiency (CE) of the i -th farm was determined by subtracting the minimum cost from the observed cost as follows:

$$CE = w_i' x_i^* / w_i' x_i. \quad (4)$$

The cost efficiency score and technical efficiency score were combined to calculate the allocative efficiency (AE), which was expressed as

$$AE = CE / TE. \quad (5)$$

The analysis of shallot farm's efficiency was performed with the DEAP 2.1 software suite (Coelli, 1996). Determinant factors affecting efficiency from shallot farming were examined by the ordinary least squares (OLS) regression model. The empirical model was specified in equation (6)

$$Y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + e \quad (6)$$

where Y_i – efficiency score for the i -th farm (technical and cost efficiency scores); X_1 to X_7 – age, experience, education level of the farmer, household size, shallot farm size, credit and training access (dummy), respectively; e – error terms.

RESULTS AND DISCUSSION

Descriptive Statistics Characteristics of Farmers and Shallot Farming. Table 1 displays the summary statistics of the variables used in this study. The survey data showed that shallot producers yielded an average of 15.24 t/ha ranging from 5.00 to 26.00 t/ha. This indicated that some farmers could achieve a quite high yield (26.00 t/ha) while others experienced a lower level (5.00 t/ha). SNV (2022) reported that the average shallot yield of farms in Tra Vinh province was about 20-25 t/ha. In comparison to the main shallot-producing province, the study by V. Vellema *et al.* (2017) found that there was a large variation in shallot yields in Soc Trang ranging from 5.00 to 35.00 t/ha in 2017. Noticeably, the reason for this low yield of the sampled growers in this study is because their shallot farming experienced unseasonal heavy rains and major storms which destroyed a large number of shallot growing areas and thereby affected the yields. Farmers in the study area used shallot bulbs bought from the main shallot-producing region in Soc Trang province.

In Vietnam, there is still no research comparing the effectiveness of shallot grown from seeds and bulbs. In Indonesia, T. Triyono *et al.* (2021) compared the income of shallot farming using bulbs and seeds in cultivation. The results revealed that the yield, income, and profit of shallot farming using seeds for cultivating were all higher than those of shallot farming using bulbs suggesting technology changes from using bulbs to seeds for higher profit.

Information related to the characteristics of shallot producers in this study are also revealed in Table 1. It can be seen that shallot farms in the selected sample are quite small in size with an average of only 0.42 ha, ranging from 0.24 to 1 hectare. The average number of household members is four people per family. The shallot farmers have mean age of 49 years, have over six years of schooling and seven years of shallot cultivating experience. In the study area, only 15% of the growers attended the courses in technical training. The low percentage of this factor could be because shallot is a new crop in the province; thus,

research and provincial supporting policies in shallot production are still limited. V. Vellema *et al.* (2017) stated that shallot farming is capital-intensive because of the high input use. However, only 1% of the

sampled farmers in this study have availed of credit access. None of these farmers participated in agricultural cooperatives so this variable is not included in the regression analysis.

Table 1. The Contribution of agroforestry practice to pesanggem household income

Variables	Unit	Mean	Minimum	Maximum	Standard Deviation
<i>Output</i>					
Shallot output	kg/ha	15,243.56	5,000.00	26,000.00	4,813.78
<i>Inputs</i>					
Seed bulbs	kg/ha	533.40	350.00	933.00	155.72
Fertiliser	kg/ha	995.77	150.00	3,435.00	436.76
Labour	man-days/ha	283.11	167.00	487.00	45.38
Seed price*	1,000 VND/kg	98.43	30.00	700.00	51.19
Fertiliser price*	1,000 VND/kg	20.35	12.20	25.56	2.61
Labour wage*	1,000 VND/day	213.49	190.00	230.00	5.42
<i>Farm-specific variables</i>					
Shallot farm size	ha	0.42	0.10	2.00	0.24
Household size	persons	3.90	1.00	8.00	1.19
Age of the farmer	years	49.45	26.00	72.00	9.82
Education level	years	6.29	0.00	12.00	2.64
Experience	years	7.26	1.00	20.00	3.25
Training access	dummy	0.15	0.00	1.00	0.36
Credit access	dummy	0.01	0.00	1.00	0.10
Member of agricultural cooperatives	dummy	0.00	0.00	0.00	0.00

Note: +1 USD = 23,647 VND (as of January 2023)

Source: compiled by the authors

Efficiency Analysis of Shallot Farms. The results of the efficiency analysis for the shallot farms in the study are displayed in Table 2. It can be seen that the average technical efficiency score of the shallot farms was relatively high at 0.838, and average technical efficiency score higher than 0.700 were achieved by over 87% of farmers. Only 28 farms (about 14%) were fully efficient, with a technical efficiency of one, indicating that most farms still have considerable potential to improve their technical efficiency.

The cost efficiency of shallot farms was found to be low while the allocative efficiency score was relatively high. The cost efficiency ranged from only 0.466 to 1, with a mean value of 0.770. In which, over one-fourth of farms acquired a cost efficiency level of less than 0.700. In contrast, the farms' allocative efficiency score was 0.917 and most farms (over 93%) achieved allocative efficiency scores of more than 0.900 (Table 2). However, in both cases, only 5 farms (2.5%) were fully efficient, indicating that approximately 97.5% of farms had cost and allocative inefficiency. Hence, these shallot producers could increase their cost efficiency by improving technical efficiency. Z. Bayramoglu and E. Gundogmus (2008) demonstrated that the improvement of cost efficiency can be achieved through the improvement of both technical and allocative efficiency. If the allocative efficiency was higher than technical efficiency, farms' inefficiency was identified for technical efficiency and

vice versa. In the current study, the allocative efficiency score was higher than technical efficiency (0.917 of allocative efficiency compared to 0.838 of technical efficiency) implying technical efficiency was identified as the primary cause of inefficiency in shallot farms.

The last column of Table 2 shows the information of scale efficiency. It can be seen that the mean score of scale efficiency was 0.724 showing that the sample shallot farms reached about only 72% of the optimal scale efficiency. Furthermore, technical efficiency scores fell below the average value for over 42% of the farms and out of 8 farms, only 4% were able to scale efficiency. The statistical analysis also clearly revealed that operating at optimal scale was only achieved in less than 4% of shallot farms in the study while the majority of them (95%) were functioning at a sub-optimal scale. It means the farmers were producing on small farms. The results of the analysis of low efficiency at small-scale production and the fact that most shallot farmers experience increasing returns to scale suggest that the efficiency of shallot production can be improved by expanding the scale of production on farms.

A previous study by T. Triyono *et al.* (2021) found that the shallot farming in Indonesia was still allocative inefficiency with an average allocative efficiency of 0.773. In Vietnam, Q. Nhut *et al.* (2013) showed that the averages of technical, allocative and cost efficiency of shallot producers in Soc Trang province were 0.93, 0.66,

and 0.62, respectively. In addition, these farms also achieved a high scale efficiency of 0.98, with 51% of farms operated at increasing return to production scale. In comparison, shallot growers in the current study acquired higher allocative and cost efficiency but lower technical efficiency. Furthermore, a greater percentage

of farms was in the increasing return to scale. The reason for the lower technical efficiency and scale inefficiency of shallot farmers in Tra Vinh province could be because shallot is quite new crops in Tra Vinh province, thus the lack of farming techniques prevents the farmers from expanding production areas.

Table 2. Efficiency results of shallot farms in Tra Vinh province

	Technical efficiency	Allocative efficiency	Cost efficiency	Scale efficiency
<i>Summary efficiency</i>				
Mean	0.838	0.917	0.770	0.724
Std. dev.	0.117	0.064	0.126	0.205
Minimum	0.537	0.639	0.466	0.236
Maximum	1.000	1.000	1.000	1.000
<i>Frequency distribution</i>				
<60%	3.96	0.00	11.39	28.22
60-69%	8.42	1.49	16.83	13.86
70-79%	22.28	4.95	25.74	15.35
80-89%	35.64	27.72	31.68	15.35
90-100%	29.70	65.84	14.36	27.23
Fully efficient farms	28.00	5.00	5.00	8.00
<i>Returns to scale</i>				
Constant (%)				3.96
Decreasing (%)				0.99
Increasing (%)				95.05

Source: compiled by the authors

In order to recognise whether inputs have been used properly by farmers, the comparison of input levels between technically efficient and cost-efficient was conducted. The data related to technical efficient input levels were acquired in the technical efficiency DEA model, while the figures of cost efficient input levels were obtained in the cost-minimising DEA model. The input is considered overuse when its ratio is greater than one. The estimated results of the study are shown in Table 3. The mean ratios of three inputs including seed, fertiliser and labour were just a little bit higher than one (1.16, 1.11, and 1.00, respectively) implying that these inputs were properly used. However, the

data regarding the percentage of over-use and under-use farms indicated that most shallot growers in the study still did not use these three inputs appropriately. Specifically, almost 97% of farms were underusing and overusing fertiliser and labour. In addition, data presented in Table 1 showed that only 15% of shallot farms were able to access technical training. These may be the reasons for unstable production efficiency and income of local farmers. The findings are in line with a statement from V. Bui and M. Nguyen (2018) that shallot producers in Tra Vinh face several difficulties including high technical risks, small production areas, and experience-based farming.

Table 3. The state of inputs used by shallot farmers in Tra Vinh province

	Seed	Fertiliser	Labour
Mean	1.16	1.11	1.00
Standard Deviation	0.24	0.31	0.13
Minimum	0.63	0.15	0.67
Maximum	2.00	1.96	1.52
Over-using farms (%)	64.85	52.48	38.61
Under-using farms (%)	10.89	44.55	58.91
Proper-using farms (%)	24.26	2.97	2.48

Source: compiled by the authors

Factors Influencing Efficiencies. Regarding determinants of farms' efficiency, the OLS model was used to regress technical and cost efficiency to characteristics of shallot producers. Table 4 displays the results of the regression analysis. It can be observed that many fac-

tors had influence on technical and cost efficiency of shallot producers including experience, household size, shallot farm size, and training access. However, credit access, age, and education level of the shallot farmer were found to be irrelevant.

Table 4. Determinants of technical and cost efficiency of Tra Vinh shallot farms

Variables	Technical efficiency		Cost efficiency	
	Coefficients	t-value	Coefficients	t-value
Age (years)	0.001	0.890	0.001	1.011
Experience (years)	-0.009**	-3.522	-0.012**	-4.479
Education level (years)	0.002	0.539	-0.002	-0.571
Household size (persons)	-0.018**	-2.879	-0.015*	-2.225
Shallot farm size (ha)	0.147**	4.594	0.173**	5.096
Credit access (dummy)	-0.066	-0.873	-0.114	-1.406
Training access (dummy)	0.060**	2.779	0.062**	2.739
Constant	0.852**	14.073	0.797**	12.389
R-square	0.215		0.243	
Sig.	0.000		0.000	

Source: compiled by the authors

The coefficient of cultivation experience of the shallot producer was negative and significant at 1% in both the technical and cost efficiency models, indicating that this factor was not likely to boost the technical and cost efficiency of the shallot farmers (Table 4). It means that less experienced farmers tend to obtain higher technical and cost efficiency than the ones who have more years in shallot farming. Similarly, A. Kumar *et al.* (2020) found that paddy and maize farmers with longer farming experience tend to adopt fewer technologies. This could be explained that less experienced producers are quite flexible and willing to apply advanced techniques in their farming in order to increase farm's efficiency. In addition, S. Sriyadi and A. Yekti (2021) indicated that shallot farmers with more experience are less afraid of risks or able to minimise the risks than those with less experience. However, P. Guha and T. Das (2020) reported that experience assists the farmers in using optimal time and appropriate inputs, and thereby decreases the farms' cost inefficiency.

The technical and cost efficiency of investigated farms is negatively impacted by the size of shallot households. Large household sizes tend to incur less technical and cost efficiency (Table 4). The reason for this can be explained by the fact that growing shallot indeed requires intensive labour and investment. This result is in agreement with the findings of previous studies. For example, A. Pratama *et al.* (2018) demonstrated that due to financial limitations, large households could not optimise the input uses resulting in low production. Similarly, T. Koye *et al.* (2022) also found that the inadequate managing skills of large household sizes in employing the workforce could be the main reason to cause low production efficiency.

The findings showed that the estimated coefficients associated with shallot farm size were all positive and statistically significant at 1%, meaning that the larger shallot farms were more efficient than the smaller ones (Table 4). Additionally, the empirical results of return to

scale showed that over 95% of the shallot farmers were operating at increasing return to scale (Table 2). Hence, these investigated farms in this study could increase technical efficiency by expanding their operation scale. This result is consistent with the findings of T. Koye *et al.* (2022) and N. Krasniqi *et al.* (2023). Particularly, T. Koye *et al.* (2022) indicated that farm size is the key input that influences the onion output and that those onion farmers who had larger plot sizes saw a significant improvement in their technical efficiency. In the present study, shallot farmers of Tra Vinh province showed potential to expand their shallot growing area. However, a lack of farming techniques may be the factor that prevents producers from increasing production areas.

Regarding accessing technical training, it was included in the regression model as dummy variable to determine its role in shallot farming efficiency in the study. It was found that both technical and cost efficiency were positively correlated with training access, indicating that training enabled shallot farmers to be more efficient. Especially in the context of this current study, where most growers have less experience in shallot farming. Thus, training could be an important way to keep up with knowledge and advanced technologies in shallot farming in order to promote farming activities more effectively. These findings were in agreement with previous studies by T. Tesema (2021) and G. Mulatu and T. Gemechu (2023). According to L. Astuti *et al.* (2020), farmers who accessed extension services could improve their farming technologies, so their technical efficiency was higher than others who did not receive any counselling. In addition, a study by T. Haryanto *et al.* (2023) observed that participating in agricultural extension programmes such as farmer field school helped the farmers increase technical efficiency.

This study also pointed out that lack of cooperation in production can be considered a limitation of shallot farmers. As can be seen, there is a large variation in shallot yield among surveyed households

and some farmers can achieve a relatively high yield (26,000 kg/ha). This shows that there are some productive farms. Sharing successes and technical advances in farming among farmers is essential. However, the results presented in Table 1 show that all surveyed farmers produced individually, and no one participated in agricultural cooperatives. FAO (2022) noted that agricultural cooperatives offer a diversity of extension services, help smallholder farmers boost yields. The result of T. Le *et al.* (2019) found that farmers in agricultural cooperatives or associations achieved higher efficiency than individual cultivators. Therefore, this study suggests that local authorities need to pay more attention to promoting the establishment, and supporting cooperatives, cooperative groups, and clubs. These could help shallot producers create producing networks, and share effective farming techniques that are useful for improving farming efficiency.

CONCLUSIONS

Shallots have been considered a valuable crop in Tra Vinh province, Vietnam. The production efficiency of crops is a significant factor in improving the livelihoods of farmers, developing the agriculture sector, and the economy of the province. The findings of this study revealed that the estimated technical, allocative, and cost efficiency were 0.838, 0.917, and 0.770, respectively. The low level of cost efficiency of shallot growers in the study was identified as technical inefficiency; hence, the shallot producers could improve their cost efficiency by adjusting farming technologies. An increasing rate of return to scale was observed among most shallot farmers (over 95%) indicating that the technical efficiency of these farms could be increased by expanding their production scale.

Factors influencing technical and cost efficiency in shallot production were also determined. The empirical results of the regression revealed that the technical and cost efficiency levels were negatively influenced by the size of the household and experience of the farmers. The statistical analysis further revealed that achieving higher technical and cost efficiency is more likely to happen for shallot farmers who have larger shallot farm sizes or access to technical training.

As a result, three recommendations have been made in this current study; (1) the local government should prioritise support for research programmes on shallot-farming techniques to improve productivity and production efficiency for the farmers; (2) the operation quality of agricultural extension centres needs to be paid more attention to play an effective bridging role in transferring knowledge and advanced technologies to shallot growers; and (3) shallot farmers should proactively access scientific data and advanced technologies in shallot farming to improve technical efficiency, thereby, they could confidently expand shallot-farm size. Nevertheless, this study focuses only on quantitative analysis, whereas qualitative and natural factors also influence the efficiency of shallot farms. Therefore, future research in shallot farming should take these factors into consideration in order to improve the performance of shallot farms.

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CONFLICT OF INTEREST

None.

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Аналіз оболонки даних щодо ефективності виробництва цибулі-шалот у Тра Віні, В'єтнам

Ле Трук Лінь

Кандидат наук з аграрної економіки
Університет Тра Вінь
940000, вул. Нгуєн Тхієн Тхань, 126, м. Тра Вінь, В'єтнам
<https://orcid.org/0009-0001-6515-0152>

Дієп Тхань Тунг

Кандидат економічних наук, доцент
Університет Тра Вінь
940000, вул. Нгуєн Тхієн Тхань, 126, м. Тра Вінь, В'єтнам
<https://orcid.org/0000-0001-9384-3776>

Луу Тхі Туй Хай

Кандидат наук з мікробіології
Університет Тра Вінь
940000, вул. Нгуєн Тхієн Тхань, 126, м. Тра Вінь, В'єтнам
<https://orcid.org/0000-0003-2380-5349>

Анотація. Шалот – багаторічна культура, яку вирощують як однорічну для отримання насіння цибулин і широко вирощують у В'єтнамі. Це легка у вирощуванні культура, яка підходить для місцевих ґрунтових умов і приносить високу економічну ефективність. Хоча шалот є відносно новою культурою для фермерів у провінції Тра Вінь, вона вважається однією з ключових культур у стратегії розвитку сільського господарства провінції. Це дослідження було проведено з метою оцінки ефективності вирощування шалоту в провінції Травінь за допомогою методу аналізу оболонки даних (DEA). Результати дослідження показали, що середня економічна ефективність склала 0,770, і лише п'ять господарств (2,5 %) були повністю економічно ефективними. Оцінка середньої ефективності розподілу ресурсів була дещо вищою за оцінку технічної ефективності (0,917 та 0,838); таким чином, неефективні фермерські господарства шалоту могли б досягти вищої економічної ефективності за рахунок підвищення технічної ефективності. Відповідно, в цьому дослідженні були визначені фактори, що впливають на технічну та економічну ефективність виробництва цибулі-шалот. Розмір домогосподарства та досвід вирощування шалоту-шалот продемонстрували негативний вплив на рівень технічної та економічної ефективності. Аналіз також показав, що ті фермери, які мали більші розміри господарств і мали кращий доступ до технічного навчання, були більш технічно та економічно ефективними. Отже, це дослідження свідчить про те, що дослідження, спрямовані на вдосконалення технологій вирощування шалоту, повинні мати пріоритетну підтримку, а якість програм технічного навчання для місцевих фермерів повинна бути підвищена, щоб підвищити технічну та економічну ефективність виробництва шалоту

Ключові слова: дельта Меконгу; Тра Вінь; аналіз оболонки даних; економічна ефективність; виробництво шалоту

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The role of ESG in the adaptation of the agro-industrial sector to climate change

Javid Huseynli

Doctoral Student, Lecturer

Academy of Public Administration under the President of the Republic of Azerbaijan
AZ1001, 74 Lermontov Str., Baku, Azerbaijan
<https://orcid.org/0009-0006-0400-9071>

Yusif Huseynov

PhD in Political Sciences, Lecturer

Academy of Public Administration under the President of the Republic of Azerbaijan
AZ1001, 74 Lermontov Str., Baku, Azerbaijan
<https://orcid.org/0000-0003-4846-8975>

Nurzat Totubaeva

PhD in Biological Sciences, Associate Professor
Kyrgyz-Turkish Manas University

720044, 56 Ch. Aitmatov Ave., Bishkek, Kyrgyz Republic
<https://orcid.org/0000-0002-5919-9363>

Mushfig Guliyev

Doctor of Economic Sciences, Professor
Azerbaijan State University of Economics (UNEC)

AZ1001, 6 Istiglaliyyat Str., Baku, Azerbaijan
<https://orcid.org/0000-0002-1104-5402>

Gulnara Azizova

PhD in Economics, Associate Professor
Azerbaijan State University of Economics (UNEC)

AZ1001, 6 Istiglaliyyat Str., Baku, Azerbaijan
<https://orcid.org/0000-0003-0465-0564>

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Abstract. The purpose of this study was to investigate the role of utilising the work of agro-industrial companies in the sustainable development of Azerbaijan. Thus, the study assessed the essence of the concept of Environmental, Social, and Governance, and its role for the state and enterprises. It was concluded that in recent years, more and more attention has been paid to this kind of principles in the corporate world, as companies realise the importance of solving environmental and social problems to attract investors and develop sustainable practices. This is also consistent with the

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*Corresponding author

concept of corporate social responsibility, which emphasises the ethical obligations of business to society. The analysis of investment flows in such companies in the agricultural sector has shown that they can significantly expand the scope of their activities and accelerate the introduction of sustainable agriculture methods around the world. It was concluded that, given the benefits that investments in these companies bring to the country, it is important to include programmes aimed at increasing the investment attractiveness of such companies in the framework of national policy. In addition, targeted government support for such companies is effective. All this remains especially relevant in the realities of Azerbaijan, as a country with a transitional economy with a fairly high role for the agricultural sector (at least within the framework of food security), and the need for economic diversification. The results obtained in the framework of the study can be used to formulate a long-term development strategy for Azerbaijan in the context of combating climate change in the agro-industrial sector

Keywords: agro-industrial sector; investments; innovations; food security; ecology; sustainable development

INTRODUCTION

Sustainable development is a concept that implies striving to meet the current needs of society without compromising the ability of future generations to meet their own needs. It provides a balance between the social, economic, and environmental aspects of development, which ensures the long-term sustainability and well-being of society. This concept is developed from the principles of social justice (ensuring that all members of society have equal opportunities to meet their needs in education, health, housing, and other spheres of life), economic efficiency (strives to create a stable and prosperous economy that ensures an even distribution of benefits and resources, and fair participation in economic activities), environmental sustainability (implies conservation and protection of the environment, efficient use of natural resources, reduction of pollution and combating climate change), cultural diversity (respect for cultural identities and traditions of different communities, support for diversity of languages, customs and beliefs) and global responsibility (striving for cooperation between countries and the world community to solve global problems such as poverty, migration, climate change, and other challenges). Sustainable development in the modern conditions of the country's development plays a critical role, since it ensures a balance between economic, social, and environmental progress, while preserving the ability of future generations to meet their needs (Anarbayev *et al.*, 2024).

Agriculture, in turn, is also one of the main areas for achieving sustainable development goals (Shi *et al.*, 2022; Yap & Al-Mutairi, 2024). This is how it provides food to the population of the country, and achieving the ability to consistently and continuously create such products is an important component for the qualitative development of the country in the future. In addition, the transition to sustainable agriculture can lead to the conservation of biodiversity and ecosystem health by preventing deforestation, soil degradation, water pollution, and a decrease in the number of wild species; this sector is one of the main suppliers of greenhouse gases, but can also play a role in mitigation and adaptation to climate change. Sustainable farming methods such

as agroforestry, carbon storage in soils, and agrotechnical techniques can reduce emissions and increase resistance to abnormal climatic conditions (Bovsh *et al.*, 2024). In other words, the very essence of agriculture in the context of its impact on the lives of citizens requires special approaches in terms of methods utilised by such enterprises.

In order to ensure the qualitative development of agriculture in the country, one of the most important roles is played by the volume of investments. This is especially true for agriculture, which has a bias towards sustainable development and innovation. Without sufficient amounts of money, the latest technologies, and the appropriate level of training, it is impossible to build a company that could achieve significant success in this area (Novruzova *et al.*, 2023). In this regard, the development of different approaches to attract funds to certain industries remains relevant. Within the framework of this study, an assessment of global trends was carried out, based on which recommendations were developed to improve the situation in Azerbaijan.

