НАУКОВІ ГОРИЗОНТИ

Засновник, редакція, видавець
ПОЛІСЬКИЙ НАЦІОНАЛЬНИЙ УНІВЕРСИТЕТ

Свідоцтво про державну реєстрацію
Серія КВ № 24997-14937 ПР від 11.10.2021 р.

Науковий журнал включено до категорії Б Переліку наукових фахових видань України, в яких можуть публікуватися результати дисертаційних робіт на здобуття наукових ступенів доктора і кандидата ветеринарних, економічних, сільськогосподарських та технічних наук зі спеціальностей – 071, 072, 073, 075, 076, 101, 133, 201, 202, 203, 204, 205, 206, 208, 211 (наказ МОН України № 1643 від 28.12.2019 р., наказ МОН України № 409 від 17.03.2020 р.).

Журнал включено до міжнародних наукометричних баз і каталогів наукових видань: Index Copernicus; Directory of Open Access Journals (DOAJ); Open Academic Journals Index (OAJI); Google Scholar; Crossref; Національна бібліотека України імені В.І. Вернадського, AGRICOLA, CAB Abstracts and Global Health (CABI), Open Academic Journals Index, Scopus.

Друкується за рішенням Вченої ради Поліського національного університету, протокол № 6 від 28.12.2022 р.

Підписано до друку 28.12.2022 р.
Формат 210×297. Ум. друк. арк. 15
Наклад 300 примірників

ISSN: 2663-2144
e-ISSN: 2709-8877

SCIENTIFIC HORIZONS

Founder, Editorial and Publisher
POLISSIA NATIONAL UNIVERSITY

Certificate of state registration
KV No. 24997-14937 PR of October 11, 2021.

The scientific journal is included in category B of the List of scientific professional periodicals of Ukraine. It enables publishing the thesis results for Doctor and Candidate degrees in economic agricultural, technical and veterinary sciences (Order of the Ministry of Education and Science of Ukraine No 1643 of December 28, 2019; Order of the Ministry of Education and Science of Ukraine No 409 of March 18, 2020). It comprises the following specialties – 071, 072, 073, 075, 076, 101, 133, 201, 202, 203, 204, 205, 206, 208, 211.

The journal is included in the international scientific databases and catalogs of scientific publications: Index Copernicus; Directory of Open Access Journals (DOAJ); Open Academic Journals Index (OAJI); Google Scholar; Crossref; National Library of Ukraine named after V. I. Vernadskiy, AGRICOLA, CAB Abstracts and Global Health (CABI), Open Academic Journals Index, Scopus.

Recommended for publication by the decision of the Academic Council Polissia National University Minutes No. 6 of 12/28/2022.

Signed for publication 12/28/2022
Format 210×297. Conventional Printed Sheet 15
Circulation 300 copies

ISSN: 2663-2144
e-ISSN: 2709-8877

НАУКОВІ ГОРИЗОНТИ

Том 25, № 10
2022

НАУКОВИЙ ЖУРНАЛ
Засновано 12 березня 1998 р.
Періодичність випуску: дванадцять разів на рік

Адреса редакції та видавництва: 10008, б-р Старий, 7, м. Житомир, Поліський національний університет, Україна. Тел. (0412) 22-04-17; E-mail: info@sciencehorizon.com.ua; www: https://sciencehorizon.com.ua.

SCIENTIFIC HORIZONS

Vol. 25, No. 10
2022

SCIENTIFIC JOURNAL
Year of establishment: Since March 1998.
Publication frequency: Twelve times a year

Address of the publishers: 10008, 7 Staryi Bvld., Zhytomyr, Polissia National University, Ukraine. Tel. (0412) 22-04-17; E-mail: info@sciencehorizon.com.ua; www: https://sciencehorizon.com.ua/en.

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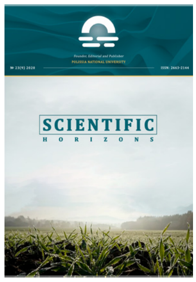

UDC 635.7: 636.92:599.325
DOI: 10.48077/scihor.25(10).2022.9-16

Influence of Plant Biological Additive on the Productivity of Young Rabbits

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Article's History:
Received: 09/26/2022
Revised: 11/08/2022
Accepted: 11/25/2022

Suggested Citation:
Sedilo, H., Luchyn, I., Fedak, N., & Mamchur, O. (2022). Influence of plant biological additive on the productivity of young rabbits. *Scientific Horizons*, 25(10), 9-16.

Abstract. The search for elements of technologies and preparations of natural origin that improve the functioning of the gastrointestinal tract of animals is relevant given that intensive growing technologies involve the use of a significant amount of various kinds of antibiotics that reduce immunity and negatively affect the quality of meat products. Preparations developed on the basis of biologically active substances from essential oils of medicinal and spicy-aromatic plants are promising in this area. The studies used the dietary supplement Activo, recommended for feeding poultry and pigs, created on the basis of essential oils of rosemary, oregano, and thyme. That is why the purpose of the study was to find out the effectiveness and safety of using dietary supplements as an element of intensive rabbit meat production. Research methods – zootechnical, laboratory, statistical. For intensive fattening of young rabbits of the newly created chinchilla type, a mixed feed recipe based on local feed ingredients was developed. It was established that with the addition of Activo to the diet of fattening young rabbits in the amount of 100, 150, and 200 g/t, their productivity at 90 days of age increased, in particular, live weight – by 2.4-5.3%, average daily growth – by 3.5-6.4%, lifetime loin width (meatiness index) by 2.0-2.4%, feed conversion improved by 4.1-5.6%. It is shown that the use of dietary supplements in the amount of 150-200 g/t of mixed feed in the diets of young rabbits with intensive production of rabbit meat reduces direct costs for the production of 1 tonne of rabbit meat by UAH 2,200 and increases the profitability of production by 5%. Thus, the use of a biological additive as an element of intensive fattening of young rabbits helps to improve the lifetime meat content and slaughter yield of young rabbits while reducing the cost of finished feed and increasing its conversion, which leads to a decrease in direct production costs

Keywords: intensive rabbit breeding, comprehensive assessment index, local feed, fattening and slaughter indicators

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INTRODUCTION

In recent years, breeding rabbits as a source of high-quality animal protein has become increasingly popular. Features of development and physiological characteristics of rabbits, namely, their small size, rapid growth rate, high fecundity, short interval between generations, and the ability to consume agricultural by-products as feed makes industrial rabbit breeding one of the promising branches of animal husbandry. In the last 5 years alone, the commercial rabbit population has increased by more than 40%. Rabbit meat is becoming a popular alternative to other dietary types of meat, as it is a source of easily digestible protein, a number of vitamins and minerals (Bashchenko *et al*., 2020; Bharathy *et al*., 2022). However, the cultivation of rabbits using intensive technologies can be accompanied by an increased risk of developing gastrointestinal diseases in animals, especially gastroenterocolitis, viral and infectious infestations, resulting in cases of animal deaths due to a decrease in the body's resistance (Trocino *et al*., 2019).

In this regard, the maintenance of young rabbits, in particular, newly created breed lines, using intensive rabbit production technologies is a resource-intensive process, so there is a constant search for ways to improve and reduce the cost of their cultivation technologies (Cullere & Zotte, 2018). Considering the growing demand for environmentally safe and organic livestock products, there are several ways to solve the problem of optimising the maintenance of rabbits in intensive technologies (Legendre *et al*., 2018). Important in this regard are measures and techniques that improve the feed conversion rate, as this reduces feed costs per unit of production, increases the resistance of animals, reduces the use of antibiotics and other substances that are unacceptable in the production of organic rabbit meat (Crovato *et al*., 2022). Among the effective measures that positively affect feed conversion in animals, the use of pro- and prebiotics in fattening diets is noted (Adhikari & Kim, 2017; Mancini & Paci, 2021). There is also evidence that enriching the diets of young rabbits under conditions of intensive cultivation with vitamin and mineral preparations improves feed conversion (Fedorchenko, 2021). Data on the optimisation of feed conversion and, accordingly, fattening properties of young rabbits with probiotic additives of various compositions have been confirmed experimentally (Honchar & Shevchenko, 2010; Tsyhanchuk, 2021). In another way to optimise the production of environmentally safe rabbit products, it is proposed to improve the rabbit-keeping system, which reduces the use of antibiotics and improves the quality of rabbit meat products (Mondin *et al*., 2021).

Another relevant way to solve this problem is, in particular, energy optimisation of diets for intensive cultivation of rabbits of highly productive hybrids (Alejandro *et al*., 2021). The balance of nutrients in the diets of young rabbits, in particular, protein (Sychov *et al*., 2018). All the described measures and techniques for improving and reducing the cost of technologies for raising young rabbits are effective, since they allow using the genetic potential of animals to the full, maximally ensuring their needs at each stage of ontogenesis (Yakubets & Bochkov, 2018; Birolo *et al*., 2022).

Thus, the investigation of the application features, the study of the productive effect and safety of various natural feed additives in rabbit fattening remains relevant and innovative. That is why *the purpose of the study* was to substantiate and develop a scheme for the use of Activo, determine the optimal doses of this additive in the diets of young rabbits, its impact on productivity, lifetime meat content and slaughter yield of animals, establish the degree of feed conversion and safety of using the additive, profitability and economic efficiency in feeding young chinchilla rabbits with intensive cultivation.

MATERIALS AND METHODS

Studies of the effect of dietary supplements on the metabolism of young rabbits were conducted in the Kolomyia branch of the Precarpathian State Agricultural Experimental Station of the Institute of Agriculture of Carpathian Region of the NAAS of Ukraine on the premises of an experimental farm that uses intensive technologies for the production of rabbit meat. The genotype of rabbits bred on the farm is three-breed crossbreeds of Chinchilla, Flandr, and Termon white (a newly created type of Chinchilla, NCCT). Young chinchilla rabbits were selected for research.

To establish the optimal dose, safety, and effectiveness of Activo, 6 groups of young rabbits of 10 animal units each (5 males and 5 females) were established by the method of analogue pairs according to the scheme presented in Table 1. The discrepancy in the age of rabbits selected in the experimental and control groups was no more than 1-2 days, the average age was 30 days, the differences in live weight of one animal did not exceed 7 g with an average weight of 521 g. The preparatory period for setting up the experiment lasted five days, the main one – 60 days.

***Table 1**. Experiment scheme*

Group	Nature of feeding young rabbits (NCCT), n = 10
I (control)	Basic diet (BD), without dietary supplements
II (experimental)	BD + 50 g Activo per 1 tonne of finished feed
III (experimental)	BD + 100 g Activo per 1 tonne of finished feed

Table 1, Continued

Group	Nature of feeding young rabbits (NCCT), n = 10
IV (experimental)	BD + 150 g Activo per 1 tonne of finished feed
V (experimental)	BD + 200 g Activo per 1 tonne of finished feed
VI (experimental)	BD + 250 g Activo per 1 tonne of finished feed

Source: *compiled by the authors*

The study was carried out by comparative analysis of growth intensity indicators of young rabbits before they reached the age of 90 days. The basic characteristics of growth intensity were determined by the absolute, relative, and average daily weight gain, feed conversion, lifetime meat index – the width of the lumbar region and slaughter indicators.

To determine the objective value of fattening and meat qualities of experimental animals, the comprehensive assessment indicator (CAI) was calculated (Luchyn, 2005) by applying indicators of average daily weight gain and lumbar width using the equation:

$$CAI=5.1(K+2H) \quad (1)$$

where CAI – comprehensive assessment indicator; 5.1 and 2 – correction factors; K – average daily increase in live weight of young animals for the growing period, g; H – width of the lower back, cm.

To meet European requirements regarding the composition and nutritional value of feed for intensively growing young rabbits, a mixed feed recipe was developed using local feed ingredients of the following composition: barley turf (10%), oat turf (10%), wheat bran (10%), sunflower meal (20%), alfalfa flour (35%), table salt (0.4%), premix (3.1%). 1 kg of such mixed feed contains 0.88 kg of dry matter, 175.0 g of crude protein, and 160.0 g of crude fibre, which provides animals with 9.19 MJ of metabolic energy.

The dietary supplement used in the study is a mixture of essential oils from extracts of medicinal and aromatic plants, microencapsulated and stabilised on a matrix of hydrogenate vegetable fats. Due to the standardised content of biologically active substances from oils of *Thymus vulgaris*, *Rosmarinus officinalis*, *Origanum vulgaris*, and bitter pepper extract, the drug affects the taste buds, which improves the taste of feed and reduces its conversion, improves the efficiency of the intestines of animals, since it has the ability to suppress pathogenic microflora, in particular, *Escherichia coli*, *Lawsonia, Salmonella*, *Clostridium perfringens*, *Enterococcus*, *Staphylococcus*, increases the intensity of growth, promotes the preservation of young animals. In the studies, a dietary supplement was used, which, in the doses indicated in the experiment scheme, was introduced into mixed feed and, after thorough mixing, fed to experimental groups of rabbits daily.

All experimental studies were conducted in accordance with modern methodological approaches and in compliance with the relevant requirements and standards, in particular, they meet the requirements of DSTU ISO/IEC 17025:2005 (2006). The animals were kept and all manipulations were carried out in accordance with the provisions of the procedure for conducting experiments on animals by scientific institutions (Law of Ukraine No. 249, 2012), the European convention for the protection of vertebrate animals used for experimental and other scientific purposes (European convention…, 1986).

RESULTS AND DISCUSSION

Rabbits are one of the most promising producers of dietary meat among farm animals, as they have a short life cycle, high fecundity, short gestation period, and a fairly high ability to convert feed (3.0-3.5 kg of complete granulated feed per 1 kg of growth) (Bojko *et al.*, 2020). Despite all these important features, the consumption of rabbit meat in the world and in Ukraine is decreasing due to the complex digestive physiology of these herbivorous rodents.

