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ЗМІСТ

Т. І. Фотіна, О. І. Шкромада, Г. А. Фотіна, А. В. Березовський, Д. С. Сластьон
Визначення токсичності експериментального дезінфікуючого засобу 9

В. Ю. Білий, С. В. Мерзлов, С. А. Наріжний, Ю. О. Машкін, Г. В. Мерзлова
Амінокислотний склад молочної сироватки та сиру під впливом різних сичужних ензимів 19

Є. Д. Ткач, А. А. Бунас, В. І. Стародуб, Т. В. Пилипчук, І. І. Гуменюк
Вплив хімічних речовин засобів захисту рослин на мікробіоценоз ґрунту 26

В. І. Красноштан, В. П. Карпенко, Р. М. Притуляк, І. Б. Леонтюк, А. А. Даценко
Ліпопероксидаційні процеси в сорго зерновому за дії гербіциду, регулятора росту рослин і біопрепарату 36

А. О. Дубицька, О. Й. Качмар, О. Л. Дубицький, О. В. Вавринович
Вплив екологізованих систем удобрення на елементи родючості та продуктивності пшениці озимої 44

Л. М. Семененко, О. В. Тарасов, С. П. Василенко, В. Л. Череп, В. К. Поліщук
Розвиток математичних моделей оцінювання безвідмовності техніки сільського господарства з урахуванням впливу зовнішніх воєнних факторів у прифронтовій території 55

Р. Ф. Садигов
Модернізаційні аспекти стратегічного управління в промислових компаніях 63

Х. Тутар, Н. Акбулаєв, Т. Сарханов
Огляд ризиків нетипової роботи в країнах ОЕСР у 1980–2020 рр. 74

Д. В. Санніков, В. І. Ковтун, М. С. Ковтун, Т. О. Терехова, К. О. Оганова
Використання сільськогосподарських земель в Україні: забезпечення та реалізація права на безпечне довкілля 86

ОГЛЯДОВА СТАТТЯ

А. М. Чаплоуцький, Р. М. Буцик, О. В. Полуніна
Особливості створення та догляду за плодовою стінкою в яблуневому саду: огляд літератури 93

CONTENTS

T. Fotina, O. Shkromada, H. Fotina, A. Berezovsky, D. Slasten
Determination of Toxicity of Experimental Disinfectant 9

V. Bilyi, S. Merzlov, S. Narizhnyy, Yu. Mashkin, G. Merzlova
Amino Acid Composition of Whey and Cottage Cheese Under Various Rennet Enzymes 19

Ye. Tkach, A. Bunas, V. Starodub, T. Pylypchuk, I. Gumeniuk
The Effect of Chemicals of Plant Protection Products on Soil Microbiocenoses 26

V. Krasnoshtan, V. Karpenko, R. Prytuliak, I. Leontiuk, A. Datsenko
Lipoperoxidation in Grain Sorghum under the Influence of Herbicides, Phytohormones, and Biopreparation 36

A. Dubytska, O. Kachmar, O. Dubytskyi, O. Vavrynovych
The Influence of Ecologised Fertiliser Systems on the Elements of Fertility and Productivity of Winter Wheat 44

L. Semenenko, O. Tarasov, S. Vasylenko, V. Cherep, V. Polishchuk
Mathematical Models for Assessing the Reliability of Agricultural Machinery, Taking into Account the Influence of Military Factors in the Front-line Territory 55

R. Sadigov
Modernization Aspects of Strategic Management in Industrial Companies 63

H. Tutar, N. Akbulaev, T. Sarkhanov
Review on the Risks of Atypical Work in OECD Countries in the 1980-2020 Periods 74

D. Sannikov, V. Kovtun, M. Kovtun, T. Terekhova, K. Ohanova
Agricultural Land Use in Ukraine: Ensuring and Implementing the Right to a Safe Environment 86

REVIEW ARTICLE

A. Chaploutskyi, R. Butsyk, O. Polunina
Features of Creating and Maintaining a Fruit Wall in Apple Orchard: Literature Review 93

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Determination of Toxicity of Experimental Disinfectant

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Abstract. Excessive use and abuse of disinfectants over the past century has created problems associated with the emergence of resistant microorganisms. In addition, there is always a potential risk to human and animal health, as the use of aggressive disinfectants can lead to diseases. The purpose of the study was to investigate the toxicity of an ex perimental disinfectant to determine the possibility of its use in the presence of humans and animals. Study material – an experimental product (water-soluble disinfection powder). Experimental studies were conducted at the premises of a certified vivarium of the ECOMEDCHIM regional centre of Sumy State University and Sumy National Agrarian University. Acute toxicity of the preparation was studied on 30 white mice weighing 19.5±1.0 and 15 white rats weighing 200±15.0 g. Determination of toxicity by prolonged oral administration was studied in two analogous groups of white rats, 6 animals each with a bodyweight of 185±10.0 g. The effect of the preparation on the state of internal organs was evaluated by comparing relative mass coefficients. The local irritating effect of the preparation was determined by skin applications on 10 rabbits weighing 2.97±0.3 kg. The disinfectant, when administered orally once at doses of 1,250, 2,500, and 5,000 mg/kg of body weight, did not cause the death of experimental mice and rats. When administered orally for 30 days at a dose of 2,500 mg/kg of body weight, the disinfectant did not cause any negative and toxic effects on the body of experimental rats, did not affect the growth and development of rats, and did not cause changes in the relative mass of internal organs. It was found that the average manifestation of erythema in rabbits is 2.46. According to the study results, it was found that the disinfectant can be classified as Hazard Class 4 according to the international standard GOST 12.1.007-76, or Category 5 according to the international global classification Global Harmonised System (GHS) (LD_{50} with oral administration exceeds 5,000 mg/kg of body weight). The results obtained give grounds to assert the possibility of using an experimental disinfectant in the presence of humans and animals

Keywords: disinfectant, acute toxicity, skin-resorptive effect, laboratory animals, erythema, oedema

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INTRODUCTION

The spread of the SARS-CoV-2 coronavirus, which causes the COVID-19 disease, has led to a sharp increase in the use of disinfectants to ensure indoor safety [1]. In animal husbandry, there is a problem with the occurrence of infectious diseases, but their outbreaks can be prevented with proper sanitary control measures. Infectious diseases of livestock are widespread all over the world. Thus, the global outbreak of African swine fever in 2018 was extremely dangerous, as 6.8 million pigs were killed. The negative impact on the environment caused by an increase in the number of livestock in a limited area is the most important environmental problem [2]. Therefore, farms need to be protected from pathogens of infectious diseases of animals to prevent the death of livestock. Due to the economic crisis, the development of disease prevention tools using financially affordable and universal disinfectants is promising [3].

However, not all disinfectants are safe to use in the presence of humans. Animal husbandry is associated with exposure to organic dust containing allergens and micro-organisms, endotoxins, and other factors such as irritating gases, ammonia, and disinfectants. These exposures have been identified as specific agents that may cause the risk of developing asthma, rhinitis, and chronic bronchitis. Therefore, there is an urgent need to focus on the impact of farming to protect farmers and others working in these and related industries from the development of respiratory diseases and allergies [4]. For example, quaternary ammonium compounds (QAC) are recommended by the U.S. Centers for Disease Control and Prevention (CDC) and the Environmental Protection Agency (EPA) for disinfection procedures specifically targeting SARS-CoV-2. However, exposure to QAC has been associated with a number of negative health effects [5]. Hospital waste and wastewater, especially without proper treatment, will put the population at risk of infection. In particular, in the context of the 2019 coronavirus disease pandemic (COVID-19) in China, it is very important to reduce risks to public health and the environment [6].

One of the components of the experimental disinfectant is thymol (2-isopropyl-5-methylphenol) – $C_{10}H_{14}O$, monoterpene phenol derived from thyme essential oil *Thymus vulgaris*. To determine the antibacterial activity against individual gram-positive substances (*Staphylococcus aureus* and *Bacillus cereus*) and gram-negative bacteria (*Salmonella Infantis, Escherichia coli* the researchers used thymol and carvacrol essential oils, which showed strong antioxidant and antibacterial potential [7]. Essential oil of Thymus vulgare caused the destruction of 90% of the biofilm in the 72-hour culture of *Chromobacterium violaceum* and *P. fluorescens* [8]. In addition, another component of the product, chloramine (sodium tosyl chloramide), contains 25% active chlorine. Studies in dentistry have shown that chloramine has antifungal and antibacterial properties, probably affecting both the cell wall and membrane permeability, and has shown low toxicity in vitro [9].

Cuprum sulphate salts have significant antibacterial activity against nosocomial pathogens with multiple preparation resistance. However, isolates of gram-negative bacteria that are not sensitive to cuprum sulphate have been isolated in a public hospital and health department in Helm, Algeria [10]. To solve this problem, the experimental preparation was created in such a way that its components complement and enhance the antimicrobial effect.

Research by scientists proves that divalent iron negatively affects resistance of *L. pneumophila* in biofilms [11]. It is determined that the surfaces of residential and livestock premises are often contaminated with micromycetes of the genus *Aspergillus* [12].

Calcium sulphate dihydrate is used as a sorbent to reduce moisture during disinfection in rooms with high relative humidity. Calcium sulphate dihydrate is also a high-quality carrier for antimicrobial substances [13]. Zeolite, as a component of a multicomponent experimental disinfectant, has significant chemical, mechanical and thermal stability [14; 15].

Due to the COVID-19 pandemic, a large number of disinfectants are used in Ukraine, but one of the main issues remains the effectiveness and safety of disinfectants used in the presence of people and animals.

The purpose of the study is to determine the degree of toxicity of the experimental disinfectant and establish the possibility of its use in the presence of humans and animals.

Research objectives include: determination of acute toxicity of an experimental disinfectant with oral administration; investigation of the toxicity of an experimental disinfectant with prolonged oral administration; investigation of the skin-resorptive and local-irritating effects of an experimental disinfectant.

MATERIALS AND METHODS

Toxicity studies were conducted on laboratory animals to determine the safety of the experimental disinfectant. The experiments included two types of studies: determination of acute toxicity with oral administration and with prolonged oral administration. Then the information received was processed and analysed.

Study materials – water-soluble disinfection powder containing the following substances (%): chloramine – 0.2; thymol – 0.1; copper sulphate – 2.0; iron sulphate – 1.0; calcium sulphate dihydrate – 45.0; kaolin – 9, zeolite – 42.0; pine-scented fragrance – 0.1. When developing the product, the study relied on the requirements for disinfectants, which are provided for by the order of the Ministry of Health "On state registration (re-registration) of disinfectants" dated 01.04.2021. An important indicator for disinfectants is the wide spectrum of antimicrobial

action and safety when used in the presence of humans and animals.

Experiments were conducted at the premises of a certified vivarium of the ECOMEDCHIM regional centre of Sumy State University and Sumy National Agrarian University. All studies on laboratory animals were carried out in accordance with directive 2010/63/EC [16] as amended by Regulation (EU) 2019/1010 and approved by the conclusion of the commission on ethics and bioethics of the Faculty of Veterinary Medicine of Sumy National Agrarian University dated 21.12.2020.

Determination of acute toxicity of an experimental disinfectant when administered orally

Acute toxicity of the disinfectant was studied in 30 white mice weighing 18.5-20.5 g and 15 white rats weighing 180-210 g. The animals were kept in accordance with sanitary norms and rules for keeping in the vivarium of the Regional Centre using specialised mixed feed. Before conducting the study, the animals were weighed. The experimental disinfectant, before being administered orally to animals, was thoroughly ground to a fine powder in a mill and intensively mixed equally with water. Immediately after mixing, the product was quickly administered to the animals in the morning, before feeding. The disinfectant was administered once using a probe with a cannula at the rate of 1,250, 2,500, and 5,000 mg/kg of body weight. Feeding of animals began two hours after the administration of preparation. Each of these doses of the preparation was administered to ten white mice and five rats.

Experimental rats and mice were monitored for 14 days after the introduction of the disinfectant. In the course of the studies, the clinical condition of the animals was monitored daily, considering their activity, feed and water consumption.

Study of the toxicity of an experimental disinfectant with prolonged oral administration

Determination of toxicity by prolonged oral administration was studied in two analogous groups of white rats, 6 animals each with a bodyweight of 185±10.0 g. The animals were kept under the same conditions as when studying the acute toxicity of the disinfectant. Immediately before oral administration, the experimental disinfectant was thoroughly ground to a fine powder, thoroughly mixed equally with water, and administered orally daily to rats of the experimental group at a dose of 2,500 mg/kg of body weight for 30 days. Rats of the second (control) group were orally administered finely ground zeolite in water in the same amount.

Throughout the experiment, the general condition of the rats, their behaviour were monitored, and the amount of food and water consumed by the animals was monitored. Rat body weight indicators were recorded before the start, on the 10th, and 31st days from the beginning of the experiment.

One day after the last administration of the experimental disinfectant, blood samples were taken from rats to determine haematological parameters and the condition of the internal organs of rats (stomach, intestines, liver, lungs, kidneys, heart, spleen) was examined. The effect of the experimental disinfectant on the state of internal organs was evaluated by comparing their relative mass coefficients [15].

Study of skin-resorptive and local-irritating effects

The skin-resorptive effect of the experimental preparation was studied in white outbred mice weighing 20-25 g. Clinically healthy laboratory animals were previously kept under 14-day quarantine in the vivarium of the clinic of the Faculty of Veterinary Medicine. The mice were then divided into experimental and control groups of 6 animals each. In mice of the experimental group, tails 2/3 of the length were treated with a 10% solution of the preparation, and in the control group, they were immersed in 0.9% sodium chloride solution. The exposure was 2 hours, daily, for 5 days. The ability of the preparation to penetrate the skin was evaluated at the end of the experiment. The clinical features of animal intoxication and the effect on the central nervous system were considered. In addition, the "swimming" method was used to assess the performance of mice. The time during which the animal could stay on the surface of the water was recorded.

The local irritating effect of the product was determined by skin applications on 10 rabbits weighing 2.97±0.3 kg, which allowed detecting the development of non-allergic contact dermatitis in them, depending on the dose of disinfectant. 2 days before the start of the experiment, 7x8 cm sections were sheared symmetrically on both sides of the spine on the back of laboratory animals, leaving a 2 cm wide strip of hair between them. A 10% solution of the experimental preparation was applied on the right side at the rate of 1 ml per 1 kg of rabbit body weight, and the same amount of 0.9% sodium chloride solution was applied on the left. To avoid licking the product from the skin during the 4-hour exposure, a plastic collar was put on the animals. After completing the experiment, the disinfectant was washed off with water. The first evaluation of skin samples was performed after 10 days. Changes in the functional state of the skin of an inflammatory nature (erythema, oedema) were determined under natural or near-natural artificial light 1, 24, 48, and 72 hours after the end of exposure according to the classification presented in Table 1.

***Table 1**. Assessment of the harmful effects of new substances on the skin of rabbits by the scoring system (according to Majda and Chrusaielska) [17] using an 8-score system*

Reaction	Rating, score
Erythema:	
Absent	0
Weak (barely noticeable)	1
Moderate severity	2
Expressed	3
Pronounced (dark red) with escharosis	4
Oedema:	
Absent	0
Weak (barely noticeable)	1
Moderate (protrudes no more than 1 mm above the skin surface)	2
Pronounced (protrudes above the skin surface and has clear borders)	3
Pronounced (protrudes more than 1 mm above the skin surface)	4
Maximum possible score	8

With a negative result, the research continued and brought the number of applications to 20. Then, the scores of skin reactions for each animal, including erythema and oedema, were summed up at a certain time interval and divided by the total number of observations. The resulting total irritation index was compared with the values presented in Table 2 and recorded in the study report [18].

***Table 2**. Degree of response to irritation in rabbits*

Response	Score
Insignificant	From 0 to 0.4
Weak	From 0.5 to 1.9
Moderate	From 2.0 to 4.9
Expressed	From 5.0 to 8.0

The results were processed using Microsoft Excel 2010 (Microsoft Corp., USA) and StatPlus 2009 professional 5.8.4 for Windows (StatSoft Inc., USA). The Student's t-test was used to assess the reliability of differences between the samples.

RESULTS AND DISCUSSION

Results of studying the acute toxicity of an experimental disinfectant with oral administration

A thorough approach is necessary to understand the risks associated with the use of the disinfectant and the measures that need to be taken to prevent the negative impact of the disinfectant on biological objects, and will allow using it for disinfection in the presence of animals and people. These hazards may be compounded by improper use or incorrect combination of incompatible substances. Since 2019, the use of disinfectants has increased due to the COVID-19 pandemic. Many cases of poisoning and allergic manifestations have been registered with the use of disinfectants [19].

The results of studies showed that a single oral administration of the disinfectant in all the above-mentioned doses did not cause toxic effects on the animal body. No deaths of experimental rats and mice were recorded (Table 3).

***Table 3**. Results of determining the acute toxicity of an experimental disinfectant*

Dose of the preparation administered, mg/kg of body weight	Animal deaths (died / total number in the experiment)	
	Rats	Mice
1,250	0/5	0/10
2,500	0/5	0/10
5,000	0/5	0/10

Due to the low toxicity of the disinfectant and the absence of death of laboratory animals after single oral administration, the calculation of toxicological parameters (LD_{50}) of the preparation was not performed.

During the entire experiment, no clinical manifestations of intoxication or side effects were recorded in experimental animals after a single oral administration of an experimental disinfectant in doses of 1,250, 2,500, and 5,000 mg/kg of body weight. The type of disinfectant selected depends on the sensitivity of microorganisms, the method of application and the structure of the material to be disinfected. There are also concerns about the safety of disinfectants for animals and farm maintenance personnel. In addition, the issue of the effectiveness of disinfectants and the prevention of the occurrence of resistant pathogenic microorganisms remains relevant [20; 21]. Therefore, the concentration of the experimental disinfectant should be sufficient to kill microorganisms and safe for its use in the presence of humans and animals.

Based on the conducted studies, it can be concluded that the maximum dose of an experimental disinfectant that does not cause the death of experimental rats and mice with a single oral administration (LD_0) is more than a dose of 5,000 mg/kg of body weight. Accordingly, LD_{50} of the preparation with a single oral administration to rats and mice will exceed the dose of 5,000 mg/kg of body weight, and therefore the experimental disinfectant can be classified as Hazard Class 4 according to the international standard GOST 12.1.007-76 [22], or as Category 5 according to the International global classification Global Harmonised System, (GHS) [23] (LD_{50} with a single oral administration exceeding 5,000 mg/kg of body weight).

Results of studying the toxicity of an experimental disinfectant with prolonged oral administration

Disinfection with chemical reagents is undoubtedly an important element of measures in the fight against animal pathogens. There are different classes of chemical disinfectants that have different effectiveness in the specific conditions of each farm. The choice of disinfectant should be based on the expected result. All types of disinfectants have advantages and disadvantages, and each has its own scope of application [24; 25]. With prolonged use of disinfectants, there is a possibility of a gradual cumulative effect in the body. It is clear that the effect of chronic toxicity of the preparation depends on the components and their concentrations. The most dangerous substances that have an evapouration effect are esters. The experimental disinfectant uses the only substance that contains essential oils – thymol, but it is of natural origin and is contained in low concentrations.

The study of the toxicity of the disinfectant with prolonged oral administration showed that administration of the preparation at a dose of 2,500 mg/kg of body weight for 30 days did not affect the clinical condition and behaviour of rats. During the entire experiment, no visible extraneous or negative effects of the preparation were recorded. The animals willingly consumed food and water, were mobile, and responded adequately to sound and tactile stimuli.

In addition, there was no significant negative effect of the experimental disinfectant, which was administered to rats for 30 days in a dose of 2,500 mg/kg of body weight, on the growth and relative weight gain of rats during the experiment compared to the weight of control rats (Table 4).

***Table 4**. Dynamics of changes in rat body weight during oral administration of an experimental disinfectant for 30 days*

Research period	Animal groups	
	Preparation was administered orally at a dose of 2,500 mg/kg	Control group
Before administration of the preparation	186.90±1.73	187.10±2.30
10	225.40±2.63	225.40±3.66
31	289.26±3.33	288.89±3.66

When dissecting animals of the experimental group, no visible pathological changes were observed in the internal organs and tissues of rats. There were also no significant changes in the comparison of the relative mass coefficients of internal organs of experimental and control rats (Table 5).

***Table 5**. Mass coefficients of internal organs to bodyweight of slaughtered experimental and control rats after 30 days of administration of experimental disinfectant*

Internal organs	Animal groups and dosage	
	Rats received the preparation at a dose of 2,500 mg/kg	Control
Liver	5.23±0.09	5.31±0.90
Lungs	0.96±0.17	0.97±0.16
Heart	0.41±0.09	0.42±0.07
Kidneys	0.77±0.05	0.78±0.06
Spleen	0.56±0.14	0.57±0.15

During haematological studies, there was no significant difference in the indicators of the experimental and control groups (Table 6). Thus, oral administration of an experimental disinfectant for 30 days at a dose of 2,500 mg/kg of body weight did not cause a significant negative effect on the body of rats in all the studied indicators.

***Table 6**. Hematological parameters in rats after administration of an experimental disinfectant on day 30*

Indicators		Animal groups and dosage		Reference value
		Rats received the preparation at a dose of 2,500 mg/kg	Control	
Haemoglobin, g/l		114.20±6.13	120.11±6.96	108.5-133.0
Red blood cells, T/l		7.02±0.76	7.06±0.83	6.50-8.25
Platelets, 10^9/l		530.6±15.6	529.7±15.1	520.0-590.0
White blood cells, 10^9/l		8.34±0.93	8.52±0.66	8.6-12.0
Leukocytal formula, %	Neutrophils	27.00±2.33	25.20±1.66	25.00-35.00
	Monocytes	1.00±0.35	1.80±0.37	1.00-5.00
	Eosinophils	0.50±0.16	0.50±0.22	0.30-0.50
	Lymphocytes	71.50±2.33	72.50±2.66	71.00-77.00

Study of skin-resorptive and local irritant effects

Experimental mice practically did not differ from the control individuals during the entire experiment, and the clinical picture of intoxication was not observed (Table 7).

***Table 7**. Indicators of the state of the body of mice after applying an experimental disinfectant to the skin of the tail*

Group	Body weight, g		TTI, relative units	Blood			Performance, min.
	Before activity	After activity		Haemoglobin, g/l	White blood cells, 10^9/l	Red blood cells, 10^{12}/l	
Control	20.2±0.81	21.8±0.79	4.5±0.23	8.5±0.50	8.610±0.48	8.960±0.60	28.3±0.79
Experiment	20.0±0.68	20.8±0.81	4.4±0.40	9.4±0.60	8.400±0.70	8.790±0.50	27.9±0.40

After processing the tails, the animals were slightly dishevelled, which can be explained by stress, and after 1 hour these signs disappeared. During daily examination, erythema and dry skin were noted in the mice of the experimental group. After stopping the experiment for another 3-4 days, a slight dryness of the tail skin remained. A slight decrease in the value of the total threshold indicator (TTI) and performance according to the "swimming" method (27.9±0.40 min against 28.3±0.79 min in the control) indicated the manifestation of inhibition processes in their central nervous system.

The use of safe disinfectants is an important vital aspect, especially in the context of an epidemic. But choosing the right tool is difficult, because there is a wide variety on the market. Therefore, before choosing a disinfectant, it is necessary to determine which pathogens should be destroyed and under what conditions [26].

One of the last considerations is the effect of disinfectants on indoor animals. Potential animal health risks pose similar threats to humans, including the risk of contact dermatitis and mucosal irritation. In addition, disinfectants can create unpleasant odours that can have a negative impact on the behaviour and well-being of animals and people. Regardless of whether the disinfectant is intended for use only on surfaces that come into contact with animals, or as a universal indoor agent, it is important that it does not cause irritation or immediately when used at the recommended concentration [27].

The results of testing the irritating effect of a 10% working solution of an experimental disinfectant on the skin of rabbits are presented in Table 8.

***Table 8**. Results of studying the irritating effect of a 10% solution of an experimental disinfectant on the skin of rabbits*

No. of animal	Weight, kg	Amount of preparation, ml	Total stimulus index, score
1	2.82	2.82	2.34
2	2.84	2.84	2.44
3	2.87	2.87	2.46
4	2.94	2.94	2.46
5	2.97	2.97	2.46
6	2.95	2.95	2.5
7	2.83	2.83	2.54
8	3.08	3.08	2.46
9	2.87	2.87	2.46
10	3.0	3.0	2.5
Average in the group	2.92±0.09	2.92±0.09	2.46±0.02

The experimental product contains chloramine, which is used to disinfect biological materials, equipment, medical supplies, and various surfaces. The ideal disinfectant for clinical practice must meet several criteria, including water solubility, bactericidal ability, and economical efficiency, depending on the purpose of disinfection and ambient temperature. However, a 5% solution of chloramine causes metal corrosion and irritates the skin and mucous membranes. Studies have shown that the average manifestation of erythema in rabbits is 2.46. According to the classification of toxicity, the experimental agent has a moderate irritating effect and belongs to the 4th hazard class [28].

Indicators that characterise the irritating effect of the experimental disinfectant solution in the maximum permissible concentration of 60 mg/m^3 on the mucous membranes of the eyes of rabbits, presented in Table 9.

***Table 9**. Results of the conjunctival test on rabbits*

No. of animal	Evaluation criteria	Research period after treatment, h				Average total reaction severity score	Degree of severity of the effect
		1	24	48	72		
1	Conjunctival and corneal hyperaemia	3	2	1	0	3.25	Moderate
	Palpebral oedema	2	1	0	0		
	Exudation	3	1	1	0		
2	Conjunctival and corneal hyperaemia	1	1	1	1	2.75	Weak
	Palpebral oedema	1	1	1	0		
	Exudation	1	1	1	1		
3	Conjunctival and corneal hyperaemia	2	1	1	0	3.25	Moderate
	Palpebral oedema	2	2	1	0		
	Exudation	3	1	0	0		
4	Conjunctival and corneal hyperaemia	2	2	1	1	3.5	Moderate
	Palpebral oedema	1	1	0	0		
	Exudation	3	1	1	1		
5	Conjunctival and corneal hyperaemia	2	1	1	1	2.75	Weak
	Palpebral oedema	1	1	0	0		
	Exudation	3	1	0	0		

Immediately after treatment with the preparation, the rabbits showed anxiety, scratched their eyes. At the same time, narrowing of the eye slit, noticeable redness of the tear duct and sclera towards the cornea, palpebral oedema, significant exudation with moistening of the eyelids and hair around the eyes were observed. These signs disappeared on their own within 72-96 hours. This fact indicates a moderate irritating effect of the experimental disinfectant on the mucous membranes of the eyes of rabbits.

CONCLUSIONS

1. Experimental disinfectant at doses of 1,250, 2,500, and 5,000 mg/kg of body weight, did not cause the death of experimental mice and rats. On this basis, the product can be classified as Hazard Class 4 according to the international standard GOST 12.1.007-76, or Category 5 according to the International global classification Global Harmonised System (GHS) (LD_{50} oral administration exceeds 5,000 mg/kg of body weight).

2. With oral administration of an experimental disinfectant for 30 days at a dose of 2,500 mg/kg of body weight, it did not cause any negative and toxic effects on the body of experimental rats, did not affect their growth and development, did not cause changes in the relative mass of internal organs, and did not lead to changes in the haematological parameters of experimental animals.

3. Disinfectant for skin applications has a weak effect on the degree of response (erythema and oedema) in rabbits.

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Визначення токсичності експериментального дезінфікуючого засобу

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Анотація. Надмірне використання та зловживання дезінфікуючими засобами протягом минулого століття створило проблеми, пов'язані з появою стійких мікроорганізмів. Крім того, завжди є потенційний ризик для здоров'я людей і тварин, оскільки використання агресивних дезінфікуючих засобів може призвести до захворювань. Метою роботи було дослідження токсичності експериментального дезінфікуючого засобу для визначення можливості використання в присутності людей і тварин. Матеріали дослідження – експериментальний засіб (порошок для дезінфекції водорозчинний). Експериментальні дослідження проводили в умовах атестованого віварію Регіонального центру РЦ «ЕКОМЕДХІМ» Сумського державного університету та Сумського національного аграрного університету. Гостру токсичність засобу вивчали на 30 білих мишах масою 19,5±1,0 та 15 білих щурах масою 200±15,0 г. Визначення токсичності при тривалому пероральному введенні вивчали на двох, підібраних за принципом аналогів, групах білих щурів по 6 тварин у кожній з масою тіла 185±10,0 г. Вплив препарату на стан внутрішніх органів оцінювали шляхом порівняння відносних масових коефіцієнтів. Місцеву подразнюючу дію засобу визначали методом нашкірних аплікацій на 10 кролях масою тіла 2,97±0,3 кг. Дезінфікуючий засіб при пероральному одноразовому введенні в дозах 1250, 2500 та 5000 мг/кг маси тіла не викликав загибелі піддослідних мишей і щурів. При пероральному введенні засобу впродовж 30 діб у дозі 2500 мг/кг маси тіла не спричиняв будь-якої негативної та токсичної дії на організм дослідних щурів, не впливав на ріст і розвиток щурів, не спричиняв змін відносної маси внутрішніх органів. Встановлено, що в середньому прояв еритеми у кролів становить 2,46 бали. За результатами дослідження встановлено, що дезінфікуючий засіб можна віднести до 4 класу небезпеки відповідно до Міжнародного стандарту ГОСТ 12.1.007-76, або до категорії 5 за Міжнародною глобальною класифікацією Global Harmonized System, (GHS) ($ЛД_{50}$ при пероральному надходженні перевищує 5000 мг/кг маси тіла). Отримані результати дають підставу стверджувати про можливість застосування експериментального дезінфікуючого засобу в присутності людей і тварин

Ключові слова: дезінфектант, гостра токсичність, шкірно-резорбтивна дія, лабораторні тварини, еритема, набряк

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Amino Acid Composition of Whey and Cottage Cheese Under Various Rennet Enzymes

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Abstract. Rennet cheeses occupy an important place in the diets of the population of Ukraine. The technology of making cheeses depends on both the quality of raw materials and the quality of enzymes that are used to curdle milk. Therefore, the study of the effect of rennet enzymes obtained using advanced biotechnology on the transformation of milk protein and amino acids into a finished product is of scientific and practical importance. Considering the above, the purpose of this study was to investigate the amino acid composition of whey and cottage cheese for the use of various enzyme preparations. Three groups of samples (n=5) were formed to set up the experiment. Cow's milk for research was selected from clinically healthy cows during the milking period. In the control group of samples, rennet of microbial origin was used for milk clotting. In the first experimental group of samples, an enzyme preparation extracted from rennet of dairy calves was used according to the method of Yu.Ya. Svyrydenko. In the second experimental group, an enzyme preparation obtained by extraction of rennet enzymes according to the method of S.V. Merzlov was used. The content of amino acids in milk, whey, and cheeses was determined by capillary electrophoresis. Studying the milk used for the experiment, it was found that the content of amino acids (lysine, methionine + cystine, tryptophane, valine, leucine, isoleucine, phenylalanine + tyrosine, proline, serine, alanine, glycine, histidine, arginine, aspartic acid and glutamine) did not significantly differ from the typical indicators of milk obtained in central Ukraine. It was found that the use of rennet enzymes extracted according to the method of S.V. Merzlov is accompanied by a decrease in the content of amino acids in serum by an average of 15.9%

Keywords: milk clotting, casein, whey proteins, enzyme preparations

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INTRODUCTION

An essential task of modern biotechnology is to develop scientific foundations and solutions for obtaining products with broad prospects for practical use. Such products include enzymes of animal origin, which are used in various branches of the national economy [1]. Rennet enzymes are used in the technology of making rennet cheeses, which are highly nutritious protein products obtained from milk by its coagulation and cutting. Rennet enzymes are obtained by extraction from the stomach of dairy calves. Rennet enzyme extract is purified by filtration, then passed through a bacterial filter and stored in sterile conditions. The two active protein components of calf enzymes are chymosine and pepsine, the standard ratio of which is 4:1, respectively. The activity of rennet enzymes depends on the factors of technological conditions of their production [2].