The role of the Environmental, Social, and Governance (ESG) concept, for the development of the economic, social, and environmental components of a country, has been considered by a large number of researchers, among which are R.M. Visconti (2023), I.R.D. de Jesus and P.P. Nascimento (2021), M. Singhanian and N. Saini (2022a). They described the role of this component from quite different angles, but did not focus on its interaction with the investment component, which is emphasised in this study. In addition, some researchers have written that there is an interaction between the performance of enterprises and their propensity to ESG. This, in particular, was emphasised by J. Brice *et al.* (2022), M. Singhanian and N. Saini (2022b), G. Zhou *et al.* (2022). All of them came to the conclusion that ESG eventually leads the company to more effective financial results, which is why they write about the role of more active application of adherence to the concept.

Within the framework of this study, more attention is paid to the use of this concept in the agricultural sector. As for the analysis of the situation in Azerbaijan,

E.A. Ibraghimov (2022) emphasised the shift in the focus of states from simply ensuring economic competitiveness to achieving a balance of sustainable development. He also noted the strong interdependence between innovation, competitiveness, and sustainable development within the current global economic system. In the framework of this study, in turn, the emphasis is slightly shifted and the main attention is paid specifically to the issues of this component in the agricultural sector. Nevertheless, little attention is paid to the issues of investing in sustainable projects in Azerbaijan. M. Mammadli (2022), in turn, partially considered the features of sustainable development in Azerbaijan, but did not consider investing in this area.

In this regard, a more detailed analysis of this component is relevant in the framework of the study. Thus, the purpose of this study was to assess the role of investments in companies in the agricultural sector, whose activities are aimed at sustainable development.

MATERIALS AND METHODS

The study analysed data on “green” investments in individual companies. The analysis included Indigo Ag (Thomas, 2023), Bowery Farming (Bowery Farming secures..., 2022), BrightFarms (BrightFarms extends its..., 2021), Kaiima Agro-Biotech Ltd. (2024), TruLeaf Sustainable Agriculture Ltd. (\$150-million investment..., 2022), GoodLeaf Community Farms Ltd. (Sokic, 2023), Rigoni di Asiago Srl. (Palazzolo, 2019), Agricool (2024), InvertiGro (2024), WayCool (Ramasubramanian, 2023) and DBN Group (DBN Group makes..., 2024). The reason for mentioning such a list of companies is that they have attracted quite large amounts of investment at various times to create sustainable development technologies in the agricultural sector.

To outline the principles of the ESG concept, a model was built that describes in detail all its components. Thus, ESG inherently consists of three components, namely: external environment (environmental), government (governance), and social (social). However, each of them includes many other components, which were depicted within the framework of the model. These include: pollution and waste, resources and land use, climate change, ecological footprint and biodiversity for the environment; leadership and corporate governance, anti-corruption and bribery, risk management, tax transparency and business ethics for public administration; health and safety, product and consumer responsibility, community impact, diversity and inclusivity, labour standards and human rights for a component of society. It is worth noting, however, that, in fact, a much larger number of them can be produced, since each of the components of ESG is quite multifaceted.

Information from individual legislative documents was also evaluated, in particular, the Order of the President of the Republic of Azerbaijan “On Approval of the National Priorities of Socio-Economic Development:

Azerbaijan 2030” (2021). At its core, this document covers a wide range of aspects of the country’s economic and social development for the future up to 2030. This strategy is focused on achieving stable and sustainable economic growth, improving the standard of living of the population, developing human capital, reducing poverty, and modernising the economy. Its main components are: economic diversification, human capital development, social protection, environmental sustainability, and others. Within the framework of the study, this document was mentioned as one of the main ones in the framework of the analysis of the ESG concept in the country.

In addition, information from the Law of the Azerbaijan Republic No. 759-IG “On Food Stuffs” (1999) was evaluated. This is the main regulatory act governing the production, turnover and quality of food products in the country. It establishes food safety and quality standards, and rules and requirements for their production, storage, transportation, and sale. The Order of the President of the Azerbaijan Republic No. 3004 “On Approval of the “State programme for reliable provision of food products to the population in the Azerbaijan Republic for 2008-2015” (2008) was also mentioned, the main objective of which is to stimulate the growth of agricultural output and increase food supplies through local production.

RESULTS

Environmental, Social, and Governance (ESG) is a concept that is used to assess the social responsibility and sustainability of companies (Barrymore & Sampson, 2021; Broadstock *et al.*, 2021). This approach considers three main aspects: environmental (assessment of the impact of the company’s activities on the environment; this may include emission management, energy and resource use, waste management, and impacts on biodiversity and climate), social (assessment of the company’s relations with its stakeholders such as employees, customers, suppliers, society as a whole. Important aspects include labour standards (employee rights, diversity and inclusion, and contributions to the local community) and managerial standards (assessment of company management systems and practices, which includes corporate governance structure, independence of the supervisory board, ethical standards, corporate transparency, anti-corruption) (Cakranegara & Sidjabat, 2021; Fang *et al.*, 2023).

Corresponding ratings are available to assess the level of commitment to ESG principles (Klinger *et al.*, 2022). They are based on an assessment of companies’ management of environmental, social, and managerial issues that are crucial for sustainable investments: they are used by investors to make informed decisions, assessing the long-term viability of companies and their impact on society, and therefore, they play a very important role in the investment decision-making process (Lankford, 2022). In turn, companies are interested in paying more attention to solving such

issues to attract more investors (Rosegrant *et al.*, 2022; Prasad *et al.*, 2023). This motivates them to more actively introduce innovative technologies into production and management processes, and improve the quality of their approach to personnel management and influence society as a whole. This concept is quite close to corporate social responsibility. Both concepts relate to

business social responsibility; they are closely linked and complement each other in creating sustainable and socially responsible business practices that consider environmental, social, and managerial aspects. In this regard, they are often considered and assessed together.

In general, the principles of ESG can be described using the model shown in Figure 1.

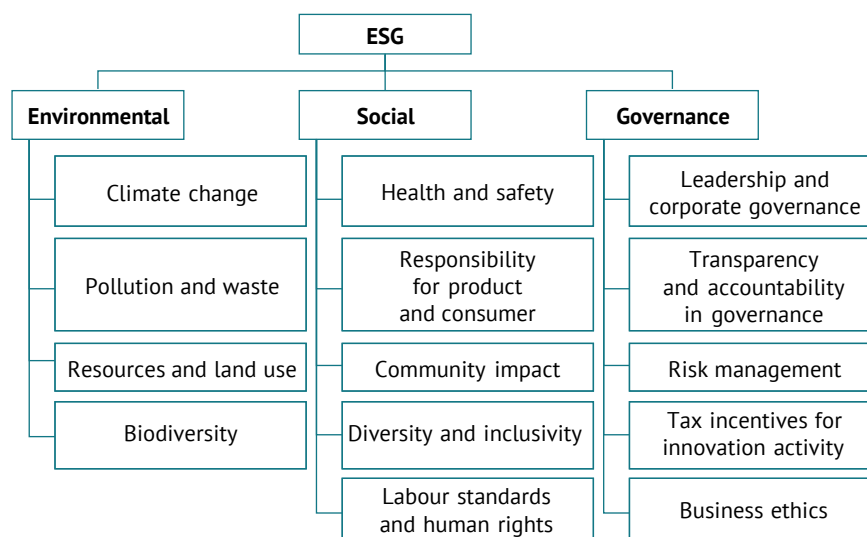


Figure 1. The concept of ESG

Source: compiled by the authors

As can be seen from Figure 1, ESG consists of three main components, which have already been mentioned above, however, they include a fairly large number of other introductory ones. They, in turn, should be considered during the development of national policy in this area, including in the agricultural sector.

To assess the role of ESG in adapting the agro-industrial sector to climate change, it is worth considering the situation in individual companies, and how investments in them have affected the ability of these enterprises to develop business. So for a start, it is worth considering Indigo Ag (USA), which has received more than USD 250 million in funding to expand its sustainable agriculture programmes and improve the quality of service to its customers (Thomas, 2023). The company itself offers products and services aimed at improving the sustainability and productivity of agriculture: its seed treatment methods increase the yield of the sector's products in a variety of conditions, including drought. Indigo Ag also facilitates communication between producers and buyers by helping with crop logistics. They have signed contracts for significant areas and initiated projects such as creating carbon credits by measuring soil carbon levels, appealing to companies seeking to reduce their carbon footprint. Internationally, Indigo Ag is working in Brazil, introducing microbial processing of soybean seeds, which significantly increases yields, and in Europe is working on the

creation of a carbon credit programme in collaboration with companies such as Beiselen.

Both existing and new investors participate in the financing round. In particular, such players as Flagship Pioneering (a biotech company), pension funds of the state of Michigan, and Lingotto Investment Management were featured. Lingotto Managing Partner James Anderson stressed the importance of supporting innovative companies such as Indigo Ag in solving climate problems. Indigo Ag has shown significant growth rates in 2022, while actively cooperating with other large companies to meet the goals of reducing emissions into the atmosphere. With the funds received, the company plans to expand the range of biologically pure products that it produces, and expand geographically. Given the significant growth rates of the company, it is worth expecting a high return on invested funds, while providing significant benefits to the country in environmental and social implications.

Another example is Bowery Farming, founded in 2015 also in the United States of America (Bowery Farming secures..., 2022). Its goal is to improve access to high-quality, local, safe, and sustainable products by creating "smart" farms near urban areas, the company produces fresher, protected, pesticide-free products with a rich taste all year round in precisely controlled conditions. The centrepiece of each farm is the patented BoweryOS, an integrated system that organises

and automates operations using software, hardware, sensors, artificial intelligence, computer vision, machine learning, and robotics. This approach minimises waste and significantly reduces the use of water and land compared to traditional agriculture. The company recently received USD 472 million in financing from well-known investors such as Fidelity Management & Research Company LLC, Temasek, GV (formerly Google Ventures), General Catalyst, GGV Capital, First Round Capital, and some well-known persons. It is expected that due to such an investment, the company will be able to significantly expand its capabilities for introducing innovations into the industry, developing its own technology platform, expanding its customer base, and attracting more qualified experts.

Another company worth mentioning is BrightFarms (BrightFarms extends its..., 2021). It is engaged in indoor agriculture; the company specialises in growing and supplying supermarkets with local salad greens that do not contain genetically modified organisms (GMO) and pesticides. The company received a loan of USD 150 million from the global investment company KKR for the purpose of accelerating growth. As a result, the company's total funding has exceeded USD 647 million, including a USD 325 million Series C stock investment round in 2021, which is the largest private fundraiser in history for an indoor farming company. The main area of their investments is to increase the efficiency of the process of growing such products both in the technological part and in terms of reducing transportation costs, energy. BrightFarms stands out in the closed farming market due to an expanding network of high-tech and environmentally friendly hydroponic farms. They prioritise research, development, and operational excellence to deliver fresh, locally grown products year-round. With ambitious expansion plans, including the creation of new farms and the strengthening of expertise in various fields, BrightFarms is ready to meet the growing demand for products grown indoors. Through the use of funds raised from investments, the company plans to expand production capabilities.

Another example is Kaiima Agro-Biotech Ltd. (2024), an Israeli agricultural technology company. Founded in 2006, Kaiima specialises in the development and commercialisation of innovative technologies to increase crop yields and sustainability. One of the main activities of Kaiima is to improve the genetics of crops using non-GMO products. They use a patented technology platform called Enhanced Ploidy Induction and Cultivation (EPIC), which allows the creation of new varieties of crops with improved characteristics such as yield, resistance to environmental stresses and nutritional value. Kaiima technology works by inducing polyploidy in plants, a process that increases the number of sets of chromosomes in a plant cell. This can lead to significant changes in the characteristics of the installation, which will potentially lead to increased productivity.

It is important to note that Kaiima's approach avoids the use of genetic modification techniques, which may be subject to regulatory restrictions in some markets. The company cooperates with agricultural partners, research institutes and seed companies around the world to further develop and commercialise its technologies. Kaiima aims to address global challenges in agriculture, such as providing food to a growing population, adapting to climate change, and reducing the environmental impact of farming practices.

Recently, Embrapa and the Israeli company Kaiima Seeds signed a cooperation agreement on the breeding of new castor oil varieties in Brazil (Santos, 2023). The purpose of this interaction is to improve the cultivation of castor oil by creating varieties with high productivity, adaptability to various conditions, and distinctive characteristics such as oil composition and disease resistance. In general, cooperation and interaction between this company and other potential partners can increase opportunities for the future development and implementation of the latest technologies.

It is also worth mentioning a company such as TruLeaf Sustainable Agriculture Ltd (\$150-million investment..., 2022). It is a Canadian company that specialises in vertical and sustainable agriculture. Vertical farming is a farming method in which plants are grown in vertical structures such as buildings, shelving or special towers. This approach allows efficient use of limited space, as cultivation takes place upwards, in several levels, instead of the traditional horizontal distribution in the field. Vertical agriculture is usually based on hydroponics or aeroponics technologies that allow plants to obtain essential nutrients through water without using soil (Kobayashi *et al.*, 2022; Oh & Lu, 2023). The method itself has several advantages, including more efficient use of water and land areas, increased yields compared to conventional methods, and the ability to grow products closer to the place of consumption, which reduces time and transportation costs. In addition, vertical agriculture can be more resilient to climate change and ensure stable production all year round in all climatic conditions. The company was established in 2011, and its main goals remain: to ensure a higher level of food security, better indicators of environmental sustainability, and to introduce innovative farming methods. They use a plant growing system called TruLeaf, which uses vertical farming techniques to grow leafy greens and grasses. This approach allows year-round production regardless of climatic conditions, reduces water consumption compared to traditional farming methods, and minimises the need for pesticides and herbicides. The company's indoor agricultural premises are designed to optimise the use of space and resources, using modern LED lighting, automated nutrient supply systems, and climate control technologies to create ideal conditions for growing plants. TruLeaf also pays great attention to sustainable development, using renewable energy

sources and implementing recycling and waste reduction measures in its activities. The company is also engaged in the promotion of research developments in this field, is constantly in the process of creating new technologies to increase the level of sustainability of agriculture.

Initially, the company attracted USD 8.5 million in investments, due to which they were able to develop their technology and begin to implement it at enterprises. In 2022, its subsidiary GoodLeaf Community Farms Ltd received funding for another USD 150 million to expand the company and create new farms in Calgary and Montreal (Sokic, 2023). GoodLeaf aims to solve the problem of long transportation routes and food spoilage by supplying Canadian consumers across the country with types of agricultural products that are traditionally imported into Canada. Considering GoodLeaf Community Farms Ltd in more detail, a big investor in it was McCain Foods Ltd among others investing more than USD 65 million as of 2021 (Sokic, 2023). Using vertical farming technology, GoodLeaf grows greens such as young spinach and micro-broccoli in a controlled indoor environment, which ensures faster growth compared to traditional farming methods in the field. The company's new 96,000-square-foot facility in Calgary, which was already mentioned above and is estimated to cost USD 56 million, will initially operate at half capacity, which will create 70 new jobs in the city. The greens grown by GoodLeaf are expected to be available at major Calgary grocery stores, and the company plans to expand further as demand increases. Considering the features of vertical cultivation technology, it is worth expecting in the future both an improvement in the company's business opportunities in the future and prospects regarding the impact on the environment.

The next company to be evaluated is Rigoni di Asiago Srl (Palazzolo, 2019). It is an Italian group of food industry companies headquartered in Asiago, Italy, known for the production of honey and sweets. Its history begins with Eliza Antonini, who initiated the production of honey after the First World War. In 1979, the district began processing and commercialising various types of honey, rapidly expanding its activities. The company's headquarters are located in Asiago, the production complex is in Fos, and the logistics centre is in Albaredo d'Adige. The company is also present in Bulgaria, where it has been producing organic fruits since 1993. In 2019, the company received EUR 50 million of loan funds from UniCredit and Banco BPM with the support of SACE SIMEST (CDP Group) to promote its growth in international markets (Palazzolo, 2019). Currently, foreign trade turnover accounts for 24% of Rigoni di Asiago's revenue, and the company is striving to expand its presence in Europe and in America. Recently, the company acquired 100% of the shares of Saveurs&Nature, a French enterprise for the production of organic chocolate: the company employs 70 people, including

32 master chocolatiers, and the annual turnover of the company is about EUR 12 million (Moore, 2022). Chocolate production, in turn, is no less important than any other type of organic products, since it also includes sustainable practices, namely organic farming, the use of environmentally friendly ingredients.

Agricool (2024) is a French agrotechnological start-up specialising in the cultivation of fresh products indoors, after entering into receivership, it began searching for a buyer. The company, founded by Guillaume Fourdinier in 2015, uses recycled shipping containers to grow herbs, leafy greens, and strawberries under controlled conditions. Agricool's innovative systems consume 90% less water and nutrients compared to traditional farming methods and run on fully renewable energy sources. Despite investments from major players such as Danone, which participated in a USD 28 million funding round in 2020, Agricool has faced financial problems due to the capital-intensive nature of indoor agriculture. In 2023, the company emerged from bankruptcy proceedings, and its assets were bought by Grosvenor Food & AgTech and Doha Venture Capital (Harvey, 2023). With the new management component of the company, it is worth expecting an improvement in the overall situation in the company and the subsequent development of this technology.

Considering the situation in Australia, it is necessary to mention InvertiGro (2024). It is located in Sydney and specialises in indoor farming technologies, offering modular vertical farming systems that can be adapted to different scales, providing flexibility in deployment and integration with existing operations. As for India, there are also start-ups in the country that attract investments. For example, WayCool Foods from Chennai is negotiating to raise USD 40 million through the issue of rights, and Lightrock is acting as the main investor. WayCool, founded in 2015, initially focused on agricultural supply chain services and later expanded into consumer products with brands such as Madhuram, Kitchenji, and Freshey's (Ramasubramanian, 2023). The company has restructured its operations over the past 18 months to improve profitability, and is optimistic about breaking even by the target date. Despite recent losses, the company aims to significantly expand its activities to other markets and increase the efficiency of its own operation. Its impact is expected to spread to more than 800 cities in India through this round of investments. In China, such an example is DBN Group (2022), a well-known high-tech agricultural enterprise that plans to become a major player in the field of agriculture through investments, paying special attention to strengthening its international influence, brand awareness, and attracting the best specialists around the world.

Thus, the above examples of companies such as Indigo Ag, Bowery Farming, BrightFarms, Kaiima Agro-Biotech, TruLeaf Sustainable Agriculture and others

emphasise the important role of investments for the subsequent development of companies in the agricultural sector, the purpose of which is to have a positive impact on the environmental and economic component. These companies use sustainable practices, innovative technologies, and strategic investments to address climate change, improve food security, and promote environmental sustainability. For most companies, attracting investments is an approach to expanding the sales market and increasing production capacity. Thus, this allows for more active promotion of innovative practices in the world, and therefore, leads to more effective results in this area as a whole. This also indicates that the public authorities should pay much more attention to increasing the investment attractiveness of companies of this kind.

Azerbaijan is currently on the path of developing the basic principles of ESG. The country is facing a number of environmental problems, including air, water, and soil pollution caused by industrial and oil and gas operations, and therefore, significant efforts are being made to pay attention to improving the environmental situation in the country. In particular, special attention is paid to the sectors of the oil and gas industry and transport, and to reducing the negative impact on the environment. All this is happening within the framework of the Order of the President of the Republic of Azerbaijan "On Approval of the National Priorities of Socio-Economic Development: Azerbaijan 2030" (2021). Social aspects include issues such as social justice, human rights, working conditions, and access to education and health care: public authorities are working to improve their social sphere, including the development of education and health care, and the provision of jobs and social protection. Transparency and accountability of the work of the public administration system is considered as one of the important achievements. The government is taking steps to improve aspects of governance, such as creating conditions for more open and transparent governance, consolidating the legal system, and fighting corruption. Many developed countries also have problems of this kind, which they are trying to solve using certain concepts with varying success. Considering all the observed problems, it is not surprising that in recent years Azerbaijan has begun to pay more attention to ESG initiatives, especially in the context of attracting investments and improving its business climate. Due to the assistance from government authorities, many companies and organisations in the country are beginning to implement sustainable development practices in their activities, including social responsibility and environmental programmes.

As for the development of agriculture, this area includes the development and implementation of methods for the sustainable use of natural resources such as land, water, and energy to minimise the negative impact on the environment. Programmes and projects

are aimed at protecting the quality of soil and water resources, including the prevention of pollution from agricultural chemicals and other industrial processes; measures to create jobs, improve access to education, health, and social services in rural areas to reduce the gap between urban and rural areas. The initiatives are aimed at ensuring fair working conditions, including the protection of the rights of agricultural workers, including on issues of wages, and workplace safety. In addition, measures are being taken to encourage the participation of agricultural enterprises in social responsibility programmes and environmental protection initiatives, and the introduction of certification systems that guarantee compliance with ESG standards in agricultural production is supported. An important component of this policy is the legislative framework, which, among other things, is aimed at ensuring food security. For this purpose, there are certain norms that are recorded in the Order of the President of the Azerbaijan Republic No. 3004 "On Approval of the 'State programme for reliable provision of food products to the population in the Azerbaijan Republic for 2008-2015'" (2008), Law of the Azerbaijan Republic No. 759-IG "On Food Stuffs" (1999). Activities are also underway to improve this legislative framework. First of all, this is done to increase the investment attractiveness of the country for such investments, both in agriculture and other sectors such as transport, energy. At the moment, it is difficult to say for sure about the effectiveness of this policy, but it is worth assuming that if it is effectively implemented, the state can get really good results in terms of achieving the sustainable development goals.

Thus, to achieve the best results, it is worth increasing efforts in this area. The country should give priority to initiatives aimed at reducing environmental impacts, especially in key sectors such as oil, gas, and transport. Public authorities should promote sustainable farming practices by promoting methods of efficient use of natural resources such as land, water, and energy. Support programmes aimed at preserving soil and water to prevent pollution from agricultural chemicals will be effective in solving environmental difficulties. This also applies to the training of educated personnel who would be able to manage such developed enterprises. It is necessary to implement such programmes through private organisations, thereby encouraging entrepreneurship in the country, along with innovative development. The support of such enterprises can also help solve some social difficulties. In addition, special attention should be paid to the possibility of attracting investments to the country, showing its focus on achieving sustainable development goals. In this context, cooperation with international organisations, whose attention can be attracted both at international meetings and at personal meetings, should also be effective.

DISCUSSION

Thus, the paper considered the ESG concept and its application in assessing the sustainability and social responsibility of companies, especially in the agricultural sector. The reviewed examples have shown that companies that are aimed at spreading sustainable technologies and are committed to the principles of ESG have the opportunity to attract investments quite successfully. This is how examples of companies such as Indigo Ag, Bowery Farming, BrightFarms, Kaiima Agro-Biotech, TruLeaf Sustainable Agriculture, were considered. It was also concluded that it is important to attract investments for the development of such technologies, and the efforts on the part of the state in this area to increase the attractiveness of such enterprises.