Intensive rabbit breeding involves the use of complete mixed feeds, which should provide the animals with all the nutrients to ensure proper and rapid development of muscle mass and maximise their genetic potential.

At 90 days of age, the average live weight of rabbits in all experimental groups varied relative to the young animals of group I (control) (Table 2). The maximum live weight of one head at this age was in the IV experimental group ($p<0.05$) – 2,850 kg for the use of Activo in the amount of 150 g/t, while for the use of this drug in the diet of feeding young rabbits of group III (100 g), it was 2,765 kg, and group V (200 g) – 2,845 kg.

Table 2*. Growth rate of young rabbits (m ± m, n = 10)*

Group	Live weight of 1 animal		Average daily rates increments, g
	When setting up an experiment, g	At the age of 90 days, g	
I	518 ± 8.04	2,700 ± 39.44	36.3 ± 0.67
II	521 ± 9.27	2,705 ± 41.8	36.4 ± 0.65
III	516 ±6.74	2,765 ± 35.78	37.6 ± 0.56

Table 2, Continued

Group	Live weight of 1 animal		Average daily rates increments, g
	When setting up an experiment, g	At the age of 90 days, g	
IV	523 ± 8.6	2,850 ± 45.95*	38.6 ± 0.62*
V	520 ± 8.66	2,845 ± 53.98*	38.8 ± 0.76*
VI	519 ± 8.84	2,695 ± 56.0	36.2 ± 0.77

Note: *p<0.05; **p<0.01; ***p<0.001*
Source: *compiled by the authors*

It was found that the highest growth rate was observed in young rabbits of groups IV and V, in the diet of which there were 150 and 200 g of dietary supplements per tonne of feed, respectively. There was a significant difference (p<0.05) in these groups compared to the control. The highest average daily increments for the period of 30-90 days were observed in IV (38.6 g) and V (38.8 g) experimental groups, slightly lower – in II (36.4 g) and III (37.6 g), and the lowest this indicator was in young rabbits of the VI experimental group (250 g of Activo per tonne of feed) and amounted to 36.2 g.

Features of rabbit digestion consist in the functioning of highly specialised colonies of intestinal microorganisms, which makes them vulnerable to its destruction in the intestines. The improvement in the productivity of young rabbits was obviously conditioned by the influence of the active components of the biological supplement, which balance the intestinal microbiota and have a complex positive effect on the health of animals.

The best indicators of fattening productivity at the age of 90 days for the introduction of 150 g of Activo per tonne of finished feed were obtained in the IV experimental group, obviously due to the effectiveness of physiological effects essential oils on the process of digestion of monogastric, herbivorous rodents, which was manifested in better food intake. Live weight of rabbits in this group increased by 150 g (p<0.05), average daily gains – by 2.3 g (p<0.05), loin width – by 0.16 cm, feed conversion improved by 200 g.

In particular, studies (Honchar & Shevchenko, 2010; Tsyhanchuk, 2021) on the assessment of the effects of probiotic supplements in the diets of young rabbits indicate positive changes in internal parameters, such as total protein, immunoglobulins and IgG, and changes in intestinal morphology and a positive effect on the microbiota of the gastrointestinal tract, thereby supporting the natural immunity of animals.

The lifetime meat index (loin width) was slightly higher in rabbits of the IV and V experimental groups relative to the control, but without a significant difference (Table 3). The width of the lower back at 3 months of age in rabbits of these groups was 6.86 and 6.84 cm, respectively. When introducing a dietary supplement of 250 g per tonne of finished feed into the diet of experimental rabbits, this figure was 6.62 cm.

***Table 3**. Fattening and slaughter indicators of young rabbits at 90-day age, (m ± m, n = 10)*

Group	Indicators				
	Width of lower back, cm	Weight of a paired carcass, g	Slaughter output, %	Feed costs per 1 kg of growth, kg	CAI
I	6.7 ± 0.112	1,352 ± 19.2	50.1	3.8	255
II	6.71 ± 0.114	1,362 ± 25.1	50.4	3.75	254
III	6.83 ± 0.087	1,407 ± 18.7	50.9	3.65	261
IV	6.86 ± 0.083	1,436 ± 23.6**	51.1	3.6	266
V	6.84 ± 0.111	1,434 ± 22.4**	51.12	3.65	267
VI	6.62 ± 0.77	1,355 ± 26.3	50.18	3.85	252

Note: *p<0.05; **p<0.01; ***p<0.001*
Source: *compiled by the authors*

Regarding slaughter indicators, there was a somewhat uneven increase in the weight of a paired carcass. According to this indicator, young rabbits of the IV and V experimental groups with the content of 150 and 200 g of Activo in the diets significantly prevailed in the control group by 84 and 82 g (p<0.01), and in terms of slaughter yield, they had an advantage over all other groups by 0.08-1.02%.

Feed costs in groups I, II, III, V, and VI were 3.8; 3.75; 3.65; 3.65, and 3.85 kg of finished feed per 1 kg of growth, while in group IV they were slightly more efficient and were at the level of 3.6 kg.

Thus, when using dietary supplements in the diet of fattening young rabbits in the amount of 100, 150, and 200 g per tonne of finished feed (III, IV and

V groups) live weight at 90-day age increased by 2.4-5.3%, average daily gains – by 3.5-6.4%, lifetime lumbar width (meat index) – by 2.0-2.4%, feed conversion improved by 4.1-5.6% compared to the control group I. The highest rate of comprehensive assessment indicator (CAI) of young rabbits, based on the average daily growth and lumbar width, was observed in animals of groups IV and V – 266 and 267 g, respectively, compared with 255 g in control animals of group I.

An important place in evaluating the effectiveness of individual elements that are introduced into the current intensive technologies for fattening animals is occupied by calculating the economic efficiency and profitability of the activities carried out, because such an analysis allows assessing the feasibility of introducing the proposed elements of feeding technology into production. Thus, the economic analysis of intensive fattening of young rabbits showed that under the conditions of enrichment of the main diet with different doses of Activo dietary supplement, two main factors that determine the cost of livestock products changed: both the cost of feed and the productivity of animals increased. The main characteristics of the economic efficiency of using Activo are shown in Table 4.

***Table 4**. Economic efficiency of the use of dietary supplements in fattening young rabbits*

Economic indicators	Group					
	I	II	III	IV	V	VI
The cost of 1 kg of dietary supplement, UAH.	1,400	1,400	1,400	1,400	1,400	1,400
The cost of 1 tonne of mixed feed, UAH.	11,000	11,070	11,140	11,210	11,280	11,350
Feed costs per 1 kg of weight gain, kg	3.8	3.75	3.65	3.60	3.65	3.85
The cost of feed per 1 kg of live weight gain, UAH.	41.8	41.5	40.7	40.3	41.2	43.7
Cost of 1 kg of rabbit meat, UAH.	59.7	59.3	58.1	57.5	58.8	62.4
Sales price of 1 kg of live weight of rabbit meat, UAH.	80	80	80	80	80	80
Net income 1 kg of rabbit meat, UAH.	20.3	20.7	21.9	22.5	21.2	17.6
Profitability, %	34	35	38	39	36	28

The data of economic analysis shown in Table 4 indicate that feed costs per 1 kg of growth in all experimental groups, except the last one, were lower than in the control. This indicator was lowest in the IV experimental group for fattening young animals with the addition of a dietary supplement of 150 g/t to the finished feed and amounted to 3.60 kg compared to 3.80 kg in the control group. The cost of 1 tonne of finished feed naturally increased linearly in all experimental groups (from UAH 11,000 to 11,350).

The intensification of animal metabolism with the use of dietary supplements provided an increase in fattening productivity of rabbits, which, in turn, led to a decrease in the cost of feed by 1 kg of growth in the II, III, IV, and V experimental groups by UAH 0.30-1.50 relative to the control group. The cost of feed per 1 kg of growth of animals of the VI experimental group that consumed feed with the addition of 250 g/t Activo was higher (UAH 43.7) than in the control (UAH 41.8).

The increase in the price of finished feed and, accordingly, the cost of feed per 1 kg of increase in the VI experimental group led to an increase in the cost of feeding young rabbits of this group. For other experimental groups, this indicator was lower, reaching a minimum in the IV experimental group, which consumed feed with the addition of 150 g/t of a biological additive.

A similar trend can be traced for the indicator of net profit and profitability of intensive rabbit meat production. The highest profitability of production in terms of direct costs was observed in young rabbits of group IV and amounted to 39%. This experimental group was fed 150 g of dietary supplement per tonne of ready-made complete mixed feed.

With the introduction of different amounts of Activo into the diet, both fattening indicators of young rabbits by group and economic indicators, in particular, the cost of feed as the main cost indicator, changed. With the increase in fattening productivity, the share of feed in the structure of the cost of rabbit growth increased and feed costs per unit of growth decreased.

Thus, it was found that the use of dietary supplements, in particular, at a dose of 100-200 g/t of mixed feed, in the diets of young rabbits in the conditions of intensive production of rabbit meat allows reducing direct costs for the production of 1 tonne of finished products by UAH 2,200 and increase the profitability of production by 5%.

A feature of young rabbits of the newly created chinchilla type (NCCT) is an intensive daily increase in live weight, which can be accompanied by an imbalance in the conversion of feed and cause disruption of the gastrointestinal tract and without correction can lead to diseases or deaths of animals, since in the conditions of intensive production of rabbit meat, the nutritional value of diets changes, new ingredients are introduced, their structure and ratio change (Abdel-Wareth & Metwally, 2020; Abu Hafsa *et al*., 2022). Under certain conditions, this can lead to enteritis and subsequent death and, accordingly, to a decrease in animal productivity (Petrescu & Petrescu-Mag, 2018; Bashchenko *et al*., 2020; Puvača *et al*., 2022).

The use of high-energy diets for young rabbits of the most common commercial crossbreeds Grimaud and Hyla improved feed conversion and increased nutrient digestibility. It was shown by Birolo *et al.* (2022) that a lower protein content in the diet has been shown to reduce nitrogen release by animals without negatively affecting growth, feed conversion efficiency, and carcass slaughter characteristics: both genotypes showed similar growth rates, but Grimaud rabbits achieved a higher slaughter yield than Hyla animals (Abdel-Fattah *et al*., 2008).

One of the ways to avoid such consequences is to include in the technology of feeding young animals new progressive, innovative additives that stimulate appetite, digestibility of feed, or have a calming effect on the intestines of animals (Hunchak *et al*., 2015; Jakubowska & Karamucki, 2021). Biological nature supplements to the diet of poultry, pigs, and cattle contain, in particular, plant metabolites of secondary origin (essential oils) and have a pronounced antimicrobial and antioxidant effect on the animal body, have a complex effect on the gastrointestinal tract, and also contribute to increasing the body's resistance to adverse environmental factors (Soltan, 2008; Samudovska & Demeterova, 2010; Lahlou *et al*., 2021). The result of this impact is an improvement in feed conversion, an increase in average daily weight gain, a reduction in fattening time, a reduction in animal deaths, and a significant economic effect (Bashchenko *et al*., 2020; Wu, 2022). The positive effect of additives of this type is conditioned by the synergistic effect of biologically active substances in the composition of essential oils from aromatic and medicinal plants, in particular, thyme, rosemary, and oregano (Stefanyshyn *et al*., 2017; Lahlou *et al*., 2021).

The use of essential oils of thyme (*Thymus vulgaris*), oregano (*Origanum vulgare*), and rosemary (*Rosmarinus officinalis*) in feeding attracted attention as potential substitutes for antibiotics that stimulate the growth of broiler chickens in terms of productivity, increased immunity and improved quality indicators of the resulting meat. Due to differences in the composition and origin of raw materials for the production of essential oils, the effectiveness of their use may differ significantly (Jakubowska & Karamucki, 2021). Despite this, the positive effect of essential oils as natural growth stimulators in broiler feeding has been shown by researchers (Legendre *et al*., 2018; Lahlou *et al*., 2021). The mechanisms of action of preparations made on the basis of essential oils on metabolic processes are still not clearly described, since there is little information about the effectiveness of their effect on the absorption of nutrients, the work of the intestines or the immune system of animals, but it has been shown that the addition of essential oils to feed inhibits the growth of pathogenic microflora in the gastrointestinal tract (Jakubowska & Karamucki, 2021; Lahlou *et al*., 2021). In the conducted studies (Stefanyshyn *et al*., 2017) the positive effect of biologically active substances of essential oils in the composition of the dietary supplement was found both in improving the life and slaughter indicators of young rabbits, and in the absence of diseases of the gastrointestinal tract or animal deaths during studies.

Biologically active components of essential oils of thyme, oregano, and rosemary stimulate the activity of beneficial bacteria, thus contributing to the balance of microflora, that is, they are an effective prerequisite for protection against pathogenic microorganisms (Abdel-Fattah *et al*., 2008; Puvača *et al*., 2022). Increasing the number of beneficial bacteria not only reduces the number of available substrates for pathogens, but also stabilises the pH of the intestine, ensuring optimal activity of pancreatic enzymes, which further leads to improved nutrient absorption and, accordingly, improved productive characteristics (Jakubowska & Karamucki, 2021; Puvača *et al*., 2022). There are also data on the anticoccidial activity of thyme and rosemary essential oils on the body of chickens (Lahlou *et al*., 2021).

Thus, a variety of biologically active substances – probiotics, lysozyme, etc. – contribute to the balance of the complex microbiota of the gastrointestinal tract of rabbits, which plays a crucial role in the digestion of feed, in the endogenous synthesis of vitamins, in stimulating the metabolism of animals, the development of an adequate immune response, and in protecting against infections, pathogens, and countering adverse environmental factors.

CONCLUSIONS

For intensive fattening of young rabbits of the newly created chinchilla type, a mixed feed recipe was developed based on local feed ingredients: barley turf (10%) and oats (10%), wheat bran (10%), sunflower meal (20%), alfalfa flour (35%), table salt (0.4%), premix (3.1%).