Brine cheeses are popular in Ukraine, and their production occupies an essential place in cheese making and belongs to the dynamically developing food industries. Cottage cheese is a source of complete protein, calcium, magnesium, and vitamins. Cheeses contain all the essential nutrients of milk, except carbohydrates.

The main operation in the production of rennet cheeses is the enzymatic coagulation of milk under the action of chymosine, resulting in a milk clot with most of the casein and whey. In animals, chymosine, similar to cheese-making technology, curdles milk at the beginning of its digestion. Thus, milk processing in the cheese production corresponds to natural physiological processes. Another function of enzymes in cheese production is to take part in the biotransformation of milk components into compounds that form the organoleptic parameters of the product.

Today, rennet enzymes are expensive, so microbial enzymes that are similar in action are widely used [3]. However, the use of enzymes of microbial origin can adversely affect the sensory parameters of cheeses. Furthermore, the demand for cheeses made using natural rennet enzymes has recently been growing.

Coagulation of milk with rennet enzyme involves two irreversible processes. Several theories of rennet coagulation are known. The hydrolytic theory of rennet coagulation mechanisms explains: under the action of the rennet enzyme, the polypeptide chains of the K-casein casein calcium phosphate complex between phenylalanine and methionine are hydrolysed, as a result of which the K-casein molecules break down into hydrophobic para-K-casein and hydrophilic glycomacropeptide. As a result, micelles lose their negative charge, and the hydrate shell is partially destroyed – the stability of the system is lost, resulting in protein flakes (stage I – induction). After K-casein loses its protective colloid functions, conditions are created for intensive coagulation involving calcium ions (stage II). At this stage, a spatial network of the clot is developed, which then, after appropriate treatment, is divided into two phases: solid (casein + fat) and liquid (milk sugar, milk proteins and salts dissolved in water) [4].

In whey, fat is present in small amounts (0.05… 0.4%), its value is in its dispersibility to balls with a diameter of less than 2 microns [5]. The main importance of proteins lies in their indispensability by other food substances [6]. Whey milk proteins (albumines and globulines) are the most biologically valuable concerning the content of essential amino acids (methionine, lysine, threonine, tryptophane). From the standpoint of nutritional physiology, they approach the amino acid scale of the "ideal" protein.

Amino acid composition is an essential indicator of dairy products and describes their biological value [7; 8]. The physiological significance of amino acids is diverse: for example, lysine promotes the body's absorption of phosphorus, calcium, and ferrum [9]. Lysine is also actively involved in muscle development, promotes recovery from injuries, maintains bone strength, regulates the synthesis of hormones, antibodies and enzymes, and can have an antiviral effect. Histidine is involved in hematopoiesis and tissue repair, and is part of the myelin sheaths of nerve cells. The body metabolises histidine to histamine, which is crucial for immunity, reproductive health, and digestion. Methionine and cysteine in animals and humans are essential for the development of immune bodies, skin and hair elasticity. Methionine promotes the absorption of selenium and zinc, the elimination of heavy metals (namely plumbum and mercury). Tryptophane is essential for the proper growth of newborns and is involved in the production of serotonin and melatonin. Valine promotes mental activity and muscle coordination. Phenylalanine is involved in the use of other amino acids. Phenylalanine is transformed by the body into tyrosine, which provides important brain functions. Isoleucine is involved in blood sugar regulation and hormone synthesis. It is mainly present in muscle tissue and regulates energy levels. Older people are more likely to be deficient in isoleucine than young people. Leucine affects blood sugar levels, is involved in the growth and repair of muscles and bones [10]. A violation of the balance of essential amino acids leads to the use of protein at the minimum level determined by the limited essential amino acid [11].

The quality of food products is affected by their chemical composition, physical properties, as well as nutritional and biological value, which depends on its amino acid composition [2]. Whey contains valuable components for the human body: lactose, milk fats, proteins, mineral salts (calcium, magnesium, phosphorus, sodium), as well as immunoglobulins, lactoferrin, and lactoperoxidase. Whey is a source of whey proteins, the amino acid composition of which is closest to the amino acid composition of human muscle tissue [12]. It is important that during the development of a milk clot, amino acids pass into cheese as much as possible, and not into

whey. When cheese is fermented with enzyme preparations extracted from rennet, compared to microbial analogues, 1.3% more amino acids remain in the cheese clot and pass into the cheese grain [13]. Milk protein in terms of the composition of essential amino acids is very close to the "ideal or reference protein" proposed by FAO/WHO [14].

The production of rennet cheeses is a complex multifunctional process wherein changing the influence of even one of the technological factors can change the dynamics of biochemical, microbiological, and physicochemical transformations of the cheese mass, which affects not only the organoleptic properties, but also the biological value of the final product [15]. Whey proteins are globular proteins and hydrophilic colloids. The presence of essential amino acids (lysine, tryptophane, methionine, threonine) and cysteine is the most valuable part of milk proteins, so their use in the cheese production is of great practical importance [16].

According to the technology of cheeses, whey is not further used in most cases, a considerable part of it is poured into the sewer. Therefore, it is important that the amino acids and minerals of milk are transferred to cheese, and not to whey as much as possible. The question of how various rennet enzymes affect the amino acid composition of the product remains unexplored.

The purpose of this study is a determination of the amino acid composition of cheese and the resulting whey due to the action of various enzyme preparations.

MATERIALS AND METHODS

In clinically healthy cows during the milking period, milk that met the requirements of DSTU 2661:2010 was selected for research [17].

Three groups of milk samples (n=5) were formed to set up the experiment. In the control group (CG), rennet of microbial origin was used for milk clotting. The experimental group I (EG-I) was tested with an enzyme preparation from rennet of dairy calves, extracted according to the Yu.Ya. Sviridenko's method (using sodium chloride solution). The experimental group II (EG-II) was tested with an enzyme preparation extracted from rennet of dairy calves according to the S.V. Merzlov method (using a mixture of lactic and hydrochloric acids).

Each sample, both in the control and experimental groups, was 1.0 dm^3. The filtered milk was cooled to a temperature of 4°C and kept for 12 hours. Pasteurisation was carried out at a temperature of 60-63°C with an exposure time of 30 minutes. Pasteurised milk was normalised by mass fraction of fat. Rennet enzyme was added to normalised milk heated to a temperature of 33°C, stirring it smoothly. The clot was cut into 15-20 mm cubes and left for 10-15 minutes, then carefully kneaded for 20-30 minutes to seal and dehydrate. Kneading was carried out with 2-3-minute stops.

The second heating of the cheese mass was not used. After sufficient compaction, the cheese mass was moved to a moulding table covered with gauze in two layers for self-pressing, which lasted 2 hours. Two days after the cheese matured, samples were taken from each sample to investigate the amino acid composition.

The amino acid composition of milk, whey, and cheese proteins was determined at the State Research Control Institute of Veterinary Drugs and Feed Additives (city of Lviv) by capillary electrophoresis using the capillary electrophoresis system "Kapel-105/105M" (Ukraine).

The method for determining amino acids in milk is based on the decomposition of samples by acid hydrolysis with their transition to free forms of phenylthiocarbamyl derivatives (FTC derivatives), subsequent separation and quantitative determination. Detection was performed in the UV region of the spectrum at wavelengths of 254 nm.

The under-study materials were processed using the method of variational statistics based on the calculation of the arithmetic mean, root-mean-square error and the reliability of the difference between the compared indicators. The probability of the results obtained and the difference between the indicators were calculated according to the Student's t-test.

RESULTS AND DISCUSSION

In the experiment, milk had the highest content of glutamine. As the concentration decreased, the amino acids were in the following sequence: leucine, phenylalanine + tyrosine, proline, lysine, serine, asparagine, isoleucine, valine, tryptophan, histidine, and glycine (Table 1). Notably, the content of amino acids in raw materials did not significantly differ from the standard indicators of milk [11].

Table 1. *Amino acid composition of experimental milk g/100 g*

Amino acids	Milk
Lysine	0.198
Methionine+Cystine	0.102
Tryptophane	0.138
Valine	0.145
Leucine	0.296
Isoleucine	0.150

Table 1, Continued

Amino acids	Milk
Phenylalanine+Tyrosine	0.288
Proline	0.247
Serine	0.173
Alanine	0.119
Glycine	0.066
Histidine	0.083
Arginine	0.100
Asparagine	0.172
Glutamine	0.561

Studying the effect of various starter cultures on the content of amino acids in milk serum after clot coagulation, it was found that under the action of enzymes of microbial origin, the lysine content was 0.044 g per 100 g.

Using an enzyme preparation from calf rennet obtained using a solution of sodium chloride (EG-I), the lysine content in milk serum was 9% lower compared to the CG. In milk whey from the EG-II (use of enzymes from calf rennet obtained by using a mixture of acids) the lysine content was significantly lower compared to the CG. The difference was 13.6%. There was a decrease in the error of methionine and histidine in milk serum from Experimental Groups I and II relative to the CG. In the experimental groups of samples, this indicator was the same (Table 2).

***Table 2**. Amino acid composition of serum, g/100 g*

Amino acid	CG	EG-I	EG-II
Lysine	0.044±0.0060	0.040±0.0043	0.038±0.0030*
Methionine + Cystine	0.009±0.0022	0.008±0.0012	0.008±0.0017
Tryptophane	0.011±0.0021	0.010±0.0032	0.009±0.0007
Valine	0.031±0.0026	0.028±0.0014	0.026±0.0013
Leucine	0.085±0.0042	0.082±0.0033	0.079±0.0028
Isoleucine	0.050±0.0047	0.048±0.0053	0.048±0.0019
Phenylalanine + Tyrosine	0.026±0.0017	0.024±0.0035	0.023±0.0026
Proline	0.027±0.006	0.024±0.0021	0.022±0.0018
Serine	0.018±0.0035	0.016±0.0027	0.016±0.003*
Alanine	0.025±0.0021	0.023±0.0019	0.020±0.0017
Glycine	0.005±0.0004	0.004±0.0002	0.003±0.0003*
Histidine	0.006±0.0004	0.006±0.0003	0.005±0.002
Arginine	0.029±0.0012	0.025±0.0014	0.023±0.0009*
Aspartic acid	0.014±0.0009	0.016±0.0011	0.016±0.0008
Glutanine	0.120±0.0012	0.108±0.0007**	0.102±0.0014**

***Note**: possible differences with the CG: p<0.05 – *; p<0.01 – ***

Studying the content of tryptophane, a decrease in this amino acid in milk serum from the second experimental group was revealed by 18.2%. The difference was a trend. The content of leucine and isoleucine was found to be within the trend in milk whey for the use of natural enzyme preparations extracted from calf rennet. It was proved that in the serum from the second experimental group of samples, the content of phenylalanine and tyrosine was 11.5% lower than in the CG. Under the action of enzyme preparations from calf rennet (Experimental Groups I and II), the residue of proline, alanine, histidine, and aspartic acid in milk serum decreases relative

to the serum obtained under the action of enzymes of microbial origin. Comparing the experimental groups with each other, it was found that in the second experimental group of samples, the content of proline, alanine, and histidine was lower by 8.3%, 13.0%, and 16.7% relative to the Experimental Group, respectively. A significant decrease in serine, glycine, arginine, and glutanine was established in milk serum of the EG-II. The difference with the control was 11.1%, 40.0%, 20.7%, and 15.0%, respectively. Thus, it was established that the use of enzymes from calf rennet extracted with a mixture of acids (EG-II) leads to the lowest content of essential and non-essential amino acids in milk whey.

Upon processing milk clots developed from each group of samples, samples of the finished product – cheese – were obtained. In cheese obtained using calf rennet enzymes (Experimental Groups I and II), the lysine content was higher by 0.08% and 0.51% compared to the CG. An increase in methionine + cystine, tryptophane, and valine was detected in cheese from the EG-II. The indicators were higher than in the CG, respectively, by 0.07%, 0.2%, and 0.07%. The content of leucine and isoleucine in cheese from the EG-II was higher than in the CG and EG-I. Indicators of the content of phenylalanine + tyrosine, proline, serine, glycine, histidine, arginine, aspartic acid, and glutanine in cheese from the EG-II were higher than in the CG by 0.6%, 0.074%, 0.18%, 0.46%, 0.38%, 0.13%, 0.15%, and 0.6%, respectively (Table 3). Thus, it is proved that upon using enzymes extracted from calf rennet (EG-II), the transformation of milk amino acids into cheese is the highest. Similarly, the yield of the finished product increases by 12%.

***Table 3**. Amino acid composition of cheese (% of the total amount) (n=5, P≥0.96)*

Amino acids	Control	EG-I	EG-II
Lysine	5.46	5.54	5.97
Methionine + Cystine	3.47	3.51	3.54
Tryptophane	3.92	4.03	4.12
Valine	4.21	4.26	4.28
Leucine	9.14	9.48	10.10
Isoleucine	4.30	4.58	4.59
Phenylalanine + Tyrosine	10.3	10.5	10.90
Proline	9.46	9.79	10.20
Serine	4.82	5.0	5.0
Alanine	2.18	2.46	2.64
Glycine	1.96	2.14	2.34
Histidine	2.02	2.08	2.40
Arginine	3.12	3.21	3.25
Aspartic acid	5.02	5.18	5.17
Glutanine	15.82	16.31	16.42

For the use of rennet enzymes obtained according to the method of S.V. Merzlov (EG-II), an effective transition of milk proteins and, accordingly, amino acids to the cheese mass was established in comparison with the variants where an enzyme preparation of microbial origin was used (CG) and rennet enzymes obtained according to the method of Yu.Ya. Sviridenko (EG-I).

It is known that casein comprises fractions, of which only one – χ-casein – is hydrolysed by chymosin. Numerous peptide bonds are also hydrolysed, and χ-casein is broken down in both soluble and insoluble fractions. Para-χ-casein is an insoluble fraction developed as a result of hydrolysis of χ-casein by chymosin. Hydrolysis of χ-casein by chymosin weakens its protective colloidal action in milk, which leads to the separation of whey and the development of a milk clot [18; 19].

Studies by A.V. Gudkov note that the nutrients of milk do not fully pass into cheese, since such components as whey proteins, lactose, and water-soluble vitamins pass into whey. However, the loss of proteins can be compensated to a certain extent by working out the technology and using efficient coagulants [12]. Scientific studies of W.L. Claeys described that the value of milk proteins depends on their digestibility and the amount of essential amino acids. Approximately 80% of milk proteins comprise casein (AS1, AS2-, B-, and KSHIN), and an important aspect in cheese production is the maximum transition of milk proteins to cheese, – similar statements are found in experiments conducted by W.Y. Park [20; 21].

Achieving enzyme stability and activity is often a complex effort. As noted by T. Hwang, their biological

activity depends on the three-dimensional native structure, hence the catalytic activity, and any considerable conformational changes can lead to their inactivation, which leads to the loss of most of the milk's nutrients [22].

Manifestations of enzyme instability arise from aggregation, loss of biological functionality, and exposure to extreme conditions or even minor changes in temperature or pH, can cause sudden changes and subsequent loss of their biological activity, accompanied by the inevitable loss of milk proteins and their transformation into whey, – states J.T. Kim [23].

CONCLUSIONS

According to these processes, in the EG-II, hydrolysis of polypeptide chains of *K*-casein and the breakdown of its molecules into hydrophobic and hydrophilic fractions occurred more efficiently, since the stabilised enzymes used had increased activity and were more resistant to environmental factors. As a result, *K*-casein completely lost the function of a protective colloid and coagulation occurred as efficiently as possible, cheese dust is formed to a lesser extent. The strength of the clot was the highest, which caused a decrease in the content of amino acids in the serum.

It has been experimentally proven that the use of enzyme preparations made using different methods does not equally affect the transformation of milk amino acids into cheese. The use of rennet enzymes extracted according to the S.V. Merzlov's method is accompanied by a decrease in the content of amino acids in whey by an average of 15.9%.

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Амінокислотний склад молочної сироватки та сиру під впливом різних сичужних ензимів

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Анотація. Сичужні сири займають важливе місце у раціонах населення України. Технологія виготовлення сирів залежить як від якості сировини, так і від якості ензимів, які застосовують для зсідання молока. Тому дослідження впливу сичужних ензимів, отриманих за удосконаленої біотехнології на трансформацію білка та амінокислот молока у готовий продукт, має наукове та практичне значення. З огляду на вищезазначене, метою цієї статті було дослідження амінокислотного складу сироватки молока та сиру за використання різних ензимних препаратів. Для постановки досліду було сформовано III групи проб (n=5). Молоко коров'яче для досліджень відбирали в клінічно здорових корів у період роздою. У контрольній групі проб для зсідання молока використовували сичужний фермент мікробіального походження. У I дослідній групі проб застосовувався ферментний препарат, екстрагований із сичугів молочних телят за методикою Ю.Я. Свириденко. У II дослідній групі застосовували ензимний препарат, отриманий способом екстракції сичужних ензимів за методикою С.В. Мерзлова. Вміст амінокислот у молоці, сироватці та сирах визначали методом капілярного електрофорезу. Досліджуючи молоко, яке використовували для експерименту було виявлено, що вміст амінокислот (лізин, метіонін + цистин, триптофан, валін, лейцин, ізолейцин, фенілаланін + тирозин, пролін, серин, аланін, гліцин, гістидин, аргінін, аспарагінова кислота та глутамін) вірогідно не відрізнявся від типових показників молока, яке отримують в центральній Україні. Встановлено, що застосування сичужних ензимів, екстрагованих за методикою С.В. Мерзлова, супроводжується зменшенням вмісту амінокислот у сироватці в середньому на 15,9 %

Ключові слова: згортання молока, казеїн, сироваткові білки, ферментні препарати

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The Effect of Chemicals of Plant Protection Products on Soil Microbiocenoses

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Abstract. With the emergence of agriculture, humankind faced numerous difficult tasks. For example, how to use the potential of the soil while saving its quality and functional properties, how to apply agricultural technologies effectively and environmentally friendly, how to make them safe for human health and biota, and many others. There are several informative and reliable recording criteria and indicator systems that fully and comprehensively describe changes in the ecological condition of the soil and agrocenoses. However, all these systems have one defect – the time from the impact of the factor to the "reaction" of the indicator. Early diagnosis of changes in the agrocenosis is possible due to the biological component of the soil, namely the microbiocenosis. Notably, that microorganisms have a large contact surface with the environment, high rates of reproduction in space and time, sensitivity to changing living conditions. The reaction of soil microbiocenosis and its activity (number of microorganisms of ecological-trophic and taxonomic groups, respiration intensity, microbial biomass content, and soil phytotoxicity) under the action of chemicals that are the basis of plant protection products (PPP) was studied in the laboratory. It was found that the number of microorganisms of different ecological-trophic and taxonomic groups under the action of a composition of cymoxanil with dimetomorph decreased by 1.5-4.5 times relative to control, chlorperifos-methyl in 1.1-2 times, and prometryn – not more than 1.5. The content of microbial biomass and the intensity of carbon dioxide emissions when using cymoxanil with dimethomorph compared to the control variant decreased by 44% and 51.4-64.8%, respectively; prometryn – by 10-13% and by 8-12%. The highest level of soil phytotoxicity was observed for variants using prometryn (20-24%), the lowest for a composition of cymoxanil with dimetomorph (7-12%). It was shown, that the high level of inhibition of test culture development with the use of prometryn associated with the class of PPP and the mechanism of its effect on the plant organism. Low indicators of soil phytotoxicity and microbiocenosis activity when using cymoxanil with dimetomorph are explained by the influence of the studied composition not only on phytopathogenic micromycetes, but also on all groups of soil micromycetes (cellulose-destroying, saprophytic) that dominate. Therefore, the influence of PPP chemicals on the microbiocenosis can be shown as follows: *PROMETRYN (the lowest level of influence) → CHLORPYRIFOS-METHYL → CYMOXANIL + DIMETOMORF (the highest level of influence)*

Keywords: microbiocenosis, microorganisms of the main ecological-trophic and taxonomic groups, emission of carbon dioxide, microbial biomass

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INTRODUCTION

The issues of soil quality, its functional properties, and the saving of a high yield were of the highest priority for humankind since the emergence of agriculture, which happened at least 10 to 23 thousand years ago [1; 2]. Soil, a natural body at the atmosphere-lithosphere interphase, is a dynamic entity teeming with life. Soil is an organic-C-mediated realm in which solid, liquid, and gaseous phases interact at a scale ranging from nanometers to kilometers and create dynamic environments conducive to the growth and development of plants and other biota [3]. One of the most important indicators for agricultural producers, both in Ukraine and in the world, is soil fertility. The territory of Ukraine concentrates in itself about 28% of the world's chernozem (black soil), which has the highest fertility rates [4].

The beginning of the XXI century combined a wide range of progressive, intensive, environmentally friendly, organic technologies for the most productive agricultural production. However, at the same time, scientists note that Ukraine's agricultural landscapes are in crisis. Sharp and ubiquitous, declining soil fertility and large-scale spread of degradation processes determine the need for significant changes in human economic activity and environmental management. Ecologically safe usage of natural resources is one of the necessary conditions for sustainable development not only of the agricultural sphere but also of society in general [5].

There are several informative and reliable recording criteria and systems of indicators that fully and comprehensively describe changes in the ecological condition of the soil and agrocenoses [6]. In practice, the system of normative agrochemical indicators – the base of physicochemical, agrophysical, and ecotoxicological indicators – is widely used. Appropriate to notice that all these bases are reliable and maximally characterise all the processes occurring in agricultural landscapes, but there is one defect – the time from the impact of the factor to the "reaction" of the indicator, which is recorded. However, the researchers from the Institute of Agroecology and Environmental Management of NAAS for several decades have been developing a system of indicators of the biological component of the soil, namely the microbiocenosis, which allows an early diagnosis of changes in the soil environment [7; 8].

Early diagnostics is possible because the microbiota is multifunctional and, participating in opposite reactions, performs a stabilising function of metabolic balance in nature. Due to the large surface of contact with the environment, it is very sensitive to changing living conditions, and the high rate of reproduction makes it possible in a short time to detect changes that occur under the influence of environmental factors [9]. Substances used in agro-industrial production, namely fertilisers, fungicides, herbicides, insecticides, acaricides, defoliants, adhesives, and many others directly affect both plants and animals and can accumulate in the soil. The stockpiling active substances of pesticides and agrochemicals are able to inhibit or stimulate the development of agronomically useful and saprophytic microflora. Direct or indirect action of pesticides may extend to the development of soil pathogens, growth, sporulation, germination of propagules, survival and competitive saprophytic activity of soil fungi [10-12].

Most of the works are dedicated to the effects of pesticides and agrochemicals on soil microflora, based on field studies that included the composition of the study preparation, soil moisture, pH, heavy metal content, weather conditions, and many other biotic and abiotic factors [13-15]. All this shows a whole system of influence, which complicates the interpretation of the results and generalisation of conclusions that relate directly to the impact of agrochemicals. Therefore, the evaluation and results of exposure to the active substance of any agrochemical or pesticide should be carried out in a laboratory with well-controlled conditions for all study variants.

The purpose of the study was to determine the response and the level of influence of active substances of the most common plant protection products (PPP) on the structure of the microbiocenosis.

MATERIALS AND METHODS

Laboratory studies were performed on soil samples taken at the Skvyra Research Station of the Institute of Agroecology and Environmental Management of NAAS (Table 1). The studies used chemicals that are the basis of the most widely used plant protection products in agriculture (Table 2).

Table 1. *Agrochemical characteristic of soil in stationary field experiments, 0-20 cm*

Type of soil	pH salt	Humus, %	Content, mg/kg of soil		
			Nitrogen which easily hydrolises	Active phosphorus	Exchangeable potassium
Typical chernozem	6.5	4.3	110	240	85

***Table 2**. Characteristics of chemicals used for research*

Name of active substance	Alternative names	Chemical formula (class)	Action	Class PPP
Prometryn	Prometryn, mercazine, gezagard, selectin, zirazin, A-1114, G-34161	$C_{10}H_{19}N_5S$ (triazines)	Inhibits the level of photosynthesis of plants by inhibiting the photosystem II	Herbycide
Cymoxanil	Cymoxanil, kurzat	$C_7H_{10}N_4O_3$ (other)	Inhibits sporulation of micromycetes by inhibiting RNA biosynthesis in their cells	Fungicide
Dimetomorf	Dimetomorf, acrobat, CME 151, forum, WL 127294	$C_{21}H_{22}ClNO_4$ (morpholines)	Breaks the development cycle of micromycete, causes antispore-forming effect due to modification of the cell wall of the micromycete	Fungicide
Chlorpyrifos-methyl	Chlorpyrifos-methyl; chlorpyrifos-methyl; cooper greencott; dowco 214; dowco 214; dowco-214; dursban methyl; dursbanmethyl	$C_7H_7Cl_3NO_3PS$ (organophosphorus compounds)	Neurotoxic effect, hydrolyses the enzyme acetylcholine esterase to acelcholine. Accumulation of acetylcholine in the synaptic cleft blocks the transfer of nerve impulses	Insectecide-acarcide

The influence of each chemical on the state of the microbiocenosis was studied in 3 concentrations (min, max, 10 * max), in accordance with the regulations of research established by the Ministry of Environmental Protection and Natural Resources of Ukraine [16; 17]. After sampling and before the beginning of the experiment, the soil was sieved through a 2 mm sieve and the remains of plants, roots, insects, worms, etc. were removed. The sifted soil was transferred to vegetative ceramic pots at the rate of 3 kg of soil (in terms of dry weight). The study included the following variants: 1. Control – whithout using chemical substances; 2. Prometryn; 3. Composition Cymoxanil + Dimetomorf; 4. Chlorpyrifos-methyl.

Control and experimental soil samples were moistened to 60% moisture content, 1-fold min concentration of active substance (1 min) was added to the experimental, 1-fold max concentration of active substance (1 max) and 10-fold max concentration of active substance (10 max), carefully mixed and composted at a temperature of + 22±2ºC for 30 days. Determination of the main indicators of the study was performed on 14 and 28 days of soil incubation [17-19].

Reactions of microbiocenosis and the level of influence on the structure were determined by the number of microorganisms of different ecological-trophic and taxonomic groups (ammonifiers, bacteria using mineral nitrogen, spore-forming bacteria, nitrogen-fixing and phosphate-mobilising microorganisms, *Azotobacter*, oligotrophs, pedotrophs, streptomycetes, micromycetes), carbon dioxide emission intensity, microbial biomass content, and phytotoxicity.

Microbiological analyses such as soil sampling, making 10-fold serial dilution of soil suspensions in physiological solution and their sowing on agar nutrient media were performed by conventional methods. The number of soil microorganisms was determined by sowing appropriate dilutions of microbial suspensions on agar media, which correspond to the trophic needs of microorganisms of the main ecological-trophic and taxonomic groups, the subsequent colonies counting. The amount of ammonifiers was determined on meat-peptone agar, spore-forming bacteria – on meat-peptone agar with the addition of glucose, micromycetes – on Czapek medium, bacteria that use mineral forms of nitrogen (on the 4th day of incubation of plates) and streptomycetes (on the 7th day of incubation of plates) – on starch-ammonia agar, oligonitrophils – on Ashbys medium diluted 100 times, pedotrophs – on medium containing soil extract [20; 21].

The content of total microbial biomass (C_{mic}) in the soil was determined by the rehydration method due to drying of soil samples at a temperature of 65-70ºC for 24 h followed by extraction with 0.5 M K_2SO_4 solution [22]. Determination of CO_2 released by the soil was performed in the laboratory from a constant temperature and humidity by the adsorption method – after alkaline adsorption and titration method determined the amount of CO_2 released from the soil [21; 23]. The phytotoxicity of the soil was measured by the Grodzinsky method in the Mochalov-Sherstoboev modification. *Raphanus sativum* seeds were used as a test culture. Inhibition of germination of radish seeds with a white tip was expressed as a percentage (%) [24].

Statistical processing of the research results, calculation of the standard deviation, and the smallest significant difference were carried on using the standard computer software package Microsoft Excel. The tests were performed in 5-fold repetition [25].

RESULTS AND DISCUSSION

Many years of soil research and determination of its impact on human life contributed to the fact that in the 1970-s 3 separate, but at the same time similar and maximally related, terms were formulated [26-28]. Namely, soil quality, soil health, and soil functionality. "Soil quality" usually describes the suitability of the soil for use in agricultural production [29]. The term "soil functionality" means the complex characteristics of particular land use with the productivity of plants and animals. "Soil health" – the ability of soil to function as a living system to maintain biological productivity and stabilisation of the health of plants, animals, and humans with the highest quality of the environment [27; 28]. Thus, soil health affects life and its characteristics, depending entirely on biodiversity and its dynamics. Moreover, numerous studies have shown that there is an integral connection between human health and soil condition [30-32].

Microbial groups of soil are represented by a set of interacting organisms that inhabit ecological niches with homogeneous conditions and carry out the transformation of energy and organo-mineral substances of this ecosystem. All connections in the grouping between members of associations of microorganisms are based on trophic interactions. Most soil microorganisms, with the exception of oligotrophs, remain inactive until the arrival of exogenous substrate [33]. The biological activity of soil is a function of its living component, which is manifested through the intensity of biological processes and is critical for ensuring the stability of ecosystems [34; 35]. Among the biodiagnostic parameters, the assessment of the number of microorganisms of the main ecological-trophic and taxonomic groups, the content of microbial biomass, the intensity of carbon dioxide emissions is especially important. The biological activity of soils is determined by the amount and composition of microbial metabolites, such as enzymes, amino acids, carbohydrates, nucleic acids, etc. These indicators not only correlate with microbial biomass but also reflect the nature of the transformation of organic matter and the specifics of environmental conditions [9; 36; 37]. Soil organic matter, comprising about 45-60% of its mass as soil organic C, is a principal source of energy for soil microorganisms [3].

The introduction of test substances presumably caused a reaction of a group of microorganisms to an exogenous factor. It was found that the number of microorganisms of the main ecological trophic and taxonomic groups directly depended on the type and composition of the test substance. The indirect effect, within statistically significant intervals, of the studied substances on the number of microorganisms of the main ecological-trophic and taxonomic groups was recorded depending on the study period (14 or 28 days) and the concentration of the introduced substance (min, max, 10 max). The number of ammonifiers for the introduction of prometryn in comparison with the control variant decreased, in the range of 10-12% (Table 3). The application of chlorperifos-methyl to the soil reduced the number of ammonifiers on the 14th day of the study by 1.3 times and on the 28th day by 1.5 times compared to the control. A significant decrease in ammonifiers was caused by the introduction of cymoxanil with dimethomorph. On the 14th day, the number of ammonifiers was noted at the level of 6.4 million CFU/g of soil, which is 1.6 times lower than in the control, on the 28th day the number of ammonifiers was 6.2 million CFU/g of soil, which is 1.7 times below control. Similar results were observed for spore-forming bacteria. On the 14th day of the study, the number of spore bacteria decreased by 28% and amounted to 1 million CFU/g of soil, and with the use of chlorperiphos-methyl – by 43% (0.8 million CFU/g of soil) compared to the control. The introduction of cymoxanil with dimetomorf caused a decrease in spore-forming bacteria 2.5 times on day 14 and 2.7 times on day 28. The introduced substances significantly affected the number of nitrogen-fixing microorganisms and bacteria that use mineral nitrogen. On the 14th day, the introduction of prometryn reduced the number of nitrogen fixers from 6.3 million CFU/g of soil (control) to 5 million CFU/g of soil on average at the applied concentrations. On day 28, reductions in nitrogen fixers fluctuated in statistically significant intervals on day 14 of the study. The introduction of prometryn into the soil reduced the number of bacteria using mineral nitrogen by no more than 10%. The introduction of chlorperiphos-methyl into the soil caused a decrease in bacteria using mineral nitrogen and nitrogen-fixing microorganisms, regardless of the applied concentration and the day of the study, by 1.1-1.3 times. Cymoxanil with dimetomorf reduced the number of nitrogen fixers compared to the control by 2-2.3 times, and the number of bacteria that use mineral nitrogen by 1.4 times.