Within the framework of this study, it was noted that investments in enterprises related to the technologies related to sustainable development are very important for the comprehensive development of the country. In addition, the connection between green finance, environmental degradation, and sustainable development was established by A.I. Hunjra *et al.* (2023). They noted that there is a positive and statistically significant relationship between green finance and the level of sustainable development. In this regard, researchers consider it important to pay sufficient attention to the development of opportunities for attracting investment in the sector to enhance the potential for sustainable development. Similar conclusions have been obtained by M.A. Nyasapoh *et al.* (2022). They concluded that investments remain a very important component for the development of renewable energy in Ghana, which means that their maximum active involvement should remain an important part of the country's public policy. All this also agrees with the fact that the development of innovations in the context of sustainable development is a very important component for the development of any country, including Kyrgyzstan, which should pay special attention to this in modern conditions (Amanova *et al.*, 2020).

Within the framework of the study, individual enterprises were noted that had the opportunity to receive significant investments by developing technologies aimed at ensuring the sustainability of agriculture (Kryvenko, 2024). The influence of the ESG-based management method on companies' results has been investigated by L. Zeng and X. Jiang (2023). They noted that companies with higher ESG ratings tend to achieve higher levels of corporate efficiency. This indicates that such companies not only succeed economically, but also achieve better results in terms of achieving the economic and social goals of sustainable development. Thus, such an effect can be calculated as a "win-win situation" for the company and the state. The study highlights that social and managerial indicators have a greater impact on improving corporate performance than environmental ones, which also shows that

government policy, market conditions, and the composition of managers influence the relationship between ESG and corporate performance. Based on this, researchers develop recommendations that companies should increase the macroeconomic role of ESG in their activities, and government authorities, in turn, should also pay more attention to it.

The dependence of ESG commitment in terms of company size was investigated by M.W. Rosegrant *et al.* (2022). They noted that in modern conditions, large companies actively adhere to these principles, which cannot be said about small and medium-sized ones. In this regard, the researchers concluded on the role of supporting small and medium-sized agricultural companies for the development of corporate social responsibility initiatives, and the implementation of sustainable resource management approaches. Researchers also noted that the application of measures related to ESG, in general, has a positive effect on the activities of companies, but not always, in connection with which they write about the role of assessing the characteristics of each of the companies to apply appropriate measures to regulate the characteristics of their activities in case of problems. And although this study did not pay much attention to the current situation in Azerbaijan, it is worth noting that the development of ESG among small and medium-sized enterprises is a higher priority than among large ones. This is conditioned by many aspects, but in general – due to the role of such companies for the welfare of the country in principle (Tkachenko *et al.*, 2023).

Within the framework of this study, it was noted that the development of human capital is an important component for the development and implementation of sustainable development technologies. The impact of aspects of the environment, social sphere and management, and the characteristics of human capital on the financial performance of state-owned agricultural companies was assessed by M.G. Pirtea *et al.* (2021). The study highlights the importance of corporate social responsibility and sustainability in the agricultural sector to increase profitability, especially against the backdrop of climate change challenges. It emphasises the need for managers of agricultural companies to prioritise such measures, especially in environmental aspects, and devote more time to staff training to improve financial performance in the future. In addition, researchers have proposed some strategies to improve the efficiency of enterprises through measures of corporate social responsibility. Thus, it can be concluded that in Azerbaijan, increasing attention to the development of better approaches to personnel training in the context of sustainable development is an important component.

The impact of the disclosure of information on sustainable development on the efficiency of agricultural companies in Europe was considered by P. Mititean (2023). The researcher wrote that the increasing

relevance of the ESG concept in recent years has led to a gradual tightening of monitoring of companies' activities in this area. The results showed that companies with a higher level of disclosure of information about sustainable development tend to achieve better operational, financial and market performance, which is also combined with past estimates. This study did not pay much attention to the development of information on sustainable development from companies in general, but it is worth noting that this is an important component of promoting this concept.

Considerable attention was paid, among other things, to education issues. Thus, improving the quality of education will lead to better work of enterprises, more effective work of researchers on theoretical and practical projects. This was partially mentioned by P. Dmuchowski *et al.* (2023), although their study has specialised in the evolution of sustainable investments in the context of major global events in general. Researchers noted that events such as the 2008 financial crisis and the COVID-19 pandemic accelerated the adoption of an environmental, social, and governance model, especially in the financial sector. Although there is a positive correlation between ESG factors and financial performance, problems persist due to vague definitions of responsible investments and data quality issues. In addition, the researchers analysed the situation in Poland, noting the need to significantly expand the markets for sustainable financing. However, the main recommendation in this area was to work on the quality of education in this area in the country. Among other things, this study highlighted the positive impact of ESG on their investment attractiveness, which ultimately is one of the important factors of their financial condition.

CONCLUSIONS

Thus, the ESG concept has become a vital basis for assessing the sustainability and social responsibility of companies. In recent years, the corporate world has been paying increasing attention to the principles of this concept, as companies realise the importance of solving environmental and social problems to attract investors and develop sustainable practices. It is closely consistent with the concept of corporate social responsibility, which emphasises the ethical obligations

of business to society. Both of these concepts create a framework that allows enterprises to integrate environmental, social, and managerial aspects into their activities, which ultimately contributes to sustainable and socially responsible practices.

The study also showed examples of how companies in various sectors, including agriculture, apply ESG principles to stimulate innovation and solve pressing environmental and social problems. From sustainable agriculture programmes to vertical farming technologies, these companies are attracting investments to develop solutions that enhance food security, mitigate the effects of climate change, and promote environmental sustainability. The described examples of companies have shown how innovative farming methods can achieve better results in terms of achieving sustainable development goals. In this regard, the development of national programmes aimed at attracting investments in such companies should become a very important component of the national policy.

In the agricultural sector, the introduction of sustainable practices is of paramount importance to address environmental degradation, ensure food security, and promote rural development. By promoting sustainable land use, water conservation and the introduction of renewable energy sources, countries can mitigate the adverse effects of climate change and contribute to the creation of sustainable agricultural systems. It is also worth noting that the ESG principles are an integral part of shaping a sustainable future for both business and society. By taking measures to protect the environment, social responsibility, and good governance, companies can achieve positive changes and create value for all parties, both for the companies themselves in the context of increasing profitability, and for enterprises and society. An assessment of the possibilities of attracting investments in sustainable agriculture in Azerbaijan is relevant for further research. In particular, in this context, it remains important to investigate foreign experience, especially in developed countries.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Роль ESG в адаптації агропромислового сектору до зміни клімату

Джавід Гусейнлі

Докторант, викладач

Академія державного управління при Президентіві Азербайджанської Республіки
AZ1001, вул. Лермонтова, 74, м. Баку, Азербайджан
<https://orcid.org/0009-0006-0400-9071>

Юсіф Гусейнов

Кандидат політичних наук, викладач

Академія державного управління при Президентіві Азербайджанської Республіки
AZ1001, вул. Лермонтова, 74, м. Баку, Азербайджан
<https://orcid.org/0000-0003-4846-8975>

Нурзат Тотубаєва

Кандидат біологічних наук, доцент

Киргизько-турецький університет "Манас"
720044, просп. Чингиза Айтматова, 56, м. Бішкек, Киргизька Республіка
<https://orcid.org/0000-0002-5919-9363>

Мушфіг Гулієв

Доктор економічних наук, професор

Азербайджанський державний економічний університет
AZ1001, вул. Істіглаліят, 6, м. Баку, Азербайджан
<https://orcid.org/0000-0002-1104-5402>

Гюльнара Азізова

Кандидат економічних наук, доцент

Азербайджанський державний економічний університет
AZ1001, вул. Істіглаліят, 6, м. Баку, Азербайджан
<https://orcid.org/0000-0003-0465-0564>

Анотація. Це дослідження було спрямоване на оцінку ролі використання роботи агропромислових компаній у сталому розвитку Азербайджану. Таким чином, у рамках дослідження було оцінено суть концепції Environmental, Social, and Governance, її роль для держави та підприємств. Було зроблено висновок, що останніми роками в корпоративному світі дедалі більше уваги приділяють подібним принципам, оскільки компанії усвідомлюють важливість розв'язання екологічних і соціальних проблем для залучення інвесторів і розвитку стійких практик. Це також узгоджується і з концепцією корпоративної соціальної відповідальності, яка підкреслює етичні зобов'язання бізнесу перед суспільством. Проведена аналітика потоків інвестицій у такого роду компанії аграрного сектору засвідчила, що вони дають змогу значно розширити сферу своєї діяльності та прискорюють впровадження методів сталого сільського господарства в усьому світі. Було зроблено висновок, що, з огляду на таку користь, що приносять інвестиції в ці компанії для країни, важливо включати в рамки національної політики програми, спрямовані на збільшення інвестиційної привабливості такого роду компаній. Крім того, ефективною є цілеспрямована підтримка таких компаній з боку держави. Усе це залишається особливо актуальним у реаліях Азербайджану, як країни з перехідною економікою з досить високою роллю аграрного сектору (щонайменше, в рамках продовольчої безпеки), а також потребою для диверсифікації економіки. Результати, отримані в рамках дослідження, можуть бути використані для формування довгострокової стратегії розвитку Азербайджану в контексті боротьби зі зміною клімату в агропромисловому секторі

Ключові слова: агропромисловий сектор; інвестиції; інновації; продовольча безпека; екологія; продовольча безпека; сталий розвиток

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Growth of value added as a factor in the development of Ukrainian agriculture in the context of accelerated integration into the EU

Oleh Skydan

Doctor of Economic Sciences, Professor
Polissia National University
10002, 7 Staryi Blvd., Zhytomyr, Ukraine
<https://orcid.org/0000-0003-4673-9620>

Vita Bugaychuk

PhD in Economic Sciences, Associate Professor
Polissia National University
10002, 7 Staryi Blvd., Zhytomyr, Ukraine
<https://orcid.org/0000-0002-7282-1794>

Inna Grabchuk

PhD in Economic Sciences, Associate Professor
Polissia National University
10002, 7 Staryi Blvd., Zhytomyr, Ukraine
<https://orcid.org/0000-0001-5548-6034>

Karyna Sych

Postgraduate Student
Polissia National University
10002, 7 Staryi Blvd., Zhytomyr, Ukraine
<https://orcid.org/0000-0002-0013-9315>

Snizhana Kubrak

PhD in Pedagogical Sciences, Associate Professor
Polissia National University
10002, 7 Staryi Blvd., Zhytomyr, Ukraine
<https://orcid.org/0000-0003-4236-1528>

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Abstract. The development of agriculture is a key factor in the sustainable development of society in the future. The country's integration into the European community creates new opportunities for agriculture and, at the same time, requires innovative approaches to the development and competitiveness of the sector in the globalised world. The study was aimed at analysing and improving the existing strategic approaches to the development of agriculture in Ukraine based on increasing gross

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*Corresponding author

value added in the context of accelerated integration into the EU. A variety of methods was used, such as analytical, statistical, functional, systems analysis, deduction, synthesis, and comparison. The analysis of the development and distribution of gross domestic product and gross value added in agriculture of Ukraine and the EU, including the specifics of the development of gross value added in Ukrainian agriculture, was carried out. The influence of European integration processes on the development of agriculture, in particular, their needs and opportunities to increase gross value added, was investigated. A model of a cybernetic system with management in agriculture for the growth of gross value added in the context of accelerated integration into the EU has been developed, which allows substantiating the forecast of changes in the format of development of Ukrainian agriculture to avoid the economy as a raw material appendage of the EU. The results of the study showed that the development of agriculture in Ukraine based on increasing gross value added in the context of accelerated integration into the EU involves the use of a comprehensive strategy that considers the specifics of the industry, European innovative approaches, and best practices of in-depth processing of products of the European Union countries. The practical significance of the study was to develop specific practical recommendations and strategies for public administration bodies, agricultural enterprises to optimise the use of the available natural resource potential for the growth of agricultural production, introducing advanced technologies for its deep processing in order to accumulate gross value added, which is the basis for the development of agriculture

Keywords: gross domestic product; gross value added; Russian military aggression; development; economy; conceptual model

INTRODUCTION

The development of individual industries is a component of the overall growth of the national economy of any country. The problem of development is particularly important in the context of agriculture, which is not only the main sector for many countries, but also a key element in solving food security and sustainable development of society. The development of Ukrainian agriculture is an urgent task that requires solving problems to optimise the use of not only resources, but also the entire production potential in the production of agricultural products with the maximum share of added value. Ukraine's integration into the European Union opens up wide opportunities for entering global value chains, which will give an impetus to the accelerated development of agriculture due to the growth of production and exports of products with a high degree of readiness. The main challenges of Ukrainian agriculture were improving the processes of processing and refining products to the highest degree of their readiness and compliance with their quality and safety with European standards. Such a statement of the problem requires substantiation of the areas of agricultural development based on in-depth processes of production and sale of finished products, which are now more important and justified from the standpoint of achieving successful integration into the EU.

The study by M. Shashyna (2020) proves that in the current conditions of rapid development and transformation in the global economic space, and in the context of globalisation and integration processes, one of the indicators that most fully reflects the development of individual business entities and economic systems in general is the amount of value added, which is considered from the standpoint of cost-oriented management. In other words, the value of the business is at the centre

of analysis, not just the product. The researcher notes that strategic areas for the development of regional and sectoral economic systems of Ukraine require gradual development based on comprehensive modernisation at all levels. Therefore, in the context of the development of agriculture in Ukraine and accelerated integration into the EU, the industry needs innovative management models, including management, communications, structures, production range, and technologies. Consideration of conclusions in the development of strategic areas for the development of agriculture in Ukraine indicates the expediency of substantiating changes in management approaches and revising basic management models in the industry.

T. Mirzoieva and M. Stepasiuk (2023) determined that Ukraine's integration into the European Union will contribute to the development of agriculture by applying the experience of European farmers in the efficient use of resources based on the use of innovative technologies for agricultural production. The researcher considers the main chains of value added generation on the example of oilseeds and focuses on the processes of in-depth processing of sunflower. Thus, the substantiation of measures to spread the European experience of gross value added generation using innovative technologies of in-depth processing can become an effective area for accumulating the added value of products sold, which will create conditions for the development of agriculture in Ukraine.

Scientific concepts of value chain development in agriculture, according to V. Rossokha and O. Nechyporenko (2024), aimed at optimising the management of natural, material and working resources, which will create favourable conditions for the adaptation of European standards of agricultural production and

increase the competitiveness of the agricultural sector of the Ukrainian economy. In the context of balanced development of agriculture in Ukraine, it is advisable to substantiate measures to reform the resource management system in the industry, which in the future will become the main source of product competitiveness growth and the economic basis for the development of this industry.

Y. Pletnyova and V. Marchenko (2018) emphasises that Ukraine has great opportunities for integration into global value chains of such a sector as the production of machinery for the agro-industrial complex, which is the key to the competitiveness of agriculture in the international context. The findings can be used to develop areas for creating an attractive external environment for agricultural development. Integration into the EU requires substantiation of priority areas for updating and improving equipment, technologies for the production and processing of agricultural products in accordance with European standards, which will become the basis for improving the efficiency of functioning and economic development of the agricultural sector of the Ukrainian economy.

According to O. Svitoyi (2022), the problem of agricultural development in the context of accelerated integration into the EU can be solved by creating clusters, which will contribute to the rational use of production potential for the production of products with high added value. The researcher proves that one of the areas of increasing the production with high value added is the introduction of modern and highly efficient machinery and equipment in agricultural production, which would allow producing and selling not raw materials, but finished products with a high degree of deep processing and processing. Such arguments are the basis for developing recommendations to strengthen state regulation in the generation of added value at the level of enterprises, industries, and to improve the performance of agricultural business.

According to Z. Kalinichenko (2023) and T. Adebayo *et al.* (2024), European approaches to the development of value chains are based on innovative ecosystems, which can become the basis for the development of highly developed sectoral and regional clusters. European regionalisation of value chains in industries supported by R&D, design, procurement, production, distribution, marketing, and service is not a new trend. Thus, there is a need to study existing European approaches to regional and global integration in order to adapt it in the Ukrainian agricultural sector of the economy. Ukraine has a chance to join the EU's integration processes as an industrial and technological centre. Involving Ukrainian enterprises in such chains will create a synergistic effect, allowing participants to join forces to achieve common goals and opportunities to increase added value, which is critical for Ukraine's agricultural development.

Approaches to processing agricultural products need to be updated and improved to meet European approaches to the generation of gross value added and the development of the agricultural sector. Integration into the EU requires effective management of agricultural development and ensuring the competitiveness of the agricultural sector. The purpose of the study was to substantiate the areas of increasing gross value added in Ukrainian agriculture, considering compliance with European standards and sustainable approaches for its development of the agricultural sector in the context of accelerated integration into the EU.

MATERIALS AND METHODS

The study was based on official documents and reports of the State Statistics Service of Ukraine (Gross Regional Product in 2019, 2021; State Statistics Service of Ukraine, 2021), and materials from the official website of the European Union (Eurostat, n.d.), the UN System of National Accounts (System of National Accounts, 2008; Project of the Recovery Plan of Ukraine, 2022), the Resolution of the European Parliament and the Council standards on the European system of national and regional accounts of the European Union (National accounts, 2006; Regulation (EU) No. 549/2013, 2013). The methodology for the generation of gross domestic product and gross value added in Ukraine is fully harmonised with the international standards of the European Union, which simplifies analytical research on their generation not only in the national economy, but also makes it possible to compare with similar indicators of other countries and identify reserves for their growth in agriculture in Ukraine.

The information basis was statistical data from the State Statistics Service of Ukraine (2021) and the Food and Agriculture Organisation of UN (n.d.) for 2015-2023 in terms of: production of real gross domestic product and gross value added; export of agricultural products and determination of its share both in the total exports of Ukraine and in world production; products of refinement and processing with a higher degree of readiness. In addition, in the process of forecasting the development of Ukrainian agriculture, given the significant impact of hostilities, not only the state of production potential was considered, but also the specifics of managing the demining of agricultural land, solving the problem of replenishing labour resources, restoring fixed assets, increasing working capital; growth of investment resources; development of innovation processes, etc.

The study of the situation with the development of agriculture based on the accumulation of gross value added in Ukraine and the EU was carried out using methods that identify the content of the object. The analytical method was used to investigate certain aspects of the agricultural development management system based on the increase in gross value added to study their characteristics, relationships, and impact on

the overall result. The features of gross value added generation in agriculture of Ukraine and the EU were analysed to determine the areas of development of Ukraine's agriculture after the war based on increasing gross value added in the context of accelerated integration into the EU. The statistical method was used to investigate data on the level of gross domestic product and gross value added in agriculture and analyse its share in the structure of the main sectors of the national economy. The functional method was used to study the role of each element of the management system for the production, processing, and export of agricultural products. Highlighting the importance of in-depth processing of agricultural products at the expense of introduction of new technologies and creation of favourable conditions for effective activity in agriculture, opportunities for growth of gross value added in the industry were identified and the areas of development of the industry were substantiated.

System analysis provided an opportunity to consider the development of agriculture as a complex system where all components are interrelated, and to determine the impact various factors (social, economic, political) affect the management of its development, based on which the results are achieved. The use of the deduction helped to explore the general principles and concepts of gross value added generation in Ukraine and European countries. The synthesis combined various elements, concepts, and aspects of creating a new holistic concept in the context of gross value added growth, which helped to substantiate the areas of agricultural development in Ukraine, which combined modern advanced approaches of European practice in the production of products with high degree of readiness. The comparative approach was used to compare approaches to the generation of gross value added in agriculture in Ukraine and the EU. It helped to understand the advantages and disadvantages of each approach to determine the best option for achieving strategic goals for the development of Ukrainian agriculture.

Based on the results obtained, specific recommendations were developed for the growth of gross value added in agriculture in the context of accelerated integration of Ukraine into the EU and solving problems that will contribute to the development of agriculture in Ukraine. In general, the study was aimed at determining the feasibility of applying European experience and best international practices in the field of in-depth processing of agricultural products, which will ensure the growth of gross value added and the successful development of the agricultural sector and the country as a whole.

RESULTS AND DISCUSSION

Development is an economic category that is based on natural changes in the economic system and in its transition from one state to a qualitatively new one using innovative techniques, technologies and management

methods in order to increase the volume of gross product and accumulate gross value added. Gross domestic product and gross value added are both macroeconomic indicators that fully characterise the level of development of the country's economy and, in particular, its industries, and microeconomic indicators that indicate the economic state of the enterprise. From a macroeconomic standpoint, gross domestic product reflects the total market value of created public goods for the year in all sectors of the state's economy that are intended for domestic consumption, export, and accumulation, regardless of organisational and legal forms of ownership of production resources. However, total value added additionally reflects the value created in the production process and is defined as the difference in the value of goods and services produced and fully used in the production (intermediate consumption) process according to the national classifier of Ukraine (2010). In relation to certain sectors of the Ukrainian economy, gross value added is calculated as the difference between gross output and intermediate consumption costs, and is determined in basic prices, considering subsidies for products and excluding taxes on them.

In other words, the components of gross value added are: remuneration of employees in the form of physical or monetary remuneration given by the employer for work performed, direct social payments and other taxes, except for production subsidies, gross profit including rents paid for the use of land, subsoil resources, patents to their owners by lessees, depreciation, and less taxes paid by enterprise owners for production activities regardless of sales or profitability of the enterprise (National accounts, 2006; Sustainable Development Strategy for Ukraine by 2030, 2017).

In terms of economic content, the concept of value added consists in managing resource costs throughout the entire product value chain, from the manufacturer to the end user. As for agriculture, the category of "gross value added" has its own characteristics, since natural resources (land, plants, natural and climatic conditions, etc.) are involved in the production process, and it is difficult to distinguish between human labour and the effects of natural processes. According to V. Zbarsky and M. Talavirya (2023) the combination of human labour and the influence of natural factors increases added value due to the increase in output, which determines agricultural activity as the most productive.

Dynamic relationships between different sectors of the economy are usually used to assess the impact of economic shocks. The generation of gross domestic product (GDP) is based on the concepts of supply and demand. The first approach to determining GDP assumes that total output is equal to total domestic demand, so GDP is the sum of public and private consumption, investment, and net exports. The second approach concerns the productive side of the economy, and states that GDP consists of gross value added (GVA) by sector, import duty,

and value added tax (Salimova *et al.*, 2020; Andreescu, 2021; Melembe *et al.*, 2021). To further study the priority of agricultural development in Ukraine, it is advisable to focus on the indicator of gross value added, since taxes and subsidies are usually very difficult to predict.

In agricultural production, value added is the part of the value that was increased not only in the process of production of agricultural products, grain, milk, meat of all kinds, honey, wool, etc., but also in the process of processing or refining to the stage of readiness, which the consumer is ready to buy and immediately consume. In other words, deepening the processing of agricultural products into finished food is currently an important component of agricultural production, which allows reducing the time for consumers to receive finished food and to add value for producers.

Agriculture plays a key role in the Ukrainian economy, providing 9% of GDP, 18% of business entities'

employment, and 6% of tax revenues (Batatin, 2022; Sansika *et al.*, 2023). The importance of the agricultural sector in the national economy is growing from year to year. Summarising the empirical material for 2015-2023 on the share of agriculture in the real gross domestic product, its slight fluctuations in the years of economic crises are noticeable, which indicates the relative stability of the agricultural sector to crisis phenomena (Fig. 1). Among the main sectors of the national economy, the contribution of agriculture to the total gross value added of the national economy averaged 10.7% in 2015-2022, second only to the processing industry by 0.3%, ahead of the mining industry by 5.7%, and electricity and gas supplies by 7.1%. During the Russian war in Ukraine, 2022-2023, there was a decrease in the share of gross domestic product and gross value added. However, the decline in agricultural production shows a lower rate compared to other industries.