Optimisation of the main diet of young rabbits by adding 100, 150, and 200 g/t of Activo led to an increase in their productivity: live weight of individuals at 90-day age increased by 2.4-5.3%, average daily weight gains – by 3.5-6.4%, lifetime width of the lower back – by 2.0-2.4%, feed conversion under such conditions improved by 4.1-5.6% relative to the control. The mass of the paired carcass of young rabbits that received the main diet with the addition of 150 and 200 g/t of dietary supplements was significantly higher compared to the control by 84 and 82 g, respectively. The slaughter yield of rabbits in these experimental groups was 51.10 and 51.12%, respectively, compared to 50.1% in the control group. Analysis of the cost of finished feed per 1 kg of growth showed that this indicator was most effective in animals receiving a diet optimised by adding 150 g/t of dietary supplement, where it was at the level of 3.6 kg against 3.8 kg in the control.

The use of Activo in the amount of 150-200 g/t of mixed feed in the diets of young rabbits with intensive production of rabbit meat reduces direct costs for the production of 1 tonne of rabbit meat by UAH 2,200 and increases the profitability of production by 5%.

Thus, optimisation of the diet of young chinchilla rabbits with intensive production of rabbit meat by adding 150 and 200 g/t of dietary supplements to mixed feed contributed to the improvement of lifetime meat content and slaughter yield while reducing feed costs and increasing its conversion, which ensured a reduction in direct production costs. The use of dietary supplements as a component of intensive fattening of young rabbits contributed to the absence of the incidence of gastroenterocolitis and other diseases of the gastrointestinal tract in animals and ensured the absence of cases of animal deaths during studies.

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Вплив рослинної біодобавки на продуктивність молодняку кролів

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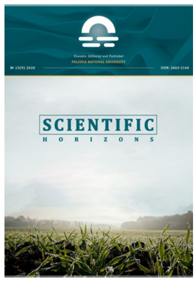
Анотація. Пошук елементів технологій та препаратів природного походження, які поліпшують роботу кишково-шлункового тракту тварин є актуальним з огляду на те, що інтенсивні технології вирощування передбачають використання значної кількості різного роду антибіотиків, які знижують імунітет і негативно позначаються на якості отриманої м'ясної продукції. Перспективними в цьому напрямку є препарати, розроблені на основі біологічно активних речовин з ефірних олій лікарських та пряно-ароматичних рослин. У дослідженнях використано біодобавку «Активо», рекомендований для годівлі птиці та свиней, створений на основі ефірних олій розмарину, материнки, чебрецю. Саме тому метою досліджень було з'ясувати ефективність та безпечність використання біодобавки, як елементу інтенсивного виробництва кролятини. Методи досліджень – зоотехнічні, лабораторні, статистичні. Для інтенсивної відгодівлі молодняку кролів новоствореного шиншилоподібного типу було розроблено рецепт комбікорму на основі місцевих кормових інгредієнтів. Встановлено, що додавання до раціону відгодівельного молодняку кролів «Активо» в кількості 100, 150 і 200 г/т, їхня продуктивність у 90-добовому віці зростала, зокрема жива маса – на 2,4–5,3 %, середньодобові прирости – на 3,5–6,4 %, прижиттєва ширина попереку (показник м'ясності) на – 2,0–2,4 %, конверсія корму покращувалася на 4,1–5,6 %. Показано, що використання біодобавки в кількості 150–200 г/т комбікорму в раціонах молодняку кролів за інтенсивного виробництва кролятини дає змогу зменшити прямі затрати на виробництво 1 т кролятини на 2200 грн. та підвищити рентабельність виробництва на 5%. Отже, застосування біологічної добавки як елементу інтенсивної відгодівлі молодняку кролів сприяє покращенню прижиттєвої м'ясності та забійного виходу молодняка кролів за одночасного зниження затрат готового корму та зростання його конверсії, що призводить до зниження прямих затрат на виробництво

Ключові слова: інтенсивне кролівництво, індекс комплексної оцінки, місцеві корми, відгодівельні та забійні показники

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua

Scientific Horizons, 25(10), 17-30



UDC 630*4:574.3

DOI: 10.48077/scihor.25(10).2022.17-30

Early and Late Wood of Scots Pine under Conditions of Varying Degrees of Lighting

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Article's History:
Received: 10/03/2022
Revised: 11/15/2022
Accepted: 12/07/2022

Suggested Citation:
Andreieva, O., Koval, I., & Smolin, V. (2022). Early and late wood of scots pine under conditions of varying degrees of lightingt. *Scientific Horizons*, 25(10), 17-30.

Abstract. The condition of pine stands in Polissia is deteriorating due to an increase in the number of outbreaks of sharp-dentated bark beetle (*Ips acuminatus*) against the background of climate change, therefore, the relevance of this problem is beyond doubt. The purpose of the study is to identify the features of the dynamics of late and early Scots pine wood (*Pinus Sylvestris* L.) in areas with varying degrees of illumination after continuous cutting in the foci of the sharp-dentated bark beetle (*Ips acuminatus*) in Polissia. Standard dendrochronological, dendroclimatic, and statistical methods are used. It is established that after continuous logging in 2013 in the adjacent areas, on the one hand, there was an increase in the radial growth of pine trees, because the nutrition areas increased and the lighting conditions of trees improved, and on the other hand, trees growing next to the logging area are weakened and have fragile cores, which indicates a loss of wood quality. After cutting, during 2014-2020, the average values of late pine trees of illuminated time trial areas compared to the corresponding values in the control were 43-45%. For early wood, these values ranged from 38-42%. The growth change indices showed, that after the 2013 logging, violations occurred for trees in illuminated temporary trial areas as opposed to the control. The most sensitive to climatic factors were tree-ring chronologies of late wood in the most illuminated trial area. An increase in the sensitivity of the radial growth of pine trees was found depending on the increase in the degree of illumination. The weakening of plantings in the most illuminated area is indicated by the fact that the greatest number of significant relationships between growth and climate were found for the tree-ring chronology of early and late wood, while there was no critical decrease in trends in late and early wood layers. The findings can be used for planning forest management activities

Keywords: *Pinus sylvestris* L., *Ips acuminatus*, tree-ring chronologies of early and late wood, continuous logging, indices of growth changes, climatic factors

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INTRODUCTION

Scots pine (*Pinus sylvestri*s L.) responds to an increase in temperature by reducing the functions of the hydraulic system, mainly the protection system. V.L. Meshkova proved that warming is a favourable condition for bark beetles, that is, the growing seasons lengthen, the growth and development rates of larvae accelerate, the reproductive potential and the success of overwintering increase. Consequently, the pest population is growing and the pressure on weakened trees is increasing. Pests can adapt to new conditions, create new populations, quickly settle and cause huge damage, which leads to the deterioration of forests and their drying up. Extreme climatic conditions have been gaining momentum since the 1880s and are considered a long-term factor increasing the mortality of Scots pine trees (*Pinus sylvestris* L.). Weather monitoring over the past 120 years shows that in Europe, air temperatures are rising at a rate of 0.18°C per decade. Bark beetles and their increasing outbreaks accelerate and enhance the impact of forest ecosystems' sensitivity to climate fluctuations (Meshkova, 2021).

C.F. Aoki and colleagues from the USA also found that in recent years, high temperatures that coincided with periods of drought have led to an increase in the number of outbreaks of sharp-dentated bark beetles (*Ips acuminatus*). Sharp-dentated bark beetle is one of the most dangerous pests of pine stands, which among wetland coniferous, wetland mixed pine-oak, upland (dry) coniferous, and upland mixed pine-oak plantations with a high percentage of pine were more likely to be infested than mixed pine-deciduous plantations (Aoki *et al*., 2018).

Scots pine is one of the main forest-forming tree species in Ukraine, which occupies 33% of the entire wooded area. Studies by V.L. Meshkova and O.I. Borysenko revealed that the predominant development of Scots pine dying in Polissia is associated with a large proportion of same-age pure pine stands, untimely thinning and relatively slow drying of felling residues, in which the bark beetle has time to complete its development. An algorithm for predicting the spread of bark beetle foci has been developed. This helps to improve the accuracy of the forecast, evaluate the survey area and pest control measures (Meshkova & Borysenko, 2018). O.Yu. Andreieva and A.F. Goychuk also emphasises that only timely removal of colonised trees can slow down the decline of pine forests (Andreieva & Goychuk, 2018; Andreieva & Goychuk, 2020).

Mortality of pine trees, which can be attributed to *I. acuminatus*, is widespread in the surveyed area of southern Finland, which was proved by J. Siitonen. The researcher found that in the dead-standing trees, the passages *I. acuminatus* are located at the top of the trunks, usually at a height of more than 5 metres, and binoculars are needed to identify passages from the ground. This means that the passages on dead trees will go unnoticed. On the other hand, *I. acuminatus* also breeds in fallen pines and logging remains with thin bark (Siitonen, 2014). However, information on the impact of cambioxylophagous pests on the condition of Scots pine in Europe is still insufficient (Frelich *et. al.,* 2021).

Dendrochronological methods are widely used in modern research on the dynamics of forest ecosystems, the response of plantings to climate change, and the assessment of plant damage and productivity (Huang *et al*., 2021; Soulé *et al*., 2021; Sun *et al*., 2021). Radial tree growth is a bioindicator that can be used to determine the level of forest damage, the response of trees to climate stress factors (Koval, 2020; Kipfmueller *et al*., 2022), increased lighting, etc. (Altman, 2020; Carter *et al*., 2021; Kraj *et al*., 2022).

An increase in the radial growth of trees after a disturbance is often referred to as a release, because after it, subdominant trees are released from the suppression of dominant trees (Altman, 2020; Carter *et al*., 2021; Venegas-González *et al*., 2022). The forest's response to disturbance depends on the magnitude, severity, and type of disturbance, which alter the succession trajectory and productivity of affected forests with significant implications for their future diversity and structure. This is partly conditioned by reduced underground competition for nutrients and aboveground competition for light (Kern *et al*., 2017; Danneyrolles *et al*., 2019; Altman, 2020), residual tree species that are not hosts benefit from such disturbances (Bretfeld *et al*., 2015). Previous studies have shown that in forests in the western United States, outbreaks of bark beetles that infect conifers have led to the rapid release of aspen (*Populus tremuloides Michx*.). However, the effect of the level of natural disturbances on such bursts of radial increment remains largely unknown. By counting dated bursts from numerous series of tree rings, it is possible to reconstruct the history of tent disturbance in a given forest area (Radaković & Stajić, 2021).

Intense, widespread disturbances responsible for at least strengthening the overall trend of climate change can affect the sensitivity of trees to climate factors (Frelich *et al*., 2021). K. Izworska *et al.* found that changes in the condition of trees after, for example, a windfall, when the stand is thinned, may be associated with a lack of water in an open stand in the summer, which was confirmed by a correlation analysis that showed an increase in the dependence of the radial growth of European larch (*Larix decidua* Mill.) in the summer from precipitation in the Slovak Tatras. The growth response of surviving larch trees after a windfall in plantings that are illuminated after this phenomenon can be compared to a similar response associated with a shift towards a lower altitude in the mountains or with a shift towards a more continental climate, where high summer temperatures and water scarcity are factors limiting tree growth (Izworska *et al*., 2022).

Due to the fact that the radial growth of trees is a complex indicator that reflects the state of trees in forest ecosystems, it makes sense to use dendrochronological methods in the study of plantings under the influence of changes in the natural environment due to continuous logging in the cells of the sharp-dentated bark beetle.

The purpose of the study consists in identifying the dynamics of late and early Scots pine wood (*Pinus Sylvestris* L.) after continuous sanitary logging in the foci of the sharp-dentated bark beetle (*Ips acuminatus*) in Polissia, in areas with different degrees of illumination.

MATERIALS AND METHODS

In pure same-age pine (compartment 22, department 25 of SE "Korostyshivske Forestry" Zhytomyr Regional Forestry and Hunting Range Administration) in wet subor conditions, three temporary trial areas (TTA) were established – on the south-eastern (most illuminated), north-western (least illuminated) sides of the area of continuous logging in 2013 in the focus of the sharp-dentated bark beetle and in the forest (control). The studied pure middle-aged pine stands grow in genetic reserves. The climate of the region under study is moderately continental. The average annual air temperature is 9.1°C. In January, this figure reaches -3.2°C, and in July – 20.5°C. 662.6 mm of precipitation falls per year, and 358 mm during the growing season (April-September). The analysis of cores (20 from each TTA) selected in 2020 was carried out using standard dendochronological and statistical methods (Cook & Kairiukstis, 1990).

To take samples of wood cores, a Swedish-made age drill (Haglof) was used to take cores with a diameter of 5 mm at a height of 1.3 m from the ground perpendicular to the longitudinal axis of the tree. The cores were placed in paper containers in which they were transported, dried, and stored. The next step was the laboratory investigation of the samples. The surface of the cores was carefully cleaned with a blade. To increase the contrast when measuring layers of late, early and summer wood, the surface of the cores was moistened with water, or chalk was rubbed into the sample. Layers of late and early wood were measured using the Henson digital instrument with an accuracy of 0.01 mm (Bitvinskas, 1974; Fritts, 1976; Cook & Kairiukstis, 1990).

Based on the measurement data, radial increment graphs are constructed for each tree, which are used for cross-dating (Holmes, 1983). The result of cross-dating is the establishment of a calendar date for each layer of wood, when performing cross-dating, extreme growth values (extremely narrow or wide layers of summer wood) were used, including rings that have a pathological structure (frost-resistant, light false rings, etc.), which are usually used to determine the correctness of dating. Segments of cores with low correlation values and cores that were not subject to dating were excluded from the sample. Methods of comparative and intra-row analysis are used to investigate general trends in changes in the radial growth of trees over time, identify growth extremes and relationships of radial growth indices with meteorological conditions.