***Table 3**. The number of microorganisms of the main-ecological trophic and taxonomic groups for the introduction of active substances PPP*

		Ammonifiers, *106 CFU/g of soil	Spore-forming bacteria, *106 CFU/g of soil	Mineral nitrogen immobilisers, *106 CFU/g of soil	Azotfixators, *106 CFU/g of soil	Phosfatmobilisers, *106 CFU/g of soil	Streptomicetes, *106 CFU/g of soil	Oligotrophs, *106 CFU/g of soil	Pedotrophs, *106 CFU/g of soil	Micromicetes, *103 CFU/g of soil	*Azotobacter*, % lumps of fouling
						14 day					
Control	–	*10.3±0.8*	*1.4±0.07*	*9.3±0.6*	*6.3*±0.4	*1.24±0.05*	*3.6±0.08*	*11.3±0.9*	*13.9±0.8*	*41.0±2.6*	*84*
Prometryn	min	9.9±0.6	1.1±0.06	8.0±0.6	5±0.3	0.9±0.06	2.2±0.1	10.7±0.5	11.9±0.6	30.4±2.1	67
	max	9.3±0.7	1±0.04	8.3±0.7	4.7±0.2	1.0±0.05	1.8±0.2	10.0±0.5	12.0±0.6	32.8±2.3	62
	10 max	9.6±0.8	0.98±0.03	8.6±0.7	5.1±0.3	0.8±0.06	2.5±0.1	10.2±0.5	11.6±0.5	31.9±2.2	68
Cymoxanil + Dimetomorf	min	6.4±0.7	0.47±0.01	6.7±0.5	3.0±0.1	0.4±0.03	0.9±0.1	8.5±0.9	9.2±1.1	17.0±2.7	45
	max	6.5±0.6	0.58±0.02	6.4±0.6	2.9±0.1	0.3±0.02	0.8±0.08	8.0±0.8	9.8±1.0	16.7±2.8	33
	10 max	6.4±0.7	0.51±0.02	6.8±0.6	2.6±0.1	0.4±0.02	1.0±0.06	8.8±0.8	9.9±1.0	17.5±2.7	48
Chlorpyrifos-methyl	min	8.1±0.6	0.81±0.06	7.1±0.8	4.1±0.2	1.0±0.06	1.6±0.13	9.2±0.7	10.8±0.7	21.8±1.4	58
	max	7.9±0.7	0.77±0.04	7.0±0.6	5.3±0.3	0.9±0.08	1.4±0.15	9.0±0.7	10.6±0.7	23±1.3	60
	10 max	8.2±0.6	0.82±0.03	7.7±0.6	4.7±0.2	0.8±0.06	1.6±0.16	8.8±0.7	10.2±0.8	19.0±1.3	54
						28 day					
Control	–	*10.8±0.9*	*1.2±0.06*	*8.9±0.7*	*6.5±0.4*	*1.1±0.04*	*3.4±0.2*	*11.1±0.9*	*13.7±1.1*	*40.9±2.6*	*88*
Prometryn	min	9.8±0.9	1±0.1	8.4±0.6	4.8±0.3	0.9±0.06	2.1±0.15	10.6±0.7	12±0.8	31.3±2.2	64
	max	8.9±0.7	0.9±0.07	8.6±0.7	5.2±0.32	0.95±0.07	1.8±0.1	9.8±0.5	11.8±1	34±2.3	65
	10 max	9.1±0.8	1.05±0.1	8.7±0.7	5±0.3	0.8±0.04	1.5±0.1	10.2±0.6	11.9±1.1	33.2±2.5	66
Cymoxanil + Dimetomorf	min	6.3±0.5	0.39±0.02	6.1±0.4	2.97±0.1	0.46±0.02	0.9±0.06	8.8±0.6	9.9±0.9	17.3±1.5	44
	max	6.2±0.6	0.4±0.03	6.06±0.5	2.64±0.1	0.3±0.02	0.88±0.07	7.8±0.5	9.2±0.8	16.9±1.4	36
	10 max	6.1±0.5	0.46±0.03	6±0.4	2.84±0.1	0.4±0.02	0.9±0.06	8.3±0.6	9.4±0.9	17.3±1.5	45
Chlorpyrifos-methyl	min	7.9±0.7	0.8±0.06	7.3±0.6	4.3±0.3	0.9±0.06	1.5±0.1	9.0±0.7	10.5±0.7	21.6±1.8	56
	max	7.8±0.8	0.75±0.05	7.5±0.5	5.7±0.2	0.8±0.06	1.3±0.1	9±0.8	10.3±0.7	22.5±2	59
	10 max	7.3±0.8	0.8±0.06	7.2±0.5	4.9±0.2	0.8±0.06	1.2±0.2	8.4±0.7	10.2±0.7	19.7±1.7	52

Promethrin and chlorperiphos-methyl did not significantly reduce the number of phosphate-mobilising bacteria compared to controls during the study period. The number of phosphate-mobilising bacteria under control on the 14th day was 1.24 million CFU/g of soil, on the 28th day – 1.11 million CFU/g of soil. When introducing prometryn and chlorperiphos-methyl, regardless of the day of the study, the number of phosphate-mobilising bacteria was noted at the level of 0.8-1 million CFU/g of soil. The application of cymoxanil with dimetomorf reduced the number of phosphate-mobilising bacteria in comparison with the control by 3 times, the number of this trophic group was fixed at 0.3-0.4 million CFU/g of soil. Similar dependencies were observed for oligotrophic microorganisms and pedotrophs. The level of growth of bacteria of the genus *Azotobacter* as an indicator of soil cultivation indicates that the introduction of cymoxanil with dimetomorph into the ecosystem reduced the percentage of fouling of lumps by bacteria of the genus *Azotobacter* by 1.8-2.5 times compared to the control. The introduction of cymoxanil from dimetomorphs compared with prometryn reduced the growth of *Azotobacter* by approximately 1.5 times and compared with chlorperiphos-methyl 1.3 times. Micellar groups of microorganisms, namely micromycetes and streptomycetes, significantly responded to the introduction of test substances.

The introduction of prometryn compared with the control reduced the number of micromycetes by 1.3 times, streptomycetes by 1.5-2 times depending on the concentration of the introduced substance. Chlorperiphos-methyl compared with the control and depending on the concentration caused a decrease in micromycetes by 1.7-2.1 times, a decrease in the number of streptomycetes was recorded at the level of 2-2.5 times. Cymoxanil with dimetomorf reduced the number of micromycetes by 2.5 times and streptomycetes by 3.5 to 4.5 times relative to the control variant.

Thus, the soil microbiocenosis actively responded to the introduction of the studied substances, which is quite indicative of the number of microorganisms of different ecological-trophic and taxonomic groups. The largest decrease in microorganisms of all ecological-trophic and taxonomic groups in the microbiocenosis compared with the control caused the introduction of cymoxanil with dimetomorf on average from 1.5 to 4.5 times; the use of chlorperiphos-methyl caused a decrease in numbers in the range of 1.1 to 2 times, prometryn reduced various ecological and trophic groups of microorganisms to 1.5 times on average.

It was found that the content of microbial biomass depended on the test (studied) substance (Table 4) and did not depend on the concentration of the test substance (min, max, 10 max) and fluctuated in the intervals of statistically significant intervals. It was found that the level of biomass did not depend on the study period (14 or 28 days).

***Table 4**. Biological activity of soil*

The active substance of the pesticide	Concentration a.s.	Microbial biomass, μg C/g of soil		Intensity of CO_2 emission of soil, mg CO_2/kg soil per day	
		14 day	28 day	14 day	28 day
Control	–	*601.3±36.1*	*597.8±29.9*	*246.8±14.8*	*241.4±16.6*
Prometryn	min	536.4±32.2	517.7±25.9	223.3±17.9	192.1±15.3
	max	521.9±20.9	504.2±36	226.7±13.6	195.1±17.6
	10 max	528.3±26.4	536.6±43	217.1±15.2	188.3±13.2
Cymoxanil + Dimetomorf	min	316.6±22.2	322.4±16.1	122.4±7.3	86.3±6.3
	max	336.4±20.2	339.5±27.2	108.5±8.7	82±6.7
	10 max	321.5±22.5	312.8±18.2	114.7±8	73.2±6.5
Chlorpyrifos-methyl	min	454.2±36.4	456.8±22.8	186.5±11.2	167.2±11.4
	max	429.7±25.8	437.2±30.6	197.1±10.8	155±11.1
	10 max	441.1±30.9	438.3±26.3	192.6±8.7	151.4±10.9

The use of prometryn reduced the content of microbial biomass by an average of 10-13%, depending on the concentration of the active substance. Studies of chlorperiphos-methyl showed that the content of microbial biomass in the studied samples ranged from 429.7 to 454.2 μg C/g of soil, which is 25% lower compared to the control version (without the introduction of any substances). The highest level of reduction of microbial biomass content was caused by the introduction of a composition of cymoxanil and dimetomorf into the soil. The obtained data correlate with the indicators of the number of microorganisms of ecological-trophic and taxonomic groups. Thus, for the experimental variants, there was a significant decrease in the content of microbial biomass by an average of 44% compared to the control variant, 36% compared with prometryn, and 25% – chlorperiphos-methyl.

The use of the studied substances affected the state of the microbial coenosis and caused a decrease in the "respiration" of the soil depending on the variant and period of the study. The concentration of the test substance (min, max, 10 max) did not significantly alter the studied indicator. The use of chlorperiphos-methyl caused a decrease in the intensity of carbon dioxide emissions by 20.7% (14 days of the study) and 31.5% (28 days). In variants with the use of prometryn on the 14th day there was a decrease in the intensity of carbon dioxide emissions by 8%, and on the 28th day – by 12%. The composition of cymoxanil with dimetomorf compared with the control variant caused a decrease in the intensity of carbon dioxide emissions by 51.4% (14 days of the study) and 64.8% (28 days of the study). There was a slight decrease in the intensity of carbon dioxide emission for variants using min, max, and 10 max concentrations of prometryn and chlorperiphos on the 14th and 28th days of the study. However, the use of a composition of cymoxanil with dimethomorph also depended on the period of application. Thus, the indicators of carbon dioxide emission intensity on the 14th day were on average 30% higher than on the 28th day of the study.

The study of soil phytotoxicity with the introduction of PPP chemicals is shown in Table 5. It was found

that the highest level of inhibition-test culture growth (from 20 to 24%) was caused by prometryn. Thus, the soil when using prometryn is slightly phytotoxic. In variants using chlorperiphos-methyl, the level of inhibition of the test culture was recorded at the level of 15-18%, at the level of control. The use of a composition of cymoxanil with dimetomorf reduced the level of soil phytotoxicity from 6 to 10%, compared with the control. That is, this composition inhibits the level of development of phytopathogenic microorganisms and the accumulation of their toxic substances in the soil. Thus, the soil of the variant using a composition of cymoxanil with dimetomorf, regardless of the concentration of the study, is not phytotoxic.

***Table 5**. Inhibition of growth of test plants at application of active substances PPP, %*

Concentration a.s.	Prometryn		Cymoxanil + Dimetomorf		Chlorpyrifos-methyl	
	14 day	28 day	14 day	28 day	14 day	28 day
Control	*18*	*16*	*17*	*18*	*16*	*17*
min	20	21	11	8	18	16
max	22	23	9	12	16	16
10 max	22	24	7	9	17	15

Thus, studies of the effect of introduced substances (prometryn, chlorperiphos-methyl and composition of cymoxanil and dimetomorf) on the state of the microbiocenosis show that the microbial group is most indicative and in a short period allows determining the impact of exogenous chemicals on the number of ecotrophic and taxonomic groups and biological activity of the soil.

Any microbiocenosis consists of microorganisms of different functional and taxonomic groups, which differ in requirements for environmental conditions, nutrition, and energy sources. The quantitative ratio between these groups depends entirely on environmental conditions (abiotic and biotic factors), in which microbial coenosis is formed [38]. As a result of the study, it was found that the soil microbiocenosis reacted most significantly to the use of a composition of cymoxanil and dimetomorf. As a result, a decrease in the number of microorganisms of all ecological-trophic and taxonomic groups, biomass content, and intensity of carbon dioxide emissions was observed. Inhibition of physiological and metabolic processes in the microbiocenosis when using a composition of cymoxanil with dimethomorph is explained by the specific effect of the studied substances. Thus, the studied composition of cymoxanil with dimetomorf affects not only phytopathogenic fungi (inhibits their reproduction) but also all groups of soil micromycetes (cellulose-destroying, saprophytic), which predominate in the formation of a pool of soil microorganisms. The use of chlorperiphos-methyl also caused a restructuring of the microbiocenosis, but the inhibition of metabolic reactions was significantly lower compared with a composition of cymoxanil and dimetomorf. The use of prometryn (the active substance of a significant amount of soil herbicides) was characterised by a slight effect on the number of microorganisms of the different ecological, trophic, and taxonomic groups and the overall biological activity of the soil. Soil microbiocenosis is not only a sensitive indicator of the influence of biotic, abiotic, or anthropogenic factors. Microbiocenosis has another function of the ecosystem level – the ability to produce biologically active substances, which have both phytotoxic and phytostimulant effects. Therefore, the state of the microbiocenosis (level of activity, restructuring), the response to exogenous factors can be assessed by phytotoxicity. It is shown that the use of a composition of cymoxanil with dimethomorph reduces the level of soil phytotoxicity to 12% compared to the control variant of 18%. When using chlorperiphos-methyl – the level of phytotoxicity remained at the level of control indicators. The highest level of phytotoxicity as a result of the research was determined for prometryn – 24%. That is, such soil where prometrin was used has phytotoxic properties. It is believed that this is due to the chemical class of the substance (herbicide) and the mechanism of action on the plant organism. Therefore, the influence of PPE chemicals on the microbiocenosis can be shown as follows: *PROMETRYN (the lowest level of influence) → CHLORPYRIFOS-METHYL → CYMOXANIL + DIMETOMORF (the highest level of influence)*.

The present research is consistent with data from other scientists who have studied the effects of pesticides and agrochemicals on microbiocenosis and plant productivity [39-46]. M. Ahmed et al. in the *in vitro* research showed that increasing the concentration of fungicide in the nutrient medium causes not only a decrease in the number of microorganisms of the genus *Rhizobium*, but also a decrease in the diameter of the colony on the nutrient medium [39]. K. Pudełko et al. emphasised that the use of the fungicide Funaben T (148 g/l carbendazine + 332 g/l thiram) with further seed inoculation with a biological product causes nodulation process of soybean plants, which leads to a decrease in qualitative and quantitative yields [40].

The issue of the influence of PPP directly on soil microorganisms was shown in the work of M.N. Filimon

et al. It was found that pre-sowing seed treatment with fungicides cypermethrin and thiamethoxam negatively affects the number of microorganisms of the main ecological-trophic and taxonomic groups. Namely, reduces the number of bacteria of the *Azotobacter* genus and bacteria that use mineral forms of nitrogen (diazotrophs), at least twice [41]. Researchers from the D.K. Zabolotny Institute of Microbiology and Virology of the NASU showed that the treatment of seeds with fungicides (Maxim Star, Vitavax, Kyoto Duo), mainly caused a decrease in the number of microorganisms in the studied groups. However, inoculation of seeds with *Bradyrhizobium japonicum* strains (UKM B-6035 and UKM B-6023) reduced the negative effect of Maxim Star and Kinto Duo fungicides on oligoazotrophic and prototrophic microorganisms. At the same time, Vitavax did not alter the number of microorganisms but inhibited the nitrogen-fixing activity of all industrial strains of inoculants [42; 43].

Results of vegetation research of the formation of the pigment system of pea and soybean plants depending on the use of different PPP in combination with biological products' inoculation showed an increase in the content of photosynthetic pigments. The growth of chlorophyll a was recorded on average by 14-18%, chlorophyll b – 45-63%, the amount of chlorophyll a+b – 20-27%, carotenoids – 9-11% [44; 45]. Scientists emphasise the increase in the activity of the photosynthetic apparatus due to the intensification of metabolic processes in plants and as a result of the more active synthesis of pigments. It is proved that PPP directly affects the condition of plants [46]. The usage of the herbicide Prima Forte 195 (in the recommended and inflated rates) causes oxidative stress in winter wheat plants. But the integrated use of Prima Forte herbicide in combination with a plant growth regulator has contributed to an increase in the rate of detoxification of xenobiotics in winter wheat plants.

Thus, the management of qualitative and quantitative indicators of soil is, first of all, the management of microbiological processes occurring in it. Therefore, a comprehensive study of the basic patterns of development of microbial groups and their functional activity depending on edaphic and agronomic factors remains relevant.

CONCLUSIONS

The soil microbiocenosis actively responded to the introduction of the studied chemicals, which are the basis of known and widely used in agricultural production PPP. In the present research it was determined that the introduction of cymoxanil with dimethomorph significantly affected the number of microorganisms of different ecological-trophic and taxonomic groups. On average, the number of microorganisms decreased by 1.5-4.5 times relative to control; the content of microbial biomass decreased by 44%, and the intensity of carbon dioxide emissions decreased from 51.4 to 64.8%; the level of phytotoxicity of the soil was in the range of 7-12%.

It was found that chlorperiphos-methyl in comparison with the control caused a decrease in the number of microorganisms of the main ecological-trophic and taxonomic groups in 1.1-2 times; reduced the content of microbial biomass by 25%, the intensity of carbon dioxide emissions by 20.7-31.5%; the level of soil phytotoxicity ranged from 15 to 18%.

It is shown that the level of phytotoxicity of the soil increases to 20-24% when using prometryn, but the indicators of the state of the microbiocenosis are at a high level in comparison with other investigated substances. Compared with the control variant, the number of microorganisms decreased by no more than 1.5 depending on the ecological-trophic group; carbon dioxide emission intensity by 8-12%, microbial biomass content – by 10-13%.

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Вплив хімічних речовин засобів захисту рослин на мікробіоценоз ґрунту

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Анотація. З моменту виникнення землеробства перед людиною постають складні завдання: як використати потенціал грунту й при цьому зберегти його якісні та функціональні властивості, як застосовувати в агротехнологіях ефективні та еколого-безпечні для здоров'я людини та біоти ЗЗР і багато інших. Існує низка інформативних і достовірно реєструючих критеріїв і систем показників, які повністю та всебічно описують зміни екологічного стану ґрунту і агроценозів, проте всі ці системи мають один недолік – це час від дії чинника до «реакції» показника. Рання діагностика змін в агроценозі можлива завдяки біологічній компоненті ґрунту, а саме мікробіоценозу, оскільки мікроорганізми мають велику поверхню контакту з середовищем, високу швидкість розмноження в просторі та часі, чутливість до мінливих умов існування. У лабораторних умовах досліджено реакцію мікробіоценозу ґрунту та його активність (чисельність мікроорганізмів еколого-трофічних і таксономічних груп, інтенсивність респірації, вміст мікробної біомаси та фітотоксичність ґрунту) за дії хімічних речовин, які є основою засобів захисту рослин (ЗЗР). Виявлено, що чисельність мікроорганізмів різних еколого-трофічних і таксономічних груп за дії суміші цимоксанілу з діметоморфом зменшувалась у 1,5–4,5 рази відносно контролю, хлорперіфос-метилу в 1,1–2 рази, а прометрину – не вище ніж у 1,5. Вміст мікробної біомаси й інтенсивність емісії диоксиду вуглецю при застосування цимоксанілу з діметоморфом порівняно з контрольним варіантом зменшувався на 44 % та 51,4–64,8 %, відповідно; прометрину – на 10–13 % та на 8-12 %. Найвищий рівень фітотоксичності ґрунту відмічали для варіантів з застосуванням прометрину (20–24 %), найнижчий для суміші цимоксанілу з діметоморфом (7–12 %). Вважаємо, що високий рівень інгібування розвитку тест-культури при застосуванні прометрину пов'язаний з класом ЗЗР і механізмом його впливу на рослинний організм. Низькі показники фітотоксичності грунту та активності мікробіоценозу при застосуванні цимоксанілу з діметоморфом пояснюються впливом досліджуваної суміші не лише на фітопатогенні мікроміцети, а й на усі групи ґрунтових мікроміцетів (целюлозоруйнівних, сапрофітних), які домінують у мікробіоценозі. Отже, вплив хімічних речовин ЗЗР на мікробіоценоз можливо показати у такий спосіб: *ПРОМЕТРИН (найнижчий рівень впливу) → ХЛОРПЕРИФОС-МЕТИЛ → ЦИМОКСАНІЛ + ДІМЕТОМОРФ (найвищий рівень впливу)*

Ключові слова: мікробіоценоз, мікроорганізми основних еколого-трофічних та таксономічних груп, емісія диоксиду вуглецю, мікробна біомаса

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Lipoperoxidation in Grain Sorghum under the Influence of Herbicides, Phytohormones, and Biopreparation

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Abstract. The use of herbicides for sowing grain cultures, including grain sorghum, is an integral condition for high yield indicators. However, upon penetrating into plant organisms, herbicides can intensify synthesis of the reactive oxygen species, which leads to the aggravation of lipid peroxidation and activates antioxidant systems, namely superoxide dismutase enzyme. It is known that phytohormones and microbial preparations, if included in the cultivation technology, can improve plants' ability to resist oxidative stress caused by xenobiotics. However, the integrative influence of herbicides, phytohormones, and microbial preparations on activity of superoxide dismutase enzyme as well as on lipid peroxidation intensity in plants of grain sorghum is understudied, which preconditioned the purpose of this study. The objects of this study were as follows: grain sorghum (*Sorghum bicolour* (L.) Moench) of the Milo W hybrid, herbicide Cytadel 25 OD, phytohormone Endofit L1 and biopreparation Bioarsenal. The study was conducted following the requirements of vegetation method. The activity of lipid peroxidation was investigated according to the number of malondialdehyde formed in the plant tissues. The activity of superoxide dismutase enzyme (EC 1.15.1.1) was investigated according to its ability to compete with nitro blue tetrazolium for superoxide anions resulting from interaction between the reduced form of nicotinamide adenine dinucleotide phosphate and phenazine methosulfate. The study revealed that under the effect of the herbicide Cytadel 25 OD, indicators of the lipid peroxidation activity in plants averaged 26.2-93.2% higher than in control sample, depending on the herbicide rate and the day after application. Activity of superoxide dismutase in these conditions exceeded that in the control sample by 18.2-96.8% on average. However, provided the joint use of herbicides, phytohormones, and biopreparation, the plants demonstrated a decrease of the lipid peroxidation activity. It lowered by 14.5-19.1% against the background of superoxide dismutase increase by 22.0-38.7% relatively to the variants where only herbicide was used. Results of the experiment attest the positive influence of the phytohormone and biopreparation on the grain sorghum's resistance to the oxidative stress caused by herbicides. The observed data can become a cornerstone for the further development of biologised cultivation technologies of this culture

Keywords: superoxide dismutase, lipid peroxidation, antioxidant defence, biologisation, oxidative stress

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INTRODUCTION

In present-day agriculture, the cultivation of agricultural crops, including grain sorghum, is unimaginable without use of numerous preparations, among which, herbicides are the most common. However, it is known that active components of herbicides can substantially affect the physiological processes not only in weeds, but also in crop plants. Upon entering the endogenous system of plants, they interfere with physiological processes, causing accumulation of reactive oxygen species (ROS) in their tissues. It is proved that superoxide radical, one of the typical ROS representatives, can provoke lipid peroxidation (LPO) through numerous chemical reactions [1; 2]. As a result, polyunsaturated fatty acids break up while reactive aldehydes develop, disrupting the DNA and amino acids' structure in cells [3].

Scientists consider the functioning of antioxidant systems among the mechanisms of protection of cells from the adverse effects of ROS. Such systems contain numerous enzymes, including superoxide dismutase (SOD) (EC 1.15.1.1). This enzyme catalyses the dismutation of oxygen superoxide and hydrogen peroxide in the initial stages of neutralisation of active radicals [4]. The efficiency of this process affects the rate at which the plant overcomes oxidative stress and becomes able to fully restore its normal metabolism.

Thus, modern-day studies [5; 6] prove that SOD plays an important role in the ROS detoxification process and activity of this enzyme increases according to the level of stress affecting the plants. In this regard, researchers of searching methods to enforce the antioxidant activity of plants to make them overcome consequences of impact of stress factors more effectively. The use of phytohormones and microbial preparations are often highlighted among the relevant means of solving this issue [7; 8]. It is known that inclusion of these components into the grain cultures cultivation technology increases antioxidant activity in plant tissues and ultimately leads to declining intensity of lipid peroxidation processes [9; 10]. However, the impact of such preparations on the specified indicators of grain sorghum plants has not been studied before, which preconditioned the *purpose of this study*.

LITERATURE REVIEW

It is proved that herbicides, as chemical substances, intensify the production of ROS in cultivated plants. In particular, herbicides based on pyrimidine and paraquat cause oxidative stress in plants via the production of ROS. The dicationic nature of these compounds contributes to their reduction to radical cations. Reduction of dications occurs involving the first photosystem to form monocation radical, which, reacting with the atomic oxygen, forms the superoxide radical [11]. Herbicide Diuron blocks electron transport in the process of photosynthesis, Norflurazon inhibits biosynthesis of carotenoids as a consequence of photooxidative processes caused by synthesis of oxygen in cells [12].

A.S. Lukatkin et al. [13] state that increased concentrations of ROS activate LPO in cells resulting in their damage. For example, treatment of winter wheat, rye, and maize plants with herbicide Topic at a concentration of 800 mg/l led to increase of lipoperoxidation activity on the first day of experiment by 16-56% depending on the crops. However, there was no substantial LPO increase at a Topic concentration of 8 and 80 mg/l. On the second day after the herbicide application, LPO level increased in the leaves of winter wheat by 90% compared to the control sample, but the same effect did not occur in rye and maize. On the third day of the experiment, all the variants showed the LPO increase, especially at herbicide concentration of 800 mg/l.

N.H. Song et al. [14] discovered that the SOD and LPO activity processes increased when herbicide Chlorotoluron was applied into the soil at concentrations of 5, 10, 15, 20, and 25 mg/kg. At the herbicide concentration of 10 mg/kg of soil, the number of thiobarbituric acid reactive substances increased two times in the plant tissue compared to the control sample. During the further increase of preparation concentration to 25 mg/kg of soil, the number of reactive substances decreased. However, histological examination of the plants using nitro blue tetrazolium proved the further increase of the oxidative stress. The SOD activity, in turn, also increased along with the preparation concentration in the soil. In particular, activity of this enzyme was 1.2-3.5 times higher than in control sample with the concentration of Chlorotoluron at 5-15 mg/kg of soil. However, further preparation concentration increase to 25 mg/kg of soil decreases the SOD activity to the control level.

V.P. Karpenko et al. [7] note that the herbicide Kalibr 75 at the concentration of 30-70 g/ha in different combinations with the phytohormone Ahrostymulin and microbial preparation Ahat-25K changed the SOD and LPO activity in plants of spring barley. The amount of malondialdehyde in the tissues of plants increased by 26.2-126.8% on the third day after the herbicide application which testifies to the rise of the LPO level. However, when the herbicide was applied jointly with the phytohormone on the background of pre-sowing seed treatment by the microbial preparation, the LPO activity was lower by 14.8-22.5% compared to the variants where only herbicide was used. The SOD activity increased by 29.9-123.9% upon treating the plants with Kalibr 75, but when it was combined with the phytohormone and applied on the background of pre-sowing seed treatment it was 16.0-27.6% which testifies to the increased ability of plants to resist the oxidative stress.

Therefore, herbicides, phytohormones, and microbial preparations can directly or indirectly impact the activity of the LPO processes and the activity of the SOD in plants. However, there is a lack of research related to the influence of preparations on the given indicators in grain sorghum plants, which mainstreamed the study in this area.

MATERIALS AND METHODS

The objects of vegetative [15] experiment were as follows: grain sorghum (*Sorghum bicolour (L.) Moench*) of the Milo B hybrid [16], herbicide Cytadel 25 OD (penoxsulam 25 g/l), phytohormone) Endofit L1 (auxins, gibberellins, cytokinins – 0.26-0.52%) and biopreparation Bioarsenal (*Beauveria Bassiana* fungi, strain MG 301 (GHA), CFU $2x10^{10}$; *Beauveria Bassiana*, strain MG 302 (DB-1), CFU $2x10^{10}$; bacteria *Azospirillum spp*. – MG 401, CFU $1.5x10^{10}$; and *Azotobacter spp*. – MG 402, CFU $1.5x10^{10}$ per 100 g of preparation) [17].

Plants were grown in plastic containers with capacity of 12 kg of absolutely dry soil, typical for the field experiments. Soil – podzolised heavy-loamy chernozem. Humus content in the topsoil – 3.5%, alkaline hydrolysed nitrogen (according to the Cornfield method) – 103 mg/kg of soil, mobile phosphorus and potassium compounds (according to the Chirikov method) – 88 and 132 mg/kg, respectively. Hydrolytic acidity – 2.26 cmol/kg of soil, soil pH – 6.2 [18]. Soil humidity was maintained at the level of 60% according to the gravimetric method. Additional lighting was provided by fluorescent lamps. Temperature was maintained at the level of 25°C. Relative air humidity – 60%.

The scheme of the experiment included 16 variants in threefold repetition: without the preparations (control sample), Cytadel 25 OD at a concentration of 0.6, 0.8, and 1.0 l/ha separately and in combinations with the phytohormone Endofit L1 (30 ml/ha) on the background of pre-sowing seed treatment by the biopreparation Bioarsenal (800 g/100 kg) and without it.

Lipid peroxidation activity was evaluated according to the number of formed malondialdehyde (MDA) in the plant tissues [19]. Solution of triton X-100, hydrochloric acid, and thiobarbituric acid (TBA) were successively added to the test tube containing the plant material (supernatant). The mixture was heated up in the heated bath for 10 minutes. Cooling was carried out at the temperature of 15°C for 30 minutes. For colour stabilisation, solutions of trilon B and ethanol were added to the reaction mixture. A sample to which all the same solutions were added, except the TBA, was used as the control sample. The resulting solutions were analysed on a spectrophotometer at the wavelength of 532 nm and with further calculations of the LPO level (in μmol/g) according to the following formula (1):

$$LPO = \frac{D * V_1 * V_3}{156 * P * V_2} \quad (1)$$

where D is the light absorption of the sample, conventional units; V_1 is the overall volume of the tissue homogenate, ml; V_2 is the volume of the supernatant that was added to the test tube, ml; V_3 is the final volume of the sample in the test tube, ml; 156 is the coefficient of the micromolar light absorption; P is the mass of the plant material sample, g.

Superoxide dismutase (EC 1.15.1.1) activity was evaluated by its ability to compete with the nitro blue tetrazolium for superoxide anions which form as a result of interaction between reduced nicotinamide adenine dinucleotide and phenazine methosulfate [20]. As a result of this reaction, nitro blue tetrazolium reduces forming hydrazine tetrazolium. In the SOD presence, the percentage of the reduced nitro blue tetrazolium decreases, which reflects on the optical density of the reaction mixture. Supernatant was prepared in the way of homogenisation of the examined material with 0.05 M solution of potassium phosphate pH 7.8 and further centrifugation at 20,000 g for 10 minutes [21]. When all components were mixed, the initial extinction of the reaction mixture was assessed using a spectrophotometer at the wavelength of 540 nm and thickness of the optical layer of 10 mm. The assessment was repeated after 10 minutes, registering the increase of the optical density of the mixture. Further calculations were performed according to the following formula (2):

$$\%\ \text{of blockage} = \frac{E_0 - E_{pr}}{E_0} * 100 \quad (2)$$

where E_0 is the extinction of reaction mixture while there is no SOD (null sample); E_{pr} is the extinction of the reaction mixture in a state of equilibrium.

In the studied samples, the SOD content (conventional units/g of raw material) was determined based on the calibration curve according to the calculated percentage of inhibition of the nitro blue tetrazolium reduction.

Statistical analysis was performed according to B. Dospehov's method [22] using Microsoft Office Excel 2019.

RESULTS AND DISCUSSION

This study found that the LPO intensity in the tissues of grain sorghum depended on the concentration of the herbicide and its combination with the phytohormone and biopreparation (Table 1).