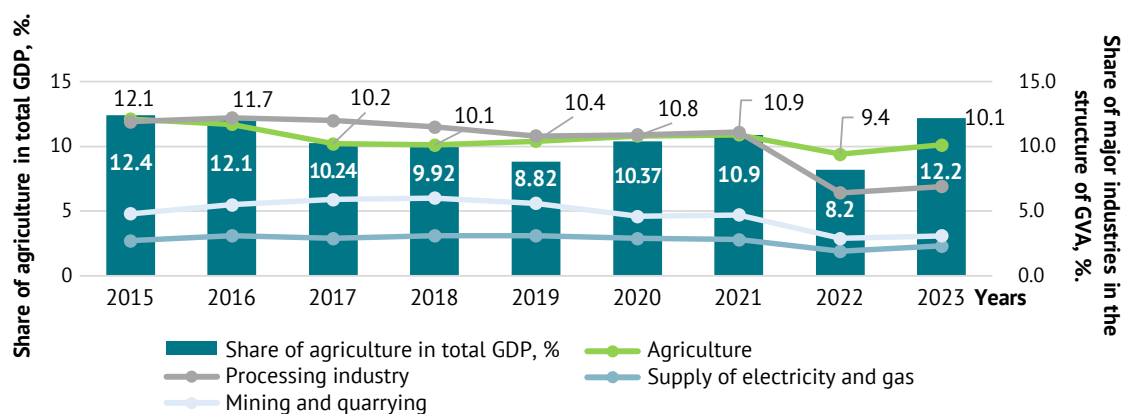


Figure 1. Share of agriculture in real gross domestic product and gross value added of Ukraine, 2015-2023

Source: calculated according to the State Statistics Service of Ukraine, n.d.; Gross Regional Product in 2019, 2021; State Statistics, 2021)

Ukrainian agriculture plays a key role not only for the economy of its state, but also contributes to global development by increasing the production and export of a significant amount of agricultural products as raw materials and finished food. However, the Ukrainian agricultural sector mainly supplies raw materials to the foreign market, which importing countries send for partial refinement, or for in-depth processing and receive goods with high added value. Such finished products are sent for sale to the foreign market, and from there they enter Ukrainian markets. Foreign companies that process and refine Ukrainian raw materials make profits ten times higher than Ukrainian producers who have grown agricultural products.

Back in 1581, the famous philosopher and economist John Giles noted that it is not economically profitable to sell raw materials for processing to other countries, and then buy the finished product from them. Four centuries have passed, and yet John Giles' scientific argument reflects the current situation of

Ukraine on the international market, which gradually limits Ukraine's potential and negatively affects the economy. Thus, domestic producers contribute to the development of other countries and improve the well-being of foreign citizens, not Ukrainian society (Batatin, 2022).

Since gross value added is the basis not only for accelerated and balanced economic development of agriculture, but also for the Ukrainian economy, it is reasonable to recognise that the time has come to change the components of the food production chain in agriculture, which was developed during the years of independence and continues now. Its emergence is associated with an imperfect strategy of the state, the influence of world players in the global market and with stable international trade ties.

Agriculture in Ukraine plays a key role not only in the national economy. Ukraine is one of the world's largest exporters of agricultural and food products. And as a result of the war, there are already real problems

in the global food market. In particular, in 2022, due to Russia's full-scale invasion of Ukraine, agricultural production decreased by 4.2% and accounted for 8.2% of the total gross domestic product. However, in 2023, Ukrainian agriculture managed to increase the volume of gross domestic product by more than 4%, and gross value added by 0.7%. The economic growth rate of agriculture is the highest among other sectors of the economy, which proves the high stability of agricultural production to external challenges, such as war, increased imports, migration of labour resources, etc.

The main reason for the decrease in production volumes was the occupation and mining of part of the land, which belonged to agricultural land and were the base of production. The area of mined fields reaches 8 million hectares, of which 6 million hectares are located in the temporarily occupied territories, 2 million hectares – in the liberated ones. This land is a food source for about 81 million people worldwide. Ukraine can overcome this challenge only by an extremely effective organisation and support of the international community. Experts estimate the losses of agriculture

as a result of a full-scale invasion on April 24, 2023 at USD 8.7 billion: USD 6 billion – losses of agricultural machinery, USD 2 billion – losses of products and resources as a result of theft or loss, USD 0.5 billion – damage to perennial crops, USD 0.3 billion – losses in animal husbandry and aquaculture. Millions of tonnes of Ukrainian grain are stuck in Black Sea ports, which has led to an imbalance in the global agricultural market (Interfax-Ukraine, 2023).

In 2015-2021, exports of Ukrainian goods to the world market grew every year, reaching USD 68.1 billion in 2021, with the share of agriculture at USD 27.7 billion (or 40.6%) (Fig. 2). In 2022, the volume of Ukrainian exports decreased by 23.92% and, in particular, agriculture by 12.8%. And in 2023, compared to 2022, exports from Ukraine decreased by 8.3% and agricultural products by only 0.3%. However, agricultural products accounted for the largest share of total Ukrainian exports, about 41%. In this case, agriculture is a strategic sector, the level of development of which determines the economic development of rural areas and the social well-being of 13 million people.

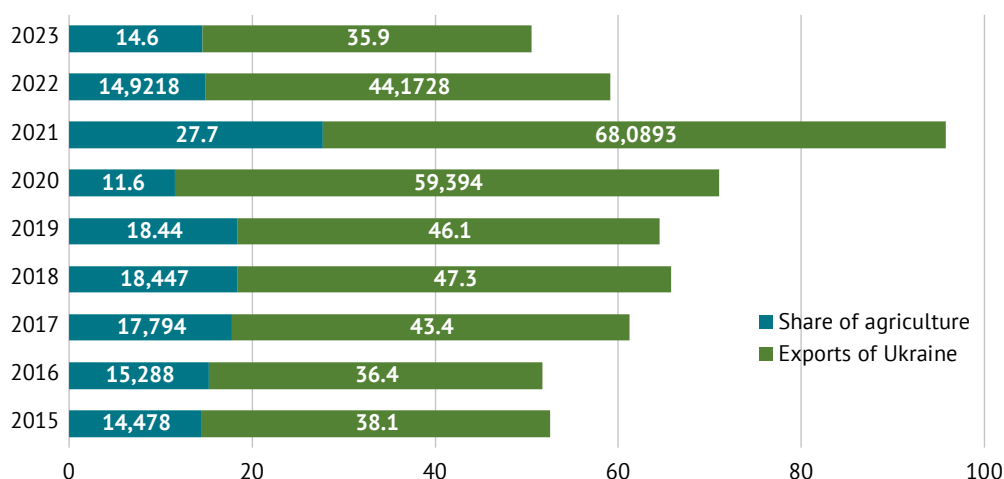


Figure 2. Share of agriculture in total exports of Ukraine, 2015-2023

Source: calculated according to the State Statistics Service of Ukraine, n.d.; Gross Regional Product in 2019, 2021; State Statistics, 2021)

Gross value added is generated in agricultural sectors unevenly. Therefore, it is advisable to analyse the trends in the development of sectors of the Ukrainian economy by the amount of gross value added created in 2015 and 2023. This would help to identify the industries that accumulate the largest GVA, and which should become a priority for recovery in the post-war period in the context of accelerated European integration. In recent years, Ukraine has become a leader in the export of low-margin products, while having successful cases in processing, in the field of crop production – sunflower oil, rapeseed, corn, soybeans, and in the field of animal husbandry – chicken, pork. In 2015-2023, sunflower was the fastest growing crop

in Ukraine and the highest exports to foreign markets (Fig. 3). The share of its exports in the global market reached more than 51.2%. Sales volumes of barley, wheat, corn, and soybeans are slightly lower, but significant in the world agricultural market.

The trend of selling low-margin types of products will continue in the future, since in the structure of crops 89 are low-margin crops, this leads to a decrease in profit compared to what can be obtained from the sale of crops with a higher margin. For comparison, developed countries mainly grow high-margin crops (80% in the structure of crop production in the Netherlands, Spain, and Italy). Ukraine is noted for its high productivity in the cultivation of grains and industrial crops,

but a significant portion of its grain crops is exported. For example, 79% of corn, 66% of wheat, and 59% of barley are intended for export. The situation with wheat is particularly noteworthy, with 35% of the harvest intended for non-food use exported as first-stage raw materials. Every year, the gross harvest of grain

and oilseeds increases, but existing granaries limit the ability to store increasing volumes of grain. It is important to note that it is high-margin crops that are more profitable, although they require a longer payback period (Regulation (EU) no 549/2013, 2013; Global value chains..., 2014; Gross Regional Product in 2019, 2021).

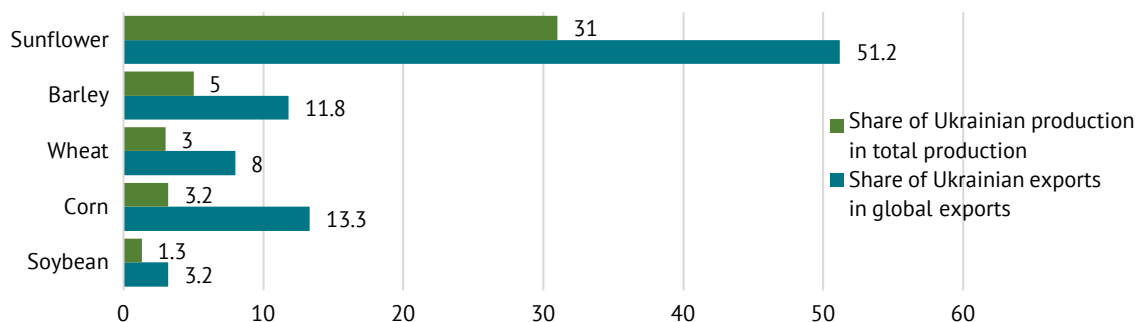


Figure 3. Ukraine's share in world production and export of agricultural products, 2015-2023, %

Source: calculated based on State Statistics (2021) and Global value chains... (2014)

In the structure of agriculture, the livestock sector occupied 21.1% in 2018, and in 2022 it decreased by 2.5% and amounted to 18.6%. In 2015-2023, there was a trend of decreasing the number of pigs, sheep, and cattle, including the dairy herd. The number of poultry increased by 6.7% in large industrial poultry farms and decreased by 0.4% in households. The main reasons for the decline in livestock in animal husbandry are its unprofitability. In 2018-2022, the profitability of cattle meat production was -24.2%. Pig meat was profitable at 2.6% and milk at 20.4%. In recent years, there has been a loss-making rate in poultry farming, in particular, poultry meat -0.2%, and eggs -19.2%. However, the increase in the number of poultry is substantiated by the increase in demand for poultry meat and eggs due to low prices and their dietary nature.

In terms of livestock products, in 2018-2023, the production and export of milk and dairy products, beef, and pork decreased, while only chicken increased. In particular, in Ukraine, the share of milk production in the total production of livestock products reaches 2%, while in the EU countries – 8-23% (Gross Regional Product in 2019, 2021). In 2021, milk production fell to a record low of 8.7 million tonnes, which is a historic low for Ukraine. This led to higher prices for dairy raw materials on the domestic market and led to the spread of falsification of dairy products, illegal imports, and problems with monopolies in trade. In addition, the lack of a legal alternative for the mandatory construction of local wastewater treatment plants for milk processing enterprises complicates the situation. The reason for these results is its poor quality. The main difference between the production of milk and dairy products, beef, and pork is the high capital intensity of products and a long payback period. Now animal husbandry is dominated by a low level of automation, manual human

labour, and a small number of premises and technologies for its further processing. As a result, low-quality and low-cost products are produced. In comparison of the production processes of raising cattle, pigs, and poultry, it is advisable to note that the production of poultry meat is less capital-intensive, labour-intensive and risky to infect poultry with diseases. The poultry industry is characterised by high export orientation and depth of chicken processing.

Over the past decades, Ukrainian agriculture has been characterised by the supply of crop and livestock products to the world market in the form of raw materials, while its processing industries occupy the lowest share in the sector. The highest share in the total supply is made up of unprocessed products intended for export, in particular, barley – 46%, corn – 84%, wheat – 54%. The share of products used for industrial processing is low: barley – 13%, corn – 3%, wheat – 19%. Milk processing volumes have tended to decrease over the past 5 years (by 17%) (Regulation (EU) No. 549/2013, 2013; Global value chains..., 2014; Statistical collection of Ukraine, 2021). In general, in 2018-2023, in the structure of agricultural exports, finished products ranged from 11% to 14%, primary processing – from 21% to 34%, and the largest part was raw materials, from 55% to 64% (Fig. 4).

As the dynamics of the structure of agricultural exports shows, in recent years, a large share was occupied by raw materials and only their primary processing. However, the number of trade agreements concluded has increased in the context of adapting quality growth processes to European standards. It is important to note that raw material prices are much lower than prices for finished processed products. Due to the fact that processing adds significant cost and allows achieving the highest quality standards, the Ukrainian processing sector has a significant potential for growth.

The transition to each subsequent stage of processing leads to an increase in value added. The shadow sector creates obstacles to the development of agriculture, with grain production and land lease being the main objects of shadow activity. Insufficient regulation

of the shadow sector of the economy primarily affects the processes of refinement and primary processing of agricultural products. The quality of exported products is mainly controlled by the customer, and the largest amount of them is sold through shadow sales channels.

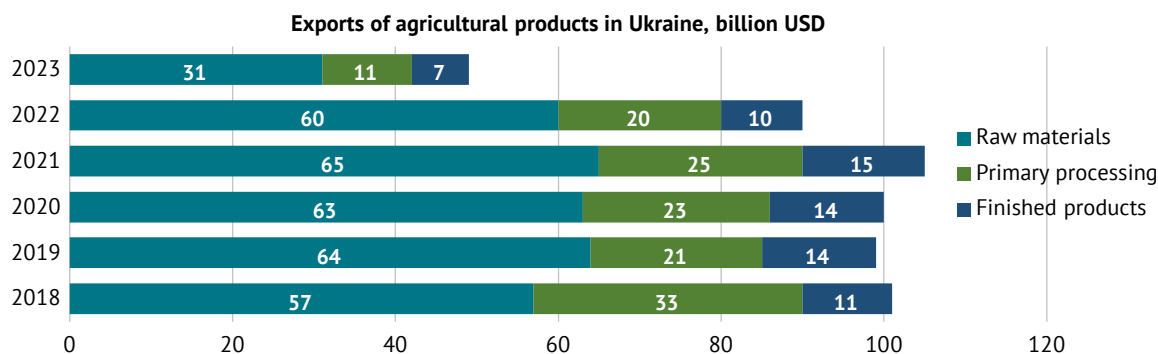


Figure 4. Dynamics of agricultural exports from Ukraine for 2015-2023, billion USD

Source: calculated based on data (State Statistics Service of Ukraine, n.d.; Gross Regional Product in 2019, 2021; State Statistics, 2021)

Thus, the agricultural productivity of Ukraine is significantly lower than that of highly developed competing countries. Value added per employee in Ukraine is significantly lower than in the leading countries in agricultural production (91% lower than in France and 67% lower than in Turkey due to the radically different distribution of crop and livestock production in the sector. In Ukrainian production, crop production accounts for 83%, and animal husbandry -17%. The structure in other countries is somewhat more balanced, the distribution is approximately 50/50%, for example, in the EU, where crop production is 57%, animal husbandry is 52% (Global value chains..., 2014; Regulation (EU) no 549/2013, 2013; Gross Regional Product in 2019, 2021).

The reason for this condition is low capacity and low degree of processing and refinement of agricultural products. Ukraine has already taken a leading position on the world market in the supply of raw agricultural products. The quality of raw materials is important for increasing the share of exports. The main reasons for the low quality of agricultural products are unsatisfactory: quality and non-compliance with scientifically based standards for the use of chemical fertilisers, the level of technological efficiency of agricultural production, transportation processes by outdated technical means, etc.

Now, monitoring the processing and refinement of agricultural products to the highest degree of their readiness will solve the problem of increasing gross value added. The lengthening of the chain of creating the gross value added of the final finished product in agriculture is the multiplier that not only leads to an

increase in prices on the product market, but is also the foundation for the economic development of Ukrainian agriculture. An example of the successful extension of the value added chain in Ukraine's agriculture is the growing share of processing sunflower seeds into finished oil, which allowed Ukraine to become a leader in sunflower oil exports on the world market in a short time. While for the oilseed crop of soybeans, there is a decrease in export volumes due to a decrease in the volume of its processing.

Ukraine is in the spotlight, and this historic opportunity can radically change the position of Ukrainian agriculture on the world market. Now it is important to focus on processing raw materials supplied by the Ukrainian agricultural sector. One agricultural crop, such as corn, can serve as the basis for the production of at least 15-20 types of products with high added value. The concept of creating a deep processing food sector of the economy is already being successfully implemented in world practice. Therefore, it is important to prepare the ground for the fastest recovery of Ukraine's agriculture after the war, which can be as difficult as the period of war. An important condition for the restoration of agriculture with deep processing is the access of farmers to advanced technologies.

Unfortunately, Ukraine's agriculture remains vulnerable in the production of products with a high level of gross value added. This situation is explained by the lack of necessary advanced technologies. Ukrainian agricultural producers who want to process grain into citric acid, fuel ethanol, glucose monohydrate, and other products are technologically limited and do not have

the ability to do so. In addition, there is no infrastructure for implementing such technologies. However, there is a need to create favourable conditions for investors not only to build their plants within international holdings for the agricultural sector of the economy on Ukrainian territory, but also to provide access to advanced technologies. This would allow developing and adapting such technologies to Ukrainian geographical and climatic conditions, which would facilitate the introduction of the latest technologies in agricultural production for its further development.

The paper by O. Ivanenko *et al.* (2021) identified that one of the main aspects of the financial policy of EU member states is budgetary allocations for economic, environmental, technical, technological, and social purposes. The costs of environmental protection are significant compared to the costs in Ukraine. This contributes to the development of innovative technologies for recycling waste and, in particular, the development of biotechnologies in agricultural production, the use of which ensures the efficiency of their use, the manifestation of which is an increase in the production of agricultural products per unit of resource consumption and an increase in profitability.

The problem of access to advanced technologies is important, and it should be understood that there are a limited number of technology development companies in the world that are willing to provide access to them. Therefore, such a “bottleneck” should be taken into account. This refers not only to the creation of factories, but also the development of complete multi-productive complexes for deep processing of agricultural products. Without the implementation of a programme of deep processing of agricultural products, Ukraine may remain in the shadows in European civilisation. Given the military situation in the country, it is important to understand that this slows down the development of agricultural production. Forecasts of Ukraine's GDP growth by 2050 by an average of 2-3% per year are limited. If this rate continues, more than 70 years will not be enough to reach the level of today's Poland, let alone reach the level of developed countries such as France or Germany.

The implementation of the programme of deep processing of agricultural products can help accelerate the restoration and development of agriculture in Ukraine. Ukrainian ambitions should reflect the desire to create a powerful agricultural production that can generate a significant amount of foreign exchange earnings and create hundreds of thousands of jobs, promote the activation of the introduction of new technologies, and create favourable conditions for business activities in agriculture, attracting both external and internal investors. This is the time to consolidate efforts and devel-

op comprehensive solutions for the stable growth of Ukrainian agriculture in the post-war period.

The big agro-processing programme is an important step in this area. Changing the strategy of agricultural production plays an important role in the development and stabilisation of Ukraine both in the military and post-war periods. Christian Ben Hell, head of Agriculture sector of the EU Delegation to Ukraine, stressed that the EU funding for this FAO project aims to restore or strengthen the functionality of agricultural value chains, which will help meet the food needs of the local population and internally displaced people in western Ukraine. This approach contributed to solving the problem of food security in the country in the near and short term and was crucial in preventing a food crisis in 2023 (Bulletin on the state of trade relations..., 2023).

Having an economy focused on raw materials, and not introducing effective tools for its transformation, the Ukrainian economy is becoming more and more dependent on imports every year. This increases the vulnerability of Ukrainian agriculture to the global market. To change this situation, it requires comprehensive projects and decisions at the state level aimed at fundamentally transforming the economy. Especially in the post-war period of agricultural restoration.

In July 2022, the National Council for the recovery of Ukraine from the consequences of the war presented a draft Recovery Plan, which presented a strategy for the development of the national economy until 2032, and outlined the priority of restoring economic activities for the transfer from a transition economy to a developing economy in the context of accelerated integration into the EU. Integration of Ukraine's agriculture into global chains of gross value added creation, which allows substantiating the priority areas for its recovery after military aggression based on value added. The strategic goal of agriculture in the context of globalisation should be to increase the competitiveness of Ukrainian products and ensure food security.

In the study by V. Bugaychuk *et al.* (2019) identified that one of the main aspects of the financial policy of EU member states is budget allocations for economic, environmental, technical, technological, and social purposes. The costs of environmental protection are significant compared to the costs in Ukraine. This contributes to the development of innovative technologies for recycling waste and, in particular, the development of biotechnologies in agricultural production, the use of which ensures the efficiency of their use, the manifestation of which is an increase in the production of agricultural products per unit of resource consumption and an increase in profitability. Based on the analysis (Table 1), the following areas and stages of development of Ukrainian agriculture are proposed.

Table 1. Areas of development of agriculture in Ukraine after the war based on increasing gross value added in the context of accelerated integration into the EU

Stages of post-war development of agriculture in Ukraine	Industries and subsectors of agriculture	Areas of development of agriculture in Ukraine after the war based on increasing gross value added in the context of accelerated integration into the EU
Sustainability – before December 2024	Crop production: grain production ■ feed production ■ vegetable production ■ potato growing ■ flax growing ■ hop growing Animal husbandry ■ cattle breeding (meat and dairy) ■ pig breeding ■ sheep breeding ■ poultry farming ■ beekeeping	■ Obtaining EU candidate status, followed by full membership; ■ establishment of logistics routes for the necessary resources for agricultural production and marketing of finished products with Western European countries; ■ compliance with quality standards of finished agricultural products; ■ overcome the influence of the shadow sector of the economy on the lease of land resources and the sale of agricultural products under corruption schemes; ■ monitoring of processing and refinement of agricultural products to the highest degree of their readiness.
Recovery – 2024-2025	Crop production: ■ grain production ■ feed production ■ vegetable production ■ potato growing ■ flax growing ■ hop growing Animal husbandry ■ cattle breeding (meat and dairy) ■ pig breeding ■ sheep breeding ■ poultry farming ■ beekeeping	■ Transition from exporting raw materials to processing should be focused on the industries where gross value added is most possible; ■ access of agricultural producers to innovative technologies of deep processing of products; ■ improving the quality standards of finished agricultural products; ■ development of multi-productive complexes for deep processing of agricultural products; ■ conditions for creating hundreds of thousands of jobs in the agricultural sector, using advanced technologies and promoting the development of business activities, which opens up wide opportunities for investors, both domestic and foreign.
Structural modernisation, integration into the EU – 2026-2032	Crop production: ■ grain production ■ feed production ■ vegetable production ■ potato growing ■ flax growing ■ hop growing Animal husbandry ■ cattle breeding (meat and dairy) ■ pig breeding ■ sheep breeding ■ poultry farming ■ beekeeping	■ obtaining the status of an EU candidate; ■ unlimited access to the markets of agricultural products of the European Union and the G7 countries; ■ development and application of advanced technologies for the production and processing of agricultural products; ■ an impetus for the transition from the export of raw materials to processing in the field of crop and animal husbandry, where the largest export revenues can be generated; ■ sale of agricultural products with a high degree of readiness; ■ building an agricultural economy based on the principles of deregulation and liberalisation.