20 samples of wood cores were taken by Presler drill from the tree trunk at a height of 1.3 m from each TTA. The values of late and early wood layers were measured with a HENSON digital instrument with an accuracy of 0.01 mm. Cross-dating was performed to determine the date of formation for each layer of wood. The concept of reference years is used to study the extreme values of radial growth, when the value of the annual ring of the current year is less or greater than the corresponding value of the previous year by 25% and 75% of trees in the sample have the same trend. A comparative analysis was performed between the chronology of pine trees in the illuminated areas and the corresponding values in the control. Tree-ring chronologies are calculated by three-year smoothing. Correlation analysis was applied to identify the relationship between radial tree growth and climate factors.

For dendroclimatic analysis, data from the Zhytomyr weather station was used (geographical coordinates: latitude: 50°15'53" N, longitude: 28°40'36" E, the height above sea level is 228 m). The influence of monthly precipitation amounts and average monthly temperatures on the radial growth of trees from June of the previous year to August of the year of study is analysed, and the relationship between the radial growth of pine trees and the hydrothermal indices according to Selyaninov, which reflects the conditions of the growing season; De Martonne, which contains information on the hydrothermal conditions of the current year and O_3 according to T.T. Bitvinskas, which reflects the hydrothermal conditions of the three previous and current years (Bitvinskas, 1974).

To identify violations in plantings under the influence of stress factors, growth change indices were calculated (*GCt*) for the year of damage (*t*), which are universal for all types of species and growing conditions (Cook *et al.*, 1990).

$$GGt = \frac{Agr2 - Agr1}{Agr1 * 100} \tag{1}$$

where $Agr1$ – average annual growth for the period n 1 before the year characterised by stress factors (t); $Agr2$ – average annual growth for the period n 2 after the action of the stress factor.

It is considered that changes in growth occurred when the index GGT exceeded the threshold of 25%. A significant violation in the planting occurs when GGT≥75%, average between 50 and 75%, and insignificant between 25 and 50%. Growth change indices are universal for all types of species and growing conditions. Using a window of reasonable length, this method filters out the response to short-term changes in temperature and precipitation. In practice, the percentage increase in growth is calculated for all possible pairs of consecutive pre- and post-windows of different values. Correlation analysis was used to establish the relationship between late and early wood on the one hand and climatic factors on the other.

RESULTS AND DISCUSSION

Late wood. It was found that the cores selected from Scots pine from the forest side are of higher quality, in contrast to the cores that are selected on the less illuminated northwest side of the logging area and the more illuminated southeast side of the logging area and which are extremely fragile. The widest layers of late wood were observed in trees on the most illuminated side, and a "release" growth was observed on the less illuminated part of the logging area, and the narrowest layers of late wood were characteristic of trees in the control area. Comparison of the size of layers of late Scots pine wood for two periods – 2006-2012 and 2014-2020. In areas with less illumination, layers of late pine wood increased by 22% in the second period (2014-2020) compared to the first period (2006-2012). At the same time, at the more illuminated TTA, this excess was 13%. For trees from the control TTA, the opposite process occurred – the values of late wood layers decreased by 24%. After 2019, the trend of late Pine layers began to decrease in illuminated areas, but this decline was not critical (Fig. 1, Table 1).

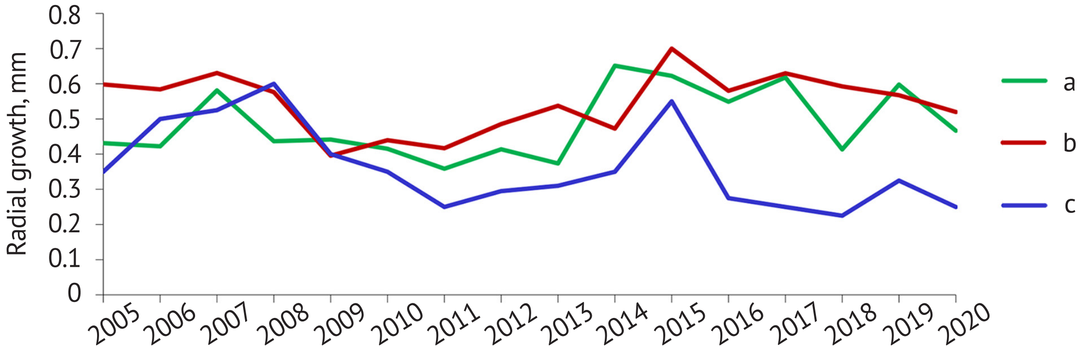

***Figure 1**. Dynamics of layers of late Scots pine wood at the TTAs with different lighting levels near the logging area of 2013*

***Note:** a – less illuminated north-western side of the logging area; b – more illuminated south-eastern side; c – forest side*

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

***Table 1**. Comparison of late Scots pine wood values at the TTA with different lighting levels for 2006-2012 and 2014-2020*

Area of sampling	Statistical factors	2006-2012	2014-2020	Reliability of the difference between the average values of radial growth for 2006-2012 and 2014-2020	
				t_{fact}	t_{theor}
a	A_{avg}/m	0.44 ± 0.03	0.56 ± 0.03	$2.86_{0.05}$	1.76
	σ	0.07	0.09		
	σ^2	0.005	0.008		
b	A_{avg}/m	0.50 ± 0.04	0.58 ± 0.03	$1.70_{0.05}$	1.76
	σ	0.09	0.07		
	σ^2	0.009	0.005		
c	A_{avg}/m	0.42 ± 0.05	0.32 ± 0.04	$1.54_{0.05}$	1.76
	σ	0.129	0.112		
	σ^2	0.002	0.001		

***Note:** a – less illuminated north-western side of the logging area; b – more illuminated south-eastern side of the logging area; c – forest side; A_{avg} – average value of the annual wood layer; m – error of the average annual wood layer; σ – standard square deviation; σ^2 – variance*

***Source:** calculated by the authors*

The excess of the average values of late wood layers for trees with less illuminated and more illuminated TTAs is comparable to the corresponding values in the control for the post-felling period (2014-2020 PP.) was 43 % and 45 %. This excess was significant: for less illuminated and more illuminated TTAs compared to the corresponding values for the control area for 2014-2020 (t_{fact}=4.49 and, respectively, t_{fact}=4.79005, t_{theor}=1.76. That is t_{fact}> t_{theor} indicates a rejection of the zero hypothesis that there is no difference between the samples (Gorkavy, 2019).

Early wood. The average values of early wood layers for the periods before continuous cutting in 2013 (2006-2012) and after it (2014-2020) are compared. It was found that in the second period, the excess of the values of early wood layers for trees with TTA on the less illuminated side compared to the first period was 20%, while for trees with more illuminated TTA, the corresponding value was 9%. The growth of early wood, on the contrary, decreased slightly (by 3%) for trees growing in the control area. After 2019, the radial growth of pine trees in illuminated areas began to decrease sharply, in contrast to the control (Fig. 2).

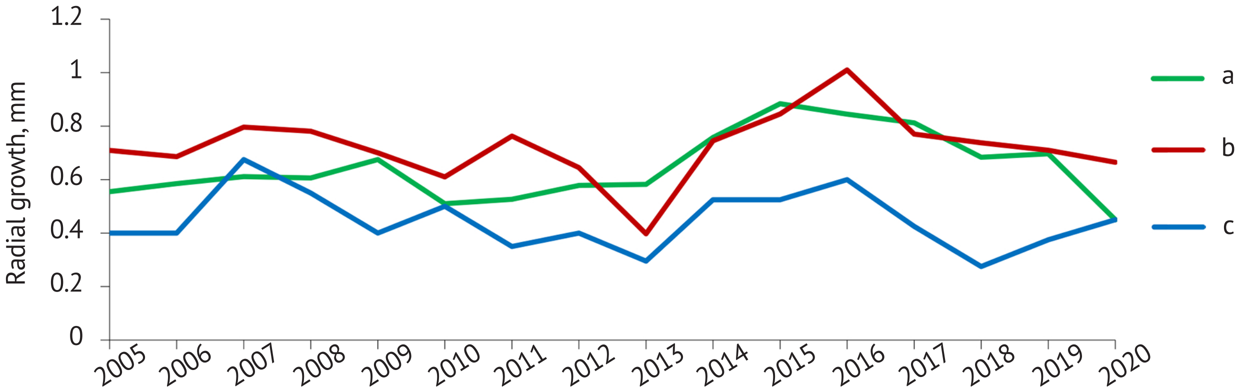

Figure 2. *. Dynamics of layers of early Scots pine wood at the TTA with different lighting levels near the logging area of 2013*

Note: *a – less illuminated north-western side of the logging area; b – more illuminated south-eastern side; c – forest side*

Source: *compiled by the authors*

When comparing the average values of early wood layers for the two periods 2006-2012 and 2014-2020, a significant difference was found only for trees growing in less illuminated TTA compared to trees growing in other areas. The average values of early wood layers on the side of a less illuminated TTA exceed the corresponding values at the control by 38%, and at the TTA with more lighting – by 42% (Table 2).

Table 2. *Statistical characteristics of layers of early Scots pine wood near the logging area of 2013*

Area of sampling	Statistical factors	2006-2012	2014-2020	Reliability of the difference between the average values of radial growth for 2006-2012 and 2014-2020	
				t_{fact}	t_{theor}
a	A_{avg}/m	0.58 ± 0.02	0.73 ± 0.05	$2.53_{0.05}$	1.76
	σ	0.056	0.14		
	$σ^2$	0.003	0.02		
b	A_{avg}/m	0.71 ± 0.03	0.78 ± 0.04	$1.41_{0.05}$	1.76
	σ	0.071	0.114		
	$σ^2$	0.005	0.013		
c	A_{avg}/m	0.473 ± 0.04	0.453 ± 0.04	$0.23_{0.05}$	1.76
	σ	0.114	0.108		
	$σ^2$	0.013	0.011		

Note: *a – less illuminated north-western side of the logging area; b – more illuminated south-eastern side of the logging area; c – forest side;* A_{avg} *– average value of the annual wood layer; m – error of the average annual wood layer; σ – standard square deviation;* $σ^2$ *– variance*

Source: *calculated by the authors*

The average values of layers of early wood of trees with TTAs with different degrees of illumination and trees from the forest side for 2014-2020 are compared. A significant difference was found between the average values of early wood layer values for trees with less illuminated TTA and the corresponding values for trees with control TTA (t_{fact}4.08>t_{theor}1.76 at the significance level of 0.05).

Growth change indices (*GCt*) for the year of damage (*t*), which express the degree of disturbance of plantings, calculated for TTAs with different lighting levels for 2013, during which continuous logging took place, is the year of the stress factor's action. The growth change indices are calculated with a 3-year window for 2010-2012 and 2014-2016. It was found that after logging in 2013, violations occurred at all at the TTAs for late wood, as opposed to early wood, where no changes occurred at the control, which indicates a greater sensitivity of late wood to changes in environmental conditions (Table 3).

Table 3*. Statistical characteristics of layers of early Scots pine wood near the logging area of 2013*

Area of sampling	A_{avg}, mm/*m*		GC_t, %	Degree of violation
		Late wood		
a	0.40 ± 0.019	0.61 ± 0.03	53	Average violation
b	0.447 ± 0.020	0.584 ± 0.065	31	Minor violation
c	0.354 ± 0.006	0.455 ± 0.064	29	Minor violation
		Early wood		
a	0.538 ± 0.020	0.866 ± 0.077	61	Average violation
b	0.672 ± 0.046	0.866 ± 0.077	29	Minor violation
c	0.377 ± 0.024	0.463 ± 0.049	23	No changes occurred

Note: *a – less illuminated north-western side of the logging area; b – more illuminated south-eastern side of the logging area; c – side of the forest; GCt – index of changes in growth after a violation of the stand due to continuous logging in 2013.;* A_{avg} *– average value of the annual wood layer; m – error of the average annual wood layer*
Source: *calculated by the authors*

Percentage of late wood. The proportion of late wood is calculated for trees with different degrees of illumination. In 2013, in the year of logging at the most illuminated TTA, the share of late wood was 57.5%, at the less illuminated TTA – 39.1%, and at the control – 40%. That is, the proportion of late wood was highest in the most illuminated TTA, which may indicate a deterioration in the condition of the plantings. Later, during 2014-2020, the share of late wood in the most illuminated TTA ranged from 36.5-45.0%, in the less illuminated TTA – 37.7-50.9%, and in the control TTA – 31.4-51.2%. That is, thinning during this period did not significantly affect the percentage of late wood (Fig. 3).

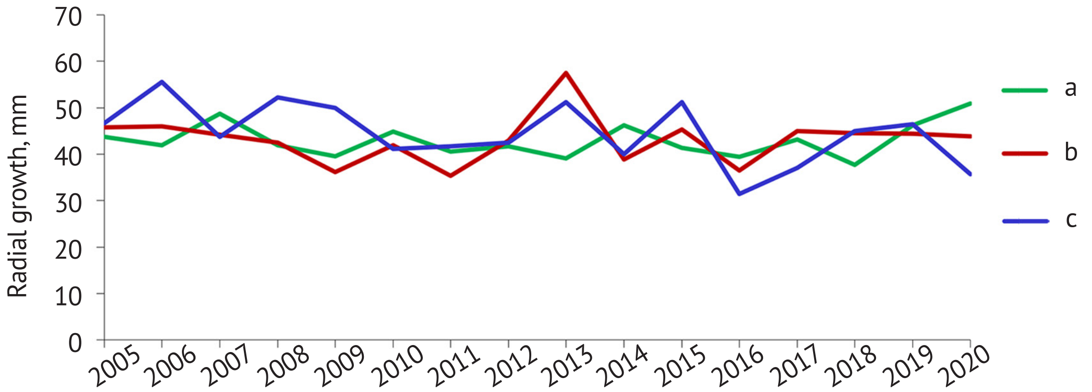

Figure 3*. The share of late Scots pine wood near the logging area of 2013*
Note: *a – less illuminated north-western side of the logging area; b – more illuminated south-eastern side; c – forest side*
Source: *compiled by the authors*

Influence of late and early wood climate on TTA with different lighting levels. A significant positive effect of March temperatures on late pine wood in a less illuminated TTA was found. At the same time, the temperatures of the growing season and autumn months of the previous year negatively affected the formation of layers of late wood. It was found that at the most illuminated TTA, the dependence of late wood on temperatures increased, as evidenced by the largest number of significant correlations between temperatures and late wood indices compared to other TTA. Significant positive correlations were found between late wood indices and winter and hydrological year temperatures. On less illuminated TTA, the positive effect of temperatures on late wood during the growing season and winter increased. For the control TTA, a significant positive effect of temperatures on late wood was found in November of the previous year and a negative effect of temperatures during August. Overall, the most negative effect of temperatures on late wood during the growing season was observed for trees with the control TTA. For trees for the most illuminated TTA, on the contrary, this effect was positive, while trees of the less illuminated TTA occupied an intermediate position (Fig. 4).