Table 1. *Activity of the LPO processes in the grain sorghum leaves under the effect of the herbicide Cytadel 25 OD, phytohormone Endofit L1 and biopreparation Bioarsenal*

Variant of the experiment	MDA content, μmol/g of raw substance	
	On the third day	On the tenth day
Without use of the preparations (control)	14.6	23.7
Cytadel 25 OD 0.6 l/ha	19.5	29.9
Cytadel 25 OD 0.8 l/ha	23.1	32.8

Table 1, Continued

Variant of the experiment	MDA content, μmol/g of raw substance	
	On the third day	On the tenth day
Cytadel 25 OD 1.0 l/ha	28.2	37.4
Endofit L1 30 ml/ha	12.1	20.3
Cytadel 25 OD 0.6 l/ha + Endofit L1 30 ml/ha	17.2	26.7
Cytadel 25 OD 0.8 l/ha + Endofit L1 30 ml/ha	21.0	30.2
Cytadel 25 OD 1.0 l/ha + Endofit L1 30 ml/ha	26.3	34.6
Bioarsenal 800 g/100 kg (pre-sowing seed treatment, background)	11.0	18.8
Cytadel 25 OD 0.6 l/ha + background	16.2	25.1
Cytadel 25 OD 0.8 l/ha + background	20.1	28.0
Cytadel 25 OD 1.0 l/ha + background	25.2	32.8
Endofit L1 30 ml/ha + background	9.9	17.3
Cytadel 25 OD 0.6 l/ha + Endofit L1 30 ml/ha + background	15.0	24.2
Cytadel 25 OD 0.8 l/ha + Endofit L1 30 ml/ha + background	18.7	26.7
Cytadel 25 OD 1.0 l/ha + Endofit L1 30 ml/ha + background	24.1	31.5
LSD_{01}	0.7	0.9

Thus, on the third day after applying the herbicide Citadel 25 OD at the concentrations of 0.6 l/ha, 0.8 l/ha, and 1.0 l/ha, the LPO intensity increased compared to the control sample by 33.6%, 58.2%, and 93.2%, respectively; on the tenth day – by 26.2%, 38.4%, and 57.8%, respectively. Apparently, such LPO intensification is a consequence of increased ROS formation during xenobiotic detoxification by the plants, in particular, involving the cytochrome P450 complex, which catalyses the penoxsulam neutralisation – an active compound of the herbicide Cytadel 25 OD [2; 23; 24]. However, upon applying the same herbicide concentrations together with the phytohormone Endofit L1, the LPO activity in the grain sorghum plants decreased by 11.8%, 9.1%, and 6.7%, respectively – on the third day, and by 10.7%, 7.9%, and 7.5%, respectively – on the tenth day compared to the variants where only herbicide was used. It is consistent with experimental results of other scientists [7; 25] which also registered a considerable decrease of the LPO intensity under the influence of phytohormones. A similar effect was also observed when the herbicide was applied at the concentrations of 0.6 l/ha, 0.8 l/ha, and 1.0 l/ha against the background of pre-sowing seed treatment by the biopreparation Bioarsenal. Thus, on the third day after the herbicide application, the LPO activity in these variants was lower than in the variants with only herbicide use by 16.9%, 13.0%, and 10.6%, respectively. On the tenth day, this indicator decreased by 16.1%; 14.6%; and 12.3%, respectively.

The lowest LPO indicators were observed in the variants where the herbicide Cytadel 25 OD was applied together with the phytohormone Endofit L1 against the background of pre-sowing seed treatment by the Bioarsenal. Under these conditions, the intensity of lipoperoxidation processes on the third and tenth day, was by 23.1% and 19.0%, 14.5% and 19.1%, 18.6% and 15.8%, respectively, lower than in the variants with only herbicide. However, it remained higher than the control sample by 2.7-65.1% and 2.1-43.9%, respectively. Evidently, the stress level was lower upon the complex use of the preparations under study than in the variants where only herbicide was used. Such changes in the LPO intensity can possibly be connected to the intensive functioning of the antioxidant systems. In this regard, to determine the reasons of the LPO activity decrease upon the complex use of preparations, the authors investigated the SOD activity.

According to the experiment results (Table 2), the SOD activity also altered in different combinations of the preparations under study.

***Table 2**. SOD activity in the grain sorghum leaves under the effect of the herbicide Cytadel 25 OD, phytohormone Endofit L1 and biopreparation Bioarsenal*

Variant of the experiment	SOD, CU/g of raw substance	
	On the third day	On the tenth day
Without use of the preparations (control)	1.24	2.36
Cytadel 25 OD 0.6 l/ha	1.56	2.79
Cytadel 25 OD 0.8 l/ha	1.97	3.45
Cytadel 25 OD 1.0 l/ha	2.44	4.12
Endofit L1 30 ml/ha	1.40	2.68
Cytadel 25 OD 0.6 l/ha + Endofit L1 30 ml/ha	1.93	3.33
Cytadel 25 OD 0.8 l/ha + Endofit L1 30 ml/ha	2.34	3.95

Table 2, Continued

Variant of the experiment	SOD, CU/g of raw substance	
	On the third day	On the tenth day
Cytadel 25 OD 1.0 l/ha + Endofit L1 30 ml/ha	2.78	4.60
Bioarsenal 800 g/100 kg (pre-sowing seed treatment, background)	1.43	2.71
Cytadel 25 OD 0.6 l/ha + background	1.99	3.42
Cytadel 25 OD 0.8 l/ha + background	2.46	4.06
Cytadel 25 OD 1.0 l/ha + background	2.91	4.74
Endofit L1 30 ml/ha + background	1.49	2.79
Cytadel 25 OD 0.6 l/ha + Endofit L1 30 ml/ha + background	2.16	3.62
Cytadel 25 OD 0.8 l/ha + Endofit L1 30 ml/ha + background	2.68	4.31
Cytadel 25 OD 1.0 l/ha + Endofit L1 30 ml/ha + background	3.18	5.03
LSD_{01}	0.14	0.17

Therewith, the activity of this enzyme increased upon the herbicide treatment of plants by 25.8%, 58.9%, and 96.8% – on the third day and by 18.2%, 46.2%, and 74.5% – on the tenth day of the experiment compared to the control sample. These changes in the SOD activity could possibly be caused by the increase of the ROS concentration in the plant tissues against the background of the xenobiotic influence. A similar effect was also described by other researchers [4; 26], who studied activity of this enzyme in plants under the influence of herbicides. In addition, application of the herbicide at the concentrations of 0.6 l/ha, 0.8 l/ha, and 1.0 l/ha in combination with the phytohormone Endofit L1 increased the SOD activity by 14.2-24.1% (third day) and 11.6-19.3% (tenth day) relatively to the samples treated exclusively by herbicides. Intensification of the antioxidant processes, namely the SOD activity, under the influence of exogenous phytohormones on plants is reflected in numerous studies [27-30], which associate this process with strengthening of the metabolism in plants. Experimental samples, where herbicide was applied against the background of pre-sowing seed treatment by the Bioarsenal demonstrated a similar tendency – on the third and tenth day, the SOD activity increased by 19.6-27.5% and 14.9-22.5%, respectively. The highest indicators of the SOD activity were observed at the compatible use of the herbicide and phytohormone against the background pre-sowing seed treatment by the biopreparation. On the third and tenth day of the experiment, the activity of this enzyme exceeded control by 0.92 CU/g, 1.44 CU/g, 1.94 CU/g, and 1.26, CU/g, 1.95 CU/g, 2.67 CU/g of raw substance, respectively, which was higher than indicators of the variants treated exclusively by herbicides 30.7-38.7% and 22.0-29.6%.

To establish the nature of the dependence between the two researched indicators, the authors of this study performed a correlation analysis, which resulted in the discovery of a strong positive connection between the SOD and LPO activity. On the third and tenth day of experiments it was 0.78 and 0.72, respectively.

The results of the study suggest that the herbicide Cytadel 25 OD at the concentrations of 0.6 l/ha; 0.8 l/ha, and 1.0 l/ha cause the increase of the ROS production, particularly superoxide radical, in the grain sorghum plants, which is accompanied by intensified lipid peroxidation. Such effect is expected, because xenobiotics cause numerous malfunctions in cells, leading to their damage [31]. As a result, antioxidant systems activate in plants, and their functions are implemented by numerous specific enzymes. Thus, the SOD activity, as one of the key antioxidants, increase along with the concentration of herbicide Cytadel 25 OD.

Phytohormones and microbial preparations allow fulfilling a genetic potential of agricultural crops better, which manifests in increasing their resistance to various forms of stress [7]. In this regard, samples under study that were treated with herbicide in combination with phytohormone Endofit L1 and biopreparation Bioarsenal demonstrate a substantial increase in the SOD activity compared to the samples treated exclusively by herbicides. Therewith, increase in the SOD activity was accompanied by simultaneous decrease of the lipid peroxidation activity, which testifies to the increase of the ROS neutralisation efficiency in the plants.

Other researchers have also observed similar results in their studies. For example, Z.M. Hrytsaienko et al. [32] note that treatment of spring barley plants with herbicide Hranstar 75 at the concentrations of 10, 15, 20 and 25 g/ha increases the SOD activity by 25.6-126.5% compared to the control sample. However, application of the herbicide in combination with phytohormone Emistym C led to a more pronounced activation of the SOD, which manifested itself in an increase of this enzyme activity by 17.6-31.7% compared to the samples treated exclusively by herbicides. Lipid peroxidation processes also altered in the experiment conditions. At the herbicide concentrations of 10-25 g/ha malondialdehyde content in the leaves of the spring barley was 32.8-130.2% higher than in the control sample. Application of the herbicide in mixtures with the phytohormone caused decrease of the LPO activity in plants compared to the samples without the phytohormone. This effect was the most pronounced in the samples with the lower herbicide concentrations (10-15 g/ha) and weakened when the

concentration increased to 25 g/ha. A possible explanation to such a regularity is a particular levelling of the protective action of the phytohormone upon higher herbicide concentrations.

N. Khan et al. [33] also observed similar results in the chickpea crops. In the stress conditions, the activity of the LPO in the plants increased, but when the seeds were pre-treated with microbial preparations before sowing and the crops were sprayed with a phytohormone – lipid peroxidation activity decreased.

W. Zhang et al. [34] discovered analogous tendencies upon treating wheat plants by phytohormones in the abiotic stress conditions. The LPO level in the wheat plants decreased by 12.6-48.6% compared to the control in the samples treated with phytohormones. Therewith, in these conditions, a substantial increase in the SOD activity was observed – by 4.7-12.4% compared to the control sample.

Therefore, the results of this study are consistent with the data observed by other researchers regarding the impact of phytohormones and microbial preparations on the intensity of lipid peroxidation processes and the SOD activity in cultural plants under herbicide stress conditions. However, the highest efficiency was registered in the samples treated by the herbicide Cytadel 25 OD in combination with the phytohormone Endofit L1 application against the background of pre-sowing seed treatment by Bioarsenal preparation.

CONCLUSIONS

Application of the herbicide Cytadel 25 OD at the concentrations of 0.6, 0.8, and 1.0 l/ha intensifies the lipoperoxidation in plants of grain sorghum. However, when the herbicide is combined with the phytohormone Endofit L1, as well as when it is used against the background of pre-sowing seed treatment by the biopreparation Bioarsenal, the LPO intensity decreases compared to the samples treated exclusively by the herbicide, which is one of the consequences of the antioxidant activity increase in plants, namely the activity of the SOD enzyme.

The most favourable conditions for overcoming consequences of the xenobiotic influence on the grain sorghum plants form in the combined use of the herbicide Cytadel 25 OD and phytohormone Endofit L1 against the background of pre-sowing seed treatment by Bioarsenal. The SOD activity in such experimental samples exceeded that of the control sample by 99.3% on average, which is 30.3% higher than in the samples treated exclusively by herbicides. The LPO reactions were suppressed against the background of the SOD activity increase and their intensity decreased by 17.2% compared to the herbicide-only samples.

Thus, integrated use of the herbicide Cytadel 25 OD, phytohormone Endofit L1, and biopreparation Bioarsenal is an expedient measure that allows decreasing the harmful influence of the herbicides on the grain sorghum plants.

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Ліпопероксидаційні процеси в сорго зерновому за дії гербіциду, регулятора росту рослин і біопрепарату

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Анотація. Використання гербіцидів у посівах зернових культур, в тому числі й сорго зернового, є неодмінною умовою досягнення високих показників урожайності. Проте, проникаючи до організму рослин вони здатні інтенсифікувати синтез активних форм кисню, що призводить до посилення процесів ліпопероксидації та активізації антиоксидантних систем, зокрема й ферменту супероксиддисмутази. Відомо, що регулятори росту рослин та мікробні препарати, за їх включення до технологій вирощування зернових культур, можуть підвищувати здатність рослин протистояти оксидативному стресу, спричиненому дією ксенобіотиків. Утім інтегрований вплив гербіцидів, регуляторів росту рослин і мікробних препаратів на активність ферменту супероксиддисмутази та інтенсивність проходження реакцій ліпопероксидації в рослинах сорго зернового вивчено недостатньо, що й обумовило мету цього дослідження. Об'єктами вивчення слугували рослини сорго зернового (*Sorghum bicolour (L.) Moench*) гібриду Майло В, гербіцид Цитадель 25 OD, регулятор росту рослин Ендофіт L1 і біопрепарат Біоарсенал. Дослід було закладено з дотриманням вимог вегетаційного методу. Активність пероксидного окислення ліпідів визначали за кількістю утвореного в тканинах рослин малонового диальдегіду. Активність ферменту супероксиддисмутази (КФ 1.15.1.1.) встановлювали за його здатністю конкурувати з нітросинім тетразолієм за супероксидні аніони, що утворюються в результаті взаємодії відновленої форми нікотинамідаденіндинуклеотиду і феназинметасульфату. В ході досліджень було встановлено, що за дії гербіциду Цитадель 25 OD показники активності пероксидного окиснення ліпідів у рослинах були в середньому на 26,2–93,2 % вищими ніж у контролі, залежно від норми гербіциду і доби після внесення. Активність супероксиддисмутази за таких умов перевищувала контроль у середньому на 18,2–96,8 %. Проте, за сумісного використання гербіциду, регулятора росту рослин і біопрепарату спостерігалось зниження активності ліпопероксидаційних процесів у рослинах на 14,5–19,1 % відносно варіантів самостійного внесення гербіциду при одночасному зростанні активності супероксиддисмутази на 22,0–38,7 %. Результати досліджень засвідчують позитивний вплив регулятора росту рослин і біопрепарату на здатність сорго зернового протистояти оксидативному стресу, що виникає внаслідок дії гербіциду. Отримані дані можуть стати підґрунтям для подальшої розробки біологізованих технологій вирощування цієї культури

Ключові слова: супероксиддисмутаза, пероксидне окиснення ліпідів, антиоксидантний захист, біологізація, оксидативний стрес

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

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

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

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INTRODUCTION

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

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

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

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

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

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

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

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

studied indicators of both soil and plants among the studied ecologised fertiliser systems.

MATERIALS AND METHODS

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

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

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

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

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

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

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

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

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

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

RESULTS AND DISCUSSION

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

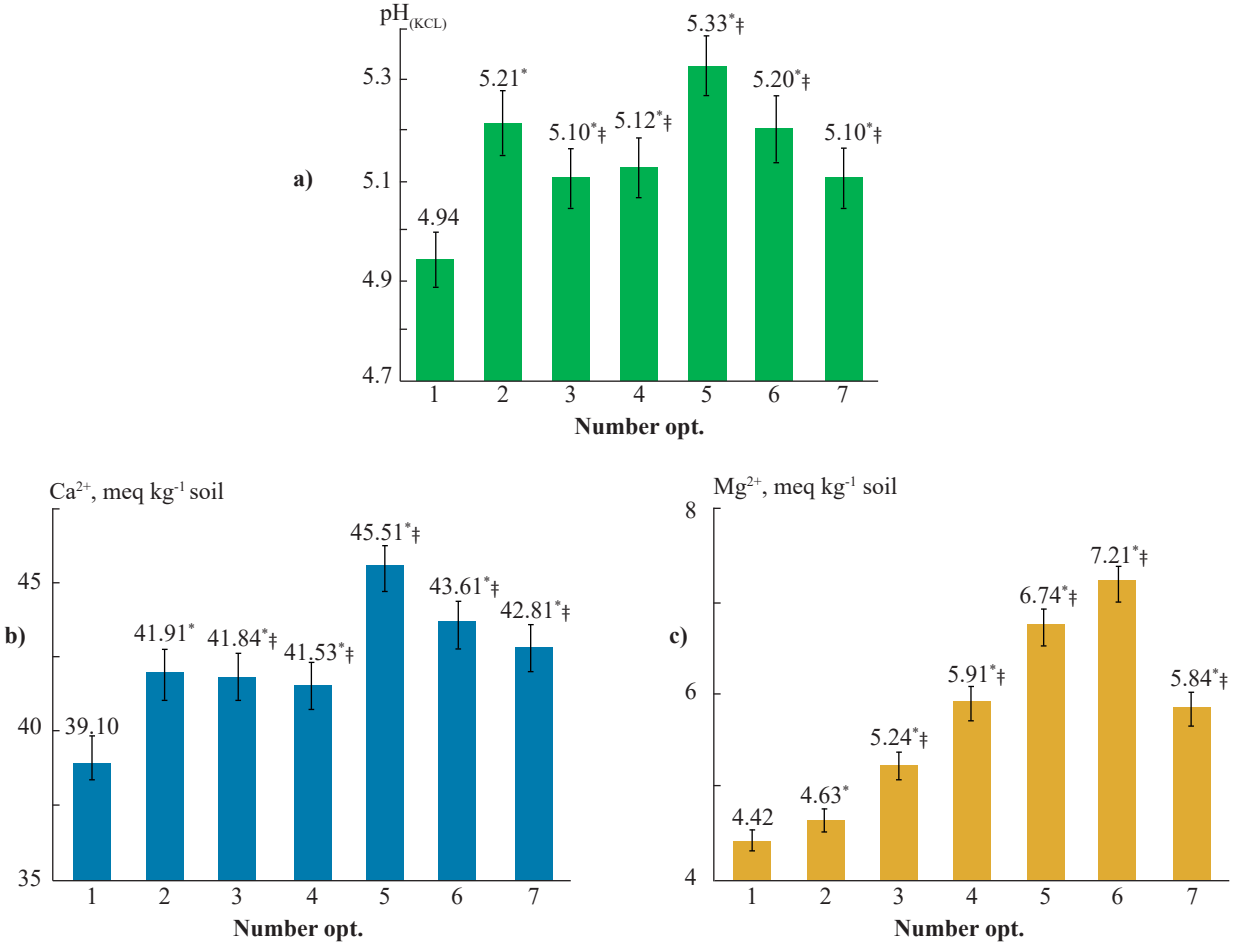

***Figure 1**. Effect of ecologised fertiliser systems on $pH_{(KCl)}$ (a), content of Ca exchange cations^{2+} (b) and Mg^{2+} (c) in soil solution (heading phase; 2019-2020)*

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

The authors of this paper suggest that the processes of biological decomposition of pea straw in the soil played one of the leading roles in the processes of Ca^{2+} and Mg^{2+} cation enrichment and alkalinisation of the soil solution on experimental variants. Indeed, previous studies have shown that crop residues can have a considerable effect on the soil pH, especially with a low buffer capacity, as well as significantly increase the

cationic exchange capacity of the soil absorbing complex [38]. Organic anions that are bound to the main Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+} cations in plant materials, are the main source of ash alkalinity. As a rule, legume straw has higher alkalinity, and, therefore, it should have a stronger effect on soil acidity compared to non-legume straw [39]. In particular, the content of Ca^{2+} pea straw is about 6 times larger than winter wheat straw (1.82% vs. 0.28%). In general, the ash alkalinity of plant residues and the mineralisation of organic nitrogen are the main causes of an increase in soil pH, while subsequent nitrification of mineralised nitrogen can lead to a decrease in soil pH [40]. Notably, biochemical decarboxylation of carboxyl groups of organic anions released during straw destruction removes protons from the soil solution, causing alkalinisation of the latter [41].

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

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

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

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

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

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

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

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

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

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

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

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

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

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

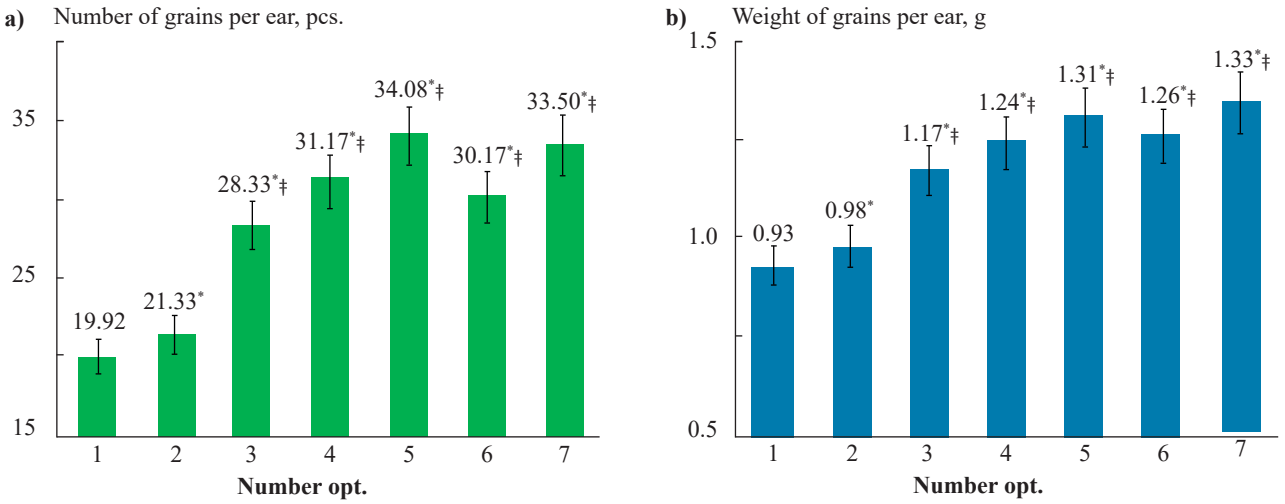

***Figure 2**. Influence of ecologised fertiliser systems on the number (a) and mass (b) of grains in a head of winter wheat (waxy ripeness phase; 2019-2020)*

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

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

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

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

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

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

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

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

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

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

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

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

CONCLUSIONS

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

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

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Вплив екологізованих систем удобрення на елементи родючості та продуктивності пшениці озимої

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

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

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Mathematical Models for Assessing the Reliability of Agricultural Machinery, Taking into Account the Influence of Military Factors in the Front-line Territory

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Abstract. As the requirements for the quality of agricultural machinery and its working conditions increase, so do the demands on its maintainability, in particular its reliability. Failure for technical reasons or due to any external factors will result in the non-achievement of the goals set, and thus in a loss of performance. Today, as a rule, there is an insufficient level of reliability of agricultural equipment during operation, and this issue receives special attention in the territories that are located in the front-line zone in the east of Ukraine in the Donetsk and Luhansk regions. This is caused by both design solutions and imperfect models that are used during projecting. In addition, external factors that can significantly affect production activities are not taken into account. These include climatic conditions, natural disasters, personnel readiness, i.e. the human factor, as well as the factor of the consequences of an armed conflict. Therefore, the purpose of the article is to offer a mathematical model for assessing the reliability of agricultural machinery, taking into account the military factor in the front-line territory. The authors provide an analytical expression of the mathematical model for assessing the reliability of agricultural machinery, taking into account the influence of external military factors. This issue is gaining special attention in the front-line territories in eastern Ukraine, where a significant part of the acreage is also located. The proposed mathematical model, in contrast to the previous ones, will allow taking into account the wear and time-related deterioration of components of agricultural machinery, as well as external military factors (damage to equipment and personnel, damage due to collision with munitions, etc.). This mathematical model can be used to set the uptime requirements for agricultural machinery in a more reasonable manner and thereby increase its productive performance. During the research, methods of probability theory were used at the stage of determining the necessary probabilities of trouble-free operation of agricultural machinery, as well as methods of queuing theory, reliability theory of technical systems and mathematical modelling when determining the maintenance time of agricultural machinery samples for failure under various conditions of its application

Keywords: Weibull distribution, war, combat, simulation, meaning

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INTRODUCTION

Technical systems, equipment and individual models of equipment in agriculture are becoming more and more complex. With the increase in requirements for the quality of agricultural machinery and its working conditions, as a result, the requirements for its maintainability, in particular for reliability, that is, the ability to perform tasks in a certain period of time with sufficient efficiency, increase. Failure of agricultural machinery for technical reasons or from any external factors (military, climate, etc.) will lead to the un-achievement of the goal set, which will negatively affect productivity and efficiency of work. Today, as a rule, there is an insufficient level of reliability during the operation of agricultural machinery samples [1; 2]. This is caused both by projecting decisions, as well as by the imperfection of the models that are used in their design and description of the process of their functioning under various operating conditions.

In addition, the influence of external factors that can significantly affect the production activities and the effectiveness of the final expected performance is not fully taken into account [3]. These include climatic conditions, natural disasters, the readiness of personnel, that is, the human factor, and in areas of military operations, that is, in front-line territories, one must not forget about the factors of external influence that are associated with the destruction of machinery during agricultural work, or collisions its consequences of hostilities in these areas (mines, ammunition, remnants of hostilities, war-torn territory, etc.) [4-7]. Today, when Ukraine is in a state of ongoing armed conflict, and part of the territory of Ukraine is the so-called front-line zone, in which there are quite large volumes of sown territories, that cannot be abandoned, then the problem of assessing the reliability of agriculture during the performance of tasks for sowing and harvesting crops from these territories, taking into account the effects of military factors, is a quite relevant and timely task of the present for agriculture of Ukraine and Ukraine as a whole [8].

The condition of any equipment changes over time, depending on the resource consumption, and under the influence of various external factors, if this is not taken into account during the design, there is a discrepancy between the required reliability of a sample of agricultural equipment and significantly low reliability, which is observed during the operation of this equipment, especially in areas close to the contact line with the enemy. This discrepancy increases if external factors are not taken into account, because a sample of equipment can also fail due to this component. This is exactly what is happening in practice, especially in the territories that are now considered front-line, but even with this status, these territories are also sown and agricultural products are harvested [9; 10].

The analysis of recent studies and publications on the issue of assessing the reliability of agricultural machinery shows that scientific tasks to ensure the reliability of serviced systems are addressed by researchers in a significant number of works. The greatest success was achieved for systems with an exponential law of duration distribution [9; 11; 12]. When applying the exponential distribution law, the process of functioning is considered through the prism of linear differential equations, which in turn are formed according to the process scheme when applying elementary formal mathematical rules. However, there are processes in which the duration is not subject to an exponential distribution, then it is difficult to describe these processes from a practical point of view and solve these equations in general, especially differential equations using frequent derivatives [13-15]. If it is necessary to solve such practical problems, statistical modelling methods are almost always used [16; 17].

In [1], a method for estimating the reliability indicator of equipment "probability of trouble-free switching on" of equipment in operation is considered. The application of the method is based on the use of operational observation data. The authors [2] outline the principles of constructing mathematical models, consider theoretical foundations of analytical and simulation modelling of technical systems functioning in the tasks of their reliability research. The authors in [3] research the application of the statistical modelling method for solving problems of reliability and operation of radio-electronic equipment. In [4], the general provisions of the methodology for system justification of reliability requirements for radio-electronic means of anti-aircraft missile systems are considered. Analytical methods for assessing the reliability of systems whose state is estimated by a homogeneous Markov process are provided by the authors in [9]. It should be noted that in the literature under consideration, when modelling the reliability of equipment, the influence of external factors that can significantly reduce its reliability is not taken into account. Therefore, the issue of assessing the reliability of agricultural machinery, taking into account the possible influence of external military factors, especially in the front-line territories, is an urgent task.

Therefore, the article is relevant because it offers a solution to this issue by clarifying the mathematical model of evaluating the reliability of agricultural machinery, taking into account the influence of external factors, which include climatic conditions, dangers associated with military operations (shelling, destruction, destruction of communications), the consequences of military operations (mining territories, the consequences of using ammunition to damage land and their residues on the sown land planes).

The purpose of the study is to offer a mathematical model for assessing the reliability of agricultural machinery, taking into account the influence of external military factors in the front-line territory.

OPERATION OF AGRICULTURAL MACHINERY AND THE PROBABILITY OF ITS FAILURE: THEORETICAL ASPECTS

When agricultural machinery performs its intended tasks, it will be affected by two streams of events: failures due to limited technical reliability and failures due to the influence of various external factors. One of the main external factors in the front-line territories includes military factors that have a direct impact on equipment through the conduct of military operations or through the consequences left as a result of their conduct, as well as climatic factors that characterise the operating conditions of equipment. The discrepancy between the declared failure of a sample of agricultural machinery and that actually observed during its operation may be explained by an incorrectly accepted hypothesis when designing samples of equipment and determining the distribution of operating time before failure of equipment, especially without resource consumption since operation, time-related deterioration and wear components.

In this regard, it is advisable to model the reliability of a non-one-parameter (exponential) distribution of a random variable of time $\tilde{T}$ working hours to failure $P(t)=e^{-\theta \cdot t}$, as often accepted, and a more general, more flexible distribution, such as two-parameter (θ, α) by Weibull distribution, $P(t)=e^{-\theta \cdot t^{\alpha}}$ (θ – scale parameter, α – a form parameter that takes into account the aging of equipment or takes into account the impact of external military and climatic factors).

During the operation of a sample of agricultural machinery, if any failures occur, its operability is restored by the repair authorities. Usually, the most time-consuming process is the process of eliminating failures caused by external military and climate factors. In the conditions of the production process, there is always a limit in the time and opportunities for timely restoration of the operability of agricultural machinery that has failed, this issue is especially relevant in front-line territories, where repair bodies and teams have a significant distance from the cultivated land. Therefore, it is justified to strive for the flow of failures of a sample of agricultural machinery due to limited technical reliability to be lower than the flow of failures due to the influence of military factors on the destruction of equipment due to combat operations or a collision with the residual effect of these operations, but this can only be achieved by increasing the average operating time for failure (to failure).

Taking into account all the above, it follows that agricultural machinery can fail if internal (limited technical reliability) and external (for example, climatic conditions, military operations) factors affect it separately or together. Then the probability of failure of a sample of equipment as a result of limited technical (own) reliability or due to external factors, as well as with the joint influence of the factors under consideration on its state, is determined as the probability of two compatible events [11]:

$$Q^0 = Q_H + Q_\beta - Q_H \cdot Q_\beta = 1 - P^0 \qquad (1)$$

where Q^0 – the probability that two compatible and independent events will occur: failures of agricultural machinery as a result of external military or other factors and failures due to limited technical reliability, as well as failures in the implementation of both these events simultaneously; Q_H – probability of failure of a sample of agricultural machinery due to limited technical reliability; Q_β – the probability of failure of a sample of agricultural machinery due to the influence of external military or other factors; P^0 – probability of trouble-free operation of a sample of agricultural machinery under the influence of these events.

During the formation of the model proposed in the article, methods of probability theory were used at the stage of determining the necessary probabilities of trouble-free operation of agricultural machinery, as well as methods of queuing theory, reliability theory of technical systems and mathematical modelling when determining the maintenance time of agricultural machinery samples for failure under various conditions of its application (taking into account the effects of external factors and without them). The research also required solving exponential and logarithmic equations, which were solved by well-known algebraic and analytical methods. The study also used methods of operations research and methods of processing statistical information, as well as comparative analysis of the obtained practical recommendations.

MODELING OF RELIABILITY OF AGRICULTURAL MACHINERY DUE TO EXTERNAL FACTORS

It is advisable to use Weibull distribution when modelling the reliability of agricultural machinery both at the design stage and during testing, which allows for a more correct calculation of the average operating time before failure, taking into account the ageing and wear of its components. At the same time, the failure of agricultural machinery due to external factors, such as military, climate, or others, can be considered practically independent of its condition, the condition of its components. In this case, the distribution of operating time before failure can be assumed to be exponential.

The probability of failure of a sample of agricultural machinery due to its limited technical reliability of agricultural machinery under the Weibull distribution of the random variable time of $\tilde{T}$ failure-free operation may be as follows:

$$Q_H\left(\tilde{T} < t\right) = 1 - e^{-\theta \cdot t^{\alpha}} = 1 - P_H(t) \qquad (2)$$

And the probability of failure due to external factors (military, climate, etc.) in the exponential distribution of the random amount of time of trouble-free operation will be determined by:

$$Q_\beta(t) = 1 - e^{-\varepsilon \cdot t} = 1 - P_\beta(t) \qquad (3)$$

where ε – coefficient that takes into account external impact (the influence of military, climate and other factors of external influence); P_1 – probability of trouble-free operation of agricultural machinery over time of t (h.) of continuous operation, taking into account limited technical reliability; P_β – probability of trouble-free operation of agricultural machinery over time of t (h.) of continuous operation, taking into account the influence of external military and climatic factors.