Source: compiled by authors based on sources (Gross value added at basic prices, 2021; National classifier of Ukraine, 2010)

The processes of development of agriculture in Ukraine after the war based on increasing gross value added in the context of accelerated integration into the EU can be presented as a model of a cybernetic system, that is, a system with management, which

means that the information aspect of system analysis will be reliable and a priority, since the description and modelling of management processes involves the use of methods of statistical information theory and cybernetics (Fig. 5).

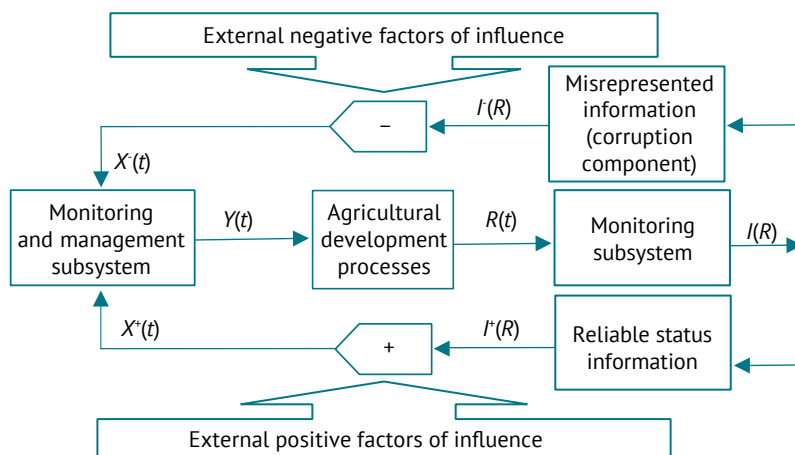


Figure 5. Cybernetic system model

Source: compiled by the authors

Thus, within the framework of statistical information theory, the source of messages X (information on the state of agricultural development by industry, namely production in the fields of crop production, animal husbandry, industrial refinement and processing of agricultural products, and external influences) is characterised by entropy $H(X)$, as a measure of uncertainty of the observer's information (control subsystem) regarding the state of observation objects (development processes based on the growth of gross value added). The entropy value can be written as the mathematical expectation of the amount of information $I(X)$ according to the well-known Shannon formula.

$$H(X) = \sum_{i=1}^n p(x_i) I(x_i) = - \sum_{i=1}^n p(x_i) \cdot \log_2 p(x_i), \quad (1)$$

where $X = (x_1, x_2, \dots, x_p, \dots, x_n)$ – source of statistically independent messages; $p(x_i)$ – probability of i -th message.

In a qualitative control system, a necessary condition is to reduce the entropy of the controlled subsystem to zero, which characterises a deterministic system, and vice versa, the maximum entropy N_{\max} corresponds to a system without control. Model of the post-war agricultural development system of Ukraine based on increasing gross value added in the context of accelerated integration into the EU with governance (Fig. 5) can be described by a set of states of the managed object (recovery processes of Ukraine)

$$R(t) = (r_1(t), r_2(t), \dots, r_i(t), \dots, r_n(t)) \quad i = \overline{1, n},$$

and multiple control influences

$$Y(t) = (y_1(t), y_2(t), \dots, y_i(t), \dots, y_m(t)) \quad i = \overline{1, m}.$$

It is possible to consider the lack of reliable information or its distortion in the real conditions of the

system's existence by introducing the conditional entropy $H(R/Y)$, which varies within the limits that show the degree of definition of the system with control:

$$0 \leq H(R/Y) \leq H(R)_{\max}. \quad (2)$$

The difference between maximum and conditional entropy determines the amount of mutual information $I(R, Y)$. This value can be taken as an indicator of the effectiveness of management in the system of agricultural development of Ukraine after the war based on increasing gross value added in the conditions of accelerated integration into the EU, which shows a decrease in the entropy of the managed subsystem by the amount of information received. Considering the properties of mutual information, it can be presented as:

$$I(R, Y) = H(R)_{\max} - H(R/Y) = H(Y) - H(Y/R). \quad (3)$$

After elementary transformations from (3), an expression that defines the limiting possibilities of control in the system is obtained:

$$H(R/Y) = H(R)_{\max} - H(Y) + H(Y/R). \quad (4)$$

Equation (4) allows drawing conclusions in the form of recommendations for improving the management efficiency of the agricultural development system of Ukraine after the war based on increasing gross value added in the context of accelerated integration into the EU, which should be considered as a decrease in the conditional entropy $H(R/Y)$:

support the process of agricultural development of Ukraine after the war based on increasing gross value added in the context of accelerated integration into the EU, as a managed subsystem, in the form of an "open system", that is, reduce the entropy of $H(R)$ by destroying the diversity (Wiener-Ashby cybernetics law) of possible states of the managed subsystem (unprofitable,

low-margin, and vulnerable agricultural production facilities) and increase the diversity of managing influences of stability and development of $H(Y)$, and actively influence the identification and reduction of destabilising external and internal (corruption) factors of influence $H(Y/R)$ on the system.

In general, among the branches of the national economy, agriculture of Ukraine before the military aggression of Russia, having a significant natural resource potential, demonstrated a slowing development not only within the state, but also with a focus on global trends. Therefore, considering the priority areas of development of agriculture in Ukraine after the war based on increasing gross value added in the conditions of accelerated integration into the EU, it is important to compare the pace of development with industries that

had faster growth rates above it, namely: processing, mining, supply of electricity, and gas industry, based on a conceptual approach in the form of a “cascade” model of economic dynamics of agricultural development processes, which is based on a nonlinear differential equation of logistics type:

$$\frac{dR(t)}{dt} = D \left[1 - \frac{R(t)}{R_{max}} \right] R(t), \quad (5)$$

where D – coefficient of dynamics of processes in the relevant sectors of the state economy, the value of which is determined by the result of the analysis of the ratio of gross value added for a certain period, considering the corrective realities of military aggression of the Russian Federation and the priority of restoring the relevant sectors of the national economy of Ukraine (Fig. 6).

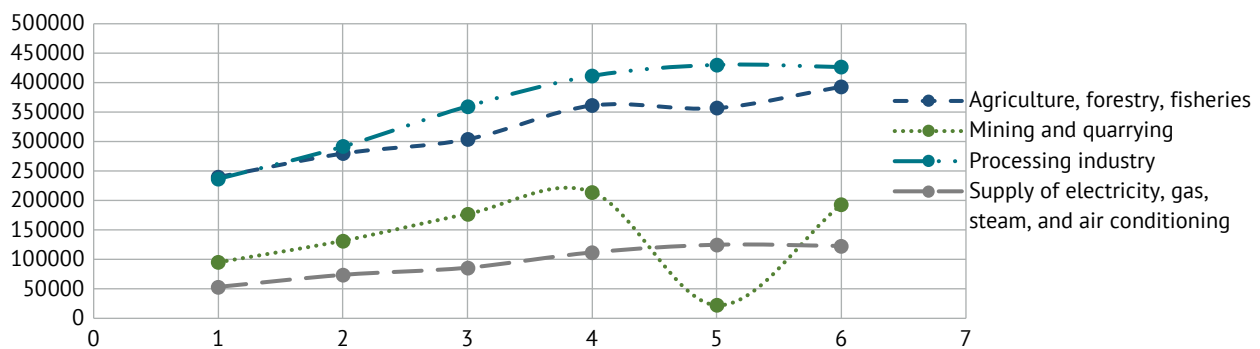


Figure 6. Forecast for the development of agriculture in Ukraine after the war based on the growth of gross value added in the context of accelerated EU integration

Source: calculated based on data (State Statistics Service of Ukraine, n.d.; Gross Regional Product in 2019, 2021; State Statistics, 2021)

According to Figure 6, based on the forecasts for the development of priority sectors of the national economy, the development of agriculture, which produces food and raw materials for the processing industry in order to solve food security problems not only in Ukraine, but also in the world as a whole, is envisaged first of all. It should be considered that the policy of the European Union is characterised by the inconsistency of sustainable development goals in the context of food security, in particular, in such areas as: migration policy, which increases inequality and problems of public access to food; limited internal resources of EU countries, in particular, the area of land for the development of organic production in order to ensure the quality and safety of food (Ireland, Denmark, Germany and Finland); the lack of effect of state funding for research and development of the agricultural sector in the event of excessive distribution of industry funds; excessive regulation of technology development to ensure production growth due to population bias towards potential risks. This means that the production approach to maintaining food security cannot be

effective due to the numerous contradictions between environmental and food safety issues. Therefore, it is advisable to transform the EU's food security policy in the context of sustainable development by developing goals for technological sustainability of the agricultural sector (Ivanenko *et al.*, 2021).

The essence of the conceptual approach is to develop a mechanism for the development of agriculture in Ukraine after the war based on increasing gross value added in the conditions of accelerated integration into the EU according to the priority scheme of effective “connection” of the relevant sectors of the Ukrainian economy at certain points in time, which, according to the belief, are determined by the maximum dynamics of recovery of priority objects of the socio-economic system (Fig. 7).

In Figure 7, the values $R_1(t)$ and $R_2(t)$ indicate the states of processes for restoring the corresponding sectors of the state's economy according to certain priorities. Figure 8 analyses the dynamics of the forecast of gross value added in agriculture after the war in the context of accelerated European integration.

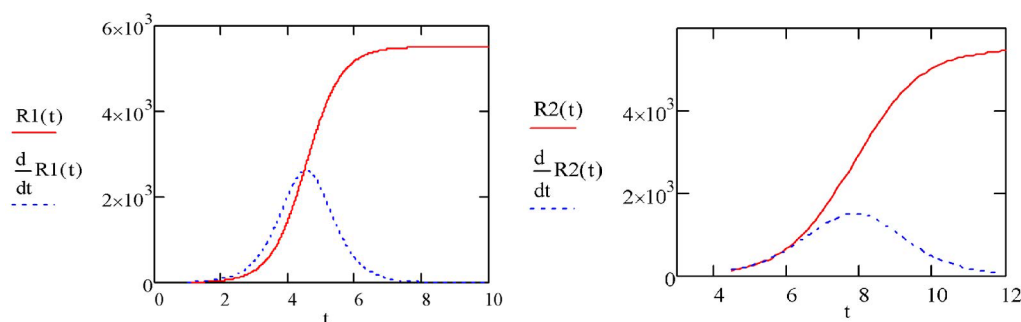


Figure 7. Illustration of "cascade" recovery at moments of maximum dynamics

Source: compiled by the authors

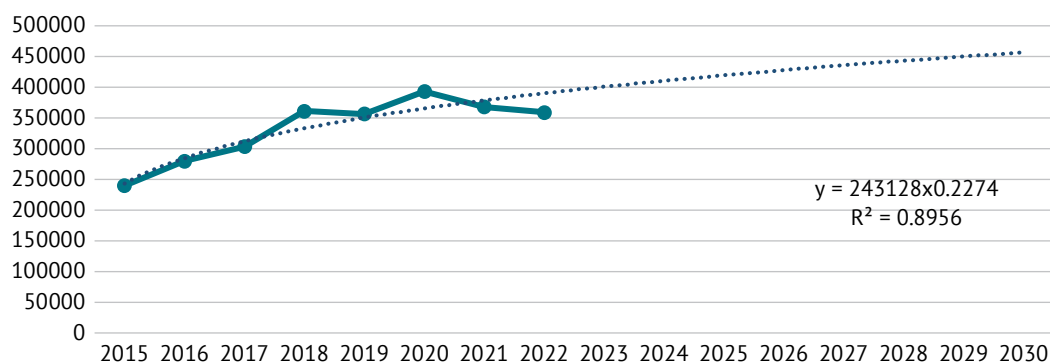


Figure 8. Forecast of gross value added of agriculture in Ukraine until 2030

Source: compiled by the authors

In the context of post-military restoration of agricultural production, the accumulation of gross value added becomes important, which is the basis for applying the achievements of scientific and technological progress to ensure the balanced development of all its branches and improve the social standards of living of the rural population. Therefore, for the agriculture of Ukraine, development means a transition from an economy with the potential of raw material exports to one that will export the finished product with the generation of gross value added. The priority of the development of agriculture in Ukraine will provide opportunities to solve the problems of food security in the world by increasing the export of agricultural products. Given this, Ukrainian agriculture can become the "engine" of the country's recovery after the war, which can affect the development of other sectors of the national economy due to the multiplicative effect.

CONCLUSIONS

The study found that the development of Ukrainian agriculture involves an increase in the volume of gross product and the accumulation of gross value added. However, in 2022-2023, there was a decrease in the share of gross domestic product and gross value added. However, the decline in agricultural production was less significant compared to other industries. In particular,

in 2022, during Russia's full-scale invasion of Ukraine, agricultural production decreased by 4.2%, which was 8.2% of the total gross domestic product. However, in 2023, Ukrainian agriculture managed to increase the volume of gross domestic product by more than 4%, and gross value added by 0.7%. The economic growth rate of agriculture was the highest among other sectors of the economy, which indicates the high stability of the agricultural sector to external challenges, such as war, increased imports, migration of labour resources, etc.

It was revealed that in 2015-2023, the share of agricultural exports in the national market was 40.6%. However, in 2022-2023, in the context of Russia's military aggression, the volume of Ukrainian exports decreased by 24% and the contribution of agriculture in it decreased by 12.8%. The share of total domestic exports of agricultural products is about 41%. However, over the past decades, the share of unprocessed products exported is more than 64%. It was proved that agriculture is a strategic branch of the national economy, the level of development of which depends on the socio-economic state of Ukraine and an important condition for its development is deep processing of products.

The areas of development of Ukrainian agriculture after the war based on increasing gross value added in the context of accelerated integration into the EU were developed in the following stages: sustainability –

in which Ukraine will receive the status of an EU candidate, followed by full membership. The next stage will be recovery, during which there will be a transition from the export of raw materials to its processing in those industries where the largest mass of gross value added is accumulated. And the third stage will be successful in developing and applying advanced technologies for the production and deep processing of agricultural products.

A forecast of the development of agriculture in Ukraine after the war based on the increase in gross value added in the context of accelerated integration

into the EU is proposed based on the model of a cybernetic system with control, and it is proved that among the priority sectors of the national economy, the development of agriculture, which produces food and raw materials for the processing industry, is the first priority, which is one of the areas of further scientific research.

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CONFLICT OF INTEREST

None.

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Зростання доданої вартості як чинник розвитку сільського господарства України в умовах пришвидшеної інтеграції до ЄС

Олег Скидан

Доктор економічних наук, професор
Поліський національний університет
10002, бульв. Старий, 7, м. Житомир, Україна
<https://orcid.org/0000-0003-4673-9620>

Віта Бугайчук

Кандидат економічних наук, доцент
Поліський національний університет
10002, бульв. Старий, 7, м. Житомир, Україна
<https://orcid.org/0000-0002-7282-1794>

Інна Грабчук

Кандидат економічних наук, доцент
Поліський національний університет
10002, бульв. Старий, 7, м. Житомир, Україна
<https://orcid.org/0000-0001-5548-6034>

Карина Сич

Аспірант
Поліський національний університет
10002, бульв. Старий, 7, м. Житомир, Україна
<https://orcid.org/0000-0002-0013-9315>

Сніжана Кубрак

Кандидат педагогічних наук, доцент
Поліський національний університет
10002, бульв. Старий, 7, м. Житомир, Україна
<https://orcid.org/0000-0003-4236-1528>

Анотація. Розвиток сільського господарства є ключовим чинником сталого поступу суспільства у майбутньому. Інтеграція країни до європейського співтовариства створює для сільського господарства нові можливості та водночас, вимагає інноваційних підходів до розвитку та досягнення конкурентоспроможності галузі у глобалізаційному просторі. Дослідження спрямоване на аналіз і вдосконалення наявних стратегічних підходів розвитку сільського господарства України на основі нарощування валової доданої вартості в умовах пришвидшеної інтеграції до ЄС. У дослідженні використовувалися різноманітні методи, такі як аналітичний, статистичний, функціональний, системний аналіз, дедукція, синтез і порівняння. Проведено аналіз формування і розподілу валового внутрішнього продукту та валової доданої вартості у сільському господарстві України та ЄС, включаючи особливості формування валової доданої вартості в українському сільському господарстві. Досліджено вплив процесів євроінтеграції на розвиток сільського господарства, зокрема їх потреби та можливості до нарощування валової доданої вартості. Розроблено модель кібернетичної системи з управлінням у сільському господарстві щодо зростання валової доданої вартості в умовах пришвидшеної інтеграції до ЄС, яка дозволяє обґрунтувати прогноз зміни формату розвитку українського сільського господарства з метою уникнення економіки, як сировинного придатку ЄС. Результати дослідження показали, що розвиток сільського господарства України на основі нарощування валової доданої вартості в умовах пришвидшеної інтеграції до ЄС передбачає використання комплексної стратегії, яка враховує специфіку галузі, європейські інноваційні підходи та передовий досвід поглибленої переробки продукції країн Європейського Союзу. Практичне значення дослідження полягає у розробці конкретних практичних рекомендацій і стратегій для органів державного управління, сільськогосподарських підприємств до оптимізації використання наявного природно-ресурсного потенціалу щодо зростання обсягів виробництва сільськогосподарської продукції, запроваджуючи прогресивні технології її глибокої переробки з метою акумуляції валової доданої вартості, що є основою розвитку сільського господарства

Ключові слова: валовий внутрішній продукт; валова додана вартість; військова агресія рф; розвиток; економіка; концептуальна модель

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Economic model of development of the feed crop-growing industry in the Republic of Kazakhstan

Kulshara Madenova

Doctoral Student

Saken Seifullin Kazakh Agrotechnical University
010000, 62 Zhenis Ave., Astana, Republic of Kazakhstan
<https://orcid.org/0009-0008-7027-1726>

Faya Shulenbayeva*

Doctor in Economics, Professor

Saken Seifullin Kazakh Agrotechnical University
010000, 62 Zhenis Ave., Astana, Republic of Kazakhstan
<https://orcid.org/0000-0003-4100-0157>

Maira Bauer

Doctor in Economics, Professor

Saken Seifullin Kazakh Agrotechnical University
010000, 62 Zhenis Ave., Astana, Republic of Kazakhstan
<https://orcid.org/0009-0000-3967-5089>

Assiya Agumbayeva

PhD in Economics, Associate Professor

Saken Seifullin Kazakh Agrotechnical University
010000, 62 Zhenis Ave., Astana, Republic of Kazakhstan
<https://orcid.org/0009-0006-3844-6819>

Balym Saginova

PhD in Economics, Senior Lecturer

Saken Seifullin Kazakh Agrotechnical University
010000, 62 Zhenis Ave., Astana, Republic of Kazakhstan
<https://orcid.org/0009-0003-2786-2751>

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Abstract. The livestock industry has experienced rapid growth, and the demand for livestock products is projected to continue increasing quickly due to population growth, improved living standards, and urbanisation. This article aims to assess the feasibility of utilising the created model for growing animal feed for meat-producing livestock during the standard planning phase of economic development. The authors categorise wheat as a reference culture. The study utilised analysis, statistical methods, economic

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*Corresponding author

modelling, and mathematical modelling. The authors assess the potential of utilising the created model to cultivate feed for livestock intended for meat production during the standard planning phase of economic development. The model predicts cost-effective feed. The authors' economic model enables the growth of the feed base, reduces the reliance on imported feed, and facilitates the expansion of meat breeds, which is the unique aspect of the study. The study emphasises the importance of strategically distributing, specialising, and concentrating beef cattle breeding in particular natural and economic contexts. It also highlights the significance of integrating large-scale production with medium and small agricultural enterprises in the meat industry. The study's practical significance lies in utilising specific structures and controlling the share of imports in feed production, along with restricting feed supply and ready-made food additives to guarantee food security

Keywords: forage crop cultivation; food supply; growth; food security; economic model

INTRODUCTION

Crop production constitutes 40% of the total agricultural output in the global economic management practice, with nearly one billion individuals employed in this sector worldwide (Mataeva *et al.*, 2018). Agriculture's crop growing sector is highly dynamic. An advanced agricultural sector will lay the foundation for establishing new food and light industries and ensuring the nation's food security (Bauer *et al.*, 2018; Soegoto *et al.*, 2022; Bhat *et al.*, 2022).

Natural pasture areas in the country allow for the production of organic products, which command a higher price and are sought after in global markets. This benefit is mainly a result of the minimal use of mineral fertilisers, pesticides, and herbicides on Kazakh territories (Robinson *et al.*, 2021). The current pasture land is only being utilised at 25-30% capacity, with available water resources to irrigate an extra 2 million hectares for stable feed production in crop rotation. Livestock development in Kazakhstan is significantly influenced by the availability of labour resources, as 45% of the population resides in rural regions.

Agriculture occupies a significantly important place in our modern society, exerting a profound influence on all of us (Misiuk & Zakhodym, 2023). It is an industry undergoing unprecedented changes. Farmers are increasingly assuming complex and vital roles in striking a balance between the need for increased productivity, environmental protection, and societal value (Shahini *et al.*, 2023). As agricultural challenges become increasingly extensive and intricate, it becomes even more crucial to work together to find the right equilibrium for achieving success – for farmers, for agriculture, and for future generations (Voronetska & Yurchuk, 2023). Moreover, agriculture plays a pivotal role in Kazakhstan's context as well. Farmers in Kazakhstan are navigating a landscape of considerable transformations and are essential in ensuring a harmonious coexistence between productivity enhancement, environmental conservation, and societal benefits. Addressing the expanding agricultural complexities in Kazakhstan calls for collective efforts and cooperation to achieve a sustainable and prosperous agricultural sector that caters to the well-being of future generations (Semenyutina & Svintsov, 2019).

To increase the production of competitive, export-oriented agricultural products and increase the country's food security, agro-industrial production requires the maximum use of the adaptive capabilities of innovative processes, technology modernisation, the harmonious use of the natural, industrial and scientific-technical potential of the territory (Chen *et al.*, 2020). In this regard, the assessment of potential resources in crop growing as factors for increasing the efficiency of the forage production industry is relevant (Moss & Havilah, 2022).

The research aims to determine the feasibility and benefits of implementing the developed model in feed crop-growing, considering cost-effective feed prediction and specialization in forage crop cultivation. The study's objectives are to collect data, evaluate trends, and examine the factors influencing the growth of the industry, assess government policies, identify challenges and opportunities of cattle breeding in Kazakhstan.

LITERATURE REVIEW

Kazakhstan is a significant crop producer, with wheat being its largest crop. It is the sixth largest wheat producer in the world, and wheat accounts for 80% of its grain production (Baitelenova *et al.*, 2021). In addition to wheat, Kazakhstan also produces barley, cotton, sunflower seeds, rice, sugar beets, flax, and minor crops such as potatoes, watermelons, and melons. The country has developed strategies to increase crop production, with a focus on boosting yields rather than expanding the area under cultivation (Yessenova *et al.*, 2023). The agricultural sector in Kazakhstan plays an essential role in the country's economic, social, and environmental development, with over a third of the population's livelihoods depending directly or indirectly on the extensive agricultural activities (Abuova *et al.*, 2020). The country's agricultural potential remains substantial, with significant untapped opportunities for further development.

The Sustainable Crop Production Program for Results (World Bank, 2021) is a comprehensive initiative aimed at fostering the advancement of environmentally sustainable and economically viable crop cultivation in the Republic of Kazakhstan. This program is specifically tailored to achieve several key objectives, including the

promotion of export diversification in the agricultural sector, the facilitation of small and medium enterprise expansion in rural regions, the enhancement of crop productivity through innovative agricultural practices, and the provision of improved agricultural advisory and support services to farmers (Ministry of Agriculture, 2022).