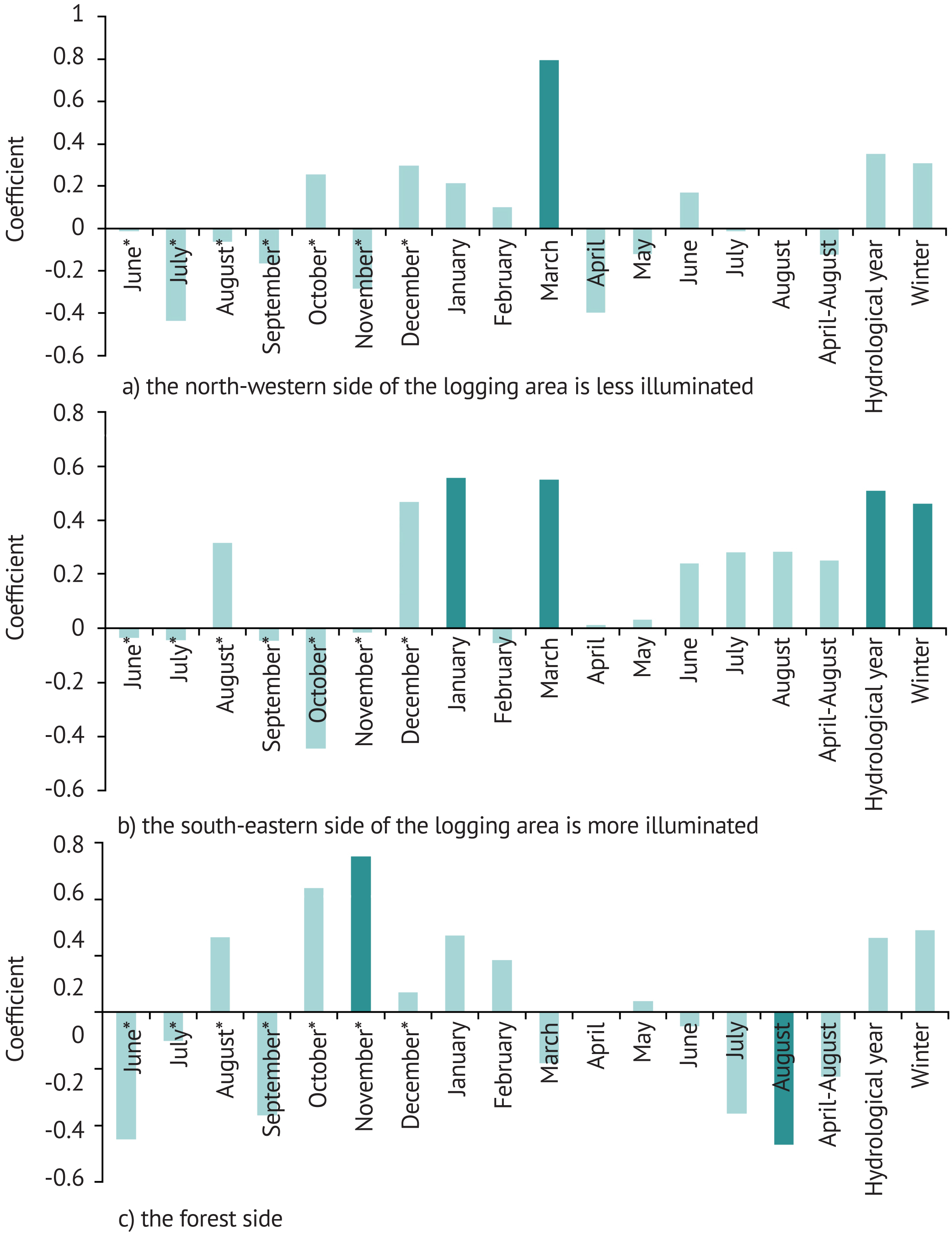

Figure 4*. Correlation coefficients between the indices of late Scots pine wood in areas with different lighting levels due to continuous logging in 2013 and the temperature of the Zhytomyr weather station for 2006-2019*

Note:* * – months of the previous year, dark green column –significant correlation coefficient at the level of 0.01 significance*

Source:* compiled by the authors*

The relationship between late wood and precipitation indices is analysed. For a less illuminated TTA, a positive effect of precipitation in June of the previous year and the current June on late wood was found. For a more illuminated TTA, a negative effect of precipitation from the previous September on the values of late wood layers was found. At the same time, for the control TTA, precipitation in August of the previous year and the growing season had a positive effect on the formation of late wood layers. Precipitation in June-August of the previous year mainly had a positive impact on the formation of late wood layers. The exception was the less illuminated TTA, which showed a significant effect of precipitation on late wood only for June of the previous year. From September 2019 to April 2020, a negative effect of precipitation on growth was found for all plots, while during the growing season, the strongest positive effect of precipitation was found for the control. Winter precipitation negatively affected radial growth at all TTAs. Precipitation in July and August is the main factor controlling the formation of late wood layers. For the control TTA, a significant effect of August precipitation on the formation of late wood layers was found (Fig. 5).

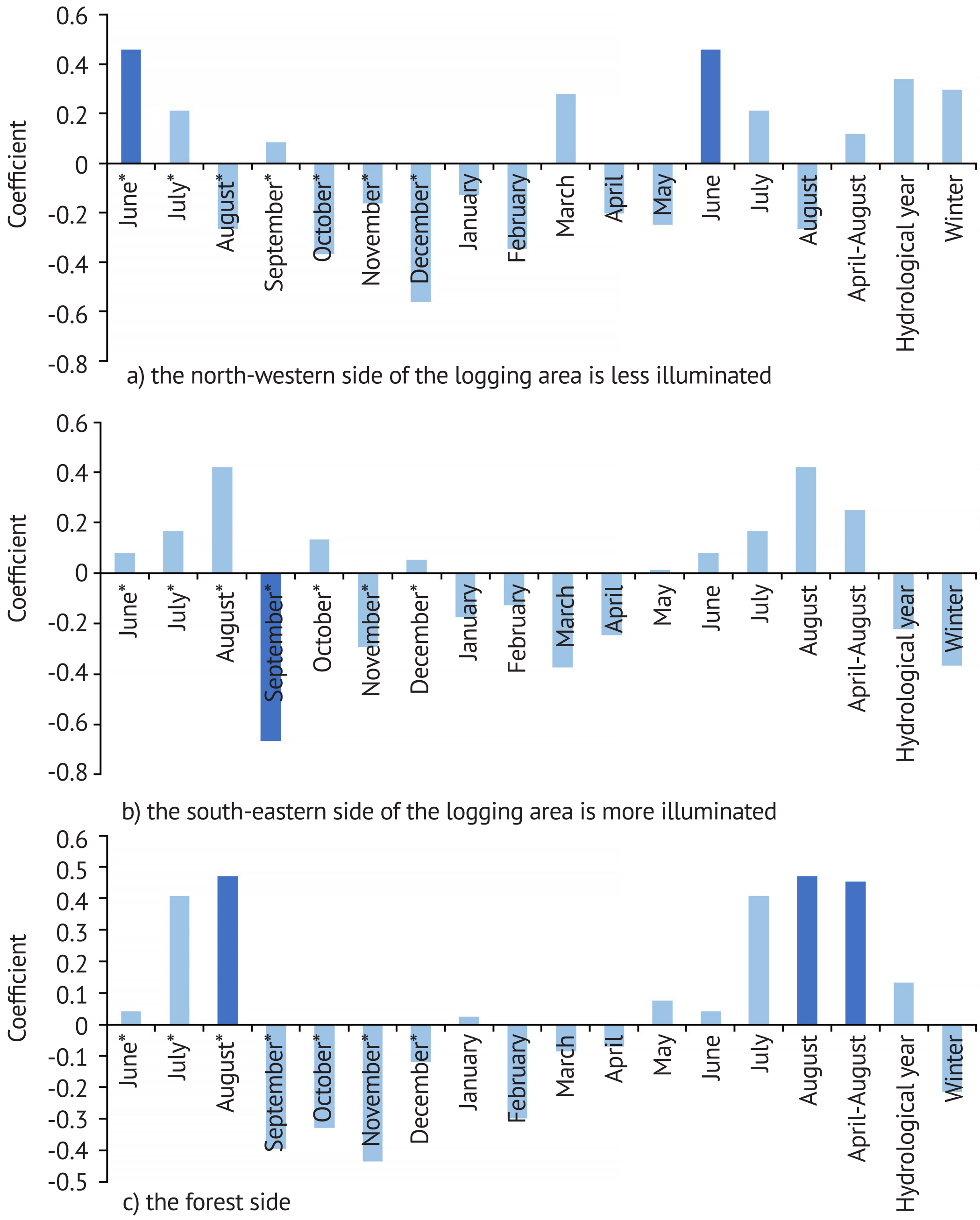

***Figure 5**. Correlation coefficients between the indices of late Scots pine wood in areas with different lighting levels due to continuous logging in 2013 and the temperature of the Zhytomyr weather station for 2006-2019*

***Note:** * – months of the previous year, dark green column –significant correlation coefficient at the level of 0.01 significance*

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

Consequently, it was found that on more illuminated TTA, late wood was more sensitive to temperature, while the tree-ring chronologies of late wood at the control TTA were more sensitive to precipitation.

A correlation analysis was performed between *early wood indexes* and temperatures. A positive effect of December temperatures of the previous year was found for two TTAs – more illuminated and the control. A significant positive effect of March temperatures on the formation of early wood layers was found for all areas with different illumination levels. July temperatures of the current year had a positive effect on the formation of early Scots pine wood at the control. Significant correlations between early wood indices and average hydrological year temperatures were found for a more illuminated area and control. From May to August, there was a positive effect of temperatures on early wood at the control, while in illuminated areas this effect was mainly negative (Fig. 6).

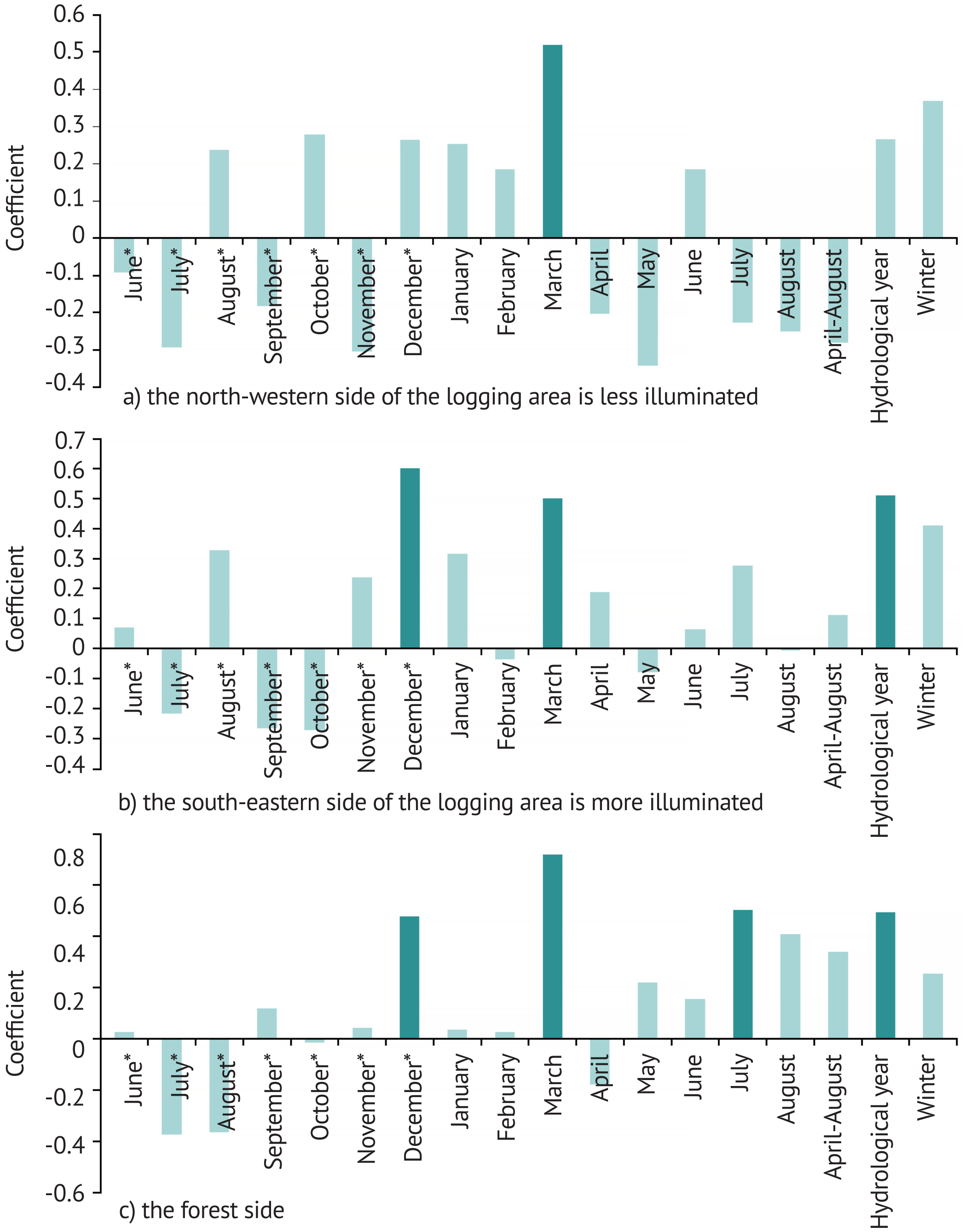

***Figure 6**. Correlation coefficients between the indices of early Scots pine wood in areas with different lighting levels due to continuous logging in 2013 and the temperatures of the Zhytomyr weather station for 2006-2019*

Note: ** – months of the previous year, dark green column –significant correlation coefficient at the level of 0.01*

Source: *compiled by the authors*

Correlations between early timber indices and precipitation over different periods were calculated. Significant negative correlations were found between early timber indices and October and December precipitation of the previous year for illuminated TTA and the control. Overall, precipitation from the previous year had a positive effect on early wood at the control, while in illuminated areas this effect decreased. In the control from August of the previous year to May of the current year (with the exception of March), the control showed a negative effect of precipitation on early wood (Fig. 7).