Substituting (2) and (3) in (1), the probability of failure of the sample of agricultural machinery due to limited technical reliability and external factors (climatic, military, etc.) during the time t h. of continuous operation is obtained:

$$Q^0(t) = 1 - P_H \cdot P_\beta = 1 - e^{-(\theta \cdot t^{\alpha-1}+\varepsilon)\cdot t} = 1 - P^0(t) \quad (4)$$

whence the probability of trouble-free operation in these conditions of use:

$$P^0(t) = 1 - Q^0(t) = P_H \cdot P_\beta = e^{-(\theta \cdot t^{\alpha-1}+\varepsilon)\cdot t} \quad (5)$$

If a scale parameter $\theta=\frac{1}{T}$ is assumed, expression (5) can be rewritten as:

$$\boldsymbol{P^0(t) = e^{-(\theta \cdot t^{\alpha-1}+\varepsilon)\cdot t} = e^{-\left(\frac{1}{T} \cdot t^{\alpha-1}+\varepsilon\right)\cdot t} \geq P_{nec}} \quad (6)$$

where $\boldsymbol{P_{req}}$ is probability of the necessary.

Whence, after logarithm, can be found the average value of the time spent before failure T when assignment of certain values ε, $\alpha<1$, t and $\boldsymbol{P_{nec}}$:

$$T \geq -\frac{t^\alpha}{\varepsilon \cdot t + ln\, P_{nec}} = \frac{t^\alpha}{-ln\, P_{nec} - \varepsilon \cdot t} \quad (7)$$

From formula (7) it is possible to find acceptable values of the coefficient that takes into account external influence ε and calculate the operating time for failure of the sample of the agricultural machinery (before failure) T, for example, by the values of the form parameter α=1.4, t=5 and different values of ε.

The obtained values ε can be used not only to determine the average time T before failure of agricultural machinery samples, but also to determine the possible number ΔN_β of decommissioned samples of machinery only due to external military or climatic factors during the time t of continuous operation, for example, for future planning of the work of repair and restoration bodies. As already noted, using the model under consideration determines the time of T trouble-free operation, when failures of agricultural machinery due to limited technical reliability will be much lower than failures due to external military and climatic factors. To do this, the ratio is introduced:

$$\frac{\Delta N_H}{\Delta N_\beta} \leq \sigma \quad (8)$$

where ΔN_H – the number of agricultural machineries disabled only due to limited technical reliability; ΔN_β – the amount of agricultural equipment disabled only due to external factors (climate and military).

As it is known,

$$\Delta N_\beta = Q_\beta \cdot (1 - Q_H) \cdot N_0 \quad (9)$$

$$\Delta N_H = Q_H \cdot (1 - Q_\beta) \cdot N_0 \quad (10)$$

where N_0 – the number of agricultural machineries in production.

A certain number of samples of agricultural machinery $\Delta N_{H\beta}$ can be disabled both due to limited technical reliability, and simultaneously due to external military and climatic factors:

$$\Delta N_{H\beta} = Q_H \cdot Q_\beta \cdot N_0 \quad (11)$$

Obviously, with the increase in the average time to failure of agricultural machinery, the number of ΔN_H disabled due to only limited technical reliability will decrease. Given that the probability of an event that is associated with the occurrence of a quantity $\Delta N_{H\beta}$, significantly lower compared to the probabilities of occurrence of values ΔN_H, ΔN_β, and also taking into account that the work of repair and restoration bodies will be mainly associated with the restoration of technical readiness of agricultural machinery disabled due to the influence of external military and climatic factors, can be considered $\Delta N_{H\beta} \approx 0$.

Substituting the values of (9) and (10) in (8), can be obtained:

$$\frac{\Delta N_H}{\Delta N_\beta} = \frac{e^{-\left(\varepsilon - \frac{1}{T} \cdot t^{\alpha-1}\right)\cdot t} - e^{-\varepsilon \cdot t}}{1 - e^{-\varepsilon \cdot t}} \leq \sigma,\ \varepsilon \neq 0 \quad (12)$$

where:

$$\boldsymbol{e^{-\left(\varepsilon - \frac{1}{T} t^{\alpha-1}\right)\cdot t} \leq e^{-\varepsilon \cdot t} + \sigma \cdot (1 - e^{-\varepsilon \cdot t})} \quad (13)$$

The logarithm of this expression, gives the value of the T operating time before the failure of the equipment during t its continuous operation:

$$T \geq \frac{t^\alpha}{\varepsilon \cdot t + ln\,[e^{-\varepsilon \cdot t} + \sigma \cdot (1 - e^{-\varepsilon \cdot t})]},\ \sigma > 0 \quad (14)$$

Equation (13) is the essence of the mathematical model. In order for the units of measurement to match, equation (13) should be written as follows:

$$T \geq \frac{1 + \alpha^{1.604 \cdot \alpha} \cdot (t - 1)}{\varepsilon \cdot t + ln\,[e^{-\varepsilon \cdot t} + \sigma \cdot (1 - e^{-\varepsilon \cdot t})]} \quad (15)$$

since when $\alpha<1$ expression $t^\alpha \approx 1+\alpha^{1.604 \cdot \alpha} \cdot (t\text{-}1)$.

In order to determine the limit values of the coefficient of accounting for external military and climatic factors ε expressions (7) and (13) are equated:

$$\frac{t^{\alpha}}{\varepsilon \cdot t + ln\ [e^{-\varepsilon \cdot t} + \sigma \cdot (1 - e^{-\varepsilon \cdot t})]} = -\frac{t^{\alpha}}{\varepsilon \cdot t + ln\, P_{nec}} \quad (16)$$

where:

$$\varepsilon \cdot t + ln\ P_{nec} = -\varepsilon \cdot t - ln\ [e^{-\varepsilon \cdot t} + \sigma(1 - e^{-\varepsilon \cdot t})] \quad (17)$$

or:

$$2 \cdot \varepsilon \cdot t = -ln\ P_{nec} - ln\ [e^{-\varepsilon \cdot t} + \sigma(1 - e^{-\varepsilon \cdot t})] \quad (18)$$

If this transcendental equation is to be solved with respect to ε, because to reach a certain value σ is possible, given not only T, but also one or another amount of generalised relative hourly losses ε, then we get:

$$\varepsilon = \frac{1}{2 \cdot t} \cdot (1 + \sigma - ln\, P_{nec} - \sqrt{(1 + \sigma - ln\, P_{nec})^2 + 4 \cdot ln\, P_{nec}}) \quad (19)$$

where σ=0:

$$\varepsilon = \frac{1}{2 \cdot t} \cdot (1 + \sigma - ln\, P_{nec} - \sqrt{(1 + \sigma - ln\, P_{nec})^2 + 4 \cdot ln\, P_{nec}}) = \frac{1}{2 \cdot t} \cdot (1 - ln\, P_{nec} - \sqrt{(1 + ln\, P_{nec})^2}) < -\frac{ln\, P_{nec}}{t} \quad (20)$$

which can also be obtained from (7).

If equation (18) is solved with respect to σ, then this value will be expressed as ε as follows:

$$\sigma = f(\varepsilon) = -(1 - \varepsilon \cdot t) - \frac{1 - \varepsilon \cdot t}{\varepsilon \cdot t} \cdot ln\, P_{nec} = (1 - \varepsilon \cdot t) \cdot (-1 - \frac{ln\, P_{nec}}{\varepsilon \cdot t}) > 0 \quad (21)$$

Thus, further calculations can be performed using the following functions: $\varepsilon=f(\sigma)$ or $\sigma=f(\varepsilon)$.

Next acceptable values ε can be calculated depending on σ and P_{nec} and unlike previously obtained permissible values $\varepsilon=\frac{-ln\ P_{nec}}{t}$, but taking into account the value σ, which is achieved by setting P_{nec}, ε, t. After that the final calculations of the values T are made for the set σ, P_{nec}, t = 5 hours.

Next, it is desirable to check the operability of the proposed mathematical model for assessing the reliability of agricultural machinery, taking into account the influence of external military factors, without taking into account time-related deterioration and wear of agricultural machinery, that is, α=1, and without taking into account the conditions of external influence, that is, ε=0, when it is not affected by military or climatic factors. Then the probability of trouble-free operation of a sample of agricultural machinery can be calculated as:

$$P^0(t) = e^{-(\theta \cdot t^{\alpha-1} + \varepsilon) \cdot t} = P(t) = e^{-\theta \cdot t} = e^{-\frac{1}{T} \cdot t} \quad (22)$$

By setting $P(t) \geq P_{nec}$ the value of the average operating time T_{av} before failure will be found under the condition: $T_{av} \leq -\frac{t}{ln\, P(t)}$.

THE RESULTS OF CALCULATIONS OF THE PROPOSED MATHEMATICAL MODEL

Preliminary calculation results are shown in Table 1, obtained in accordance with the proposed mathematical model under pre-defined conditions, and correctly reflect the situation with determining the average operating time T_{av} before failure without taking into account time-related deterioration and wear of agricultural machinery (α=1) in the process of its operation in the military and without taking into account the influence of the external military and climatic factors (ε=0). So, for t=5 hours required to achieve P_{nec}=0.95 value T_{av} makes up 98 h≈100 h.

Table 1. *The value of the average operating time of agricultural machinery before failure (h) without taking into account the influence of external military and climatic factors at α=1, ε=0*

Continuous operating time of agricultural machinery	Possible values $P(t) = e^{-\frac{1}{T} \cdot t} = P_{nec}$				
	0.6	0.7	0.8	0.9	0.95
t=1 hour	2	3	5	10	20
t=2 hours	4	6	9	19	39
t=3 hours	6	8	13	28	58
t=4 hours	8	11	17	38	78
t=5 hours	10	14	22	47	98
t=7 hours	14	20	31	66	136
t=10 hours	20	28	45	95	195

Next, it is worth considering another special case of determining the reliability indicators of agricultural machinery based on the proposed method of mathematical modelling of its reliability taking into account time-related deterioration and wear of components (α>1), but without taking into account external factors (ε=0). In this case, the probability of no-failure operation is determined by:

$$P^0(t) = e^{-(\theta \cdot t^{\alpha-1}+\varepsilon)\cdot t} = P(t) = e^{-\theta \cdot t^{\alpha}} = e^{-\frac{1}{T}\cdot t^{\alpha}} \quad (23)$$

Given the condition that $P(t) \geq P_{nec}$ the value of the average time of operation T_{av} before failure will be found from:

$$T_{av} \geq -\frac{t^{\alpha}}{ln\ P(t)} = -\frac{1+\alpha^{1.604\cdot\alpha}\cdot(t-1)}{ln\ P(t)} \quad (24)$$

Value T_{av} (h) depending on the possible P_{nec} and time t (h) of continuous operation, as well as, for example, by the parameter α=1.4 (which takes into account, for example, resource costs of about 70%) are shown in Table 2.

***Table 2**. Value of the average operating time of agricultural machinery before failure (h), taking into account time-related deterioration and wear of components (α>1), but without taking into account the influence of the external military and climatic factors (ε=0), α=1.4 and ε=0*

Continuous operating time of agricultural machinery	Possible values $P(t) = e^{-\frac{1}{T}\cdot t^{\alpha}} = P_{nec}$				
	0.6	0.7	0.8	0.9	0.95
t=1 hour	2	3	5	10	20
t=2 hours	5	7	12	25	51
t=3 hours	9	13	21	44	91
t=4 hours	14	20	31	66	136
t=5 hours	19	27	43	90	186
t=7 hours	30	43	68	145	297
t=10 hours	49	70	113	238	490

And finally, in the most general case, taking into account time-related deterioration and wear of components (α>1), as well as external climatic and military factors (ε≠0), the probability of trouble-free operation of agricultural machinery will be determined by:

$$P^0(t) = e^{-(\theta \cdot t^{\alpha-1}+\varepsilon)\cdot t} = e^{-\left(\frac{1}{T}\cdot t^{\alpha-1}+\varepsilon\right)\cdot t} \quad (25)$$

Given the condition that $P(t) \geq P_{nec}$ the value of the average time of operation T_{av} before failure will be found from:

$$T_{CP} \geq -\frac{t^{\alpha}}{\varepsilon \cdot t + ln\ P_{nec}} = -\frac{1+\alpha^{1.604\cdot\alpha}\cdot(t-1)}{\varepsilon \cdot t + ln\ P_{nec}} \quad (26)$$

the following condition must be met $\varepsilon < -\frac{ln\ P_{nec}}{t}$.

However, to fulfill the condition $\varepsilon < -\frac{ln\ P_{nec}}{t}$, we take, for example, ε=0.0063 and calculate the value T_{av} depending on the previous values P_{nec} and t, which are shown in Table 3. Missing data in Table 3 cells at P_{nec}=0.95 indicate an unrealised technical value T_{av}>1000 hour per t=7 and non-fulfilment of the condition $\varepsilon < -\frac{ln\ P_{nec}}{t}$ at t=10.

***Table 3**. Value of the operating time of agricultural machinery before failure, taking into account time-related deterioration and wear of components (α>1), as well as the influence of external climatic and military factors (ε≠0) at α=1.4, ε=0.0063*

Continuous operating time	Possible values $P(t) = e^{-\left(\frac{1}{T}\cdot t^{\alpha-1}+\varepsilon\right)\cdot t} = P_{nec}$				
	0.6	0.7	0.8	0.9	0.95
t=1 hour	2	3	5	10	22
t=2 hours	5	8	13	28	68
t=3 hours	9	14	23	54	144
t=4 hours	14	21	35	87	267
t=5 hours	20	29	50	129	481
t=7 hours	33	49	85	249	–
t=10 hours	56	86	157	592	–

CONCLUSIONS

In the article, the authors consider the current issue of improving a mathematical model for assessing the reliability of agricultural machinery, taking into account the influence of the external military and climatic factors in the front-line territory in the east of Ukraine.

The mathematical model proposed by the authors, unlike the previous ones, will allow taking into account wear and time-related deterioration of components of equipment samples, as well as external factors (climate, military, etc.). Thus, according to the results of a numerical experiment, without taking into account time-related deterioration and wear of equipment components, the operating time before failure is T=100 hours. Using this mathematical model without taking into account external factors – about T=200 hours. Additional consideration of external factors makes it necessary to bring the operating time before failure to about T=500 hours that provides a probability of trouble-free operating of at least 0.9-0.95. It is believed that with the help of the proposed mathematical model, it is possible to set more reasoned requirements for the reliability of agricultural machinery samples, thereby increasing their productive work in high-risk areas (front-line zones).

The direction of further research is the introduction of the developed model into the design system of individual samples of agricultural equipment, which will perform tasks related to the cultivation of agricultural territories in the front-line zones in the territories of Donetsk and Luhansk regions. Samples that will be used in these areas will need to have certain technical features of their operation in order to increase the level of trouble-free operation.

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Розвиток математичних моделей оцінювання безвідмовності техніки сільського господарства з урахуванням впливу зовнішніх воєнних факторів у прифронтовій території

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Анотація. Із підвищенням вимог до якості техніки сільського господарства та умов її роботи, як наслідок, зростають вимоги до її надійності, зокрема до безвідмовності. Відмова з технічних причин або від будь-яких зовнішніх факторів призведе до недосягнення поставленої мети, а й значить до зниження продуктивності роботи. На сьогодні переважно спостерігається недостатній рівень безвідмовності техніки сільського господарства під час експлуатації, особливої уваги це питання набуває на територіях, які знаходяться у прифронтовій зоні на сході України в Донецькій та Луганській областях. Це викликано як конструкторськими рішеннями, так і недосконалістю моделей, які застосовуються під час проектування. Крім того, не враховуються зовнішні фактори, які суттєво можуть вплинути на виробничу діяльність. До них можна віднести кліматичні умови, стихійні лиха, підготовленість персоналу, тобто людський фактор, а також фактор наслідків збройного конфлікту. Тому метою статті є запропонувати математичну модель оцінювання безвідмовності техніки сільського господарства з урахуванням воєнних факторі у прифронтовій території. Автори наводять аналітичний вираз математичної моделі оцінювання безвідмовності техніки сільського господарства з урахуванням впливу зовнішніх воєнних факторів. Особливої уваги це питання набуває на прифронтових територіях на сході України, де знаходиться також значна частина посівних площ. Запропонована математична модель, на відміну від попередніх, дозволить врахувати зношення, старіння комплектуючих зразків техніки сільського господарства, а також зовнішні воєнні фактори щодо ураження техніки та персоналу, пошкодження її унаслідок зіткнення з боєприпасами тощо. За допомогою даної математичної моделі можна більш аргументовано задавати вимоги з безвідмовності зразків техніки сільського господарства, тим самим підвищити їх продуктивну роботу. Під час дослідження було використано методи теорії ймовірностей на етапі визначення необхідних ймовірностей безвідмовної роботи сільськогосподарської техніки, а також методи теорії масового обслуговування, теорії надійності технічних систем та математичного моделювання під час визначення часу обслуговування зразків сільськогосподарської техніки на відмову за різних умов її застосування

Ключові слова: розподіл Вейбулла, війна, бойові дії, моделювання, значення

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Modernization Aspects of Strategic Management in Industrial Companies

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Abstract. In the scientific work, the author investigates the issue of modernisation of strategic management at industrial enterprises, as well as analyses a number of theoretical and methodological aspects in this area. The topic analysed in the article is important because today the creation and application of more advanced management technologies is a particularly important issue, as the development of new and existing industrial enterprises depends on management, in particular. Successful industrial management is one of the most significant issues affecting the social and material well-being of the population, as well as the development of the country's economy. Therefore, there is a need to develop theoretical and practical foundations of strategic management at industrial enterprises, successful implementation of startup projects, strategic development programs for expansion and development of production. To achieve this, the article provides proposals and recommendations for improving the process of strategic management, development of management technology and defines the principles of their application in management. The article considers the issue of the modernisation of strategic management in order to accelerate the process of industrialisation. The article considers the formation of industrial parks and the use of modern technologies in management. To this end, the concept of strategic management at industrial enterprises and the issue of its improvement have been scientifically clarified. The article considers strategic combinations of management at industrial enterprises. The issue of harmonisation and coordination of their implementation with the organisational structure is also substantiated. The article explains the necessity and scientifically practical issues of the strategic management subconcepts application

Keywords: industry, industrial parks, management system, organizational structure

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INTRODUCTION

In the world practice, state support for the activities of industrial enterprises is widespread, and the main goal is to increase their competitiveness and facilitate access to international markets. Among the measures of state support for industry are the promotion of investment, international trade and exports, the construction of infrastructure, the creation of industrial parks and clusters, support for technology transfer and the widespread application of innovations.

Today, the industrial revolution is entering a new phase in the world. The industry is developing rapidly. Industrial areas are expanding, enterprises are being merged in industrial parks, as well as technoparks are being created, and these sectors are trying to strengthen their position in international markets. All this requires the creation of new management models. The development of new and existing industrial enterprises depends on the management [1; 2]. To put it in another way, they argue that it is not because of the fact that the economic system has reached its limits. On the contrary, the managerial knowledge could be used to help deciding democratically on how to manage strategically the use of the economic resources. By doing so, you reconnect with a classical Marxist idea: compared to previous economic systems, capitalism indeed represented progress in many regards – including managerial knowhow – but it is time now to replace capitalism with socialism in order to move on to a new phase of human progress [3].

Research in strategic management is very important to identify problems in the macro and micro spheres, to eliminate them, to ensure the sustainability of industrial enterprises [4; 5]. Today, there is strong competition between industrial enterprises in the world. Nowadays, competition has become a struggle for survival between enterprises. One of the main conditions for the competitive operation of enterprises is the implementation of proper strategic management [6]. To this end, the author has put forward their proposals in the field of strategic planning to expand the competitiveness of enterprises, strengthen financial capacity, improve market positions, and present more advanced principles of strategic management.

One of the main issues in the development of industry is the modernization of management systems and adaptation to modern needs in this sphere. The modernization of management technologies and applies them in industrial enterprises affects the development of individual industries and serves the development of the country's economy as a whole. *The main purpose of this research is to study* the management mechanisms to achieve modern technologies for strategic management of enterprises. In this regard, the author presents the system of *objectives of the study* as follows:

- approach the development of the industrialization process from the micro-environmental aspect;
- to study the conceptual basis of strategic management in industrial enterprises;
- to identify modern technologies of strategic management in industry;
- to increase the functionality of management in ensuring the joint activities of the participants of industrial parks;
- to determine the model of the organizational structure of industrial unions.

STRATEGIC ASPECTS OF MANAGEMENT IN INDUSTRIAL ENTERPRISES

Industry is the main sector of the national economy. The development of production is the basis of the country's economic development [7; 8]. From this point of view, industrial management is one of the most pressing issues of the time. Improvement of the industrial enterprise creates conditions for the implementation of its structure, new infrastructure-related projects and the creation of new jobs. The creation of new jobs occurs as a result of the formation and development of industrial enterprises, which affects the improvement of the social and material well-being of the population. From this point of view, it should be noted that the successful management of industry is considered to be one of the most important issues affecting the development of the country's economy [9].

In the context of the tendencies of modernization of industrial enterprises, different theories have been formed from time to time and explained in different ways. These theories can be classified in the context of economic modernization as follows: preventive development theory; dependent development theory; contrast theory to modernization [10]. Each of these theories serves the expansion and dynamic development of industries. The development of industry requires its comprehensive modernization. Such modernization targets all aspects of the industrial enterprises. Complex modernization in the processing industry can be effective in the following areas:

- significant improvement of the management structure and transition to mobile management;
- full automation of management;
- to use the necessary opportunities of digital marketing;
- increasing the productivity of marketing research and advertising activities;
- improving the system and forms of organization of the production process within the managed system;
- attracting innovations;
- automate the chain of technological processes as much as possible;
- improvement of existing technologies and modernization of production accordingly;
- application of improved sales forms;
- increase the sales efforts by using online sales programs;
- analysis of sales channels, etc.

The main purpose of this research is to modernize strategic management. It should be noted that the modernization of management is primarily due to its high level of implementation. The effective application of strategic management in the enterprise is primarily due to the application of its attributes in a related qualitative form [11]. The main attributes of management are its functions, methods, principles and subsystems. The author has studied the quality matrix of the coherent application of the functions and methods of strategic management. Table 1 shows the quality matrix for the implementation of any management functions during the strategic period. This matrix determines the effect of the application of different functions together with the relevant methods. However, only three management functions are classified in this matrix. Because it is possible to approach the functions mentioned in the matrix from a strategic point of view.

Table 1. *Quality matrix of execution of various functions by related methods*

	Planning	**Marketing**	**Controlling**
Economic method	Product volume planning. Determining the full cost. Income planning. Economic efficiency design	Market research. Pricing. Income	Rewarding, Sanctions, Fines
Administrative method	Formation of the normative base. Formation of organizational structure, Defining the management mechanism	Regulation of trade relations	Control mechanisms. Administrative measures. Disciplinary measures
Socio-psychological method	Determining the social needs of employees. Planning of social events	İnterests of society. Customer satisfaction	Regulation of social relations

Source*: prepared by the author*

The Table 1 is a roadmap that characterizes the guiding, executive and final state of the application of methods in management activities. By applying the matrix, managers have the opportunity to predict the results of the implementation of economic, administrative and socio-psychological methods in management at the planning, marketing and control stages [12]. The quality matrix of management characterizes the results of the application of any function by appropriate methods. This description is a beacon for the successful implementation of the management function of managers to make management more productive.

The Fourth Industrial Revolution differs from previous revolutions in its pace of development. The current revolution has the potential to improve the quality of global life and increase incomes for the population. The Industrial Revolution is based on the development of the digital economy and its contribution to society. In modern times, technology is growing rapidly, industries serve to increase the level of people's shyness, produce new products for people, meet their needs with new types of services. The digital economy allows people to place orders, make purchases, make payments, hold meetings, and so on. Such a pace of development gives a reason to say that in the near future people will not be surprised by high-level scientific and technological innovations [13]. These innovations will further increase efficiency and productivity, and reduce communication and transportation costs. Such conditions will facilitate trade, reduce trade costs, increase the effectiveness of supply chains, open new markets and grow the world economically.

In the Fourth Revolution, the United States played an important role in its successful industrialization policy. The basis of the US industrial revolution was the close connection of industrial enterprises with scientific research. Universities in Louisiana have created a consortium to support advanced manufacturing and education. Meanwhile the Massachusetts Institute of Technology has developed a number of programs to bolster next generation manufacturing. There are numerous other programs nationwide many with a regional focus, but all aimed at empowering the nation's collective capabilities [14].

In recent years, the industrial structure in Azerbaijan has been gradually optimized, the share of the mining sector has decreased, the share of the processing sector has increased and favorable conditions have been created for the development of the non-oil sector [15]. One of the main reasons for the development is the proper economic policy pursued in the country and the strengthening of state care for economic infrastructure. Today it can be said that Azerbaijan achieves its economic development by pursuing an industrial policy. Recently, the enrichment of the competitive environment of the national economy in the field of industry, increasing the share of the non-oil sector in industrial production is the result of successful economic policy pursued in the country. In this re-gard, the modernization of the material and technical base of production, the transformation of scientific and technological progress into a productive force and the improvement of management systems in industry is one of the important issues. At present, the process of industrialization is progressing rapidly in Azerbaijan. The course of this process attracts attention from two main aspects: 1. State regulation of the development of the industrialization process; 2. Achieving a modern management system in the industry [16].

The first aspect of the issue is an integral part of the economic policy of the state. Today, ensuring the comprehensive development of the national economy, as well as the formation, diversification and dynamic development of high-tech industries are the main economic priorities in the country. As a successful result of this policy, many industrial enterprises have been built and put into operation in recent years within the framework of state programs on socio-economic development of the country's regions. As mentioned above, improving corporate management is a prerequisite for successful industrialization. Management in industry is a system of economic and administrative measures related to the organization and implementation of production activities. In industry, management plans production and ensures its implementation using the team's capabilities [17; 18].

The management system covers the efficient use of production, procurement, finance, information, personnel and other sources in enterprises, ensures the achievement of goals and acts as an optimal mechanism for their interaction. Improving the management of industrial enterprises is associated with the formation of an improved strategic management mechanism. R.A. Fathuddinov [19] considers the strategic management of the organization as the basis of modern management in the context of sustainable environmental change and increasing competition. It assesses the role of the organization's innovation strategy in management and presents its responsibilities as follows:

• investigate the impact of innovation management on organizational development;

• formation of habits of different organizations to classify competitive innovative behaviors;

• development of the ability to form innovative strategies in the field of mass, serial and individual production;

• providing methodological recommendations on innovations in innovative enterprises and organizations.

It is difficult to imagine the process of modernization without innovative development. Because it contains a wide range of the latest innovations. It is difficult to produce a high-quality product at a lower price without technical and technological modernization of the existing production process [20]. Therefore, attention to this important issue continues in all countries of the world. According to this research, there is a constant need to improve the management system of industrial enterprises. The measures needed in this area are as follows:

• A new strategic managerial mechanism must be established for the company's existing management system.

• Management in industrial enterprises should be carried out in accordance with the strategic development plan.

• The organizational structure of the enterprise should be organized in accordance with the strategic development plan and scope of activities.

• In order to increase the professionalism of human resources in industrial enterprises, constant management care should be provided.

• Modern industrial management models and mechanisms should be applied according to the current situation.

Modernization of management systems of industrial enterprises requires the formation of a new management mechanism or improvement of the existing mechanism. The classification of these mechanisms is reflected in Table 2. The creation of a new management mechanism is based on setting strategic development plan. The company's strategic development plan is a set of strategic goals [21]. Therefore, setting the strategic plans begins with the definition of the right strategic goals. The strategic goals of large industrial enterprises reflect all aspects of the enterprise's activities and become richer [22]. The strategic goals in transnational corporations, technoparks, industrial parks are wide and multifaceted. In this regard, for such structures the author proposes to form subsystems of the strategy and present the classification of the strategy in Table 2.

***Table 2**. Classification of strategies*

No.	Classification of strategies	Purpose of the strategy
1	Base strategy	Overall strategy and mission
2	Diversification strategy	Strategies for different areas of activity of the enterprise
3	Differential strategy	Strategic goals for each area of activity
4	Functional strategy	Combinations to achieve strategic goals.
5	Controlling strategy	Monitoring the implementation of activities during the strategic period

***Source**: prepared by the author*

As it can be seen from the Table 2, such concepts, being functional subsystems of the basic management strategy, participate in various phases of the strategic development of the company, play an important role in achieving the overall mission and purpose of the organization. The different forms of strategy outlined in the table above serve to achieve a common strategy. however, in the table below, the strategy is classified into different subsystems (Table 3).

***Table 3**. Hierarchical structure of strategy*

No.	Levels of strategy	Subsystems of strategies
1	General firm strategy	Base strategy; corporate strategy; functional strategy
2	Management strategy	Strategic planning; strategic controlling
3	Field strategy	Production strategy; financial strategy; marketing strategy
4	Applied strategy	Investment strategy; product strategy; price strategy; sales strategy; competitive strategy
5	Target combination of strategy	Economic efficiency; development prospects

***Source**: prepared by the author*

The application of such concepts is very important in terms of creating large-scale production areas and forms of industrial associations. Consumer application of these concepts is important for industrial enterprises, as well as industrial parks, technoparks and clusters and processing enterprises producing other competitive products. One of the main conditions of the management system is to improve the organizational structure of industrial enterprises. The organizational structure should be organized in such an optimal way as to achieve the goal of increasing the efficiency of management in industrial enterprises. Therefore, a purposeful management model must be established while designing or overhauling the organizational structure of an enterprise. This model should consist of the following four blocks that are organically connected to each other (Fig. 1).

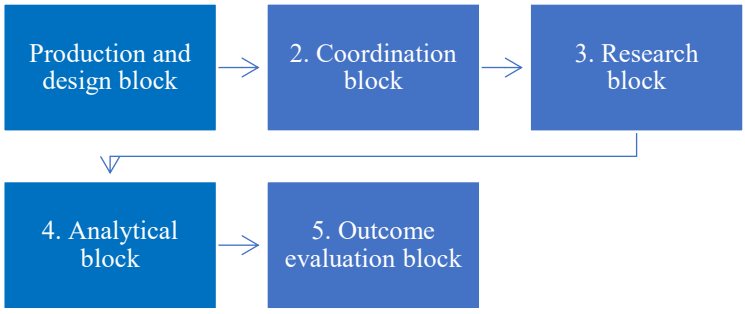

***Figure 1**. An organic model of strategic management*

The model of organizational structure will allow to target the development of all areas of financial and economic activity of the enterprise. The above-mentioned blocks allow to define the right strategy and achieve it at the required level. An effective model of strategic management modernization must meet the requirements of efficient production organization [23; 24]. In other words, the following requirements must be kept in focus for the development of the mechanism of sustainable development of production in industrial enterprises:

- use of the latest management tools;
- ensuring a high level of profitability of enterprises with minimal costs;
- analysis of external and internal factors affecting sustainable development;
- prepare an immediate and adequate response to changes in the external and internal environment;
- minimization of waste to the environment, their processing and utilization;
- development and implementation of targeted projects to neutralize production;
- achieving the set goals.

Summarizing the above, the author can emphasize that according to international experience, the modernization of industrial enterprises can be carried out on the basis of different scenarios: preparation of the general scenario; application of different modernization scenarios; take into account the effects of uncertainty; preference for concessions in the process of script development. But the choice of scenario depends on the strategic goals, the direction of the enterprise, the breadth of the plan, the size of the organizational structure, the number of employees and so on. These complex measures will allow the industrial companies to develop a concept that includes new production, optimal allocation of supplies, minimization of downtime, production cycle, modernization of the entire technological chain.