P. Romanovska *et al.* (2023) conducted a study on a statistical weather-driven crop model that accurately predicts wheat yields in Kazakhstan at the oblast level up to two months before the harvest. The model can accurately predict the total wheat production for Kazakhstan with R2 values ranging from 0.86 to 0.73. The forecast model can complement existing forecasting methods to help countries in Central Asia meet their food demand. The model demonstrates high accuracy in predicting wheat yields during the growing season up to two months prior to harvest (Bissenova *et al.*, 2023). The model benefits from low computational power and minimal input, relying solely on yield and weather data. In conjunction with this study, the work of P. Romanovska *et al.* (2023) emphasises the importance of collaboration and scientific rigour, as well as the importance of addressing food security and resource efficiency in agricultural development.

In their study, S. Suieubayeva *et al.* (2022) show that the agricultural industry in Kazakhstan is facing several problems, including corruption, issues related to subsidies, and a lack of a clear mechanism for tracking problems at a lower level. The population of Kazakhstan has experienced a shortage of vegetables and fruits, which are on the market at inflated prices. The article recommends building a model for assessing the state of problems to improve the level of development of the agro-industrial complex. The article concludes that the agricultural industry needs high-quality assistance from state executive bodies and subsidies to improve its scientific and technical equipment and post-harvest processes.

These research efforts, policy initiatives, and programs collectively form a crucial framework for advancing food security, reducing corruption, and promoting the long-term sustainability of Kazakhstan's agricultural industry.

METHODOLOGY

The study was conducted from 2020 to 2023 on the territory of different regions of the Republic of Kazakhstan (Akmola region, Kostanay region, North-Kazakhstan region, Northern Kazakhstan). The study followed a systematic approach to investigate the state of the cattle breeding industry in Kazakhstan and its relationship with government interventions. The research commenced with Stage 1, where the authors identified a significant challenge: a low proportion of breeding stock in the industry. Proceeding to Stage 2, comprehensive data were collected, encompassing breeding stock proportions, production figures, input costs, and market demand. A comparative analysis was carried out,

benchmarking these metrics against highly developed countries to provide context.

In Stage 3, the researchers constructed a mathematical model. Using differential equations and numerical modelling, the model captures the complex relationships between variables such as production, input costs and market demand, allowing scenario analysis to assess the potential impact of government policies. In addition, the model allows for the assessment of product quality according to international standards. Ultimately, by combining the results of mathematical modelling and product quality analysis, the model elucidates the intricacies of the impact of public policies on industry development and product quality, offering invaluable information for policy makers and stakeholders. Let $P_V(t)$ be the amount of sown feed crop in the process of growth in fields, measured in tons (Wu *et al.*, 2023). The change in this value will be calculated by the formula (1):

$$P_V(t) = P_V(t)kw - P_{Vr}(t) + 0.05P_{Vrmax}(t), \quad (1)$$

where kw is the coefficient of influence of weather conditions, which is in the range from 0 to 1 and shows how much of the harvest entrepreneurs can lose if weather conditions affect negatively. Ideal weather conditions: $kw = 0$. On average, a quarter of the potential harvest is possible due to adverse weather conditions during the year; $P_{Vr}(t)$ is the amount of harvest that was actually harvested in a given year; 0.05 – coefficient showing how much feed crops were planned for one day if this process was planned for 20 days (Tsuru, 2023); $P_{Vrmax}(t)$ is the available amount of feed culture that can be obtained if the given area is a certain number of seed.

It is equal to zero when there is no sowing, and in the days of sowing is determined according to the formula (2):

$$P_{Vrmax}(t) = \begin{cases} 0, & t \notin [244; 263] \\ P_{Vrmax}, & t \in [244; 263] \end{cases} \quad (2)$$

In this model, P_{Vrmax} will be considered a constant value and determined by the formula (3):

$$P_{Vrmax} = SDsz \, nz \, kk \, np, \quad (3)$$

where S – the area of fields planned for feed crop, hectare; Dsz – crop rotation necessary to obtain large harvests, because when processing the culture on the same field (plot), the soil is depleted, the risk of developing diseases and pests increases. Crops are placed on the fields so that each of them returns to its previous place no earlier than 3-4 years later (Li *et al.*, 2022). The time during which cultures pass each field in a certain sequence is called crop rotation; nz – the grain dissimilarity coefficient, that is, the average coefficient showing the loss of seed due to the loss of germination ability; kk – the tillering coefficient of grain; tillering is a process in which elevated lateral shoots are formed from the buds of a tillering node, that is, cereals, and similar

herbaceous plants; np – the sowing rate of the material, tons per hectare; the sowing rate is an important indicator that affects the harvest in the future, since the density of the standing of the plants determines how much they will receive nutrients, water, sunlight.

Simultaneously, in Stage 4, the Runge-Kutta method was employed to implement the mathematical model. This numerical technique allowed for the simulation of variable interactions over time, providing a more accurate representation of system dynamics. Stage 5 involved an analysis of agricultural product quality. Through systematic data review and comparative analysis with international standards, it was revealed that the agricultural products in Kazakhstan did not meet

the required global quality standards. In Stage 6, the findings from both the mathematical modelling and product quality analysis were integrated.

RESULTS

In agriculture, taking into account the natural, climatic, economic, social and environmental conditions, different regions of the country have developed various specialisation of production, which reflects the inter-regional division of labour (Nurgazy *et al.*, 2019). The region of Northern Kazakhstan, including the Akmola, North Kazakhstan, and Kostanay regions, has grain and livestock specialisation, crop production predominates in gross agricultural output (Table 1).

Table 4. Gross agricultural output of Kazakhstan and Northern Kazakhstan for 2020-2023, bln KZT

Region	2020	2021	2022	2023
Akmola	189.6	227.7	258.1	745.7
Kostanay	195.2	223.9	247.8	721.4
North-Kazakhstan	270.8	294.7	363.6	851.3
Republic of Kazakhstan	1815.1	2040.8	2256.3	7741.9

Source: compiled by the authors based on Bureau of National Statistics (2023)

As a result of a radical economic reform in agriculture in Northern Kazakhstan, a multi-layered economy was formed based on a variety of forms of ownership and management. The transition to the formation of marketable meat on the market in private farms led to a decrease in the productive

qualities of the herd, a low yield of meat in slaughter weight, and low-quality characteristics of meat (Baimukanov *et al.*, 2021). Analysis of the cattle stock in Kazakhstan and the Akmola region, presented in Table 2, shows a steady tendency to increase over the years.

Table 2. Cattle stock in Kazakhstan and Akmola region from 2019 to 2022, thousand heads

Indicators	2019	2020	2021	2022	2023	Increase in 2023 compared to 2019, %	Increase in 2023 compared to 2022, %
Total number of cattle, thousands of heads							
Total in Kazakhstan	6,279.2	6,496.4	6,515.6	6,813.9	8,538.05	35.99	25.31
including:							
agricultural organisations	307.5	385.3	394.6	552.3	806.6	162.2	46.0
peasant households	884.2	1,202.5	1,394.1	1,724.7	3,373.8	281.6	95.62
personal subsidiary plots	5,087.5	4,908.6	4,726.9	4,536.9	4,357.4	-14.37	-3.95
Akmola region							
Akmola region	401	400.1	421.8	484.9	458.4	14.3	-5.47
including:							
agricultural organisations	72.7	89.1	115.5	128.2	134.3	84.67	4.76
peasant households (farms)	46.9	46.0	70.3	135.1	92.3	96.76	-31.67
personal subsidiary plots	281.4	265.0	236.0	221.6	231.7	-17.64	4.56

Source: compiled by the authors based on Bureau of National Statistics (2023b)

The gradual increase in livestock requires an increase in the food supply for the meet stockbreeding industry. An effective way to solve this problem is to expand the sown area for growing feed crops on the fields of agricultural entrepreneurs. Requires the formation of a complex of high-quality varieties of feed adapted to local growing conditions. In order for agricultural entrepreneurs to be interested in growing feed crops in their fields, a pricing strategy for the sale of feed in the

market will be calculated, which takes into account the climatic conditions of the region and the state agrarian policy aimed at economic support for the development of meat stockbreeding through budget subsidising and financing mechanisms.

Thus, the crop rotation condition Dsz may be equal, for example, to the value presented in formula (4):

$$Dsz \in \{0.5; 0.33; 0.25\}. \quad (4)$$

Suppose that $Dsz = 0.5$, which means that in the first year, 50% of the available area will be sown with feed crops, and in the second year, the remaining 50%. Provided that the harvest begins on the 225th day of the year (approximately mid-August), the amount of harvest that was actually harvested in a given year is determined by the formula (5):

$$Pvr(t) = \begin{cases} 0, & t \neq 225, \\ P_v(t), & t = 225. \end{cases} \quad (5)$$

Denote $Ps(t)$ – the amount of feed that does not meet the International Grain and Feed Trade Association (GAFTA) standard (raw materials). Then the change equation $Ps(t)$ looks like this, as indicated in formula (6):

$$Ps(t) = -Ps(t) a_1 + Pvr(t) - Ps(t) u_2(t), \quad (6)$$

where a_1 is the share of raw materials that entrepreneurs want to bring to the GAFTA standard ($a_1 \in [0; 1]$). This value may be limited by the financial and production capabilities of enterprises; $u_2(t)$ is the share of raw materials that the state wants to bring to the GAFTA standard after purchasing raw materials from entrepreneurs ($u_2 \in [0; 1 - a_1]$) (Bavorova et al., 2019).

$Pp(t)$ – the amount of feed that meets the GAFTA standard (product), and can, accordingly, be implemented as a finished product, makes up a proposal on the feed crop market, the equation of change of $Pp(t)$ can be written as (7):

$$Pp(t) = Ps(t) a_1 - \min\{Qd(t); Pp(t)\} + Ps(t) u_2(t), \quad (7)$$

where $Qd(t)$ – the final consumer demand for feed crop at a given time; $Ps(t) a_1$ – the amount of feed that enterprises plan to bring to the GAFTA standard; $Ps(t) u_2(t)$ – the amount of feed that the state plans to bring to the GAFTA standard; $\min\{Qd(t); Pp(t)\}$ is the amount of feed that meets current demand at a given time and thus reduces supply (Yang et al., 2022).

Accordingly, the change in demand is written in the form (8):

$$Qd(t) = a - bP(t) - \min\{Qd(t); Pp(t)\}, \quad (8)$$

where $P(t)$ – the price of feed crop on the market at the current time; a – the amount of feed crops that consumer would be willing to buy at zero cost; b – the slope of the demand curve, showing how the demand for the product will change when the price changes (increases or decreases) by 1%; $a - bP(t)$ the increase in demand at a certain point in time depending on the price according to a linear law (Srinivas 2009).

The change in the price of feed that complies with the GAFTA standard is set taking into account its coefficient of elasticity Ep (Kunchambo et al., 2021). Thus, the change in the price of feed, taking into account the coefficient of elasticity, can be written by the formula (9):

$$\dot{P}(t) = -Ep(Pp(t) - Qd(t)). \quad (9)$$

Denote the money of entrepreneurs $Cp(t)$ (USD). Then the change of money of entrepreneurs $Cp(t)$ will be calculated by the formula (10):

$$\dot{Cp}(t) = -cpar(t) - Pvr(t)(1 + toll) - Ps(t) a_1 pb + r_1(t) \min\{Qd(t); Pp(t)\} P(t)(1 - tax) + Cd(t) u_1(t) + Ps(t) u_2(t) z, \quad (10)$$

where $cpar(t)$ is the cost of fertilisers, field processing, herbicides, etc. $Pvr(t)$ is the cost of seed that must be purchased by entrepreneurs from abroad to sow the current field area; $toll$ – state duty that must be paid for the import of seed in the country (tax for international trade); pb – the cost of processing raw materials for the product – bringing the feed to the GAFTA standard by drying and cleaning; tax – business income tax; $r_1(t)$ – the share of all sales owned by entrepreneurs at a given time; $u_1(t)$ – the share of state money used for direct investment by enterprises at a given time; $Cd(t)$ – state money; z – the price of government procurement of raw materials from private enterprises (McCain, 1995).

Assume that the cost of fertilisers, field tillage, herbicides $cpar(t)$ is zero when there is no crop in the fields during growth, as well as in winter. Define the cost of fertilisers and technical treatment according to the formula (11):

$$cpar(t) = \begin{cases} \frac{Pv(t)kpqn}{kpq}, & t \in [60; 151][245; 334], \\ 0, & t \notin [60; 151][245; 334] \end{cases}, \quad (11)$$

where kpq – the cost-effectiveness ratio for processing the fields, showing how much feed can be processed by a unit of money under conditions of applying a certain number of mineral fertilisers, herbicides, etc.; $kpqn$ – a depreciation coefficient showing the proportion of mineral fertilisers, herbicides, machinery for work that wears out daily, transferring its value to the potential amount of feed crop yield.

The seed purchase take place immediately before the feed crop sowing process (Cabrera-Capetillo et al., 2023). Then the cost of the required seed will be determined as the product of the area of the available fields, planting rates in tons per hectare, crop rotation conditions for feed crops and seed prices per ton. This condition can be written in the form of formula (12):

$$Pvr(t) = \begin{cases} SpzDsz, & t = 244, \\ 0, & t \neq 244 \end{cases}, \quad (12)$$

where pz is the price of seed per ton.

The share of all sales belonging to dependent entrepreneurs $r_1(t)$ is defined as the ratio of the share of feed crop brought by enterprises to the GAFTA standard to the amount of feed crop shares those enterprises and the state have brought to the GAFTA standard in total, as shown in formula (13):

$$r_1(t) = \frac{a_1}{a_1 + u_2(t)}. \quad (13)$$

Denote the state's money as $Cd(t)$. Then the change in the state's money $Cd(t)$ will be calculated by the formula (14):

$$\dot{C}d(t) = -Cd(t)u_1(t) - Ps(t)u_2(t)pb + Pvpr(t)toll + r_1(t)\min\{Qd(t); Pp(t)\}P(t)tax + r_2(t)\min\{Qd(t); Pp(t)\}P(t) - Ps(t)u_2(t)z, \quad (14)$$

where $r_2(t)$ – the share of all feed crop sales owned by the state. It is defined as the ratio of the share proved by the state to the GAFTA standard of feed culture to the sum of the shares of feed crop, as shown in formula (15):

$$r_2(t) = \frac{u_2(t)}{a_1 + u_2(t)}. \quad (15)$$

Considering the above, the limitation of the system is determined:

■ the sum of the shares of feed culture, which enterprises and the state in total bring to the GAFTA standard at a certain point in time, cannot exceed 1 in accordance with (16):

$$a_1 + u_2(t) \leq 1, \quad (16)$$

■ each of the particles of feed culture, which enterprises and the state bring to the GAFTA standard at a certain point in time, cannot be less than 0 in accordance with (17):

$$a_1 u_2(t) \geq 0, \quad (17)$$

■ the share of state money that it provides entrepreneurs with as subsidies for the development of production lies in the range from 0 to 1 in accordance with (18):

$$u_1(t) \in [0; 1], \quad (18)$$

■ time-dependent model parameters are integral in accordance with (19):

$$Pv(t), Pv_r(t), Pv_{rmax}(t), Ps(t), Pp(t), Qd(t), P(t), Cp(t), Cd(t), cpar(t), Pvpr(t), r_1(t), r_2(t) \geq 0, \quad (19)$$

■ at each moment of time, demand deviates from supply no more than by a given value, as indicated in formula (20), according to the theory of equilibrium of Walras:

$$(Qd(t) - Pp(t))^2 < e. \quad (20)$$

The authors will consider modelling the income of the state and entrepreneurs as target functions, which are written in the form (21):

$$I_1 = \int_0^T (Cd(t)) dt \rightarrow \max, \quad (21)$$

$$I_2 = \int_0^T (Cd(t)) dt \rightarrow \max. \quad (22)$$

To perform the calculations of the constructed economic-mathematical model, it is necessary to have a single objective function, therefore, having completed the convolution, the objective function in the form is obtained (23):

$$I = \int_0^T (Cd(t)) dt + Cp(t) dt \rightarrow \max. \quad (23)$$

Taking into account the initial conditions of differential equations, there is (24):

$$Cd(0) = Cd_0; Cp(0) = Cp_0; Pv(0) = Pv_0; Ps(0) = Ps_0; Pp(0) = Pp_0; Qd(0) = Qd_0; P(0) = P_0. \quad (24)$$

Combining all the above equalities, differential equations, restrictions and initial conditions, a model of the state's influence on the development of the feed crop growing industry is obtained (25-45):

$$P\dot{v}(t) = -Pv(t)kw - Pv_r(t) + 0.05Pv_{rmax}(t), \quad (25)$$

$$Pv_{rmax}(t) = \begin{cases} 0, & t \notin [244; 263] \\ Pv_{rmax}, & t \in [244, 263] \end{cases} \quad (26)$$

$$Pv_{rmax} = SD \text{ sz } nz \text{ kk } np, \quad (27)$$

$$Dsz \in \{0.5; 0.33; 0.25\}, \quad (28)$$

$$Pv_r(t) = \begin{cases} 0, & t \neq 225, \\ Pv(t), & t = 225 \end{cases} \quad (29)$$

$$Ps(t) = -Ps(t)a_1 + Pv_r(t) - Ps(t)u_2(t), \quad (30)$$

$$P\dot{p}(t) = Ps(t)a_1 - \min\{Qd(t); Pp(t)\} + Ps(t)u_2(t), \quad (31)$$

$$Q\dot{d}(t) = a - bP(t) - \min\{Qd(t); Pp(t)\}, \quad (32)$$

$$\dot{P}(t) = -Ep(Pp(t) - Qd(t)), \quad (33)$$

$$\dot{C}p(t) = -cpar(t) - Pv_r(t)(1 + toll) - Ps(t)a_1pb + r_1(t)\min\{Qd(t); Pp(t)\}P(t)(1 - tax) + Cd(t)u_1(t) + Ps(t)u_2(t)z, \quad (34)$$

$$cpar(t) = \begin{cases} \frac{Pv(t)kpqn}{kpq}, & t \in [60; 151][245; 334] \\ 0, & t \notin [60; 151][245; 334] \end{cases} \quad (35)$$

$$Pvpr(t) = \begin{cases} S \text{ pz } Dsz \text{ np}, & t = 244, \\ 0, & t \neq 244 \end{cases} \quad (36)$$

$$r_1(t) = \frac{a_1}{a_1 + u_2(t)}, \quad (37)$$

$$\dot{C}d(t) = -Cd(t)u_1(t) - Ps(t)u_2(t)pb + Pvpr(t)toll + r_1(t)\min\{Qd(t); Pp(t)\}P(t)tax + r_2(t)\min\{Qd(t); Pp(t)\}P(t) - Ps(t)u_2(t)z, \quad (38)$$

$$r_2(t) = \frac{u_2(t)}{a_1 + u_2(t)}, \quad (39)$$

$$a_1 + u_2(t) \leq 1, \quad (40)$$

$$a_1, u_2(t) \geq 0, \quad (41)$$

$$u_1(t) \in [0.1], \quad (42)$$

$$(Qd(t) - Pp(t))^2 < e, \quad (43)$$

$$Pv(t), Pvr(t), Pvrmax(t), Ps(t), Pp(t), Qd(t), P(t), Cp(t), Cd(t), \\ cpar(t), Pvrp(t), r_1(t), r_2(t) \geq 0, \quad (44)$$

$$Cd(0) = Cd_0; Cp(0) = Cp_0; Rv(0) = Pv_0; Ps(0) = Ps_0; \\ Pp(0) = Pp_0; Qd(0) = Qd_0; P(0) = P_0. \quad (45)$$

The constructed economic and mathematical model of the state's influence on the development of the feed crop growing industry is presented in the form of a system of differential equations with initial conditions, that is, the Cauchy problem. However, it also contains a system of constraints and an objective function in the form of an integral. That is why the solution to this problem should be carried out in 2 stages:

The first stage is the solution of the Cauchy problem in numerical form without taking into account the maximisation of the objective function, provided that the state exposure parameters are $u_1, u_2(t) = 0$.

The implementation of such a numerical solution is possible according to the 4-5 order Runge-Kutta method. To numerically solve a system of differential equations with initial conditions by the 4-5 order Runge-Kutta method, in the Matlab environment there are such built-in functions as ode23 and ode45, which differ in their accuracy of calculations. The ode23 function calculates the result up to 3 decimal places, and ode45 – a maximum of 6 decimal places.

The syntax for the ode45 function is as follows (46):

$$[t, X] = \text{ode45}(' <function_name>', t0, tf, x0, tol, trace), \quad (46)$$

where $<function_name>$ – a string variable, which is the name of the M-file in which the right-hand sides of the system of differential equations are calculated; $t0$ – the initial moment of time; tf – the final point in time; $x0$ – the vector of initial conditions; tol – calculation accuracy; $trace$ – a flag that regulates the output of intermediate results and is equal to zero by default.

The 4-5-order Runge-Kutta method is one of the most common methods for solving systems of differential equations with initial conditions. Below is his abridged algorithm. Suppose that on the interval $[a, b]$ it is necessary to find a numerical solution of differential equation (47):

$$y' = f(x, y), y(x_0) = y_0. \quad (47)$$

Divide the segment $[a, b]$ into n equal parts with the help of points (48):

$$x_i = x_0 + i h (i = 0..n), \quad (48)$$

where, (49)

$$h = \frac{b-a}{n}. \quad (49)$$

In the Runge-Kutta method, successive values y_i of the desired function are determined by the formula (50):

$$y(i+1) = y_i + \Delta y. \quad (50)$$

If to expand the function y in the form of a Taylor series, and also restrict to terms up to h^4 inclusive, then, respectively, the increase in the function Δy can be represented in the form (51):

$$\Delta y = y(x+h) - y(x) = hy'(x) = \\ + \frac{h^2}{2} y''(x) + \frac{h^3}{6} y'''(x) + \frac{h^4}{24} y^{IV}(x). \quad (51)$$

Instead of the direct calculations that appear in the formula (51), the Runge-Kutta method determines 4 numbers by the formula (52):

$$\begin{cases} k_1 = hf(x, y), \\ k_2 = hf\left(x + \frac{h}{2}, y + \frac{h_1}{2}\right) \\ k_3 = hf\left(x + \frac{h}{2}, y + \frac{h_3}{2}\right) \\ k_4 = hf(x+h, y+k_3) \end{cases} \quad (52)$$

If to give the numbers $k_1; k_2; k_3; k_4$ weights $\frac{1}{6}, \frac{1}{3}, \frac{1}{3}, \frac{1}{6}$, then the weighted average of these numbers, respectively, are accurate to the fourth power to Δy , which is determined by formula (52), as shown in formula (53):

$$\Delta y = \frac{1}{6}(k_1 + 2k_2 + 2k_3 + k_4). \quad (53)$$

Using formula (53), (54) is obtained:

$$\Delta y_i = \frac{1}{6}(k_1^{(i)} + 2k_2^{(i)} + 2k_3^{(i)} + k_4^{(i)}). \quad (54)$$

Also, for each pair of values and using formulas (52) values are determined (55):

$$\begin{cases} k_1^{(i)} = hf(x_i, y_i), \\ k_2^{(i)} = hf\left(x_i + \frac{h}{2}, y_i + \frac{k_1^{(i)}}{2}\right) \\ k_3^{(i)} = hf\left(x_i + \frac{h}{2}, y_i + \frac{k_2^{(i)}}{2}\right) \\ k_4^{(i)} = hf(x_i + h, y_i + k_3^{(i)}) \end{cases} \quad (55)$$

Finally, the following approximation will be calculated by the formula (56):

$$y(i+1) = y_i + \Delta y_i. \quad (56)$$

Having solved the Cauchy problem in numerical form using the Runge-Kutta method, the result of the model's behaviour is obtained without taking into account the maximisation of the objective function, provided that the state does not affect the model in any way. The second stage – to take into account the influence of the state with the help of two tools listed

in the model, namely: providing money to enterprises for the development of production and purchasing raw materials from enterprises for its further processing and sale. It is known that the state influence parameters $u_1(t), u_2(t) \in [0,1]$.