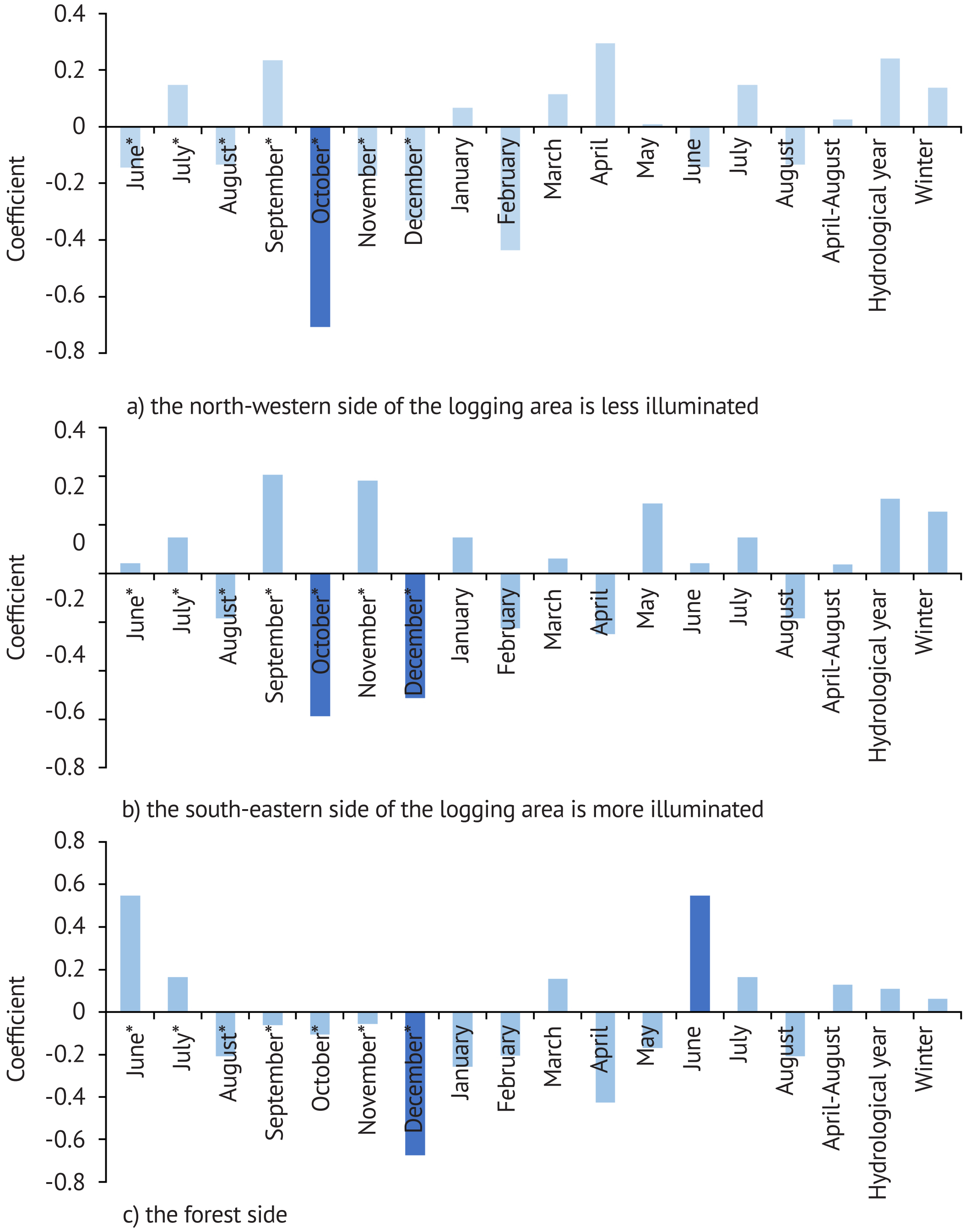

***Figure 7**. Correlation coefficients between the indices of early Scots pine wood in areas with different lighting levels due to continuous logging in 2013 and precipitation of the Zhytomyr weather station for 2006-2019*
***Note:** * – months of the previous year, dark blue column – significant correlation coefficient at the level of 0.01 significance*
***Source:** compiled by the authors*

The relationship between hydrothermal coefficients and late and early wood indices was studied. Significant mean negative relationships were found between early wood for illuminated TTA on the one hand and hydrothermal index, De Martonne, and O_3 indices – on the other side (Table 4).

Table 4. *Correlation coefficients between tree-ring chronologies of Scots pine growing in conditions with different lighting levels and hydrothermal coefficients*

Hydrothermal coefficients			
Hydrothermal humidification coefficient according to G.T. Selyaninov (hydrothermal index)			
Types of wood	a	b	c
Late wood	-0.15	-0.02	-0.16
Early wood	-0.37	-29.86	-0.28
De Martonne			
Late wood	-0.19	0.17	-0.18
Early wood	-29.86	-29.86	-0.09
O_3			
Late wood	0.19	-0.02	-0.02
Early wood	-0.04	0.11	0.29

Note: ** – significance at the level of 0.05; a – less illuminated north-western side of the logging area; b – more illuminated south-eastern side of the logging area ; c – forest side*
Source: *calculated by the authors*

The study found that early wood was most sensitive to climate changes in illuminated areas, as evidenced by the highest correlation between early wood and the de Martonne aridity coefficient. This coefficient has been preferred in climate research by Spanish scientists because it can better distinguish between different climatic conditions (Moral *et al*., 2016).

Studies of radial growth of European larch (*Larix decidua*) in a centuries-old group of trees in the Slovak High Tatras, it was found that after the catastrophic storm of 2004, a surge in radial tree growth, which was calculated from the growth change index, occurred within 4.6 years (Izworska *et al*., 2022). In study study, in a same-age pine stand that is most illuminated, the radial growth of pine occurred faster, that is, the next year after continuous logging.

10-year-old loblolly pine plantation *Pinustaeda* L.) in southeastern Oklahoma (USA) was thinned out. The percentage of late wood, the date of transition from early wood to late, growth and climate variables were measured within two years after logging, which did not significantly affect the percentage of late wood in the annual ring (Cregg, 1988). In this study, the change in the light regime also did not significantly affect the percentage of late wood, that is, its density after continuous logging in 2013 in a pine plantation during 2014-2020.

Studies of the reaction of early and late oak wood (*Quercus petraea* (Matt.) Liebl.) on climate factors in northeastern Serbia, late wood was found to be more sensitive to climate changes than early wood. Late wood showed a positive response to precipitation during the summer months (June and July) of the current growing season. At the same time, the size of early wood layers did not show a direct dependence on climatic factors. It was found that temperature does not significantly affect oak growth. Precipitation during the summer months was a crucial climatic factor that led to years with exceptionally wide or narrow layers of late wood (Radaković & Stajić, 2021). The influence of climatic factors on the growth of black pine, which grows at low altitudes in western France, was estimated by comparing the indices of early and late wood with monthly data on temperature and precipitation for the period of 1922-1991. Late wood formation was found to be more sensitive to climate than early wood formation. It was found that the summer drought was the main factor limiting the growth of trees. The extreme reduction in growth has particularly highlighted the impact of low precipitation (Lebourgeois, 2000). In the control, a higher dependence of late wood layers was found on precipitation (positive effect for the previous August and April-August), and for early wood – on temperature (positive effect of temperatures in the previous August, March, July, and hydrological year on early wood). After continuous logging in 2013, the dependence of late wood on temperatures increased at the most illuminated TTA.

Winter photosynthesis and an advance in the time of restoration of cambial activity were possible reasons for the positive correlation of winter temperature with early wood. The cool and humid spring also contributed to growth, as it affected the water balance of trees at the beginning of the growing season (Lebourgeois, 2000). The temperature of February is the main climatic factor associated with the radial growth of Scots pine in Latvia (Elferts, 2007). This study also revealed a positive effect of March and winter temperatures on the formation of early and late pine wood.

Studies of the radial growth of Scots pine in Mongolia and China have shown that the growth of natural forests was closely related to the climatic factors of the previous year, while the growth of plantation stands was associated with the climatic factors of the growing season of the current year (Sun *et al*., 2021). The study by French researchers has established that seedlings of black Pine (*Pinus nigra* ssp. *laricio* VW. Corsicana) had metabolic disorders due to carbon starvation conditioned by droughts (Guehl *et al*., 1993). This study revealed the influence of climatic factors both in the previous year and in the current year on the formation of layers of early and late pine wood, despite the fact that the studied pine trees are crops. Thus, the most sensitive wood to the hydrological conditions of the growing season and the hydrological year was early wood in the most illuminated area, which is located closest to the logging area. Hydrological conditions negatively affected the formation of early and late wood for the TTA, where the most weakened trees grow, as evidenced by the negative correlation coefficients between the chronologies of early and late wood with the Selyaninov hydrothermal index and the de Martonne index.

Studies of European larch after the windbreak have shown that the main change after the catastrophic phenomenon is associated with a lack of water in an open tent in the summer. This is supported by significant positive correlations between growth and July precipitation. The growth response of larch trees that survived the windfall can be compared to a similar response associated with a shift towards a lower altitude in the mountains or with a shift towards a more continental climate, where high temperatures in mid-summer and water scarcity are factors limiting growth (Izworska *et al*., 2022). Similar results were obtained in this study. In illuminated areas, the dependence of the increase on temperatures increases, especially for late wood. In these illuminated areas, the negative impact of precipitation in the autumn months of the previous year on early and late wood is also increasing. During these months, the soil moisture reserve is formed for the next year.

CONCLUSIONS

On the borders with the area of the continuous sanitary logging of 2013, the cores of Scots pine selected in 2020 turned out to be extremely fragile, in contrast to the cores selected in the forest. After continuous logging in 2013, a surge in radial growth was observed in 2014 and lasted until 2017, after which it sharply decreased in contrast to the control. For trees in illuminated temporary trial areas, compared with the corresponding values, the control showed an excess of the values of late wood layers by 43-45%, and early – by 38-42% due to an increase in feeding areas and improved lighting conditions. The growth change indices showed, that after the 2013 logging, violations occurred for trees in illuminated temporary trial areas as opposed to the control.

Dendroclimatic analysis revealed an increase in the sensitivity of early and late wood, depending on the increase in the degree of illumination. The weakening of plantings in the most illuminated area is indicated by the fact that for the chronologies of early and late wood, the greatest number of significant relationships between growth and climate were found, while there was no critical decrease in the trends of late and early wood layers. It was found that in more illuminated temporary trial areas, late wood is more sensitive to winter and early spring temperatures, and a positive effect of temperatures during the hydrological year on growth was also found. At the same time, the tree-ring chronologies of late wood on the control are more sensitive to precipitation, and early – to temperatures.

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Рання та пізня деревина сосни звичайної в умовах різного ступеню освітлення

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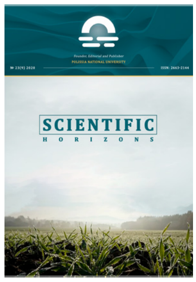
Анотація. Стан соснових насаджень в Поліссі погіршується у зв'язку зі збільшенням кількості спалахів верхівкового короїда (*Ips acuminatus*) на тлі зміни клімату, тому актуальність цієї проблеми не викликає сумнівів. Мета дослідження – виявлення особливостей динаміки пізньої та ранньої деревини сосни звичайної (*Pinus Sylvestris* L.) на ділянках із різним ступенем освітлення після суцільної рубки в осередках верхівкового короїда (*Ips acuminatus*) в Поліссі. Застосовано стандартні дендрохронологічні, дендрокліматичні та статистичні методи. Встановлено, що після суцільної рубки 2013 року на ділянках, розташованих поряд з цією рубкою, з одного боку відбулося підвищення радіального приросту сосни, бо збільшилися площі живлення та покращився режим освітлення дерев, а з іншого боку дерева, які ростуть поряд зі зрубами є ослабленими и мають крихкі керни, що свідчить про втрату якості деревини. Після рубки, упродовж 2014–2020 рр. перевищення середніх величин шарів пізньої деревини сосни для дерев освітлених тимчасових пробних площ порівняно з відповідними величинами на контролі становили 43–45%. Для ранньої деревини ці величини коливалися в межах 38–42%. Індекси зміни приросту показали, що після рубки 2013 року порушення відбулися для дерев на освітлених тимчасових пробних площах на відміну від контролю. Найбільш чутливими до кліматичних чинників виявилися деревно-кільцеві хронології пізньої деревини на найбільш освітленій тимчасовій пробній площі. Встановлено підвищення чутливості радіального приросту сосни в залежності від збільшення ступеню освітлення. Про ослаблення насадження на найбільш освітленій ділянці свідчить те, що для деревно-кільцевої хронології ранньої та пізньої деревини виявлено найбільшу кількість значущів взаємозв'язків між приростом та кліматом, при цьому критичного зниження трендів шарів пізньої та ранньої деревини не відбулося. Результати досліджень можна використати для планування лісогосподарських заходів

Ключові слова: *Pinus sylvestris* L., *Ips acuminatus*, деревно-кільцеві хронології ранньої та пізньої деревини, суцільна рубка, індекси зміни приросту, кліматичні чинники

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
***Scientific Horizons*, 25(10), 31-42**



UDC 631.427:633.11:11.89
DOI: 10.48077/scihor.25(10).2022.31-42

Regularities in the Development of Soil Biological Activity and Winter Wheat Productivity under Ecologised Fertiliser Systems

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Article's History:
Received: 10/11/2022
Revised: 11/23/2022
Accepted: 12/13/2022

Suggested Citation:
Dubytskyi, O., Kachmar, O., Dubytska, A., & Vavrynovych, O. (2022). Regularities in the development of soil biological activity and winter wheat productivity under ecologised fertiliser systems. *Scientific Horizons*, 25(10), 31-42.