MODERNIZATION OF COORDINATED MANAGEMENT IN THE INDUSTRIAL UNIONS

Modern management must respond to today's economic systems. Thus, modern management should provide for the systematic management of the activities of enterprises and organizations in accordance with modern forms. At

present, the organizational forms of enterprises in the world economy, their regional structural forms, economic relations between these structures, the formation of economic unions between individual enterprises, enterprises with divisional structures formed from the organizational unity of various fields are the object of modern management. The effective management of such organizations and unions still requires the search for new mechanisms of modern management. In the previous section, the possibility of using different scenarios in determining the management mechanism was discussed. In the implementation of modernization, industrial enterprises have the following goals;

- ensuring sustainable development and optimal production structure;
- ensuring the production of new types of products;
- ensuring the production of new types of environmentally friendly products;
- extensive use of natural resources;
- ensuring environmental safety of production;
- significantly accelerate turnover and increase profits.

All of the above targets are related to factors of production. Factors of production are directly related to the formation, development, improvement and expansion of production, as well as increasing the pace of production and play a leading role as an internal factor. The existing production strategy as a subsystem of strategic management includes the following:

- improvement of existing equipment and technologies;
- increasing the supply of quality, progressive and improved raw materials and supplies;
- achieve the application of innovations in production;
- successfully use the principle of economy by reducing the cost of production;
- strengthening market positions by improving product quality;
- improving the quality of research, development of new commodity projects related to new types of products.

Improvement of modern management should be carried out from 3 organizational aspects: in a union of enterprises (in industrial associations); in large companies that combine different areas; in a network of enterprises incorporating regional structures. The first aspect is the union of industrial enterprises. The union of industrial enterprises is based on the activities of enterprises in both spatial and related forms. In recent years, many industrial parks, industrial zones and technoparks have been created around the world. The formation and expansion of production facilities in this area, the acceleration of innovation are considered serious steps taken in the world.

The author can show industrial zones, industrial parks, technoparks and industrial districts in the world as industrial associations. Today, technoparks are important as a leading form of industrial unions. Technopark combines universities and research centers to constantly improve industrial production and innovate, and prefers knowledge and research in its activities. Technoparks are a complex that combines industrial enterprises, educational institutions, research centers, shopping malls, business centers, exhibitions, service facilities, vehicles, settlements, securities and so on. Such complexes play a important role in the business world. But among them, research institutions play a leading role. Because it is the responsibility of research institutes or universities to create a scientific and theoretical basis for the application of high technologies in the activities of techno parks. But the leading role of economic development in this union belongs to manufacturing enterprises. Because the basis of the development of the national economy is production. The main purpose of technology parks is to integrate certain aspects of industrial production, increase the welfare of society, increase the competitiveness of organizations and, as a result, contribute to the country's economy [25; 26].

There are big and leading technoparks in the world. For example, Silicon Valley in the United States, Adlershof in Germany, Tsukuba in Japan, Biopolis in Singapore and other Technoparks can be shown in these aspects. Already there are more than 60 technoparks in Russia. Technoparks established in Azerbaijan, Belarus, Ukraine, Moldova, Kazakhstan and other similar countries organize the production of high technologies in their countries. The management of such complexes requires further improvement of the strategic management system. Among the innovative infrastructure of strategic management, attention is drawn to industrial areas, industrial parks, and technology parks. The main goal of work in this direction is to create more favorable conditions for the development of industrial enterprises, including small and medium-sized entrepreneurs, support the development of the non-oil sector, provide employment, develop local production, reduce the dependence of the Azerbaijani economy on external imports.

Other goals of creating industrial unions or parks are the renewal of existing production facilities, the production of competitive products and their introduction to the local and foreign markets. According to Strategic Roadmap for the Production of consumer Goods in Azerbaijan at the Level of Small and Medium Entrepreneurship [27] in order to accelerate the process of industrialization in the country and to achieve dynamic development in this area, the Azerbaijani state exempted the residents of industrial unions from property taxes, profit tax, land tax and customs duties for 7 years from the date of registration. It has taken incentive steps to exempt imported technological equipment and machinery for production purposes from value added tax. Such steps encourage entrepreneurs to become residents of industrial parks. The introduction of incentives for entrepreneurs working in industrial parks is an impetus for the development of industry in the country.

As it was mentioned above, the main aspect of the successful implementation of the industrialization process is the achievement of better and modern strategic management in the industry. In the company's strategy, it is important to make management decisions aimed at long-term development, study the environment and evaluate internal factors. In this case, one should study, investigate external environmental factors and determine the degree of their impact. It can be said with confidence that the ongoing industrial revolutions are taking industrial policy to a new level. This policy ensures the development of industry in terms of increasing economic efficiency. However, in most traditional industries of the country, the technical and technological level of production, the management system does not meet the requirements of innovative economic development. Therefore, the author considers it expedient to carry out modernization in the relevant areas in the context of strategic management. From this point of view, in the article, the author has presented a modern model of the strategic management mechanism of industrial parks. Such models can be applied not only in industrial parks, technoparks, but also in other business associations [28].

The author wants explain that research centers or universities are the central figures of technoparks. Thus, residents of technoparks receive innovations, ideas, as well as the results of research or research materials, innovation projects, business projects, proposals from research centers or universities. From this point of view, these research centers or universities will also determine the basis for the coordinated activities of companies that are members of industrial unions or parks. They can identify areas for coordinated development and regulate those relationships. From this point of view, the author can say that coordinated management can be important in the development of residents entering industrial and techno parks. The source of this management is research centers or universities. When such industrial unions are established, first of all, its investment and information environment, as well as the activities of the union members must be closely linked. Technoparks and clusters mainly include the following enterprises: production facilities, innovation infrastructures, universities or research institutes, service enterprises, consumers, other necessary structures. (audit, insurance company, bank, etc.). Industrial parks with such a structure have very favorable conditions for the systematic operation. International experience shows that the creation of innovation-oriented industrial associations ultimately guarantees the following:

• creation of new production capacities and modernization of existing ones for the development of production enterprises in the conditions of transition to the new technological system;

• production of export-oriented products that allow to obtain high value;

• implementation of organizational and technological measures that can create a synergistic effect;

• strengthening the position of competitive processing industry products in domestic and foreign markets.

By managing internal coordination, an industrial union can operate sustainably, expand its financial capabilities, and strengthen its competitiveness. The management of such parks is not based on administrative methods, but mainly on liberal and coordinated management methods. What does liberal method mean? The word liberal means freedom in Latin. Liberal style gives freedom to lower structures in management. Liberal leaders share much of the power with inferior leaders. In other words, lower leaders have power in their sphere of activity, having most of the managerial powers [29]. In a liberal style of management, the leaders of the enterprise prefer the socio-psychological method of management. Because they trust the leaders working at the lower levels of government, they provide them with social care. They provide them with social care. Liberal leaders place more emphasis on the principles of independence and the rule of law in their activities.

However, the liberal approach to coordinated management in the field the author is researching is completely different from the form used in management. Thus, liberalism in coordinated management gives full freedom to the members of the union. It should even be noted that the employees of this union are not functionally dependent on each other at all. Thus, the maximum provision of liberalism does not make the residents of the union dependent on each other.

According to this research, the proposed coordinated management in the industrial union can be applied in a liberal style. Because liberal methods give independence and freedom to all resident enterprises that join the union. The coordination function plays a key role in the management of such associations. Residents have no functional dependence on the union apparatus. It means that as the industrial environment expands, their need for administrative management decreases. In this case, the administration is replaced by liberalism. It replacement increases the coordinated activity of union residents within the industrial parks. As it has been mentioned, Techno Park is an industrial union based on the related activities of resident enterprises in one place or region. Such cooperation encourages the enterprices financial and economic unity. Such regional associations allow residents to get closer to each other, provide them with scientific, technical and material support, increase employment in the area, and create conditions for a flexible division of labor (Fig. 2).

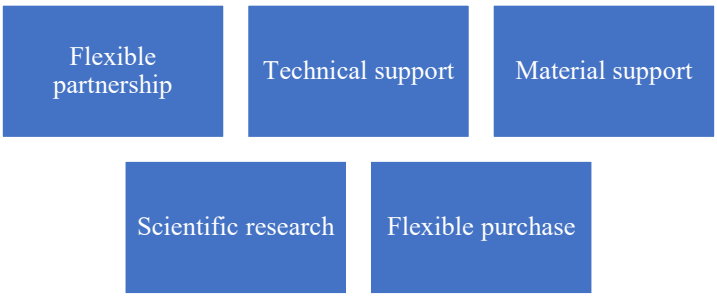

***Figure 2**. Benefits of the corporation in industrial unions*

As can be seen from Figure 2, cooperation creates a number of opportunities for the industrial union. The effective use of these opportunities creates conditions for the development of the union [30]. Having such opportunities and using them effectively requires the application of effective strategic coordinated-management. Effective management activities that serve the formation and development of new industrial unions require the existence of modern management principles. The purpose of modern management in this context is: activate joint financial and economic activities of enterprises; increase their support for each other; commercialization of research centers; achieve the joint development of each of them. As can be seen, the coordinated management of union members must serve the interests of all union members. Such management should focus on the joint, organized activities of the members of the park. Modern coordinated-management of industrial parks involves the implementation of the following measures:

- coordinated-management of economic and financial relations between enterprises;
- regulation of economic relations between them, elimination of problematic situations;
- ensuring their access to funding from a single source;
- coordinating the activities of enterprises with research centers;
- protection of economic rights of enterprises included in the Union.

For effective management, it can be divided into sectoral and regional networks. Depending on the type of activity, these areas may include manufacturing, construction, hotels, restaurants and so on. But in all cases, the research center or institute is the central figure in management (Fig. 3).

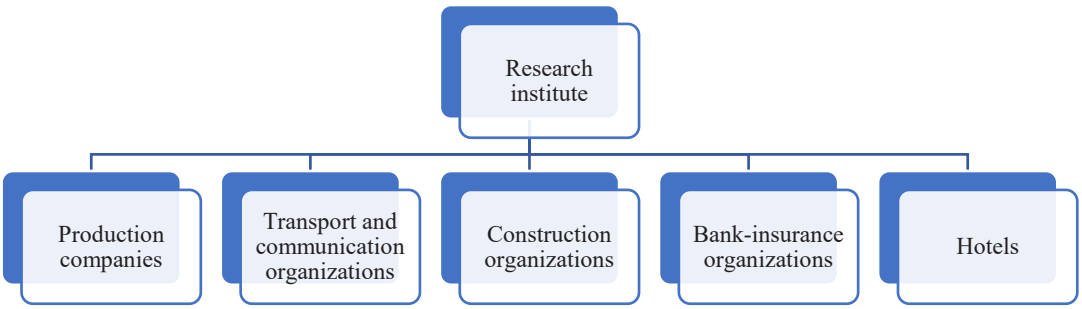

***Figure 3**. Sectoral structure of techno parks management*

But the coordinated-management of the parks may be focused by different region divigions. Such a classification synthesizes cross-sectoral coordination with territorial coordination. A research institute or university examines each area of the park, identifies problems, and identifies areas for development. The well-coordinated management structure also delegates the work to specialized groups. The economic entities included in the structure may vary depending on the type of activity, the volume of products produced, and the number of employees. These systems do not arise from the random organizational and administrative combination of different enterprises, but from the need for economic, organizational and technological processes to complement each other in chronological order. Also, companies, cooperatives, joint stock companies, associations, which are included in the system and operate in various fields, and other entities themselves have an independent management structure (production areas, workshops, departments, farms, service areas, etc.). Although these structures are not managed from a single center, they become the goal of coordinated management for joint activities, production, processing, logistics and sales of quality products (Fig. 4).

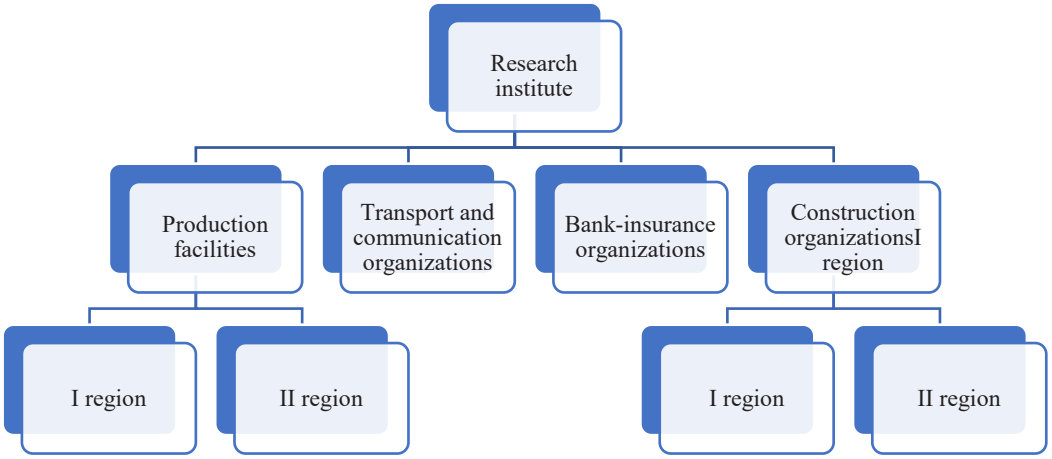

***Figure 4**. Sectoral and regional structure of the technopark*

If the park is very large from a regional point of view, for example, if it covers any part or area of the city (such as Silicon Valley in the US or Biopolis in Singapore), coordinated management targets can be set for different regions. Regional structures are formed independently of the sectoral structure, so regulation of economic relations between them are based on decentralization [31]. The main purpose of creating a regional structure is to classify the number of enterprises in different sections for research and explore. There is no administrative dependence in this division either. Such a management mechanism allows the application of the principles of sectoral and regional research of technoparks coordinatively.

The management mechanism, the principles of coordination should be carried out by the Research Institute or the university, which is the central figure of the technopark. Such a management mechanism coordinates, regulates and supports economic entities independently of each other. As a result, the organizations entering the park support each other, act in a coordinated manner, and act as an active subject in the implementation of the plans. Because such a division of labor encompasses a particular region or union in an organization, the scope of economic benefits is also wide.

CONCLUSIONS

By conducting research, the author has achieved the following contributions in order to form and improve strategically important coordinated management in the process of modernization of industrial enterprises:

- formation of the main strategic concept of modernization;
- formation of the content of highly changing strategic decisions on modernization of the enterprise;
- establishment of integrated scenarios related to strategic coordinated management;
- defining the criteria of efficiency of modernization;
- selection of an improved version of the modernization strategy;
- development of mechanisms to achieve the strategy.

The author believes that these contributions will be important in the management of industrial enterprises and will lead to effective results in coordinated management.

The research paper presents a new model of strategic planning for the analysis of environmental factors in order to increase the competitiveness of enterprises. For this purpose, the explores the conceptual foundations of strategic planning, the issues of potential analysis of its capabilities in order to develop the competitiveness of the enterprise. This is because the ability to compete and sustain operations makes it necessary to target most components of an enterprise's economic activity. This allows the existing and future capabilities of the enterprise on these components to be compared with competing enterprises. The author comes to the conclusion that the role of strategic management in expanding the activities and ensuring the development of industrial enterprises is great. In accordance with the process of industrialization, strategic management issues are important in the formation and development of industrial enterprises. The author assesses the importance of strategic management in industrial enterprises as follows:

- successful implementation of strategic management requires the creation of an improved management apparatus, consisting of various organizational and structural forms.
- It is important to have an organizational structure analysis and evaluation block to assess the effectiveness of management and to further improve it in the future.
- The participation of research institutions and universities in innovation-oriented industrial unions is mandatory.
- It is necessary to apply differential strategies in enterprises with a wide range of activities.
- It is possible to achieve strategic development of the activity in terms of effective application of management. Such structures, reflecting the essence, content, management mechanisms of the organization's management, ensure the interaction of individual structural units and achieve a systematic application of management.

Research shows that strategic coordination is formed, developed and ensures a successful outcome under the influence of management relationships between the subjects and structures of management. In other words, the application of improved management mechanisms is the basis of the sustainable operation of the enterprise. The issue of comprehensive modernization of strategic management in the country consists primarily of the implementation of state modernization policy in this area, the application of a comprehensive and systematic modernization strategy of industries and capital modernization of processing enterprises.

Examining the regulatory role of coordinated management of industrial parks, the author came to the following conclusion. The coordinator of the industrial parks must ensure the implementation of the following measures:

- elimination of problematic situations between enterprises, regulation of economic relations;
- regulation of financial and economic relations between enterprises;
- to assist in increasing the financing opportunities of enterprises;
- coordinate the activities of enterprises with research centers;
- protection of economic rights of enterprises included in the Union.

The strategic management process in industrial enterprises should target all aspects of the strategy in the implementation of the modernization process, including organizational strategy, marketing strategy, competition strategy, investment, innovation strategies and control strategy as a subsystem of management activities. Modernization of strategic management is associated with the application of new methods in this area, updating technologies for the application of management principles, the formation of modern management structural units, improving strategic management subsystems and further strengthening coordination between them.

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Модернізаційні аспекти стратегічного управління в промислових компаніях

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Анотація. У науковій роботі автором досліджено питання модернізації стратегічного управління на промислових підприємствах, а також проаналізовано ряд теоретико-методологічних аспектів у цій сфері. Проаналізована в статті тема є важливою, оскільки на сьогодні особливо актуальним питанням є створення і застосування більш досконалих технологій управління, оскільки від менеджменту, зокрема, залежить розвиток нових і діючих промислових підприємств. Успішне управління промисловістю є одним із найважливіших питань, що впливають на підвищення соціального та матеріального добробуту населення, а також розвиток економіки країни. Відтак виникає потреба в розробці теоретичних і практичних основ стратегічного управління на промислових підприємствах, успішній реалізації стартап-проектів, програм стратегічного розвитку для розширення та розвитку виробництва. Для цього в статті надано пропозиції та рекомендації щодо вдосконалення процесу стратегічного управління, розвитку технології управління та визначено принципи їх застосування в управлінській діяльності. У статті розглядається питання модернізації стратегічного управління з метою прискорення процесу індустріалізації. У статті розглядається формування індустріальних парків і застосування сучасних технологій в управлінні. Для цього науково роз'яснено поняття стратегічного менеджменту на промислових підприємствах та питання його вдосконалення. У статті розглядаються стратегічні комбінації менеджменту на промислових підприємствах. Також обґрунтовано питання гармонізації та узгодження їх виконання з організаційною структурою. У статті пояснюється необхідність і науково-практичні питання застосування підконцепцій стратегічного управління

Ключові слова: промисловість, індустріальні парки, система управління, організаційна структура

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Review on the Risks of Atypical Work in OECD Countries in the 1980-2020 Periods

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Abstract. The rapid change in working models establishes a new workforce structure and working systems. This situation creates the problem of unregistered employment and atypical work by individualising business dealing. Economic, social and technological developments, especially in the 1970s, have impacted working life worldwide, and atypical employment forms and working models have gradually replaced typical employment types. Being flexibile, it is aimed to adjust the working days and hours according to the demand differences and changes in the market, sustainability of the enterprises, increase in productivity and employment, and the establishment of the work and life balance of the employees. However, with the spread of flexibility practices over time and the intensification of atypical working styles, some losses have begun to occur in employees' vested rights regarding working conditions. Informal work causes another problem, such as unorganised and irregular labour. The purpose of the study is to examine the problems caused by atypical work. The research used descriptive statistical method since it is convenient to follow the developments in a particular field and identify the factual situations. The authors have collected data from World Labour Organisation and OECD sources and analysed these collected data according to descriptive statistical techniques. Using the trend analysis method, the authors have analysed the workforce structure and union density change in the analysed period based on numerical data. The research has established that atypical work causes insufficient instrumentality and status problems in the study period and disorganisation of labour. Based on research results, it can be stated that such working models as teleworking, working from home, and atypical work may lead to various social and psychological problems in the future

Keywords: labour, working model, part-time work, disorganisation of labour, precarisation

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INTRODUCTION

According to the generally accepted classification, publicity has reached the information society by passing through the stages of primitive, agricultural, and industrial societies. The factors that make this classification possible are always the economic, cultural, and political factors and the ways of doing business that enable the ownership of the production means and their exchange. Throughout history, the type of work and workplace differed with the change and development of civilisation [1-5]. Every civilisation and social stage has brought its way of doing business. Different business systems of each society are determined by the level of technology reached. Today, with the opportunities provided by the everyday use of information and communication technologies, it is necessary to determine how new working methods such as "virtual work", "virtual workplace", "atypical employment", and "atypical work" are affected. In addition, it is necessary to determine what consequences the said working method has in favour or against whom, including the employee and the employer, this is essential in keeping projections about the future.

In conventional ways, people were working depending on a place of work. This situation was a status opportunity in the organisational hierarchy and satisfaction provided by workplace friendship in a favourable organisational climate. This process had changed considerably when the employee, who joined the organisation with muscular strength and partly mental power in the industrial society, started to work using "the power of knowledge" in the information society. In addition to such sectors as agriculture, industry and service, the "information business" emerged, which allowed the appearance of a new sector called "information sector" [6-7]. Today, humanity witnesses the rise of new business models called "Virtual Workplace" or "Virtual Corporation", virtual work, atypical work, distance work, and Internet technology. Nowadays, to define the way of doing business, such concepts as "teleworking", "virtual organisation," "network organisation", and "virtual office" are used. Despite the variety of concepts and the lack of clarity in the literature, it is evident that the concepts of "job", "workplace" and "employee" have lost their conventional meaning. The distance between work-workplace-employees, which cannot be separated in the conventional sense, is combined with virtual networks [8-12]. This inseparable triad led to a new and dangerous class called precarisation in atypical work. On the other hand, an individual who loses the idea of space due to atypical work becomes alientated from work and themself. Although there are enough publications on the alienation of the employee, the gap in the literature on the problem areas of atypical work and precarisation makes this study relevant, functional and necessary.

Humanity is going through a period in which every rule, principle, job, and method of doing business in a conventional way is transformed. Work, which means applying labour to a solid object, has changed form and applied to abstract/virtual entities. It is not easy to predict how this process will turn out today. This process is radically changing the human-work relationship. Earlier, the object was the work itself. Today, this conventional subject-object relationship has been disrupted with artificial intelligence, expert systems, and the adaptation of various algorithms to the job. It is essential to identify and even emphasise the place of people in the human-work relationship. Although the way of working in a workplace and between certain hours is caused by different reasons, such as the COVID-19 pandemic, the gap created by eliminating the idea of the workplace from human life must be filled with such measures as close communication and interaction [13-18]. The workplace where employees spend a considerable part of their lives is also the environment where they modernise and socialise by applying their workplace friendship, knowledge and skills. To eliminate the feeling of emptiness and abandonment caused by the removal of workplaces which have such essential functions from human life, it is necessary to frequently communicate through live and video connections on various platforms. It is essential for atypical employees who do not have a workplace yet to meet their socialisation and solidarity needs by establishing various non-governmental organisations.

Developments in the way they appear now show that people will work in more than one job simultaneously in the future. Currently it has different applications, such as "multi-career" and "atypical career". The new working class has more than one skill and ability in these new ways of doing work, which is implemented as atypical work. In addition to the obligation mentioned above, atypical work has problems working without status, precarious working, working without organisation, and working without a contract. This study tried to determine the development of atypical work in OECD countries during 1980-2020. For this purpose, the authors have tried to identify what is atypical work in OECD countries. In addition to the fundamental question of the study, the authors aimed to answer the following sub-questions:

- What is the evolution of employment indicators in OECD countries during the period under review?
- Is atypical work increasing in OECD countries?
- Does atypical work in OECD countries cause the problem of labour disorganisation?

THEORETICAL OVERVIEW

Atypical nature of work and the problem of alienation from work

In terms of motivation theories, there are three types of factors that push people to work, and the first of these is "instrumentality". According to the instrumentality factor, work is beneficial for an individual, and it becomes a motivating factor if it can meet their physical and psychological needs. Otherwise, the instrumental reason

necessary for an individual to do the job disappears. The second benefit that the job provides to the individual is self-fufilment. The need for self-actualisation is met in two ways. The first is the psychological satisfaction created by the person seeing their work, and the second is the social satisfaction provided by the appreciation of other people. Social satisfaction is also the third reason that directs a person to work and makes work meaningful. However, the atypical study contains fundamental problems in providing this satisfaction. In virtual organisations that do not exist but can be processed as if they exist, human beings do their job anywhere far from a block of concrete and natural environment. The employee is at work but not in an abstract and virtual universe, not in the real world [8; 10; 11; 19]. Here but not at work. Therefore, it is not easy to define the framework of the atypical work. The main factor that makes the definition difficult is that the work is real and the workplace is virtual. The employee in the virtual business environment has lost their real social universe and works in a simulated business environment, in an artificial environment that does not meet the needs of reality.

The most typical example of atypical work is virtual work. Virtual work differs from conventional business forms by not allowing the employee to touch and feel the virtual product produced by the employee. Virtual works do not give the employee a feeling of seeing and perceiving their work in three dimensions, and therewore cannot give satisfaction. This situation pushes the business to "virtual alienation". Alienation has been used for physiological, psychological, sociological, economic, political, and theological issues. Despite all these different uses, the word alienation can be grouped under two headings in terms of meaning. The first one is separation from self and the other is distancing from people and inability to adapt to social processes. Alienation is the process that disrupts the integrity of harmony in an individual's daily life. Alienation can be evaluated in three different ways. The first is the loss of interest in the society in which a person lives, cultural values, and the distribution of roles [20; 21]. In this kind of alienation, the person experiences powerlessness and loneliness caused by the inability to grasp social processes. Another alienation is the alienation of labour that occurs due to the division of labour as the employee loses control over the work in the production process. Virtual alienation occurs with the vague sense of pleasure the worker experiences due to virtual barriers between their work and themself.

Today, people become alienated from society and themselves due to various reasons such as industrialisation, technology, changes in social structure. A person loses the ability to behave naturally, sensitively and sincerely. The shape of production, the forms of specialisation, and the current production methods prevent free and natural development. The main factor that causes alienation in jobs and social processes causes people to move away from their natural order. Today's atypical jobs and employment styles do not allow the employee to be involved in the work processes. Human nature is denied in this new type of work; independence, creativity, curiosity, and the ability to think independently are hindered [22-24]. People cannot fully comprehend their place in automation-based business forms requiring general information and communication technologies. The person who has to do business with artificial intelligence and expert systems is alienated by moving away from naturalness and complying with the machine's rhythm.

Near risk areas of atypical study

Advanced information technologies prevent employee from integrating themself into the business processes. The excessive automation of the work makes the employee depend on the machine and surrender to the operating logic of the automation. Excessive dependence on the work processes and the technology used causes the employee to feel worthless. According to the success motivation theory, a theory of motivation, the individual has two basic needs. The first is that the essential factor motivating people to work is achieving. The second need is the need of the individual to establish a relationship with his/her environment. Even if the current meaning of the work meets the individual's need to achieve to a certain extent, it is not enough to meet their social needs [25; 26]. In industrial psychology, this new meaning of work can cause employees to feel lonely and worthless. Employees obtaining a corporate identity depends on having a physical structure of the work. The experience of having the necessary knowledge, skills and abilities to do a job enables the development of identity and, therewith, gives an employee a social status. In the conventional sense, the identity of the job is lost in case of retirement and unemployment, while the opportunity to obtain identity and status is lost in atypical work.

Different individuals perform different functions at work and some workplaces consist of people who do not know each other. However, in the conventional sense, work is also the source of friendship and social communication outside the family [27]. The job enriches the employee's field of personal relationships. This wealth is only possible when there is physical interaction. Otherwise, the artificial interaction provided by the virtual environment does not provide a suitable environment for the enrichment of personal relationships. Atypical work, in a way, means a disorder. The human biological system also has a functioning order, as any system. In terms of time management, planning, and ordering priorities, irregularity disrupts the person's life order and family life.

In an atypical study, it is possible to do or postpone the work at any time. When people have a job, they have a workplace and colleagues and take on new social roles. In classical organisations, the individual is in contact with other people, such as his/her colleagues, managers, and

subordinates. The employee's role is interrelated with the role of a large number of employees. In atypical work, people have to carry out their work in electronic cells away from their social environment and in environments of spacelessness. With the impact of the pandemic, jobs are moved to homes in the compulsory remote work process [28-30]. However, this working system causes people to lose their colleagues. Knowledge work, which requires intense attention and mental focus and makes it difficult for a person to be a family member, damages the conventional family structure.

A job that will save people from loneliness and contribute to being a social person must meet the social needs of people, which are expected from work. Only in this way can the individual protect their integrity and get rid of the feeling of loneliness and strangeness. Unfortunately, atypical work at home cannot respond to the individual's psychological needs, nor does it fulfill their social role. Access opportunity provided by knowledge work and information organisation eliminates realistic interactions. Virtual access does not allow interaction and leaves people alone. Atypical work is quickly adopted due to the sense of freedom provided by adaptation to change and mobility.

Atypical study and problem areas

Atypical work pushes an individual to insufficiency in social relations and isolates them. In an atypical study, people lose the opportunity to communicate face-to-face, and human-centred interaction turns into tool-centered communication. The new communication, which has increased widespread access, loses its depth and content contrary to expectations. Icon-based simplifying media narration moves away from the content of face-to-face communication. At the same time with the increase in communication channels due to virtual networks, humans' loneliness is expanding. In vehicle-centred communication, the isolation of the individual, who has gained extraordinary opportunities in ways such as the Internet and satellite communication, increases. Minds conditioned by the magic of easy access cannot find a real opportunity for interaction. Even when the employee devotes themself in atypical work, it is impossible to live in peace due to the uncertainty of tomorrow. The problems of atypical work are still understudied. The negativities caused by the atypical work on the human element of the organisation are beginning to emerge [31-33]. It is not yet known how an individual accustomed to loneliness in an artificial environment surrounded by webs will overcome asociality. Among these uncertainties, common forms of atypical study can be identified as follows [34]:

Working in satellite centres. It is away from the workplace but connected to the business with a network system. Working centres called satellite offices belong to a single company. The company designs satellite offices. Satellite offices, which have personal computers, telephones, Internet, and other information and communication technologies infrastructure, are atypical employment places where employees from different departments work. In this work method, employees are neither at home nor at work. Satellite offices are places where a modern employee is alone with information and communication technologies.

Neighbouring study centres. These centres are also designed to enable an atypical way of working. The difference between neighbouring study centres from satellite offices is that they are designed and used by more than one organisation. Employees in neighbouring work centres represent different interests. Neighbouring study centres, which form organisational design contrary to synergy creation and group dynamics, are mechanical/electronic environments purified from organisational culture and climate.

Telework at home. Teleworking at home is the most common example of atypical work. Telework or virtual work can be in an environment where the employee can only communicate indirectly, away from the workplace and colleagues. When working at home, it turns into an office and the person is far from the motivational group dynamics of the workplace and disrupts the warm climate of their own home. With information and communication technologies moving to the house, the house loses its "home" quality, becomes the workplace branch, and loses its conventional character.

Mobile work. The most atypical type is mobile work. It does not work depending on any fixed location that works in a mobile operation. The idea of space loses its conventional meaning in mobile workers. Mobile workers are often travelling. These include information and communication technologies from home, car, hotel, etc. They work by establishing a connection with the central office. Mobile workers are the travelers of the information societies.

Part-time job. A part-time job is a form of employment that requires fewer hours per week than a full-time job. These usually work in shifts and alternately. If an employee works less than 30 hours per week, they are considered part-time worker. According to the International Labour Organisation, part-time workers account for almost 50 percent of total employment in most developed countries except the United States (I.L.O. Part-Time Work Convention No. 175).

The most critical drawback of atypical work is career development. Employees should generally have clear information about career opportunities in the organisation. Since atypical work is carried out in independent environments outside the organisation's hierarchical structure, it causes the employee to stay away from the career competition environment of the workplace. The organisation's hierarchical structure responds to the employee's desire to rise. The most important disadvantage of the atypical work method, devoid of hierarchy, rank and competition, is that it does not respond to the human desire to rise. Humankind has realised its desire to rise

by competing with other employees in the conventional workplace. It can be argued that non-destructive competition has had a considerable motivational effect on human productivity [35; 36]. Although atypical work provides the employee with the flexibility of movement, it causes social isolation and adaptation problems to the environment in the long term. Atypical work deprives employees of motivation tools such as participation in decisions, jobs, and work processes.