Divide the segment into 100 intervals with a step of 0.01. Thus, there are 101 limiting values for each state influence parameter. In this case, the maximum number

of combinations that need to be sorted out is 10,201. It is impractical to select a larger number of iterations due to the limited capabilities of a personal computer that calculates 1 iteration in about 11 seconds, and 10201 iteration – respectively with = 11 s × 10,201 iteration = 32 hours. To solve the modelling problem, it is first necessary to identify the initial conditions (Table 3) and set the values of the model parameters (Table 4).

Table 3. Model parameter values (data for 2023)

The name of the indicator	Denotion	Value
The area of fields planned for feed crop, million ha	S	16
Business income tax	tax	0.26
The cost of processing raw materials per product, KZT	pb	250,175
State duty for the import of seed in the country	$toll$	0.20
Seed price per ton, KZT	pz	2,343,500
State purchase price of raw materials from private enterprises, KZT	z	323,800
Weather coefficient	kw	0.000757
Crop rotation condition	Dsz	0.7
Feed dissimilarity coefficient	nz	1
Tillering ratio	kk	36.9
Material sowing rate, t/ha	np	0.30
The share of raw materials that entrepreneurs wish to process	a_1	0.027
Depreciation rate	kpq	0.027
Cost-effectiveness ratio for field processing	$kpqn$	0.0085
The amount of feed crops that consumer would be willing to buy at zero price, t	a	10,000,000
The slope of the demand curve	b	1,000
Price elasticity of demand	Ep	0.01

Source: compiled by the authors based on Bureau of National Statistics (2023a, 2023b)

Table 4. Initial conditions of the model (data for 2023)

The name of the initial condition	Denotion	Value
The initial amount of sown feed crop in the process of growth in the fields, million tons	$P_V(0)$	27.5
The initial amount of feed that does not meet the GAFTA standard (raw materials), million tons	$P_S(0)$	0.14
The initial amount of grain that meets the GAFTA standard (product), million tons	$P_P(0)$	0.19
The initial price of grain per 1 ton, KZT	$P(0)$	532,550
The initial amount of money of enterprises, tn KZT	$C_P(0)$	16.83
The initial amount of state money, tn KZT	$C_d(0)$	49.72
Initial consumer demand for feed crops, t	$Q_d(0)$	0

Source: compiled by the authors based on Bureau of National Statistics (2023a, 2023b)

It should be noted that the availability and quality of feeding resources directly impact the growth and size of the beef cattle population. Adequate and nutritious feed supports optimal growth rates, reproduction, and overall health, enabling a larger and more sustainable population of cattle.

DISCUSSION

The primary food crops cultivated in Kazakhstan are wheat (60.3%), barley (14.9%), and potatoes (16%), as reported by D. Wang *et al.* (2022). Water scarcity and soil alkalinity are the primary constraints on wheat yield, whereas soil alkalinity is the main limiting factor for barley. The current distribution of staple crops in Kazakhstan is not ideal, but the suggested distribution plan

of “Northern-Wheat, Southern-Barley, and Wheat, and Western-Potatoes” is expected to increase crop productivity significantly. The complementary findings of the author’s research can be supplemented by policy analysis and growth modelling, creating a more complete understanding of agricultural optimisation in Kazakhstan.

G. Lukhmanova *et al.* (2019) identify the primary paths of innovative development for ensuring the sustainability of farmers in the country and suggest recommendations for advancing innovation in the agricultural sector. The authors propose that the modernization policy for the agricultural sector should consider the industry’s operational specifics, epistemological origins, and developmental drivers. The integration of the approaches of G. Lukhmanova *et al.* (2019) and the authors

of this paper could create a robust strategy combining data-driven models with tailored policies for sustainable agricultural growth and innovation in Kazakhstan.

L.A. Tokhetova *et al.* (2020) highlighted the Republic of Kazakhstan's potential for cultivating eco-friendly agricultural production due to its vast agricultural land, numerous farms, and inclination towards producing environmentally sustainable goods. Since 2016, Kazakhstan experienced a decrease in organic agricultural areas by 114 thousand hectares, representing 0.1% of all farmland in the country in 2020. This reduction was linked to the coronavirus pandemic and the global economic crisis. With the authors' results these studies can provide a comprehensive understanding of sustainable agricultural practices, inform policy decisions, and address both environmental and economic aspects, leading to a holistic approach for the development of Kazakhstan's agriculture in a sustainable and economically viable manner.

A study by T. Atakulov *et al.* (2024) conducted in southern and southeastern Kazakhstan introduced innovative techniques to maximize agricultural output through double cropping systems and developing a "green conveyor" for animal feed. Researchers identified plant species suited for two annual harvests based on local climate conditions and established a system involving winter rapeseed and triticale as primary crops followed by corn as an intermediate crop for both grain and silage. This approach led to increased yields, with rapeseed producing 676 cnt./ha and triticale generating 648 cnt./ha during their respective growth phases. Additionally, corn provided extra grain and silage yields of 73.0 and 720 cnt./ha respectively. Compared to no intermediate crops, the inclusion of corn resulted in significantly higher overall feed unit yields ranging between 198.4 and 236.0 cnt./ha. The most profitable outcome occurred when sowing intermediate crops, resulting in net incomes of 143.8-160.8 thousand KZT/ha and profitability levels of 89.8-97.5%.

G. Samenova (2022) discusses the importance of modernizing and innovating agriculture in Kazakhstan, particularly focusing on corn production as a strategic yet understudied aspect. In 2021, corn cultivation covered approximately 301 thousand hectares in Kazakhstan, split between grain corn (63%) and silage corn (37%). The Almaty region accounted for half of the total grain corn produced in the country. Over 25 different corn seed origins were offered to Kazakhstani farmers who planted over 150 diverse corn hybrid varieties. However, 60% of these seeds were imported into the country. To improve the corn industry, Kazakhstan must address challenges related to the modernization of farm machinery and agricultural techniques. Additionally, the seed system needs enhancements at every stage of the corn production chain, including the adoption of innovative solutions (Drobotko & Kachanova, 2023).

The COVID-19 pandemic has worsened global food security, which was already compromised by climate change and armed conflicts (Babayev, 2023). This has led to a high demand for methods to improve cereal production efficiency. A study by V. Uteulin and S. Zhientaev (2022) was conducted to develop a methodological approach to enhance cereal production efficiency, which relied on time series to determine trends and make projections. The research was conducted in the Kostanay region, which experienced severe weather conditions in 2019, leading to a significant decrease in cereal production. The study anticipates substantial potential for increasing cereal production in the region and proposes an action plan to enhance efficiency. This plan includes optimizing state support, creating accessible crop insurance, boosting cereal yields, improving logistic infrastructure, and implementing thorough monitoring of cereal production. The study performed an econometric analysis of cereal production trends in the Kostanay region. It identified negative trends but highlighted that the region continues to be a significant producer of cereal crops and high-quality wheat.

The mathematical model developed by the authors is built on economic theories related to cattle population growth and feed crop production, using mathematical modelling and numerical simulations. Variables were chosen based on trends, policy assessments, and factors influencing the feed crop industry. This model aids decision-makers by providing scenario analyses and policy impact assessments. Its reliability stems from its rigorous mathematical basis and real-world data alignment, though complexities in modelling real-world dynamics could be a potential weakness. The model's strength lies in its comprehensive approach and practical solutions for industry sustainability.

CONCLUSIONS

The study showed that the growth and sustainability of beef cattle in Kazakhstan is inextricably linked to the availability and quality of forage resources. Sustainable development requires an integrated, evidence-based approach that includes optimising growing practices, fertiliser use, protecting domestic producers and implementing sustainable pasture management practices. The data reveal significant growth in the gross agricultural output across regions such as Akmola, Kostanay, and North-Kazakhstan, with the Republic of Kazakhstan's output reaching an impressive 7741.9 billion KZT in 2023, a substantial increase from 2256.3 billion KZT in 2022. Similarly, the cattle stock has shown notable growth, with the total number of cattle in Kazakhstan increasing to 8538.05 thousand heads in 2023, up from 6813.9 thousand heads in 2022.

Comparing the data for 2019 and 2023, as well as for 2022 and 2023, we see a marked increase in both agricultural output and cattle numbers, indicating the

positive impact of feed optimisation and government support policies. This upward trend emphasises the direct correlation between feed quality and cattle health and growth. The study recommends further optimisation of government support policies, including enterprise financing and strategic raw material procurement, to further increase forage crop production. In addition, adherence to international quality standards and the introduction of stratified crop specialisation are necessary to significantly increase beef cattle numbers in the next 5-10 years.

The prospects for further studies in the field of beef cattle population growth and sustainability in Kazakhstan

are highly promising. Ongoing research should prioritize the optimization of feeding resources, including sustainable crop cultivation techniques and nutritional analysis, to ensure a consistent supply of high-quality feed. Additionally, economic modelling and policy analysis should continue to guide evidence-based decisions, particularly in terms of government support policies.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Економічна модель розвитку галузі кормовиробництва в Республіці Казахстан

Кульшара Маденова

Докторант

Казахський агротехнічний університет імені Сакена Сейфулліна
010000, просп. Женіса, 62, м. Астана, Республіка Казахстан
<https://orcid.org/0009-0008-7027-1726>

Фая Шуленбаєва

Доктор економічних наук, професор

Казахський агротехнічний університет імені Сакена Сейфулліна
010000, просп. Женіса, 62, м. Астана, Республіка Казахстан
<https://orcid.org/0000-0003-4100-0157>

Майра Бауер

Доктор економічних наук, професор

Казахський агротехнічний університет імені Сакена Сейфулліна
010000, просп. Женіса, 62, м. Астана, Республіка Казахстан
<https://orcid.org/0009-0000-3967-5089>

Асія Агумбаєва

Кандидат економічних наук, доцент

Казахський агротехнічний університет імені Сакена Сейфулліна
010000, просп. Женіса, 62, м. Астана, Республіка Казахстан
<https://orcid.org/0009-0006-3844-6819>

Балим Сагінова

Кандидат економічних наук, старший викладач

Казахський агротехнічний університет імені Сакена Сейфулліна
010000, просп. Женіса, 62, м. Астана, Республіка Казахстан
<https://orcid.org/0009-0003-2786-2751>

Анотація. Галузь тваринництва переживає стрімке зростання, і, за прогнозами, попит на продукцію тваринництва продовжуватиме швидко збільшуватися завдяки зростанню чисельності населення, підвищенню рівня життя та урбанізації. Метою цієї статті є оцінка доцільності використання створеної моделі вирощування кормів для м'ясного скотарства на етапі стандартного планування економічного розвитку. Автори визначають пшеницю як референтну культуру. У дослідженні використано аналіз, статистичні методи, економіко-математичне моделювання та математичне моделювання. Автори оцінюють потенціал використання створеної моделі для вирощування кормів для худоби, призначених для виробництва м'яса, під час стандартної фази планування економічного розвитку. Модель прогнозує економічно ефективні корми. Розроблена авторами економічна модель уможливіє зростання кормової бази, зменшує залежність від імпортних кормів та сприяє розширенню м'ясних порід, що є унікальним аспектом дослідження. Дослідження підкреслює важливість стратегічного розподілу, спеціалізації та концентрації м'ясного скотарства в конкретних природних та економічних умовах. Воно також підкреслює важливість інтеграції великомасштабного виробництва з середніми та малими сільськогосподарськими підприємствами в м'ясній промисловості. Практичне значення дослідження полягає у використанні специфічних структур і контролі частки імпорту у виробництві кормів, а також обмеженні пропозиції кормів і готових харчових добавок для гарантування продовольчої безпеки

Ключові слова: вирощування кормових культур; постачання продовольства; зростання; продовольча безпека; економічна модель



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Diagnostics of financial stability of agricultural enterprises of dairy cattle breeding of the Republic of Kazakhstan: Study of foreign crisis-forecasting models

Aliya Akhmetova*

Master of Science, Senior Lecturer

S. Seifullin Kazakh Agro Technical Research University
010011, 62 Zhenis Ave., Astana, Republic of Kazakhstan
<https://orcid.org/0000-0002-2051-2033>

Gizat Abdykerova

PhD in Technical Sciences, Associate Professor

S. Seifullin Kazakh Agro Technical Research University
010011, 62 Zhenis Ave., Astana, Republic of Kazakhstan
<https://orcid.org/0000-0001-9797-7245>

Zina Shaukerova

PhD in Economics, Acting Associate Professor

S. Seifullin Kazakh Agro Technical Research University
010011, 62 Zhenis Ave., Astana, Republic of Kazakhstan
<https://orcid.org/0000-0003-2464-5834>

Ainur Bulasheva

PhD in Economics, Associate Professor

S. Seifullin Kazakh Agro Technical Research University
010011, 62 Zhenis Ave., Astana, Republic of Kazakhstan
<https://orcid.org/0000-0003-0929-5661>

Aigul Akhmetova

PhD in Economics, Associate Professor

S. Seifullin Kazakh Agro Technical Research University
010011, 62 Zhenis Ave., Astana, Republic of Kazakhstan
<https://orcid.org/0000-0003-2957-8239>

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Abstract. Dairy farming, as one of the components of agriculture in Kazakhstan, plays a crucial role for the effective development of the industry and the country, which makes its constant study relevant. Thus, the purpose of this study was to examine different models for predicting the performance of dairy farming enterprises and their financial stability. The methods that were applied within the study were analysis, forecasting, and abstraction. Within the framework of this study, the authors considered various

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*Corresponding author

models of ensuring financial stability for the enterprises of this sphere in the Republic of Kazakhstan. Furthermore, the state of the dairy industry in Kazakhstan was assessed, emphasising its significant potential to contribute to the agricultural sector. Some difficulties that arise within the framework of the development of this sphere in the country were described, such as dependence on imports of certain types of products and insufficient production of certain types of goods of the industry. Shortcomings also exist in terms of milk quality and its export, specifically to China. The study also proposed crisis prediction models. One of them was a model based on the logit regression approach, which included seven coefficients that helped to identify organisations experiencing financial difficulties, assess the boundary values of financial stability, rank organisations, and accurately predict the risk of financial crisis. It was shown that its use can allow for increased efficiency in the functioning of agriculture. The study brought new knowledge for the research of the agricultural sphere of the Republic of Kazakhstan. The findings provide a better understanding of the foreign features of forecast model construction and allow enterprises and government representatives to improve the construction of such models

Keywords: finance; macroeconomics; trade; investment; econometric analysis

INTRODUCTION

Agriculture as a whole serve not only as an industry for the production of raw materials and goods, but also as an important part of the life of the country. The level of agricultural production directly affects the food security of the country. Thus, identifying problems at an early stage can lead to prompt implementation of measures to prevent potential future bankruptcies. Given the reasons described above, it is relevant to revise the recommendations that enhance the management of financial security of agricultural enterprises, ensuring their sustainability and growth in an unstable environment. The deepening of this topic will make it possible to assess the financial condition of the subjects of agrarian-industrial complex and improve the accounting, analytical, and financial tools used in managing the development of agricultural enterprises. In modern conditions, many enterprises cannot assess their stability in the face of various crises that may arise (Gutsul *et al.*, 2023). This creates additional risks for companies that, in the event of certain situations that cannot be foreseen, they will not be able to resist difficulties or will suffer significant losses. Improving the methodology of crisis models will considerably reduce the risk of such an outcome. The importance of the study is also in identifying promising areas for improving the methods of measuring the financial stability of domestic agricultural enterprises based on foreign practices in diagnosing financial crises. This will help in forecasting and making informed management decisions to improve the financial health of agricultural organisations.

The general study of the current state of Kazakhstan's economy has been worked on by quite a considerable number of scientists. Thus, M. Sadyrova *et al.* (2021) investigated innovation processes in Kazakhstan. Researchers have noted that there is a clear trend within the country towards an increasing role for the latest technologies (both in terms of production and as part of a more global policy of the state in long-term development). Although scholars have

described certain steps that have already been taken and should be implemented in the country in the future in this area, but they are not enough to build a full-fledged policy. A. Figus and D. Shaikin (2019) investigated the features of socio-economic development of the country. Scholars have written that Kazakhstan is making considerable strides towards becoming a major global player by emphasising enlightened reforms and technological advance. They analysed government plans for the future development of the country but did not themselves propose any improvements or alternatives for them. Zh. Aigazin (2021) in turn assessed the economic trends in the state in the aftermath of the COVID-19 crisis, forming predictions on how the situation may evolve in the future. A.T. Aimen *et al.* (2022) studied the state of dairy products in Kazakhstan. They emphasised that certain problems do exist within the industry (lack of competition, lack of productive capacity, low involvement of scientific production), and proposed methods of solutions for them. Y. Akhmedyarov *et al.* (2023) noted the opportunities for the development of sustainable dairy production in the country. They considered the environmental and economic factors affecting the possibilities of sustainable development mechanism in the country. They also looked at technologies that states could use for these purposes, although they paid little attention to public policy issues.

Thus, the purpose of this study was to assess the current state of development of the dairy sector in Kazakhstan and to draw conclusions about what models can be used to forecast future trends in the industry. This will allow for a more precise definition of public policy in this sector.

MATERIALS AND METHODS

During the study, statistical data related to the assessment of the current state of agriculture and the dairy sector in Kazakhstan was also analysed. For this purpose, data on the distribution of agricultural enterprises

of Kazakhstan by financial results, distribution of agrarian formations by their number and volumes of milk production were used. The source of data for all three of these indicators was the Bureau of National Statistics of Agency for Strategic Planning and Reforms of the Republic of Kazakhstan (2023). All calculations and plots were performed in Microsoft Excel.

The main approach during the study was systematic. It allowed an assessment of the factors affecting Kazakhstan's dairy sector within a single system where they interact with each other. This made the generated evaluation model more accurate and qualitative. Several main scientific methods were utilised within the study. Based on data analysis, the specific features of formation of crisis-models of agricultural enterprises both in Kazakhstan and in other countries were evaluated. The historical method helped to draw conclusions about current trends in the development of the industry based on known information about how it has evolved in the past. Forecasting made it possible to assess future scenarios of its development, based on the same known past and present data. The comparison method was used to evaluate different methods of crisis modelling to assess their strong and weak characteristics. Furthermore, statistical methods of research were applied, specifically, statistical modelling to describe the models of crisis forecasts based on the data of the Republic of Kazakhstan. Data characterising the development of agriculture and, namely, the dairy sector, were subjected to statistical processing to form conclusions. The study employed the tabular method, which made it possible to present the information analysed during the study in a compact way. The same applies to the graphical method because the study used figures to show individual statistics within the research.

Nevertheless, this study, like any other, has certain limitations. Thus, only a few crisis-forecasting models were analysed within the framework of the study, which may partially distort the final conclusions. Furthermore, there has been no comparative analysis of both the state of the dairy industry between individual countries and the effectiveness of certain models under different economic conditions. The study also does not assess the environmental part of the impact of the activities of such enterprises in the country, which may be especially relevant given the spread of the concept of sustainable development in the world. The study is also based solely on the analysis of statistical information and the evaluation of theoretical data, but for more accurate results, a survey of stakeholders, such as the authorities or dairy producers, may also be effective. All this indicates the importance of conducting additional research in this area.

RESULTS

To begin with, it is worth assessing the development of the dairy industry in Kazakhstan as a whole. The dairy

industry has considerable potential for the development of the entire agricultural sector, contributing almost KZT 500 billion annually to the agricultural economy. Although there are around 800 dairy farms in the country, the average scale is small, with an average of 150 head per farm, while larger farms of more than 1000 head are rare. Despite the sector's potential for steady cash flow and the scarcity of the domestic market, entrepreneurs are discouraged by some of the complexities, including the need for considerable one-time investments, irrigation requirements, and difficulty in recruiting skilled staff. The need for a consistent long-term strategy is crucial as businesses are hesitant due to changes in government support rules, leading to a lack of confidence in creating long-term projects. This points to the need to create strong links between public authorities and enterprises to improve development opportunities for the industry.

Kazakhstan has a shortage of quality milk faced by dairy producers, resulting in dependence on imported milk powder. This shortage could lead to lower production turnover and potential company closures. The decline in milk supply over the past five years has outpaced producer growth, creating challenges for processors. Compensation of raw milk shortages with imported milk powder makes producers dependent on external prices, which affects their competitiveness (Raimbekov *et al.*, 2018). The region's Department of Agriculture emphasised the tightening of requirements for the quality of raw materials from 2025, stressing the importance of animal feed supply and condition. To address the shortage problem, it is worth increasing dairy production in the country by investing in dairy farming projects, which can also be influenced by the government through both direct injections of funds and by offering incentives for such enterprises by reducing their taxes or credit rates (Amirbekova *et al.*, 2022).

In general, one can identify several major issues in the dairy sector of Kazakhstan related to its production and imports. There are approximately 908 dairy enterprises in Kazakhstan, and they generally have problems meeting microbiological requirements for raw milk and problems with testing of milk quality parameters, which affects exports to China. Adjustments to the requirements for dairy products made from milk other than cow's milk are also proposed. Thus, it is relevant to review conformity assessments and consider cancelling some declaration schemes based on rules adopted in 2013 (Kazakhstan has a big..., 2023).

In State program for the development of the agro-industrial complex of the Republic of Kazakhstan for 2017-2021 (2017), SWOT analysis revealed that one of the weaknesses of the agricultural sector is low productivity and limited profitability of agricultural producers. Consequently, Kazakhstan has expressed significant concerns about the sustainability of agricultural production. Financial instability of agricultural business

is manifested in the main financial and economic indicators of the agricultural sector of the Republic of Kazakhstan. Thus, over the period from 2010 to 2021, the share of agricultural enterprises reporting negative financial results has been steadily fluctuating at the level of at least 21% of all enterprises in the agricultural sector, as presented on Figure 1.

As can be seen from Figure 1, the highest percentage of unprofitable results was observed among agricultural enterprises in 2013 – 48.3% and in 2015 – 39%. At the end of 2023, the share of unprofitable enterprises decreased to 21.8% (compared to 45% in 2010). Data on the location of agricultural units across the country are presented in Figure 2.