Abstract. Restoration and optimisation of soil processes is an important task of modern agriculture and one of the reserves for increasing agricultural production. Under the current conditions, this becomes possible with the integrated introduction of ecologised fertiliser systems. The purpose of the study is to investigate the regularities of the development of biological features of grey forest soil, the interdependencies between them, and the productivity of winter wheat in ecologised fertiliser systems. The following methods were used in the study: field, laboratory and analytical, biochemical, mathematical and statistical. Patterns of changes *in situ* of cellulolytic, proteolytic, and actual dehydrogenase activities of the soil, the carbon content of labile humus, and the number and weight of winter wheat grains per unit area were similar to each other. There was a decrease in cellulolytic activity, the smallest increase in the remaining biological characteristics of the soil under the use of pea straw, compared to the control. The greatest cellulolytic or proteolytic activity occurred in pea straw + $N_{30}P_{45}K_{45}$ + biostimulator + humus fertiliser or pea straw + $N_{30}P_{45}K_{45}$ + biostimulator + microbiological fertiliser, respectively, dehydrogenase – in 2, and the content of labile humus – in the first of these 2 variants. The availability of carbon and nitrogen allowed explaining the identified patterns in a relevant way. The positive Pearson correlation coefficients between plant productivity and soil biological activity, labile humus content, and enzymatic activity, and the insignificant partial correlation coefficients between these variables are partly conditioned by multicollinearity and multivariate interdependencies. In the future, the research would provide a deeper understanding of the patterns of development of biological properties of the soil under ecological fertiliser systems. This would help to improve the elements of greening to adjust the ratio of potential and actual fertility to the optimal level. Scientific results can become a basic basis for the development of effective soil-protecting organic and mineral fertiliser systems for economic and industrial structures of various levels of intensity and financial viability

Keywords: cellulolytic and proteolytic activity, dehydrogenase activity, labile humus, winter wheat productivity, correlation

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INTRODUCTION

Due to the significant decrease in manure production over the last period and the low level of mineral fertiliser use, soil fertility should be maintained mainly by returning organic substances formed during photosynthesis to biological circulation (Hamaliei & Shkarivska, 2009; Tanchyk, 2009). One of the most significant in terms of volumes, relatively cheap, and annually replenished resources of organic matter are by-products of plant origin. Among other things, they have the ability to maintain a sufficient level of fertility, in particular, the content of labile organic matter, the optimal intensity of biochemical processes in the soil (Smetanko *et al.*, 2018; Starchevskyi & Starchevskyi, 2018).

The use of post-harvest residues compensates for the lack of organic matter by 20-25%. However, ploughing straw without fertilisers creates conditions for the consumption of organic and inorganic nitrogen by cellulose-destroying soil microorganisms, thus causing a deterioration in soil fertility. Moreover, the disadvantage of conventional technologies for sealing plant residues is the need to apply a significant amount of nitrogen fertilisers, which, however, have little effect on the assimilation of nutrients contained in straw by plants (Mazur *et al.*, 2003)

Thus, one of the important areas in modern agriculture is the development of agrotechnical approaches aimed at improving the ecological state of the soil, improving its fertility and quality of agricultural products through the use of straw of grain or leguminous crops, preparations of biological compounds, which include beneficial microorganisms, humus substances, plant growth stimulators (Tonkha *et al.*, 2002). Extremely important in this context is the use of chelated microfertilisers, which have the ability to increase the yield and quality of agricultural products (Klymenko, 2017).

Straw, as an annual carbon-containing fertiliser, improves physical and chemical properties, enhances the activity of microflora, and increases the humus content in the soil (Yurkevych & Kovalenko, 2009; Moldovan & Vovkolup, 2012). Under these conditions, the decomposition of fibre is important, the intensity of mineralisation of which covers the area of mobilisation processes in soils, and indicates the provision of available forms of carbon (Trembitska, 2011). According to some researchers, reflecting the most accurate set of conditions affecting the plant, the intensity of cellulose decomposition is one of the indicators of soil fertility (Patyka, 2009). According to the latest cited studies, the use of grain straw + $N_{116}R_{10}K_{90}$ on podzolized chernozem for winter wheat led to a twofold increase in cellulolytic activity compared to the control.

The relationship of microbiological processes with effective soil fertility is characterised by proteolytic activity, as an indicator of the intensity of which the level of soil nitrogen supply largely depends. Proteolytic enzymes catalyse the hydrolysis of soil protein compounds to amino acids, which, as a result of subsequent biochemical processes, are metabolised with the release of mineral forms of nitrogen. The latter play an important role in the life of soil microorganisms and agricultural crops. In chernozem conditions, typical use of winter wheat straw 3 t/ha + $N_{40}R_{40}K_{40}$ in repeated crops provided activation of proteolytic processes by 11%, relative to the control (Moskalevska & Patyka, 2014; Demianiuk *et al.*, 2016).

In the metabolism of substances and energy in the soil, an important place belongs to biological catalysts of redox reactions involved in the synthesis and decomposition of humus substances. Dehydrogenases are the most widespread among such enzymes in the soil. They catalyse the transfer of hydrogen ions and electrons (dehydrogenation) during the oxidation of organic compounds using metabolic cofactors, in particular NAD (P)+ as acceptor molecules. These enzymes are important indicators of the ecological state, including the level of vital activity of microorganisms, and the amount of humus substances that are decomposed by microorganisms. In the conditions of dark grey podzolized soil in the crops of Bunias orientalis for the introduction of $P_{60}K_{60}$ dehydrogenase activity was 12% higher than in the control group. However, the use of only nitrogen fertilisers or with $P_{60}K_{60}$ significantly reduced this enzymatic activity. Among other things, this showed an increase in the intensity of biochemical processes of oxidation of organic compounds during the formation of humus substances (Arkhypenko, 2002).

Since the functioning of microbial complexes and their enzymatic activity ensure continuous processes of transformation of organic substances in the soil, the analysis of relevant biochemical processes provides potential opportunities for revealing the directions and mechanisms of the formation of humus substances (Naidonova, 2015). The labile part of the soil organic matter is most sensitive to the effects of agricultural practices and biochemical properties of the soil. Compounds of this fraction have a high level of hydrophilicity, a significant specific amount of nitrogen-containing, carboxyl, and phenolic functional groups, and, accordingly, a low optical density. With the participation of redox and oxidative enzymatic activities, plant residues are mineralised in the soil. One part of them becomes a source of easily accessible nutrients for microorganisms and plants, while the other part forms one of the fractions of labile humus. According to well-established concepts, the content of mobile humus forms largely depends on the intensity of cellulolytic and proteolytic processes aimed at releasing carbon and nitrogen into the soil, and redox enzymatic activities involved in *de novo* formation of humus substances (Nannipieri, 2012; Piotrowska-Długosz, 2019).

At the same time, there are insufficient experimental data and theoretical ideas in the scientific literature regarding the interdependencies between the intensity of biochemical processes and the content of NaOH-extracted labile organic matter in the soil, and their impact on crop productivity. In addition, the analysis of the peculiarities of using ecologised fertiliser systems for growing agricultural crops is present in the Ukrainian scientific literature in a limited volume. However, significant relevance is inherent in the study and implementation of innovative technologies with a set of ecologised fertiliser systems, aimed, in particular, at achieving optimal intensities of biological processes both in plants and in the soil. In this context, it is important to investigate the influence of these fertiliser systems on the development and interdependence of biological characteristics, in particular, the enzymatic activity of the soil, the formation of labile humus, and the corresponding ratios with the productivity of cultivated crops.

The purpose of the study is to find out and explain the patterns of changes in the biological properties of grey forest soil, the interdependencies between them and the productivity of the winter wheat according to ecological fertiliser systems. To do this, the following tasks were set: 1) investigate the pattern of changes *in situ* of cellulolytic, proteolytic, and potential dehydrogenase activity of the soil, the content of labile humus carbon in it under the conditions of ecologised fertiliser systems; 2) study the regularities of the formation of ear productivity (the number and weight of grains per 1 m^2; 3) calculate and explain the values of the obtained correlation coefficients (Pearson, partial) between plant productivity and soil biological activity, labile humus content, and enzymatic activities.

MATERIALS AND METHODS

The study was conducted in the field during 2017-2019 in the experimental field of the Institute of Agriculture of the Carpathian Region in the conditions of an experiment to study the crop rotation productivity in the village of Stavchany, Lviv district, Lviv Oblast. Microplot experiment, plot area – 1 m^2, the distance between sections – 1 m, repetition – 6 times. The experiment scheme was 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 the Benefis variety.

Experimental fertiliser systems were assembled on the basis of pea straw + $N_{30}P_{45}K_{45}$ with the addition of a biostimulator, humus, microbiological, or chelated fertilisers. The characteristics of the drugs are given below.

Terra-sorb biostimulator; preparation 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 I Mn – 0.1% each, Mo-0.001%.

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

Microbiological fertiliser – eco-grunt; it contains microorganisms *Basillus subtilis*, *Rhodococcus erytropolis* in the amount of 1,000 mln. units/g^{-1}.

Chelated fertiliser – rozasol 18-18-18+125+ME, its composition: 18% N, P, K; B – 128, Mn – 400, Cu – 94, Fe – 325 and Zn – 287 mg/kg^{-1}. Trace elements, in addition to boron, are in chelated form with EDTA. The preparation 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 acidic soils.

The preparations were used as follows: the terra-sorb biostimulator (BS) treated winter wheat crops in the phases of spring tillering and entering the tube – 0.5 l/ha^{-1}; humus fertiliser (HF) – eco-impulse was applied to the corresponding plots 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 tubing; chelated fertiliser (CF) was applied in the tubing phase at a dose of 3.0 kg/ha^{-1}.

The soil of the experimental plots is grey forest, lightly gleyed and loamy. The determination of physicochemical and agrochemical parameters of the soil before laying the experiment is carried out: pH(KCl) – 4.85, hydrolytic acidity Hr – 25.81 mg-eq/kg^{-1} soil, the sum of absorbed bases S – 55.23 mg-eq/kg^{-1} soil, easily hydrolysed nitrogen content – 98.0 mg/kg^{-1}, available phosphorus and potassium exchange (0.2 H NCL) – 108.4 and 87.2 mg/kg-1 soil, respectively; the level of total humus according to Tyurin in Nikitin's modification – 2.1%.

Climatic conditions over the years of research (2017-2019) had their own characteristics. This period was characterised by temperature changes and sharp changes in precipitation, especially in the spring and summer periods. The amount of precipitation during the growing season was in the range of 599-602 mm, except for 2017-2018, when it was 114 mm higher than normal. The temperature background for this period was higher than normal by 1.4-1.6°C. In general, the growing conditions of winter wheat were quite satisfactory, the maturation of crops took place in favourable conditions.

In situ cellulolytic, *in situ* proteolytic activities (CA, PA) of the soil were determined according to DSTU 8644:2016 (2017). The substrate of the first among these fermentative activities was cellulose fibres of linen cloth, the second – gelatine coating of photo paper. Carriers with each of the substrates were placed vertically in the soil at a depth of 30 cm (lower edge) in the field, pressed on the sides, and left for 30 days (for CA) or 10 days (for PA) after the onset of the corresponding phase of ontogenesis of winter wheat – spring tillering, earing. Before and after the application, linen and photo paper were weighed in the soil thickness on analytical scales Radwag AS 220/R2, Poland (±0.0001 g). Each of the listed enzymatic activities was calculated as a percentage of the mass ratios of carriers together with substrates after and before application: (final mass·100%) / initial mass. in addition, after the onset of the above-mentioned periods of plant development, soil samples were taken (depth 0-30 cm) from experimental variants, and their preparation for laboratory and analytical work was carried out in accordance with DSTU ISO 11464-2001 (2003). The selected soil samples were used to measure potential dehydrogenase activity (DA) according to the Galstyan method according to DSTU ISO 23753-1:2010 (2010), the carbon content of labile humus (C-LH, soluble in 0.2 m NaOH) according to the Tyurin method according to DSTU 4732:2007 (2008). Values of extinction of triphenylformazane formed as a result of dehydrogenase reactions, and Cr^{3+}-containing products of organic carbon oxidation with potassium dichromate $K_2Cr_2O_7$, measured at the wavelength λ = 590 Nm on the KFK-2 electrophotocolorimeter. The listed indicators were determined in 3 repetitions and 2 analytical parallels (in general, n = 6), averaged between the specified phases of ontogenesis. Biometric indicators of crop structure elements – the number and mass of grains per unit area of sowing (3 repetitions, 4 plants per repetition, n = 12) were determined in the waxy ripeness phase. Analytical scales (±0.0001 g) (Radwag AS 220/R2, Poland) were used to measure the grain mass. For the calculation of the tested elements of the yield structure, the study used some principles of generally accepted approaches outlined by V.O. Yeshchenko (2014) and their specifics formulated by R.A. Avramenko and H.V. Kirsanova (2004). The final values of each trait were obtained by averaging their values over two years of research (2017-2019).