Atypical work and precarisation problem

Since atypical work is a form of work without status and contracts, these people often work for lower wages than others. The basic (root) fee is usually not included in wages. Another negative aspect of the atypical work is that, generally, atypical employees do not have any social security benefits. According to a study conducted in the USA, one-fourth of those working at home were lonely and asocial. In a study conducted in England, 60% of the teleworkers stated that isolation from social processes is the biggest drawback. In a large-scale study on the benefits and drawbacks of telework by Hudson's Bay Company, most telework states missed exchanging views with colleagues [35]. In addition to their needs and social security, people want to be psychologically satisfied financially, economically, and physically.

Temporary and part-time workers, especially programmers, software developers, and system designers in information technology, work part-time to form the new semi-unemployed class characteristic of the information society. These people are mainly self-employed and called "crowd workers"; conditional workers and new migrants. Atypical employment finally causes a new problem called precarisation. It produces insecure employment or job security, labour instability, insufficient average monthly wages, rapid change, low social position, and unstable work [37-39]. Unfortunately, people whose working conditions have deteriorated with precarisation and become insecure and unprotected must continue their low-status lives during their retirement.

A new marginalised working class is emerging in the business world due to atypical work. These are chronically unemployed, disadvantaged suburban residents, those in need of social assistance, industrial transformation victims, job seekers, and part-time workers. A class of socially non-settled people who do not have fully guaranteed employment and stable earnings, "low status", most of them lack social and political rights and security. Working independently from the workplace in precarisation leads to the disappearance of employees' organisational support and professional isolation [37; 40-42]. Isolation is a state of loneliness and separation. Aside from the psychological and social conditions, it has been established that the essential concrete drawback of atypical work is the disorganisation of labour. This research aims to present the effect of an atypical study on the labour force, discuss the subject, and contribute to the literature on this subject.

MATERIALS AND METHODS

Research design

In this study, the authors used the descriptive statistics method to examine the problem areas of atypical work in a certain period. Another reason for choosing the descriptive statistics method is that it is suitable for the subject and purpose of the research, and it was used to answer the research questions. In research-based descriptive statistics, it is aimed to establish the current state of the object or phenomenon. Descriptive research aims to draw a portrait of an organisation, individual, group, situation, or phenomenon. Descriptive statistics collect, interpret, and summarise data [43; 44]. Since the descriptive statistical method is based on quantitative data analysis, various descriptive tables support the analysis [45; 46]. Descriptive statistics describe the basic features of the data in a study. They provide simple summaries about the sample and measures. Together with simple graphical analysis, they form the basis of every quantitative data analysis. With descriptive statistics, they describe what the data shows. Descriptive statistics convert numbers and quantitative data obtained from observations into descriptive indices. The descriptive statistical technique was used because of its compatibility with the approach of this research [44].

Sampling

The study sample consists of 24 OECD countries, including 20 founding countries in 1961 and four other countries that joined the organisation until 1973. The founding countries are the USA, Germany, Austria, Belgium, United Kingdom, Denmark, France, the Netherlands, Ireland, Spain, Sweden, Switzerland, Italy, Iceland, Canada, Luxembourg, Norway, Portugal, Turkey, and Greece. The countries that joined the OECD later and the years they joined are as follows: Japan (1964), Finland (1969), Australia (1971), New Zealand (1973). Other countries that joined after 1994 are Mexico, Czech Republic, Hungary, Poland, South Korea, Slovakia, Chile, Estonia, Slovenia, Israel, Latvia, and Lithuania.

Collection and analysis of data

In this study, the authors aimed to obtain the most appropriate data from OECD countries, to create a mind map of how the atypical study followed a course at ten-year intervals in 1980 and beyond. For this reason, the research sample was determined according to the purposeful sampling method. The study examined the problematic areas of atypical work in OECD countries in the post-1980 period by examining the new forms of work conducted differently, such as atypical or mobile work, while determining this impact on organised labour [47].

RESULTS AND DISCUSSION

Atypical employment is growing every day with new working technologies. The COVID-19 pandemic has been one of the imperative factors affecting this process. While

the rate of atypical employees to total employment was 8.5% in 2008, it increased to 12.3% in 2013 [48]. Although the share of temporary employment decreased between 2000 and 2012 (12.5%), it increased to 13.6% in 2016 [49]. In a considerable part of the 28 European Union member countries, atypical employment had a share of 37.2% of all employees in 2016. In 28 member countries of the European Union, 19.5% of the employees are part-time, 12% fixed-term, 10% self-employed, and 1.7% temporary office workers. Among the EU countries, the rate of people called precariat in the Netherlands, where the most atypical employment is (82.5%), is at the level of Spain (51.2%) and Germany (45.8%). It is at the level of Bulgaria (12.9%), Estonia (18.8%) and Hungary (19.2%). Table 1 shows the proportion of atypical workers among all employees in European countries.

***Table 1**. Proportion of atypical workers among all employees in European Countries (15-64 age group, %, 2011-2019)*

European Union	2011	2012	2013	2014	2015	2016	2017	2018	2019
European Union – 27 countries (2020 and later)	38.8	38.9	38.6	38.6	38.5	38.2	37.9	37.3	37.2
European Union – 28 countries (2013-2020)	39.1	38.9	38.8	38.8	38.6	38.4	38.1	37.4	37.3
European Union – 15 countries (1995-2004)	39.4	39.2	39.0	39.1	39.1	38.9	38.7	38.1	38.1
Eurozone – 19 countries (2015 and later)	39.3	39.4	39.2	39.2	39.3	39.1	38.8	38.4	38.3

***Source**: [49]*

The above ratios show that as economies grow, precariatisation also grows. The precariat class grows the economies, but they cannot get a share from the growing economies; they continue to be the cause of wealth but the victims of poverty.

Part-time workers in Canada usually work less than 30 hours per week [50]. Part-time work ranges from 1-34 hours per week [51]. In July 2020, it was determined that approximately 23.29 million people were working part-time in the USA [52]. Part-time workers in the US do not have the benefits of health insurance. Although the numbers are unclear, the US Women's Policy Research Institute suggests that the proportion of women working part-time is nine times higher than men [53]. In 2015, the average percentage for women was 32.1% in Europe, while this rate was 8.9% for men [54]. Another problem with employment is an East-West division in the EU. While part-time work is seen as a marginal attitude even among women in Central and Eastern European countries, Western European countries have adopted this much more broadly. The highest rate of part-time work in Europe is in the Netherlands, and the lowest is in Portugal (Table 2).

***Table 2**. Total part-time employment rate OECD, % of employment, 1980-2019*

Countries	1980	1990	2000	2010	2019
Australia	n.d.	n.d.	23.76	24.85	25.54
Austria	n.d.	n.d.	11.75	19.17	20.02
Belgium	9.76*	13.51	19.26	18.32	16.87
Canada	14.29	16.97	18.1	19.56	18.95
Denmark	20.56*	19.16	15.29	19.15	19.2
Finland	n.d.	7.59	10.36	12.48	14.56
France	10.3*	12.17	14.25	13.68	13.44
Germany	13.37*	13.42	17.58	21.84	22.04
Greece	7.24*	6.7	5.34	8.91	10.46
Iceland	n.d.	22.17*	20.41	18.36	15.71
Ireland	8.02*	9.99	18.08	24.86	20.58
Italy	8.02*	8.88	11.71	16.37	18
Japan	11.08	13.57	15.95	20.24	25.16
Luxembourg	7.27*	7.61	12.97	15.78	11.64
Netherlands	18.54*	28.15	32.07	37.15	36.96
New Zealand	n.d.	19.65	22.16	21.84	19.79
Norway	n.d.	21.78	20.21	20.45	20.14
Portugal	n.d.	7.62	9.34	9.57	7.11
Spain	n.d.	4.64	7.54	12.16	13.22
Sweden	n.d.	14.48	14.04	14.5	13.72
Switzerland	n.d.	n.d.	23.04	26.14	26.87
Turkey	n.d.	9.33	9.35	11.48	9.5
United Kingdom	18.43*	20.11	23.3	24.63	23.06
OECD – Total	**13.21***	**13.15**	**13.89**	**16.67**	**16.7**

***Note**: * – data of the year closest to the years for which no data are available*
***Source**: [48]*

Another form of atypical work is temporary employment, a fixed-term, project, or task-based work, and this situation continues to be a problem for the employees. Although some employees prefer to have temporary jobs because they combine work with training, this causes unsecured and unorganised work. People are working in temporary employment according to the terms of daily work or periodic employment contract. Temporary employment is an atypical form of employment in the form of low-income and informal wage employment, and it means nothing but postponing the unemployment problem [55]. Temporary employment in EU and OECD Member Countries is shown in Table 3 (1980-2019).

***Table 3**. Temporary employment Total OECD, % of dependent employment, 1980-2019*

Countries	1980	1990	2000	2010	2019
Australia	n.d.	n.d.	4.84	5.23	5.27
Austria	n.d.	n.d.	7.94	9.35	8.69
Belgium	5.39*	5.31	9.13	8.12	10.92
Canada	n.d.	n.d.	12.48	13.35	12.79
Denmark	12.45*	10.79	9.74	8.43	10.86
Finland	n.d.	n.d.	16.46	15.56	15.76
France	3.34*	10.53	15.44	15.1	16.39
Germany	n.d.	10.53	12.74	14.53	11.95
Greece	16.24*	16.55	13.47	12.6	12.51
Iceland	n.d.	14.43	12.18	12.36	7.78
Ireland	6.11*	8.49	5.95	9.64	9.76
Italy	6.61*	5.22	10.11	12.68	16.99
Japan	9.61	10.61	14.52	13.75	n.d.
Luxembourg	3.25*	3.38	3.4	7.1	9.18
Netherlands	5.82*	7.61	13.66	18.5	20.25
New Zealand	n.d.	n.d.	n.d.	n.d.	7.79
Norway	n.d.	n.d.	9.3	8.44	7.98
Portugal	n.d.	18.33	19.93	22.8	20.78
Spain	n.d.	29.82	32.18	24.74	26.26
Sweden	n.d.	n.d.	15.24	16.4	16.55
Switzerland	n.d.	n.d.	11.54	13.11	12.66
Turkey	n.d.	14.4	20.34	11.44	11.58
United Kingdom	5.5*	5.24	6.96	6.11	5.18
United States	n.d.	n.d.	4.48	4.21	3.95
OECD – Total	**9.17**	**10**	**11.63**	**11.88**	**11.77**

***Note**: * – data of the year closest to the years for which no data are available*
***Source**: [49]*

Atypical work is essentially the result of the strategy of labour disorganisation. The most damaging aspect of this strategy for employees is that the unions that protect rights of the employees lose power in this process. Whatever the name of regular employment or precariatisation, the basic strategy is the disorganisation of labour. Whatever the name of atypical employment or precariatisation, the basic strategy is the disorganisation of labour. While around seventy percent of the workforce was unionised in the 1970s, there was a dramatic decline in union membership in the 1980s and early 1990s. When the unionisation rates of OECD member countries were examined, it was established that the purpose of labour disorganisation has been achieved to a large extent. Employers' efforts to prevent their workers from joining the union became fundamental for employees [56]. To keep employees away from unionisation and disorganise their labour, the labour disorganisation has been adopted with the modern human resources movement such as horizontal organisational structures, downsizing, human resources movement, and reserve workers. Union membership, 36% in the early 1940s and around 70% in the 1970s declined to 12% in 2018 due to the labour organisation strategy [56; 57].

***Table 4**. OECD Union density ratios in the countries (1960-2018)*

Countries	1960	1970	1980	1990	2000	2010	2018
Australia	50.2	44.2	49.6	45.4	24.8	18.4	13.7
Austria	60.1	56.7	51.7	46.8	36.9	28.9	26.3
Belgium	41.5	42.1	54.1	53.9	56.2	53.8	50.3
Canada	29.2	31	34	32.8	31.2	30.1	25.9
Denmark	56.9	60.3	78	74.6	74.5	67.2	66.5
Finland	31.9	51.3	69.4	72.8	74.3	70.3	60.3
France	19.6	21.7	18.3	9.8	9.5	9	8.8
Germany	34.7	32	34.9	31.2	24.6	18.9	16.5
Greece	n.d.	n.d.	n.d.	n.d.	24.9*	22.2	20.2*
Iceland	n.d.	n.d.	n.d.	n.d.	89.4	85.2	91.8
Ireland	45.3	53.2	57.1	51.1	36	33.5	24.1
Italy	24.7	37	49.6	38.7	34.4	35.5	34.4
Japan	32.2	35.4	30.8	25.2	21.5	18.3	17
Luxembourg	n.d.	n.d.	n.d.	n.d.	43.2*	35.1	31.8
Netherlands	41.7	38.4	34.8	24.6	22.6	19.5	16.4
New Zealand	n.d.	56.3	69.1	49.6	22.4	21.4	18.8
Norway	60	56.8	57.9	58.5	52.4	50	49.2
Portugal	n.d.	n.d.	54.8	29.3	20.5*	19.6	15.3*
Spain	n.d.	n.d.	13.3	13.3	17.4	18.3	13.6
Sweden	64.6	67.7	78	81.5	86.6	70.2	64.9
Switzerland	31	24.9	27.5	22.5	20.2	17.6	14.9*
Turkey	12.1	29	39.5	35.2	16	10.7*	9.2
United Kingdom	40.5	44.8	52.2	39.6	29.7	26.8	23.4
United States	30.9	27.4	22.1	15.4	12.9	11.4	10.1

***Note**: * – data of the year closest to the years for which no data are available*
***Source**: [58]*

It is observed that unionisation rates in OECD countries decreased considerably from 1998 to 2018 (Table 4) "Union density" has continuously decreased in OECD countries since the 1980s [59]. Unionisation rates in developed western countries continue to decline today. The 1973 oil crisis, which is considered the turning point of neoliberalism, effectively reduced the density of unions in the USA. The adoption of the Taft-Hartley Act during this period was a great misfortune for unions in the United States [57; 60; 61]. In this process, unions were initially created, but those who developed the strategy that labour will not always remain a factor of production were weakening the organised workforce.

The risks of atypical work in OECD countries emerged, especially when capitalism developed new business models to overcome the crisis after the oil shock in 1973. In this study, the authors tried to determine the situation by doing a trend analysis of the last 40 years to determine whether this new working model favours the workforce, called atypical working or precarisation. The figures above show that precarisation means eliminating or weakening organised labour in firms [62-64]. In addition, it was concluded that the strategy implemented to weaken the organised workforce in front of companies brings risks such as the loss of employees' unions and working without security and status. Based on the principle that the value and meaning of jobs are measured with their results, it was determined through trend analyses that remote and atypical working is not favourable for employees. Thus, the authors concluded that atypical work creates a situation against the labour force. It was determined that the results confirm the authors' assumption that atypical employment leads to many psychological and social problems of the employees with concrete indicators.

Studies conducted on the subject with the literature review show that atypical employment and remote work are significantly higher in OECD countries, especially in the Netherlands. Due to the economic crisis of different intensities since 2008, the rate of atypical work in the total workforce increased [41; 65; 66]. As in many other fields, literature studies also constitute a disadvantaged group of women in this problematic area in atypical employment. Atypical employees among the total employees

in Europe increased from 12.7% in 1987 to 20.9% in 2009. This rate is 36.5% for women. Atypical employment rates are higher than 30%, especially in France, the Netherlands, Luxembourg, and Austria. It is demonstrated that atypical work, presented as a contemporary study model and ultimately leads to the emergence of a new class called precariat, increases daily [42; 67; 68]. Although atypical business models have been proposed in employment and labour market regulation as a solution to precarisation, it is evident that this will not be enough to solve the problem [39; 41; 69; 70]. It can be argued that this class, called the precariat, may cause critical social problems in the future. It is understood that information and communication technologies have led to new employment models such as remote work and atypical work. On the other hand, not wanting an organised power and adopting the strategy of labour disorganisation causes the emergence of irregular and unstable class in OECD countries, although there is yet no class-consciousness [65; 71-73]. It is necessary to consider what problems this unstable and irregular class will cause in the future.

CONCLUSIONS

This study focuses on the possible risks of atypical working models on the labour force. The research focused only on OECD member countries and the implications of atypical work on union density. Lack of access to data on some of the studied countries appeared to be a limiting factor. On the other hand, the research does not cover other important countries. The problem of precarisation began in 1961, the year when union movements and organised labour gained importance and the OECD was established; however, the authors could not obtain sufficient data about these periods. Another limiting factor in this matter was that the countries that joined OECD after 1994 were not included in the sample. On the other hand, the research covers a substantial sample; it supports the problems of the atypical work with particular indicators and examines the subject in-depth. Discussion of the effect of atypical work on the workforce in the long term and a large sample supported by numbers makes the research original, functional and essential in contributing to the literature.

The research results show that atypical and non-contractual work called precarisation leads to a new class. Drawing attention to social and economic problems of this class in the future makes the research theoretically and practically important. The research findings show particular risk factors based on the argument that atypical study involves risks. It can be argued that this will raise some social and economic problems in the long run. It is necessary to take precautions and develop new business models with security, status, and contracts. In addition, the study covers the reflections of atypical work on union density but does not cover the relationship between atypical work and poverty. The authors propose to consider this issue in another study.

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Огляд ризиків нетипової роботи в країнах ОЕСР у 1980–2020 рр.

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Анотація. Швидка зміна робочих моделей виявляє нову структуру робочої сили та робочі системи. Така ситуація створює проблему незареєстрованої зайнятості та нетипової роботи через індивідуалізацію способу ведення бізнесу. Економічний, соціальний і технологічний розвиток, особливо з 1970-х років, вплинув на трудове життя в усьому світі, і нетипові форми зайнятості та робочі моделі поступово замінили типові види зайнятості. З гнучкістю вони спрямовані на коригування робочих днів і годин відповідно до відмінностей попиту та змін на ринку, стійкості підприємств, підвищення продуктивності та зайнятості, а також встановлення балансу між роботою та життям працівників. Однак із поширенням практики гнучкості з часом і посиленням нетипових стилів роботи почали відбуватися деякі втрати в набутих правах працівників щодо умов праці. Неформальна робота викликає ще одну проблему, наприклад, використання неорганізованої та нерегулярної праці. У цьому дослідженні автори статті мали на меті вивчити проблеми, викликані нетиповою роботою. У методі дослідження використано описову статистичну техніку, оскільки в такий спосіб зручно відслідковувати розвиток подій у тій чи іншій галузі та виявляти фактичні ситуації. Були зібрані та проаналізовані дані дослідження з джерел Всесвітньої організації праці та ОЕСР відповідно до описових статистичних методів. Використовуючи метод аналізу тенденцій при аналізі даних, було розглянуто структуру робочої сили та зміну щільності профспілок за аналізований період на основі числових даних. Результати дослідження визначили, що нетипова робота викликає проблеми недостатньої інструментальності та статусу в досліджуваний період і дезорганізації праці. На основі результатів дослідження можна стверджувати, що такі робочі моделі, як дистанційна робота, робота з дому та нетипова робота, можуть призвести до різних соціальних і психологічних проблем у майбутньому

Ключові слова: праця, робоча модель, неповний робочий день, дезорганізація праці, прекаризація

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Agricultural Land Use in Ukraine: Ensuring and Implementing the Right to a Safe Environment

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Abstract. Safe land use of agricultural territories implies the mandatory preservation of the state's land resources, which are its crucial strategic resources. The relevance of this study is conditioned upon the abundance of issues of safe land use in Ukraine, specifically in the agricultural sector of Ukraine, not least due to the difficulties of exercising the citizens' right to safe use of agricultural land. The main purpose of this study is the theoretical investigation of the possibilities of ensuring the right to a safe environment upon using agricultural land in Ukraine, with an assessment of the real possibilities of its practical implementation in modern economic conditions. The basis of the methodological approach in this paper is a combination of methods of systematic analysis of key aspects of safe land use applicable to agricultural land, with the method of abstract-logical research of the main aspects of the exercise of the citizens' right to a safe environment upon using agricultural land in Ukraine. The main results obtained in this paper should be considered the definition of the main priority areas for the development of the available legislative system in Ukraine in the context of ensuring the safety of agricultural activities and the assessment of the role of the state in ensuring the proper level of environmental safety of agricultural land use in terms of the prospects for the preservation of the agricultural land available in the country. The results that were obtained in this study, as well as the conclusions formulated on their basis, have substantial practical significance for agricultural workers concerned about the qualitative solution of problematic issues concerning the ensuring and practical implementation of their legitimate right to a safe environment upon using lands that belong to the agricultural sector of the national economy

Keywords: safe land use, agricultural lands in Ukraine, agricultural lands, land resources, soil fertility, safe environment

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INTRODUCTION

It is considered that any improvement of the land use process in the context of the existing land management system necessarily violates the sustainability of land resources and may adversely affect the future reproductive ability of agricultural land [1]. To date, the phrase "sustainable land use" is very widely used in the international practice of territorial planning and, apart from the immutability of borders, as a purely technical parameter, implies several aspects of both an economic and environmental nature.

The exercise of the right to a safe environment upon agricultural land use involves the consistent implementation of an entire range of legislative measures aimed at creating conditions for safe land use in the context of the implementation of the full range of practical tasks that have been set for enterprises operating in the agricultural sector of a single state and individual landowners [2]. Nowadays, in terms of the realities of the economic situation that has developed in Ukraine, ensuring the right to a safe environment upon agricultural land use in Ukraine should be interpreted as a guarantee of the safety of land use by the state, supported by regulations strictly governing both the order of land use and the measure of responsibility for violation of this legislative right. In any case, national regulation of issues of safe land use in this context is mandatory because otherwise, without a regulatory framework that clearly governs all conditions for the exercise of the right to a safe environment upon agricultural land use in Ukraine, it will be impossible to achieve high-quality regulation of all controversial issues that inevitably arise in the practical solution of issues concerning the agricultural land use [3].

The issues of increasing the efficiency of agricultural land use are of key importance in the context of practical aspects of land management activities in modern Ukraine. These issues cause certain difficulties in their practical resolution, from the standpoint of the natural and economic processes taking place today, and in some cases also predetermine the inapplicability of conventional approaches to obtaining information about the factual state of affairs in national agriculture. When discussing the real possibilities of exercising the right to a safe environment upon agricultural land use, one should consider the environmental situation in a particular region of agricultural activity, as well as the factual state of the land at the time of the start of any activity related to its development for economic purposes. It is necessary to consider the terrain, the total area of agricultural land that is used for arable land, hydrological factors and climatic features of a particular geographical region, as well as to pre-assess all possible consequences that may occur due to interference with the environment [4]. It is important to take into account the multifactorial nature of the issues of efficient agricultural land use. Furthermore, upon developing a qualitative assessment of the efficiency of the practical agricultural land use, it is necessary to focus not only on economic and statistical factors, since such an approach invariably imposes many restrictions on the assessment of lands on which no information is available, and indicates the almost complete impossibility of introducing the concept of potential efficiency [5].

The main purpose of this study is to assess the degree of ensuring and exercising the right to a safe environment upon agricultural land use in Ukraine, in the current global economic situation in general and in Ukraine in particular. The theoretical and practical results obtained in this study can be further used to assess the current efficiency of the national policy in ensuring sustainable land use and protection of agricultural land.

MATERIALS AND METHODS

The basis of the methodological approach in this paper is a combination of methods of systematic analysis of key aspects of safe land use applicable to agricultural land, with the method of abstract-logical research of the main aspects of the exercise of the citizens' right to a safe environment upon using agricultural land in Ukraine. This study employed an information and theoretical base, which constitutes an analysis of the main legislative acts governing the order of land use in Ukraine and key aspects of the exercise of the right of Ukrainians to a safe environment upon agricultural land use, as well as containing the results of an analysis of available scientific publications made by a number of Ukrainian and, predominantly, foreign authors, which address the issues of ensuring high-quality legal protection of land use safety regarding the agricultural land use. This study was conducted in three stages.

At the first stage of this study, an information and theoretical base was formed, which served as the basis for subsequent research of the subject matter. To facilitate the perception of the information provided, as well as to ensure the most objective and qualitative picture of the research, all information borrowed from foreign publications and cited in this paper was translated into English. In addition, at the first stage of this study, the authors conducted systematic analytical research of the main aspects of safe land use regarding agricultural land. The study reviewed the current legislation on agricultural land use in Ukraine, defining the procedure for the long-term development of land relations in the country, as well as the possibility of changes and amendments to the current land legislation.

The second stage of this study involved an abstract and logical examination of the main aspects of exercising the citizens' right to a safe environment upon agricultural land use in Ukraine. Furthermore, this stage of the study included an analytical comparison of the results obtained with the results and conclusions of other researchers of numerous issues related to the subject under study to clarify and supplement the available results and

more clearly define the conditions and prospects for the development of land legislation of Ukraine, which directly affect the regulation of land and property relations in the agrarian sphere, are designed to ensure the safety of land use in the country and the qualitative exercise of the right to a safe environment upon agricultural land use in Ukraine. The priority legal aspects of ensuring the environmental safety of agricultural enterprises in Ukraine were identified, which are essential in the context of the exercising the Ukrainians' right to a safe environment upon agricultural land use.

The final stage of this study, based on the results obtained, formulated the final conclusions, which logically reflect on and summarise the results of the entire set of the study performed within the scope of the subject matter.

RESULTS

According to the current provisions of the Land Code of Ukraine [6], "Agricultural lands are recognised as lands provided for the output of agricultural products, agricultural, research, and educational activities, the placement of appropriate production infrastructure, including the infrastructure of wholesale markets of agricultural products, or intended for these purposes". Thus, the provisions of the legislation in force in the country currently emphasise the output of agricultural products as one of the main purposes of agricultural land. Furthermore, the current legislation ensuring the safety of agricultural activities stipulates the rights of land use of agricultural enterprises, institutions and organisations, personal family-operated and husbandry farms to land. According to the provisions of Article 27 of the Land Code of Ukraine, "Agricultural enterprises, institutions and organisations, personal family-operated and husbandry farms that unite in associations and other legal forms retain the right to their land plots, unless otherwise stipulated by the current agreement".

The interrelation between the state with economic entities in modern market conditions is reflected by the legal and economic mechanisms of state regulation of agricultural activities. At the same time, the nature of such interrelation is different, since it reflects the relationship mediated by commodity-money relations [7]. Considering the current legislative provisions, due to the amendments introduced into the Land Code of Ukraine through the implementation of Draft Law No. 2194, which involves changing not only the Code itself, but also some legislative acts aimed at improving the available management system and governing the existing relations in the land use system, there is a radical change in the available land management system through the transfer of state-owned lands located outside settlements, including lands with agricultural purposes, to municipal ownership of urban, rural, and settlement councils. Therewith, local self-government bodies receive the authority to change the purpose of agricultural land that is privately owned, as well as to approve detailed plans of the territory outside settlements. In the current situation, the full use of agricultural land in Ukraine is a resource and economic condition for ensuring the national security of Ukraine on the one hand and the security of its citizens on the other hand.

Ensuring and implementing the right to a safe environment upon agricultural land use in Ukraine involves mandatory consideration of the following factors:

1) determination of priorities of national policy on agricultural land use;

2) introduction of a system of state regulation of relations between owners of agricultural land plots;

3) development and consistent implementation of national programmes to optimise agricultural land use;

4) mandatory land management of agricultural enterprises, with the designation of the requirements for the safe use of agricultural land;

5) development of plans for the consistent development of agricultural enterprises and organisations, in the order of their land management and considering the principle of the suitability of agricultural lands for conducting economic activities on them.

In this context, determining the priorities of national policy on agricultural land use is of priority importance from the standpoint of the need to determine the citizens' rights to agricultural land use. Therewith, issues of state regulation of legal relations between owners of agricultural land plots should include a clear, consistent differentiation of citizens' rights to the safe use of land plots intended for agricultural activities in the context of legislative protection of the rights and freedoms of citizens involved in the process of land management and land cultivation for economic purposes [8].

To date, the main tasks of state regulation of the right of citizens to a safe environment upon agricultural land use in Ukraine are as follows:

– consistent creation of conditions for the qualitative reproduction of agricultural land;

– limiting the impact of external factors, representing various aspects of anthropogenic activity;

– ensuring the continuous and consistent development of national policy in the field of determining the rights and freedoms of citizens in the context of the efficient agricultural land use.

The national policy on determining the rights and freedoms of citizens in the field of efficient and safe use of agricultural land involves the development and adoption of numerous regulations, including those designed to ensure the environmental safety of land use, as an integral component of safe land use in the country. In this context, one of the priorities of national policy in this area is the consistent provision of environmentally friendly food products to citizens, as well as the creation of conditions for ensuring environmental safety at all levels of agricultural production and agricultural activities [9].

In the current economic situation in Ukraine and in the world, one of the key areas of national policy on ecology and environmental protection concerning the agricultural activities is the consistent introduction of effective mechanisms for the arrangement of agricultural land and agricultural activities, subject to full adaptation to the available natural landscapes, as well as the steady development of environmentally friendly technology used in modern agricultural production, conservation, and restoration of natural soil fertility on agricultural lands. Furthermore, the key objectives of the system of state regulation of agricultural land use, from the standpoint of the regulatory provisions of Article 1 of Law of Ukraine No. 1264-XII "On Environmental Protection" [10], it is "…regulation of relations in the field of protection, use, and reproduction of natural resources, ensuring environmental safety, prevention, and elimination of the adverse environmental impact of economic and other activities, conservation of natural resources, the genetic fund of wildlife, landscapes, and other natural complexes, unique territories and natural objects associated with historical and cultural heritage". In this context, the role of the state in ensuring and implementing the right to a safe environment upon agricultural land use in Ukraine is to create and maintain in proper condition a system of measures aimed at preserving both the natural resources themselves, which constitute national property, and which, by definition, include agricultural land, and the creation of conditions necessary for agricultural activities, the maximum efficiency of which can be achieved provided that environmental protection and compliance with all measures of environmental safety of agricultural land use.

To date, Ukraine has developed an integral system of legal regulation of relations between all participants in agricultural production. The provisions of this system include both individual regulations of a departmental nature and state laws, as well as technical regulations for the agricultural land use. In this context, a substantial step towards ensuring and exercising the right of citizens of the country to a safe environment will be the adoption of a draft law aimed at stimulating the production of organic agricultural products. An essential aspect is the formulation of the concept of organic products as such, which is the product of the activities of agricultural production enterprises, the purpose of which is to be consumed by citizens, as well as the use as animal feed and planting material, and the process of putting out products of this kind involved strict compliance with the laws of Ukraine in the field of organic production in strict accordance with existing technological and environmental standards. In this context, the key issues of ensuring and exercising the right of citizens to a safe environment upon agricultural land use in Ukraine should be resolved in compliance with all legal norms of environmental safety of agricultural production and disposal of land resources owned by agricultural enterprises.

DISCUSSION

High-quality and professional land management should ensure the balanced and consistent development of the economy, as well as the improvement of the general state of the environment based on sustainable, rational, and completely environmentally safe land use. The problem of rational management of land resources and effective use of land, combined with the development of sustainable land use on this qualitative basis for the favourable resolution of food security problems, has its objective solution at various levels of territorial administration, from the national to the local level. The entire system of state land management should be built in such a way as to fully ensure all land and resource aspects of national security, wherein food security, undoubtedly, should be assigned a key role [11].

The current unfavourable environmental situation poses the task of a comprehensive and complete understanding of the experience of the national environmental policy, based on the accumulated experience in the field of safe land use and a clear definition of the main causes of failures in the field of agricultural safety. These problematic issues are of particular relevance in the context of the course adopted to accelerate the economic development of society, which is fully impossible without ensuring and exercising the right to safe use of agricultural land [12; 13].

To date, any definitions of the concept of safe land use have not been objectively covered in the academic literature, as well as in regulatory documents. In general, the exercise of the citizens' right to a safe environment upon agricultural land use involves the creation of a state of general security, ensuring protection from any possible impacts, both internal and external, that may interfere with agricultural activities on the land. Notably, the security of land use of a purely ecological nature in the current understanding of the European Union implies ensuring the protection of both human life and health, as well as the environment, socio-economic, and industrial facilities from the ever-increasing risk of exposure to natural and anthropogenic threats [14].