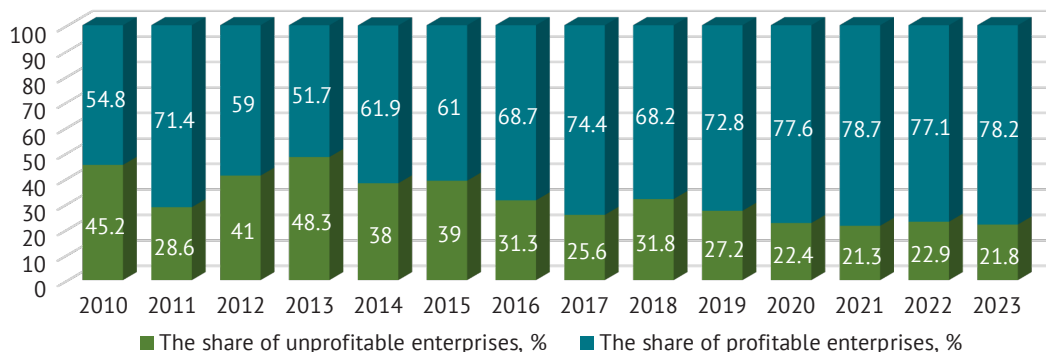


Figure 1. Distribution of agricultural enterprises in Kazakhstan by financial results for 2010-2023

Source: compiled by the authors of this study based on data from Bureau of National Statistics of Agency for Strategic Planning and Reforms of the Republic of Kazakhstan (2023)

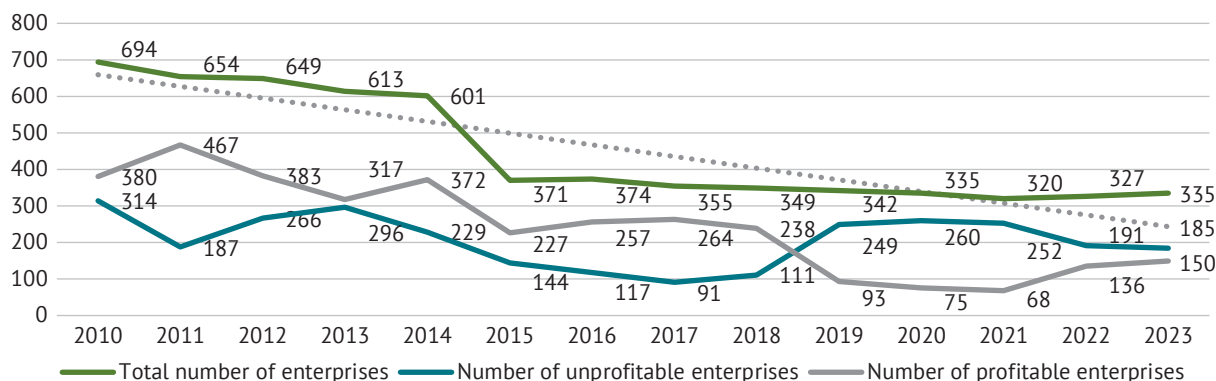


Figure 2. Distribution of agricultural formations in Kazakhstan by their number for 2010-2023

Source: compiled by the authors of this study based on data from Bureau of National Statistics of Agency for Strategic Planning and Reforms of the Republic of Kazakhstan (2023)

Much of the decline presented in Figure 1 can be explained by the data from Figure 2. Thus, there was almost 52% decrease in the number of agricultural enterprises between 2010 and 2023. Therewith, the most substantial reduction in the number of enterprises occurred against the background of general financial instability in the country in 2015: 38% of agricultural entities declared their insolvency. Consequently, in the face of intense competition and global market integration, the evolution of the agricultural sector highlights

the growing importance of strategic management for agricultural organisations. A critical objective of strategic management includes the development of practical methodologies that can identify, assess, and analyse the prevailing threats to the financial stability of agricultural enterprises (Vaintrub et al., 2021). Although statistics on dairy farming in Kazakhstan are rather limited, they can still be found in free sources. Thus, the volume of milk production of all types in the country is presented in Figure 3.

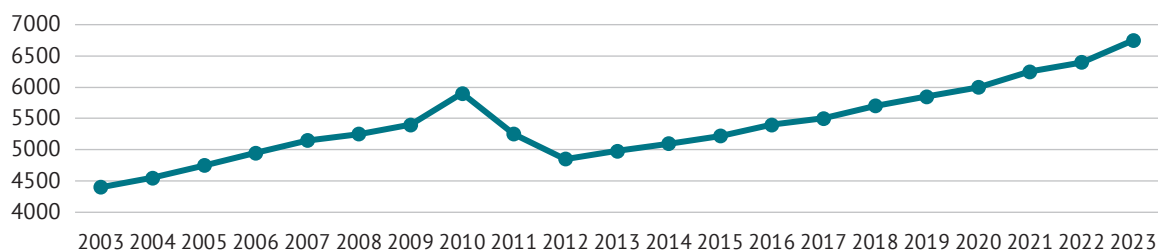


Figure 3. Milk production volumes in Kazakhstan in 2003-2023, thousand tonnes

Source: compiled by the authors of this study based on data from Bureau of National Statistics of Agency for Strategic Planning and Reforms of the Republic of Kazakhstan (2023)

As Figure 3 shows, the volume of production of these products in the country as a whole is increasing over the selected period, which indicates the development of this sphere in general. This is coupled with the information discussed above regarding the development of the dairy sector in Kazakhstan as a whole. Nevertheless, this does not cancel the difficulties that exist in terms of import substitution of certain types of milk, specifically, milk powder. This indicates the need for further increase in production in this sector and increased attention to it by public authorities.

Within the framework of this study, the ability to assess the financial health of agricultural enterprises played a significant role, for which many approaches,

methods, and techniques, indicative and computational measures were generally created. Nevertheless, the main focus in the development of the methodology of financial stability assessment is the creation of a factor model. They make it easier to identify signs of financial distress in agricultural organisations and allow the identification of the concrete category of financial strength that an organisation maintains. Such factor models should be built on certain indicators that describe the financial stability, economic potential, and recent performance of the enterprise. The resulting value of the functions should reflect the degree of financial stability within the organisation. Some of these are presented in Table 1.

Table 1. Comparative characteristics of crisis forecasting models

Sources of the crisis forecast model			
	$Z=0.717X_1+0.847X_2+3.107X_3+0.42X_4+0.995X_5$	$Z=1.03X_1+3.07X_2+0.66X_3+0.4X_4$	
X_1	The ratio of net working capital to total assets	The ratio of working capital to total assets	
X_2	The ratio of retained earnings and reserve capital to total assets	The ratio of profit before taxes and interest to total amount	
X_3	The ratio of profit before tax and interest to total assets	The ratio of profit before tax to the amount of short-term liabilities	
X_4	The ratio of equity to the value of total debt	The ratio of revenue (net) to total assets	
X_5	The ratio of revenue (net) to total assets	-	
	Z-score value	Threat of bankruptcy	
	less than 1.23	high	
	1.23–2.9	uncertainty	
	over 2.9	low	
Sources of the crisis forecast model			
	$Z=0.063X_1+0.092X_2+3.057X_3+0.001X_4$	$Z=0.53X_1+0.13X_2+0.18X_3+0.16X_4$	
X_1	The ratio of working capital to total assets	The ratio of profit from sales to the amount of short-term liabilities	
X_2	The ratio of profit from sales to total assets	The ratio of working capital to the amount of liabilities	
X_3	The ratio of retained earnings to total assets	The ratio of short-term liabilities to total assets	
X_4	The ratio of equity to debt	The ratio of revenue to total assets	
	Z-score value	Threat of bankruptcy	
	Less than 0.037	High	
	Over 0.037	Absent	
	Z-score value	Threat of bankruptcy	
	Less than 0.2	High	
	Over 0.3	Absent	

Source: compiled by the authors of this study based on E.I. Altman et al. (2017), G.L.V. Springate (1978), K.O. Appiah (2011), R.J. Taffler (1982)

At the initial stage of building the identification model, a set of indicators relating to both production and financial activities is established. To assess the characteristics of agricultural production in different sectors, this set should include indicators related to financial stability and economic efficiency. Moreover, these indicators need to be normalised for geographical differences, as agricultural organisations can vary substantially in size, production intensity, and resource availability. Therefore, the indicators selected for analysis should be relative. Hence, there is a need for a diagnostic model of financial stability that can consider not only the impact of numerous factors, but also the unique aspects of agricultural production. Furthermore, these models should be regularly updated using the latest statistical data and should be adapted to the evolving economic situation in the industry, the region, as well as to changes in financial regulations, accounting practices, and reporting standards. When building crisis prediction models, it is crucial to choose appropriate modelling tools, such as mathematical methods, to create an understanding of the subject under study, in this case the risk of financial crisis. The purpose is to make this simulation model as close to real data as possible. It is key that the model is interpretable in terms of its content and user-friendly in its application (Feil *et al.*, 2020).

Learning from the experience of developing multivariate crisis forecasting models, as observed by W. Zhu *et al.* (2022), along with understanding the financial features of agricultural enterprises in Kazakhstan, it is possible to calculate an integrated indicator to assess financial stability based on the previously established crisis forecasting model. Meanwhile, the indicators selected for analysis, reflecting the financial condition of organisations, provide insight into financial stability from various perspectives, including both the sustainability of financial conditions and development potential. Consequently, the crisis forecasting model includes the most significant indicators characterising the structure of the balance sheet of the enterprise and its economic activity. The crisis prediction model can be described as follows (1):

$$Z = 27 - 5X_1 + 15.96X_2 - 15X_3 - 1.16X_4 - 63.68X_5 - 0.39X_6 + 47.44X_7, \quad (1)$$

where Z – value of the crisis forecasting model; X_1 – current liquidity ratio; X_2 – financial leverage ratio; X_3 –

turnover ratio of current assets; X_4 – working capital ratio; X_5 – ratio of financial liabilities to assets; X_6 – return on equity; X_7 – turnover ratio of total assets.

This model suggests that if the tested function $F(Z)$ gives a value equal to or less than zero, there is no probability of financial crisis. Conversely, if the value of the function $F(Z)$ for the tested enterprise is equal to or greater than one, the probability of a financial crisis increases. The logit regression model is universal because it relies on annual cluster and discriminant analysis. This approach mitigates fluctuations in the production and financial performance of enterprises, including timing differences. Such adaptability is particularly important in agriculture, where natural and climatic conditions substantially affect the sustainability of agricultural enterprises (Läpple and Thorne, 2019).

The proposed logit model offers several advantages for agricultural producers in Kazakhstan. It consists of calculating seven coefficients that can be easily substituted into functional equations. Thanks to this approach, it becomes possible to identify agricultural organisations experiencing financial difficulties and assess the “boundary” values of financial sustainability ratios, indicating the transition from one level of financial sustainability to another. The model ranks agricultural organisations according to their proximity to the point of financial distress, providing an accurate prediction of the risk of financial distress. This emphasises its practical relevance in assessing and managing financial stability.

To assess the financial stability of an enterprise, it is recommended to attribute it to a certain class of risk by the nature of its financial and economic activities, considering both their quantitative and qualitative attributes. Similarly, four clusters of enterprises were identified according to the type of their financial stability, and the overall indicator was presented in the form of a range of values: thus, the groups with a low level of crisis risk have a value below -51, with an average risk – from -50 to -11, with a risk greater than average – from -10 to 0, with a high level of risk – above 0. The present study is based on the use of factor model to diagnose the presence of signs of financial crisis in agricultural organisations. Table 2 shows the grouping of enterprises by type of financial stability, as well as the average values for each group.

Table 2. Logit model value (Z) according to the type of financial sustainability of agricultural organisations

Year	Group of enterprises according to the level of crisis risk	Number of objects in a group	The average value of group indicators							
			Z	X_1	X_2	X_3	X_4	X_5	X_6	X_7
2022	Low risk level	3	-77.11	20.52	0.07	1.02	0.95	0.05	16.41	0.49
2023		3	-95.73	24.98	0.04	0.95	0.96	0.04	10.87	0.48
Absolute change (+, -)		0	-18.63	4.46	-0.03	-0.07	0.01	-0.01	-5.54	-0.01
Average for 2 years		x	-86.42	22.75	0.05	0.99	0.95	0.04	13.64	0.48

Table 2. Continued

Year	Group of enterprises according to the level of crisis risk	Number of objects in a group	The average value of group indicators							
			Z	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆	X ₇
2022	Moderate risk level	4	-16.12	5.75	0.41	1.14	0.81	0.28	13.47	0.42
2023		3	-14.68	6.61	0.27	1.07	0.85	0.21	10.51	0.44
	Absolute change (+, -)	-1	1.44	0.87	-0.14	-0.07	0.04	-0.06	-2.95	0.02
	Average for 2 years	x	-15.4	6.18	0.34	1.1	0.83	0.24	11.99	0.43
2022	Above average risk level	3	-3.41	4.18	0.26	1.39	0.75	0.2	10.94	0.53
2023		2	-3.58	3.5	0.83	1.18	0.81	0.36	8.43	0.36
	Absolute change (+, -)	+1	-0.17	-0.68	0.57	-0.21	0.06	0.16	-2.51	-0.17
	Average for 2 years	x	-3.5	3.84	0.54	1.29	0.78	0.28	9.69	0.45
2022	High risk level	1	2.79	1.53	0.82	1.62	0.34	0.45	6.13	0.55
2023		3	6.03	2.54	0.42	1.25	0.57	0.27	5.91	0.48
	Absolute change (+, -)	+2	3.24	1.01	-0.4	-0.37	0.23	-0.18	-0.22	-0.07
	Average for 2 years	x	4.41	2.04	0.62	1.44	0.45	0.36	6.02	0.52

Source: compiled by the authors of this study

According to the crisis prediction model for 2022-2023 (as presented in Table 2), 8 farms (representing 72.7%) do not face an immediate threat of financial crisis in 2022, as indicated by logit regression values below zero. Of these, six farms maintained a satisfactory level of financial sustainability, three farms exhibited a less than adequate level of sustainability, and two farms were approaching this critical state.

DISCUSSION

Based on the information analysed above, it is possible to offer certain recommendations related to the long-term development of the dairy sector. Thus, establishing strong and consistent links between government agencies and dairy enterprises to build trust and increase development opportunities is still important. It is also important to provide financial support to dairy farm projects, including direct injection of funds, tax reductions, and favourable loan rates. Small and medium-sized enterprises in the industry should also be given attention, and support programmes should be considered to help them overcome the obstacles they face when operating in the market. It is also important to disseminate among enterprises in the sector the new possibilities of building models for assessing the financial stability of companies, using factor models such as logit regression. It is important to update them frequently and adapt them to changing economic conditions, industry changes, and financial regulations. It is also important to develop a methodology for identifying, assessing and analysing threats to the financial stability of agricultural enterprises. It is also important to introduce crisis prediction models, using appropriate mathematical techniques to simulate real financial conditions. The application of these recommendations can considerably increase the efficiency of the industry in the long term.

C. Foroni *et al.* (2022) evaluated some methods to improve current forecasts of gross domestic product (GDP) growth during the COVID-19 crisis and

recovery period using mixed MIDAS and UMIDAS models with monthly indicators. These techniques include combining forecasts from different specifications or models, extending the model by moving average, using similarity approaches for estimation, and applying certain overlap corrections to bring the forecasts back on track. The researchers suggest that careful thought about the external indicators used to build the model is critical to improve the reliability of forecasts during significant economic shocks, after which additional indicators, econometric models and real-time data can be explored to improve forecasts. One can indeed agree with this, given that the choice of external factors influencing the model will considerably change the data it will produce and what decisions will be made based on it (Anarbayev *et al.*, 2023). It even determines the choice of the model as a whole. Thus, it is really worthwhile to devote more attention to the evaluation of the factors analysed within the models.

A comparable study was also conducted by L. Bargaglia *et al.* (2023). They discussed the challenges of economic forecasting during the COVID-19 pandemic, considering the uncertainty and the need for accurate data for policy makers. The results of the paper emphasised the importance of prompt provision of big data in predicting the rapidly changing economic landscape. Scholars have written that it is important to use multiple models and modify them as the reality of the world economy changes. This also suggests the role of progressively updating the relevance of data and information during research. This was also mentioned earlier in the present paper: while the application of individual models in the dairy sector in Kazakhstan can indeed help to increase the efficiency of the industry, it is important to continuously monitor the changes taking place in the context of the role of the influencing factors on the industry as well as their quantification.

C.L. Beber *et al.* (2021) investigated certain topical features of milk market development in the EU countries. Researchers described that milk production is

expected to shift from unification countries to developing nations. Conducting their study within Germany, the researchers described that to maintain or increase their global market share, German dairy companies would have to process milk outside the country. However, international competitiveness is under pressure due to growing domestic demand and high production costs, while the value of commodity exports is relatively low. Developing countries face serious environmental challenges and addressing them is critical to their access to modern supply chains and developed markets (Oleksandrenko & Levis, 2023). This may indicate that in the future one should expect production capacities to move to Kazakhstan as well, and thus a comparative increase in the country's role in the international dairy production arena.

H. Nozari *et al.* (2021) studied the possibilities of applying green marketing in the dairy industry. Researchers have described the role of using selected emerging technologies in this area, such as the Internet of Things, as well as evaluated its potential application in marketing activities. Furthermore, the scientists noted that the use of such technologies, among other things, will help to achieve considerably better performance in the field of dairy farming, including the reduction of harm from its side to the environment. In the present study methods of support for the dairy sector were also mentioned, but they consisted of somewhat different principles than those proposed by scientists (and primarily on the application of the latest forecasting models, strengthening trust between the state and enterprises). However, the development of technology can also have a positive impact on the industry, for which the state should also make efforts, specifically through financial support (Tulush *et al.*, 2023).

R.S. Mor *et al.* (2021) were concerned with modeling distribution efficiency in the dairy industry. Within the framework of the study, the researchers selected 22 elements of distribution practices for factor analysis for statistical analysis and model building. Hypothesis testing showed that all the factors analysed have a positive effect on distribution efficiency in the dairy industry. Thus, an effective information system improves coordination. Effective marketing of products in rural areas and flexible logistics systems are also considered essential factors in achieving marketing objectives (Moldabekova *et al.*, 2022). All these factors mentioned by the researchers in their study should also be considered by entrepreneurs in Kazakhstan when forming long-term development strategies.

G. Gebreyohanes *et al.* (2021) investigated dairy development trends in Ethiopia. Researchers have noted that this area has significant growth potential, but concerted efforts by both government and the private sector are needed to overcome the challenges. Although continuous efforts are being made to create value chains in the dairy sector, they are fragmented and have certain

challenges. Private sector investment also plays a massive role in development. The researchers, on the other hand, recommend building a sustainable resource system, strengthening regulatory institutions, establishing dairy clusters, expanding extension services, investing in breed improvement research, implementing breeding policies, adopting a value chain approach, stimulating the private sector, encouraging milk consumption, and strengthening the market. In general, the present study has also proposed recommendations related to the development of the dairy sector. They consisted mainly in the introduction of improved methodologies for analysing crisis-forecasting strategies in enterprises. Nevertheless, the recommendations proposed in the analysed source are also of sufficient quality to be used to support the industry.

Thus, analyses of the dairy industry in Kazakhstan show that the sector has significant potential to contribute to the agricultural economy, and although there are some difficulties, these can be resolved if certain components of government policy are applied. Furthermore, the companies themselves can also influence this if they properly build a long-term development strategy. Nevertheless, it is also important how the state and enterprises will interact and whether they will be able to reach an understanding. Only if the actions of both parties prove to be pro-industry should significant improvements be expected.

CONCLUSIONS

The findings of this study emphasise the importance of considering the indicators of financial stability along with the indicators of economic efficiency in diagnosing financial crises in agricultural enterprises. These include such indicators as animal productivity, calf yield per 100 head, milk yield per 1 cash unit, fixed assets maintenance costs, feed consumption, labour costs per 1 centner of milk per head, profitability of milk production. Moreover, the results of the correlation assessment revealed strong relationships between most of these indicators, indicating their interrelated and interdependent nature. Additionally, models were developed to establish the relationship between the risk of financial crisis and the key factor indicators to address this issue. Using a set of concrete indicators, this analysis not only identifies the factors leading to a decline in the financial sustainability of agricultural enterprises, but also provides a tool for forecasting and creating a science-based information base that can serve as a guide for managing the activities of agricultural enterprises.

Using logit regression models offers several advantages over discriminant models. They are more versatile, easy to apply, and can be used to identify agricultural enterprises facing financial crisis. Moreover, the results of these models can help determine "threshold" values of financial strength ratios. These models also

allow ranking agricultural enterprises according to their proximity to the brink of financial crisis, which proves their practical usefulness. Relevant for follow-up research is the assessment of crisis models for business sectors other than dairy in Kazakhstan and other countries. Furthermore, it is important to provide a broader list of public policy recommendations that could have a positive impact on agriculture in the country, as well as

the formation of more advice to businesses to conduct such activities in the country.

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CONFLICT OF INTEREST

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дослідження зарубіжних кризово-прогнозних моделей**

Алія Ахметова

Магістр, старший викладач

Казахський агротехнічний дослідницький університет імені С. Сейфулліна
010011, просп. Жениса, 62, м. Астана, Республіка Казахстан
<https://orcid.org/0000-0002-2051-2033>

Гізат Абдикерова

Кандидат технічних наук, доцент

Казахський агротехнічний дослідницький університет імені С. Сейфулліна
010011, просп. Жениса, 62, м. Астана, Республіка Казахстан
<https://orcid.org/0000-0001-9797-7245>

Зіна Шаукерова

Кандидат економічних наук, в.о. доцента

Казахський агротехнічний дослідницький університет імені С. Сейфулліна
010011, просп. Жениса, 62, м. Астана, Республіка Казахстан
<https://orcid.org/0000-0003-2464-5834>

Айнур Булашева

Кандидат економічних наук, доцент

Казахський агротехнічний дослідницький університет імені С. Сейфулліна
010011, просп. Жениса, 62, м. Астана, Республіка Казахстан
<https://orcid.org/0000-0003-0929-5661>

Айгуль Ахметова

Кандидат економічних наук, доцент

Казахський агротехнічний дослідницький університет імені С. Сейфулліна
010011, просп. Жениса, 62, м. Астана, Республіка Казахстан
<https://orcid.org/0000-0003-2957-8239>

Анотація. Молочне тваринництво, як одна зі складових сільського господарства в Казахстані, відіграє дуже важливу роль для ефективного розвитку галузі та країни, що робить актуальним її постійне вивчення. Таким чином, метою цього дослідження стало розглянути різні моделі для прогнозування діяльності підприємств молочного тваринництва, їхньої фінансової стабільності. Методами, що застосовувалися в рамках дослідження, були аналіз, прогнозування та абстрагування. У рамках даної роботи було розглянуто різні моделі забезпечення фінансової стабільності для підприємств даної сфери в Республіці Казахстан. Крім того, було оцінено стан молочної промисловості в Казахстані, підкреслюючи її значний потенціал для внеску в сільськогосподарський сектор. Було описано деякі труднощі, які виникають у рамках розвитку цієї сфери в країні, такі як залежність від імпорту окремих видів продукції та недостатність виробництва окремих видів товарів галузі. Недоліки існують і в розрізі якості молока та його експорту, зокрема – до Китаю. У рамках роботи було також запропоновано моделі прогнозування криз. Однією з них були модель, заснована на підході логіт-регресії, що містила сім коефіцієнтів, які дають змогу ідентифікувати організації, що відчувають фінансові труднощі, оцінювати граничні значення фінансової стійкості, ранжувати організації та точно прогнозувати ризик фінансової кризи. Було показано, що її використання може дозволити збільшити ефективність функціонування сільського господарства. Робота приносить нові знання для вивчення сільськогосподарської сфери Республіки Казахстан. Вона дає змогу краще зрозуміти зарубіжні особливості побудови прогнозних моделей і поліпшити їхню побудову з боку підприємств і державних представників

Ключові слова: фінанси; макроекономіка; торгівля; інвестиції; економетричний аналіз

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Тел. (0412) 22-04-17
E-mail: info@sciencehorizon.com.ua
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