Regulatory provision of the right to use agricultural land requires many actions from the current government, among which special attention should be paid to the development of comprehensive forecasts of the progressions of dangerous and unfavourable situations, as well as timely planning and implementation of measures to prevent them. In this context, it becomes clear that apart from the development and practical implementation of state mechanisms for the exercise of fundamental human rights and freedoms, a key place should be given to conscious processes of agricultural management, as a counterbalance to the well-developed decision-making process that contributes to the optimal provision of the right to safe conduct of activities in the field of agricultural land use [15].

In the current Land Code of Ukraine, agricultural

lands are defined as being of the greatest importance from the standpoint of preserving the national land resources. This approach is based primarily on considerations of ensuring the national food security and ensuring a high-quality supply of agricultural products to citizens. Problematic issues of increasing the efficiency of agricultural land use are gaining a high degree of relevance in the context of protecting the human right to life and the right to conduct professional activities. The guarantee of effective solution of such problematic issues is the creation of stable internal output of agricultural products and the development of necessary reserves and stock. In general, the problem of qualitative improvement of the efficiency of practical use of agricultural land is fully resolved in the light of the exercise of the human right to life and the protection of their key vital interests and priorities, as well as the right to a safe natural environment and the safe use of natural resources [16]. The land itself is of key importance, since it acts as the main means of production.

The main essence of the state mechanism of legal and organisational regulation of the main problematic issues of the use of agricultural land is the organisational, as well as mainly administrative regulation of key processes of agricultural production, the activities of business entities, the essential markets that exist today, of which the land market should be prioritised. It is the land market that performs the function of a direct acting mechanism, and the main aspects of its functioning are based on the legislative system adopted in a particular state. The authority of public authorities is of key importance in the context of the coherence of the legal mechanism of state regulation of issues related to ensuring the safe disposal of agricultural land [17]. The role of the state apparatus in extreme conditions increases dramatically, while in conditions of full-fledged market functioning it performs the function of governing numerous monopolisation processes, practical use and protection of land resources, especially land intended for agricultural activities, ensuring socio-economic rights and needs of all categories of citizens, as well as upon regulating the activities of enterprises belonging to the public sector of the economy.

To date, the available mechanism of state regulation of agricultural enterprises by purely economic methods includes an integral system of methods of exerting direct influence on the economy of business entities, which ensure the practical implementation of their complex of economic interests, direct benefits from entrepreneurial activity, as well as freedom of economic choice and manoeuvre, initiative and independence, the development of appropriate conditions for a full-fledged, civilised competition. Using economic mechanisms fully in its own interests, the present-day state attracts business entities to implement its decisions based on their direct interest [18].

A number of modern researchers under the state regulation of the safety of the use of agricultural land understand the purely organisational activity of the competent state authorities to ensure the rational use of agricultural land and ensure their protection. Therewith, rational land use, implemented based on scientifically sound methods of effective exploitation of land resources and their conservation, is a qualitative basis for the implementation of national programmes of efficient agriculture, factoring in the rights and freedoms of citizens who cultivate this land. In modern economic literature, the essence of the concept of rational use of land resources is frequently defined as achieving maximum efficiency in the consistent implementation of key goals and objectives of land use, considering the interaction of agricultural land with other natural factors, and while ensuring high-quality protection of land upon its use for practical purposes – as a mandatory condition for conducting any activity and the main means of production in agriculture [19; 20].

A consistent transition to a market economy takes place against the background of a sharp strengthening of economic mechanisms for governing the existing social relations, which also affects the use of natural resources and their protection. Therewith, even during such a transition, there is no question of replacing or eliminating the legal mechanism in the field of the use and protection of agricultural land resources. On the contrary, in this area, unlike many others, the legal mechanism for protecting and ensuring the rational use of land resources has never lost its importance. In general, to assess the effectiveness of the methods of state regulation of agricultural activities used, it is necessary to limit the list of measures aimed at setting benchmarks for the effectiveness of such activities, as well as to ensure that the procedure for monitoring the achievement of the goals set in this context is maintained [21]. The study of problematic issues of ensuring and exercising the rights to a safe environment in the use of agricultural land gives grounds to consider state regulation of the safe use of agricultural land resources as a very complex and multifaceted process that includes auxiliary aspects and mechanisms that allow increasing the efficiency of the legal policy of the state amidst a wide range of tasks for the qualitative acceleration of the economic development of the state and society, which should be promptly resolved in the near future.

In modern conditions, compliance with the safety requirements of agricultural production is an essential condition for preserving soil fertility and ensuring the preservation of high-quality standards of agricultural products consumed by all segments of the population of any state. Concern for the preservation of life and health of citizens is currently one of the priority tasks of economic development of any country, which is of key importance for exercising the citizens' right to a safe environment upon the use of agricultural land. The implementation of this right requires the introduction into practice of a perfect legal mechanism that could consolidate the accepted sequence of compliance with environmental standards, directly from the manufacture of agricultural products to its processing and receipt of agricultural raw materials and food products [22]. Therewith, the main principles of ensuring the safety of agricultural production, which is essential from the standpoint of

exercising the right of citizens to a safe environment upon agricultural land use, are mandatory compliance with all environmental safety requirements at all stages of agricultural production.

Today, despite all the efforts of the state to ensure compliance with all the requirements of environmental and legal safety of agricultural activity by citizens, the production technologies used in this area, as well as, consequently, the quality of agricultural raw materials and finished products are at risk. Measures to remedy the current situation should be developed at the state level, involving specialists for joint activities, both in the field of agriculture and in the development and adoption of regulations that expressly govern such activities [23].

Ensuring and exercising the right to a safe environment upon the use of agricultural land in a modern, economically developed state, implies mandatory complex interaction of both the state and legislative authorities on the one hand, and the entire system of agricultural production on the other hand. Therewith, sustainable agriculture primarily implies the sustainability of conducting all types of agricultural activities directly on the land, permitted by the provisions of the current legislation of the country [24]. From a practical standpoint, this does not at all mean the chance of resisting all possible impacts on this sphere, both internal and external, including natural phenomena that adversely affect agricultural activity on land, as well as negative phenomena of a purely economic nature. Nevertheless, the consistent evolution of agricultural land use with the preservation of the main types of agricultural activities permitted by law, as well as favourable environmental conditions, necessarily implies the introduction of principles of state management of this process, with mandatory compliance with regulations governing the conduct of such activity. It is the role of the state that is of key importance in ensuring and implementing the right to a safe environment upon using agricultural land, regardless of the type of state system and the degree of its direct involvement in all stages of the agricultural production.

CONCLUSIONS

The conducted study of the prospects of ensuring and implementing the right to a safe environment upon agricultural land use in Ukraine led to the following conclusions: Ensuring and exercising the right of citizens of Ukraine to a safe environment upon using agricultural land can be achieved exclusively through the consistent introduction into the practice of land use of regulations governing the system of relations between landowners in the country and enterprises, as well as private entities that solve practical issues of the use of agricultural land. Therewith, the introduction of cardinal changes to the normative acts of the current legislation does not always ensure the achievement of the proper level of exercising the rights of citizens to ensure the safe use of agricultural land and really protects their legitimate rights to use agricultural land for their intended purpose.

To date, the issues of ensuring and implementing the right to a safe environment upon the agricultural land use in Ukraine have not been fully clearly settled, despite the existence of an integral system of legal regulation of relations between all participants in agricultural production that has developed in the state. In the current situation, the exercise of the right of citizens to the safe use of agricultural land can be achieved through strict adherence by all participants in the agricultural land use, to all adopted legislative norms on the use of agricultural land and regulations in the field of environmental conservation, ecology of agricultural activities.

Environmental aspects of ensuring the right of citizens of the country to a safe environment upon the use of agricultural land are determined by the current regulations, namely the Law of Ukraine No. 1264-XII "On Environmental Protection". All enterprises and individuals operating in agricultural land use are required to comply with the provisions of this regulation regarding the key issues of land use and environmental conservation upon the use of agricultural land in Ukraine.

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Використання сільськогосподарських земель в Україні: забезпечення та реалізація права на безпечне довкілля

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Анотація. Безпечне землекористування сільськогосподарських територій передбачає обов'язкове збереження земельних ресурсів держави, які є її найважливішими стратегічними ресурсами. Актуальність цього дослідження обумовлена великою кількістю нерозв'язаних проблем безпечного землекористування в Україні безпосередньо в аграрному секторі економіки країни, не в останню чергу через складнощі реалізації права громадян на безпечне використання земель сільськогосподарського призначення. Основною метою цієї статті є теоретичне дослідження можливостей забезпечення права на безпечне навколишнє середовище при використанні земель сільськогосподарського призначення в Україні з оцінкою реальних можливостей його практичної реалізації в сучасних економічних умовах. Основою методичного підходу у цій роботі є поєднання методів системного аналізу ключових аспектів безпечного землекористування, що стосуються земель сільськогосподарського призначення, з методом абстрактно-логічного дослідження основних аспектів реалізації права громадян на безпечне середовище при використанні сільськогосподарських земель в Україні. Основними результатами, отриманими в даній роботі, варто вважати визначення основних пріоритетних напрямів розвитку наявної в Україні законодавчої системи в контексті забезпечення безпеки ведення сільсько-господарської діяльності та оцінку ролі держави у питаннях забезпечення належного рівня екологічної безпеки використання земель сільськогосподарського призначення з точки зору перспектив збереження наявних на сьогодні сільськогосподарських угідь у країні. Отримані в даному дослідженні результати, а також сформульовані на їх основі висновки мають суттєве практичне значення для сільськогосподарських працівників, стурбованих належним вирішенням проблемних питань щодо забезпечення та практичної реалізації свого законного права на безпечне навколишнє середовище при використанні земель, що належать до аграрного сектору економіки держави

Ключові слова: безпечне землекористування, сільськогосподарські угіддя в Україні, сільськогосподарські угіддя, земельні ресурси, родючість ґрунтів, безпечне середовище

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Features of Creating and Maintaining a Fruit Wall in Apple Orchard: Literature Review

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Abstract. The establishment of rational terms and methods of mechanised pruning of apple trees on dwarf rootstocks determine the relevance of the subject under study. The purpose of this review is to highlight the current state and issues associated with tree pruning to improve the technology of growing and increasing the productivity of plantations yielding high-quality fruit with a rational period of mechanised pruning of apple trees on a dwarf rootstock. Proceeding from the analysed literature sources, this paper highlights the current state and development trends of horticulture. A gradual increase in apple production in Europe observed, but an important factor limiting the growth of fruit production is labour productivity accompanying the laborious processes of tree trimming and harvesting. The seasonal nature of work involving numerous skilled workers leads to a shortage of labour force in horticulture. With the increase in wages and the decrease in the number of workers in agricultural production, the introduction of elements of mechanised care for plantations, namely mechanised pruning of the crown, is gaining more significance. The solution to the problem is to improve modern technology of growing apple orchards, using mechanised pruning and the formation of fruit wall in particular. This will allow balancing the available number of employees involved in fruit cultivation and orchards area, and, if necessary, moving away from seasonal work. This paper investigates the specific features of the use and the influence of different periods of mechanised pruning, in particular in winter (0 BBCH), in the pink bud phase (59 BBCH), in early summer (74 BBCH), after harvesting (93 BBCH), and considers the mechanisms used for this purpose. The study proves the positive influence of this technology on improving setting illumination of the crown and the content of chlorophyll in the leaf, optimisation of growth processes with a considerable increase in the number of formed buds. The increase in yield and its marketable quality is accompanied by reducing the size of the fruit, the ripening time of which is somewhat delayed. However, the chemical composition and taste of the fruits are not inferior to the cultivation technology involving manual pruning. The practical significance of the obtained results is to improve the technology of growing apple trees using mechanised pruning and manual maintenance of the inter-tree space, which ensures a considerable reduction in the need for skilled manual labour and increases productivity

Keywords: apple tree, mechanised pruning, pruning term, fruit formations

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INTRODUCTION

Apple tree is a leading fruit crop in Europe and it is third in terms of fruit production in the world, after citrus fruits and bananas [1]. Apples are a valuable food product with high flavouring qualities, dietary, prophylactic-curative and therapeutic properties [2]. Almost half (47.8%) of world gross apple production amounts to 76 million tonnes and is produced for China, while 13.9% or 9.6 million tonnes are produced the countries of the European Union [3-7].

The main areas are concentrated in Poland, Italy, Romania, and they have doubled in the last decade [8]. The important factor limiting the growth of fruit production is labour productivity accompanying labour-intensive processes of tree pruning and yield gathering. The availability of farm labour is becoming an issue for agriculture, especially for time-sensitive and labour-intensive operations [9]. Considerable seasonality and high complexity of operations create serious roadblocks due to the lack of labour force in gardening. In the past few years, the availability of these workers has been affected negatively [10].

During 2007-2013 in the EU, the total number of workers employed in agriculture decreased by almost 20% [11]. There is a shortage of skilled workers in countries where most fruit is produced considering the low level of hourly wages [12]. The solution to improve the modern technology of growing apple orchards. It is essential to increase the productivity of fruit orchard to meet the needs of population in horticultural products. New technologies should be introduced based on the use of high-yielding varieties, orchard of intensive type, and plant care systems [13].

Pruning is of particular importance in modern fruit orchards with high tree density as one of the main agro-technological factors preventing the alternate bearing tendency and ensuring efficient fruit production. Conventional pruning methods are associated with the considerable cost of manual labour and do not ensure the annual high yields of quality fruits. Hence the urgent development and implementation of mechanised elements for the orchard maintenance, namely mechanised pruning. This allows balancing the available number of employees involved in fruit cultivation and orchards, and, if necessary, leave precise seasonal work to machines. By adjusting the parameters of the ground part, mechanised pruning achieves the best coverage of the centre of the crown, improves air circulation, making the fruiting stabilised and improving crop quality.

The purpose of this study is to determine the method and time required for mechanised pruning, which provides the optimal parameters of the crown of apple trees and increases their productivity, as well as to investigate the results of the impact of pruning apple trees on fruit yield and quality.

IMPORTANCE AND FEATURES OF PRUNING FRUIT TREES

Pruning fruit trees is an essential agrotechnical measure, which helps regulate growth and fruiting, improve fruits' quality, and also contribute to efficient maintenance of soil and plants. Even formation of generative buds and fruiting throughout the crown is achieved by pruning due to regulation of the crown size [14]. When choosing the optimal pruning method, several factors are considered, such as the garden intensity level, term of execution, cultivar-rootstock combination, planting density, garden age, crown shape, height, and size of crowns [15]. Apart from the spread, no less important factor is the type of fruiting variety [16; 17].

The most efficient use of light by all tree parts, compact sizes, high yields of qualitative fruits, as well as low labour costs for formation comprise some of the main requirements for choosing the crown shape [18]. Crown pruning is described by considerable predominance of manual labour. Pruning an apple orchard requires 80-120 hours of work. This is 1/5 of the total production cost [19]. Therefore, the leading place in modern technologies is given to such methods of pruning that offer stable yields of qualitative fruits with minimum possible labour costs and production facilities. In this connection, introduction of elements of mechanised orchard maintenance, namely mechanised crown pruning, becomes increasingly more relevant.

Since the 1960s, efforts have been made to introduce mechanical pruning on most fruit plantations. The first pruning machines were implemented in the USA for pruning citrus trees. Trees were trimmed from with cutting bars or rotational saws. Gardeners became interested in this technology and tried to apply mechanical pruning to apple, pear, and peach trees [20].

Automation technologies are now used extensively in agriculture, while production operations for tree fruit crops still largely depend on manual labour. Manual pruning is a labour-intensive and costly task in apple production. Mechanical pruning is a potential solution [21]. With the adoption of mechanisation, the agricultural sector will have witnessed a considerable increase in production efficiency [22; 23].

In California, plum trees and olives were both pruned and harvested mechanically [24]. Some robot-friendly canopy architectures such as tall spindle, V-trellis, and fruiting wall are promising for the development of mechanical pruning systems [25].

The limited availability of farm labour is a severe concern for the agricultural industry. To address this issue, mechanical pruning i.e., hedging on fruit trees has been investigated by several researchers [9; 23; 26].

THE EFFECT OF MECHANISED PRUNING ON THE FERTILITY OF APPLE TREES

Recently, mechanised pruning has successfully passed production tests in different areas of horticulture and countries of the world. Mechanised pruning becomes one of the most efficient agrarian measures concerning the influence on the growth and fertility of fruit plants by efficiently limiting the height and width of fruit trees crown.

To a greater extent, the choice of equipment depends on the phase of tree development when it is used.

In winter, mechanisms equipped with circular saws are usually used. Such technology is capable of pruning the branches of considerable diameter, but saws are frequently filled with tiny sawdust and the quality of a cut drops. In summer, working units based on segment-type knives and rotating blades are usually used, which can cut branches up to 2.5 cm in diameter.

Fruit wall is formed as a result of mechanised pruning, the lower part of which is annually pruned on both sides at a distance of 40 cm from the trunk and the upper part – at a distance of 25 cm [27]. In the first year there is a decrease in fertility due to a substantial reduction in the volume of the crown after the introduction of mechanised pruning, the previous level of which is restored next season, and then slightly exceeds the productivity of the garden for manual pruning (Table 1) [28; 29].

Table 1. *Productivity of different varieties of apple trees in different ways of pruning trees*

Variety	kg/tree		Mass (g)		Number of fruits	
	Control	Mech. pruning	Control	Mech. pruning	Control	Mech. pruning
Red Prince	32.3	35.4	192	176	168	201
Primo	32.8	32.6	185	175	181	190
Decosta	28.0	36.6	213	210	138	175
Jonagored	26.1	22.7	241	218	113	116

The mechanically pruned trees have better fertility than the manually pruned trees. This is explicable because without detailed pruning, more fruit buds are preserved in the crown [9]. To promptly achieve the optimal area of a fruit wall (13-17 thousand m^2/ha), it is important to keep a rational tree planting scheme of 0.8 m in the row for diploid varieties and 1 m for triploid ones. The width of row spacing is close to the value of crown height, and their direction is from the north to the south.

The first mechanised pruning while reformation of existing plantation should be done in winter (0 BBCH) for giving the crowns proper dimensions, and again in the beginning of summer, and then only once a year – in the beginning of summer. Depending on the region, the most optimal term for early-summer pruning is the emergence of foliage (8-12 leaves) on newly formed shoots. As a result, short shoots or rhizomes are formed in shortened growth in summer, the growth of which is weakened after several years of summer pruning.

Almost half a century ago in France, L. Lorette proposed an alternative method of pruning – with mechanised shortening of current year shoots by ¼-½ length. This way, regrowth of shoots occurs from less developed buds near the base of the shoots – growth is weaker with a greater probability of differentiation of generative buds. The best time to shorten the shoots is the period immediately before the end of shoot growth and the formation of the apical bud. Weak trees do not need summer pruning [30; 31].

The reaction of trees to pruning shoots depends on the biological characteristics of the variety, length, thickness, and their location on the branches and in the crown, orientation in space and the degree of pruning. The more the shoot is shortened (closer to the base), the lower the growth activity and the smaller the angles of formation of new shoots [32].

A. Masseron and L. Roche found that mechanised pruning in summer causes less stress for the plant, inhibits excessive growth and provides 35-40% more light in the centre of the crown, improves air circulation and stimulates the formation of generative buds for next year's harvest and stabilises fruiting [33-35]. In autumn, nutrients accumulate mainly in the trunk, main branches and root system. The stock of plastic substances remains almost unchanged after removing numerous branches during winter period. Therefore, in spring, the tree develops a considerable number of strong vertical shoots [36]. Summer removal of shoots reduces the reserve amount of carbohydrates which reduces the growth activity in the next season.

In this case, it should be reactivated by winter pruning. Good illumination of crown by mechanised pruning and weaker growth of shoots initiate formation of numerous generative buds, thereby ensuring high yields of qualitative fruits. However, mechanised pruning remains impossible without additionally treating the crown manually. All operations on formation and preparation of trees for mechanised pruning, further pruning of hard-to-reach areas of the crown are being performed manually to this day [37]. All the branches growing towards row spacing are pruned mechanically, the problem is posed only by bent branches under the crown, which cannot be mechanically removed, strong nourishing shoots in its middle part and excessive growth and thickening at the apex.

Upon contour pruning they cut out the so-called "windows" by pruning individual shoots at the top and in the centre of the crown closer to the main branch, which contributes to better illumination of the central part of the crown to improve the access of light to the centre of the crown and reduce labour costs for manual additional treatment [38]. Different illumination of the crown affects anatomical structure of the leaves. According to A. F. Kovalov, with decreasing light in the lower part of the crown, the thickness of the columnar parenchyma, where the bulk of chloroplasts is localised, is 12-30% less compared to the leaves from the upper part of the crown [39].

G. Lafer found that reaction of apple trees to mechanised pruning depends on when this procedure is performed. The strongest growth of shoots was observed after winter pruning and by one third less in early-summer. Moreover, the number of shoots with a generative bud at the end was 48% and 68%, respectively [40; 41]. The number of shoots of the current year with a top generative bud reaches 90% depending on the pomological variety and time of performing mechanised summer pruning [42].

Shoots pruning changes the correlation between fruit-bearing formations. After pruning the shoot by half (mainly on two- and three-year-old trees) the share of spurs is 36%, hastula – 23%, and brindilles – 41%, and without pruning (mainly on two- and three-year-old trees) – 60%, 12%, and 28%, respectively [43]. According to L. Roche, damage to fruits upon the mechanised pruning in the summer does not exceed 0.3% [44]. Because the fruits are located on the periphery of the crown and are exposed to direct sunlight from the beginning of formation, the fruits become "seasoned" and receive almost no damage from sunburn. Fruits become smaller after several years of mechanised pruning in summer.

According to French studies, mechanised pruning makes the fertility more stable over the years of operation of the garden, and sometimes not inferior to its manual counterpart. Golden Delicious variety, planting scheme 4×1.25 m. Thinning of flowers and sets was not performed (Fig. 1).

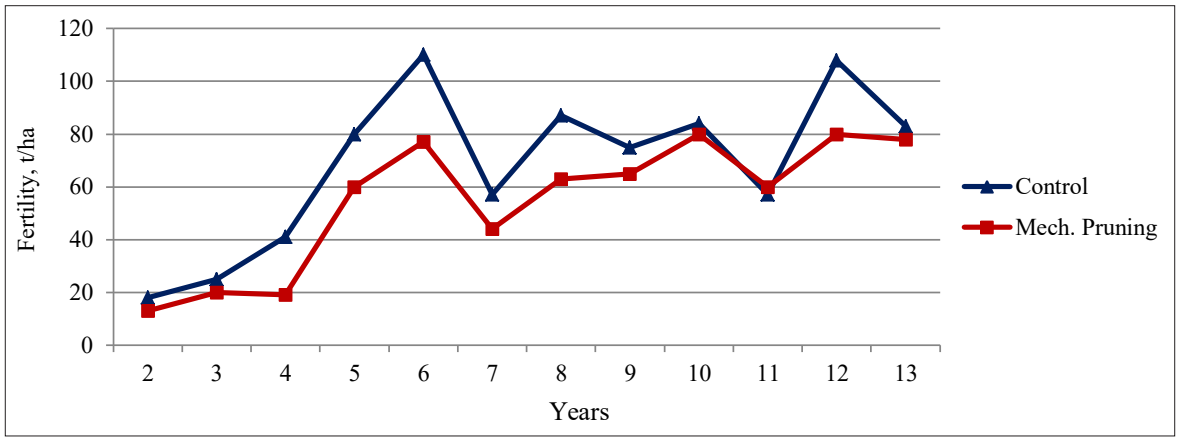

Figure 1. *Fertility of Golden Delicious trees*

Source: *[45]*

THE EFFECT OF MECHANISED PRUNING ON THE QUALITY OF APPLE FRUITS

According to G. Poldervaart and A. Urbaniec, after mechanised pruning of trees in summer for several years, the fruits starts growing smaller – their diameter becomes 2-3 mm smaller. However, this is not considered as a disadvantage for large-fruit varieties (Jonagored), as presented in Figure 2 [46].

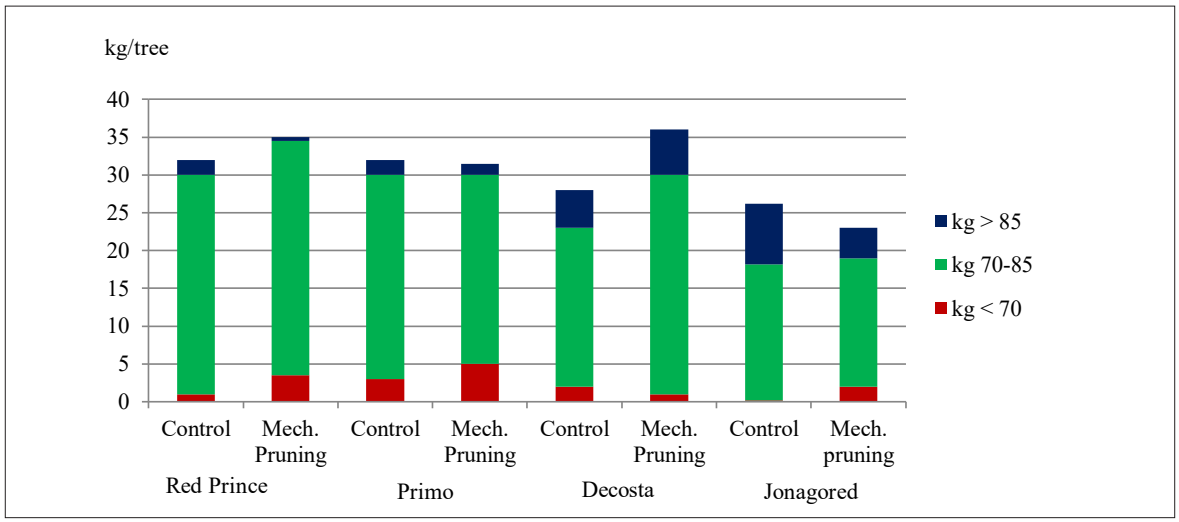

Figure 2. *Distribution of fruits by size*

Source: *[29]*

Pruning is recommended in the "pink bud" phase (59 BBCH) to stimulate tree growth activity and restore the fruit/leaf correlation, as well as form larger fruits [47]. However, pruning the garden during this period is quite difficult because this phase is short. Although similar results can be achieved by performing this operation after harvesting. With mechanised pruning, the quality of the fruit is the next best to the fruits of manually pruned crowns, except for "juiciness" and "crunchiness" for reasons not yet studied (Fig. 3).

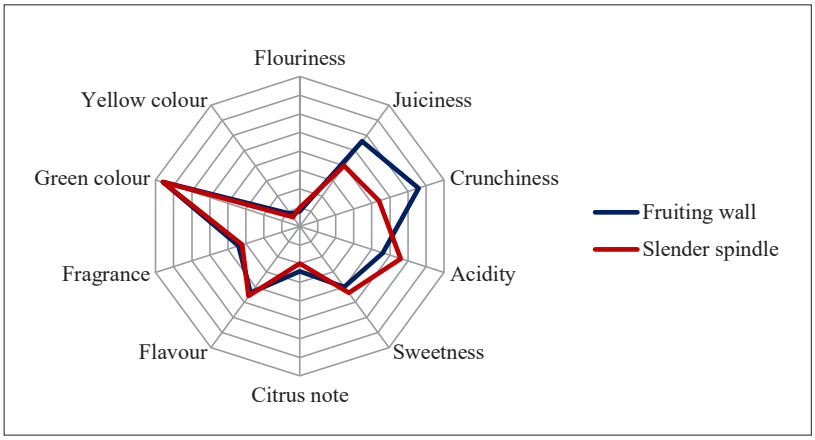

***Figure 3**. Fruit quality as a result of mechanised pruning*

***Source**: [45]*

As a result, the beginning of ripening of the crop is delayed by approximately a week (Table 2), a higher percentage of marketable fruits, especially apples of higher marketable grade, fewer fruit with sunburn.

***Table 2**. Ripeness of fruits as a result of mechanised pruning*

Variety	Hardness (kg/cm²)		Sugar content (°brix)		Starch value (1-10)	
	Control	Mech. pruning	Control	Mech. pruning	Control	Mech. pruning
Red Prince	7.8	8.1	12.3	12.8	6.7	6.4
Primo	7.7	8.2	12.6	12.5	6.6	6.2
Decosta	8.2	7.6	12.7	12.9	7.6	7.1
Jonagored	8.3	8.2	13.3	13.8	7.1	6.8

***Source**: [29]*

Contour pruning of trees requires only 2-3 hours per hectare of mechanical pruner and up to 40 hours per hectare of manual after-treatment, which is only 30-40% of labour costs compared to conventional manual pruning, which requires up to 160 labour hours per hectare [48]. Thinning of flowers becomes more efficient due to easier access to the inner part of the crown (fruiting wall), while labour productivity during harvesting increases by 17% upon shifting the fruiting zone to the periphery of the crown [29; 49-52].

CONCLUSIONS

The purpose of this study was to establish the features of mechanised pruning and its impact on fruit quality and fertility of apple trees. Mechanised pruning with fruiting wall formation is used to maintain the balance between growth and fruiting in the apple orchard as a result of the constant increase in manual labour costs and the reduction in the number of workers involved in agriculture. This cultivation technology is becoming more widespread in horticultural farms across Europe, reducing labour costs, increasing garden productivity and improving the quality of cultivated products.

It is established that to form a crown, the first mechanised pruning with a fixed width of 40 cm from the trunk in both directions at the bottom and 25 cm at the top of the tree. In subsequent years, the shoots outside the crown were pruned annually whenever 8-12 would appear on newly formed shoots. This method of pruning helps reducing labour costs and increasing orchard fertility. Yields become more stable every year and a higher number of fruits is formed. The quality of the fruits grown by mechanised pruning is the net best to the fruits grown on manual pruned crowns, although the harvest begins to ripen approximately a week later than usually.

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Особливості створення та догляду за плодовою стінкою в яблуневому саду: огляд літератури

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Анотація. Встановлення раціональних термінів і методів механізованого обрізування яблуні на карликових підщепах визначає актуальність теми дослідження. Метою цього огляду є висвітлення стану та проблем, пов'язаних з обрізанням дерев, удосконаленням технології вирощування та підвищення продуктивності насаджень з отриманням високоякісних плодів при раціональному терміні механізованого обрізування яблуні на карликовій підщепі. На основі проаналізованих літературних джерел висвітлено сучасний стан і тенденції розвитку садівництва. Спостерігається поступове зростання виробництва яблук у Європі, але важливим фактором, що обмежує зростання виробництва плодів, є продуктивність праці при трудомістких процесах обрізування дерев і збирання врожаю. Сезонний характер робіт із залученням великої кількості кваліфікованих робітників призводить до дефіциту робочої сили в садівництві. Із підвищенням заробітної плати та зменшенням чисельності робітників у сільськогосподарському виробництві все більшого значення набуває впровадження елементів механізованого догляду за насадженнями, зокрема механізованого обрізування крони. Вирішення проблеми полягає зокрема у вдосконаленні сучасних технологій вирощування яблуневих садів із застосуванням механізованого обрізування та формування плодової стіни. Це дасть змогу збалансувати наявну кількість працівників, зайнятих на вирощуванні плодів у садах, і, при необхідності, відійти від сезонних робіт. У статті розглянуто особливості використання та впливу різних періодів механізованої обрізки, зокрема взимку (0 BBCH), у фазі рожевого бутона (59 BBCH), на початку літа (74 BBCH), після збирання врожаю (93 BBCH), та розглянуто механізми, що використовуються для цього. Доведено позитивний вплив даної технології на покращення освітленості крони та вмісту хлорофілу в листі, оптимізацію ростових процесів зі значним збільшенням кількості утворених плодових бруньок. Підвищення врожаю та його товарної якості супроводжується зменшенням розміру плодів, термін дозрівання яких дещо затягується. Однак за хімічним складом і смаковими якостями плоди не поступаються технології вирощування при ручному обрізуванні. Практичне значення наукової роботи полягає у вдосконаленні технології вирощування яблуні з механізованим обрізуванням та ручною обробкою міждеревного простору, що забезпечить значне зниження потреби в кваліфікованій ручній праці та підвищить урожайність насаджень

Ключові слова: яблуня, механізоване обрізування, термін обрізування, плодові утворення

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