Statistical analysis of results, in particular *ANOVA* (subject to the level of significance α = 0.05), performed using Excel 11.0.6560.0. To calculate the estimate of the standard error of the difference between the means – *SEDM*, values of the Student's *t* coefficients, and degrees of freedom *df*, the study used the formulas given in (Woodward, 2014) corresponding to the values of *P* – function *T.DIST.2T* of the specified Excel software suite. Data validation for normal distribution was performed in STATISTICA Version 10. For subsequent analyses, the data were logarithmised. Pearson correlation coefficients, partial correlation coefficients, and their significance levels were calculated using STATISTICA Version 10.

RESULTS AND DISCUSSION

The results of the conducted studies (Fig. 1) showed that the application of pea straw alone (variant 2) caused a significant increase (P<0.001–0.01) of *in situ* proteolytic activity (PA), potential dehydrogenase activity (DA) of soil, carbon content of labile humus C-LH by 2.20%, 0.006 mg of triphenylformazane g^{-1} soil, 0.27 g/kg^{-1} soil, respectively, but a decrease (P<0.01) of *in situ* cellulolytic activity (CA) by 1.20% compared to the control (variant 1). Application of pea straw + $N_{30}P_{45}K_{45}$, and the specified combination with the addition of elements of greening BS, BS + HF, BS + MF, CF (options 3, 4, 5, 6, 7) has led to simultaneous growth of CA, PA, potential DA, and C-LH content in the soil on 4.71-6.44%, 3.64-7.64%, 0.011-0.019 mg triphenylformazane g^{-1} soil, 1.24-1.93 g/kg^{-1} soil, respectively, compared to variant 1 (P<0.001). In the group of variants 2-7, the lowest level of all these indicators occurred in variant 2, the highest values of CA, DA, C-LH – in variant 5, PA – in variant 6.

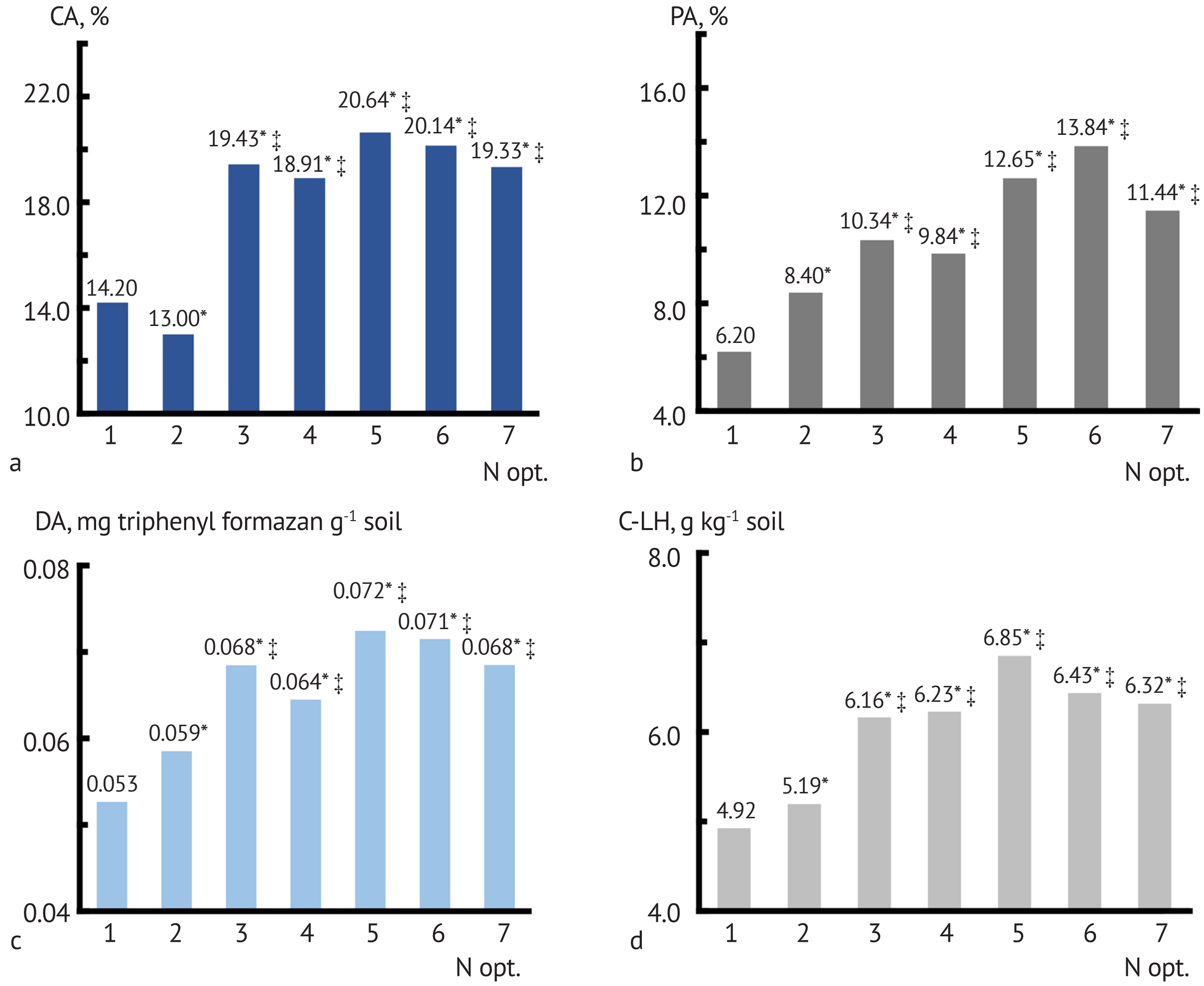

***Figure 1**. Influence of ecologised fertiliser systems on in situ cellulolytic (a), proteolytic (b), potential dehydrogenase (c) activity of soil and carbon content of labile humus (d) (average between spring tillering and earing phases; 2017-2019)*
***Note:** Significance level of differences between the average values according to ANOVA data: a – P<0.001, b – P<0.001, c – P<0.001, d – P<0.001; symbols *, ‡ – the level of significance of the difference relative to options 1, 2, respectively, P<0.001-0.01*
***Source:** compiled by the authors*

The authors of the work suggest that in the studied *in situ* CA, PA are involved in depolymerases that catalyse both the hydrolysis of the corresponding high-molecular compounds and the fragments formed from them (Piotrowska-Długosz, 2020; Sobucki *et al.*, 2021). Since enzymes adsorbed on clay minerals and captured by humus substances (Nannipieri *et al.*, 2012; Piotrowska-Długosz, 2019; Piotrowska-Długosz, 2020), it is reasonable to assume that a significant part of CA, PA was caused by "protected", "attached" enzymes on the applied carriers.

The introduction of legume residues with low C:N into the soil leads to the rapid growth of copyotrophic bacteria, microbial activity and the release of nutrients that meet the needs of the crop (Rao *et al.*, 2019). However, temporary nitrogen immobilisation in the early stages of straw decomposition usually causes nitrogen (N) deficiency in the soil (Li *et al.*, 2019). It is also known that the activity of soil enzymes is induced by the substrate and suppressed by end products. In particular, β-glucosidase activity is stimulated by organic carbon (OC), NH_4^+, whereas protease activity is activated by low and suppressed by high concentrations of OC (Vazquez *et al.*, 2019). The addition of inorganic N(IN) inhibits the hydrolysis of OC, protein, and chitin, while the addition of organic N(ON) stimulates these processes (Tian *et al.*, 2022). Obviously, the lack of N in the soil, in particular, is probably NH_4^+, on suppressed CA in variant 2, compared to variant 1. However, a lack of IN stimulated, and a small lack of ON probably did not significantly affect PA, which was larger under such conditions than in the control.

In general, the intake of organic residues (plants, manure, etc.) causes an increase in the carbon (C) content of microbial biomass (MBC) and soil enzymatic activity as a result of an increase in the availability of a C-substrate that stimulates microbial activity (Zhao *et al.*, 2016). This is consistent with the increase in variant 2 of potential DA – an important indicator of soil microbial activity (Kumar, 2013; Acosta-Martínez & Waldrip, 2014; Piotrowska-Długosz, 2019). A simultaneous decrease in CA, an increase in PA, and a slight increase in C-LH levels may indicate that microbiological processes are focused on compensating for the lack of ON in the first place. This is consistent with the view that increased N availability is required to enhance C uptake by microorganisms (Bowles *et al.*, 2014).

Introduction of straw + $N_{30}P_{45}K_{45}$ in variant 3 obviously led to a decrease in the C:N ratio in the soil and, consequently, to an increase in the rate of consumption of high-carbon organic compounds by microorganisms compared to the control. The intake of N levelled the restriction of the activity of C-metabolic enzymes, and caused an increase in their activity (Chen *et al.*, 2020), in particular CA. Growth of PA in variant 3, at first sight, contradicts the thesis that mineral forms of N inhibit protease activity (Piotrowska-Długosz, 2020; Tian *et al.*, 2020). Obviously, straw + $N_{30}P_{45}K_{45}$ reduced N-restriction on microbial biomass formation and P-restriction on metabolic processes in microorganisms (Chen *et al.*, 2017), directly or indirectly activating the growth and reproduction of bacteria and fungi by changing their ratio (Li *et al.*, 2019; Chen *et al.*, 2020). This may, at least in part, be the reason for the activation of enzyme synthesis and secretion (Piotrowska-Długosz, 2019), in particular, the growth of PA. Changes in hydrolase activity were accompanied by a predictable increase, probably in the content of C and N nutrients and, consequently, a documented increase in C-LH, DA (Bowles *et al.*, 2014; Singh *et al.*, 2018).

The obtained results do not coincide with the data of the vegetation experiment by R. Chen *et al.* (2014), according to which the addition of both corn straw and corn straw + mineral N to the substrate led to an increase in β-glucosidase activity (Chen *et al.*, 2014). Leucine aminopeptidase activity increased in the first case and decreased in the second case, while the specific rate of microbial growth was the opposite. The action of the 1st factor was mediated by K-strategists (N-restriction + microbial resource extraction), while the action of the 2nd factor was mediated by r-strategists (stoichiometric decomposition theory). Obviously, more detailed studies are required to determine regularities that are implemented in variants 2, 3.

It is reasonable to assume that the effect of BS or CF on the background of straw + $N_{30}P_{45}K_{45}$ (variants 4 and 7, respectively) caused the activation of photosynthesis and growth processes in winter wheat plants. At the same time, the stimulation of photosynthesis C_3- plants, for example, with high concentrations of CO_2, leads to an increase in risk deposits and a subsequent increase in the enzymatic activity of C-, N-, and P-cycles in rhizospheric soil. These patterns are accompanied by mineralisation of risk deposits, competition for N between plants and microorganisms (Nannipieri *et al.*, 2012). Microbial activity in the rhizosphere is stimulated by the entry of labile OC from rhizome deposits and exudates. A sufficient level of OC supply reduces the differences between fermentative activity in the rhizosphere and bulk soil (Tian *et al.*, 2020). BS or CF on the background of straw + $N_{30}P_{45}K_{45}$ caused the growth of CA, PA, and DA, primarily in the rhizosphere, and in general, in the soil in variants 4 and 7, compared to the control. A slight decrease in the listed indicators, especially PA in variant 4, compared to variant 7, at least in part, may have been caused by stronger competition between microorganisms and plants for N and C in the first case. Changes in the C-LH content under such conditions were closest to CA, DA.

Adding HF to straw + $N_{30}P_{45}K_{45}$ + BS (variant 5), obviously, led to the enrichment of the soil with easily accessible forms of OC, ON (humic acid salts), which, in turn, led to an increase in microbial biomass and enzymatic activity as a result, in particular, an increase in the availability of C-substrate (Zhao *et al.*, 2016), and was also one of the reasons for the increase in the content of C-LH in the soil, relative to the control. After applying MF on the background of straw + $N_{30}P_{45}K_{45}$ + BS (variant 6) the soil was enriched with microorganisms *Basillus subtilis*, *Rhodococcus erytropolis*, which are known destructors of straw (stubble). Obviously, this led to the formation of additional "exogenous" microbial activity, which contributed to the total fermentative activity of the soil and probably indirectly activated autochthonous microorganisms, generally causing an increase in the C-LH value.

According to the current soil continuum model, the decomposition and stabilisation of soil organic matter (SOM) depend on the ability of reducing organisms to access SOM and on the protection of SOM by soil minerals. The stability of SOM is determined not so much by its chemical composition, but by the interaction of the latter with environmental factors, in particular, with solubility, the size of molecules, and their functional properties. Microorganisms, their metabolites, and decomposition products are considered as the main input of SOM (Schmidt *et al.*, 2011; Lehmann & Kleber, 2015; Rao *et al.*, 2019). Plants and their residues, microbial exoenzymes, are also important for SOM formation (Paul, 2016; Rao *et al.*, 2019). This pattern of SOM persistence suggests that it exists in forms ranging from less degraded to more decomposed and eventually undergoes oxidation by soil microorganisms (Schmidt *et al.*, 2011; Lehmann & Kleber, 2015). Consequently, the idea of operationally obtained humus fractions loses its original meaning, but remains important for understanding their meaning and functions (Lehmann & Kleber, 2015). D.C. Olk *et al.* (2019) argue the relevance of NaOH-extracted humic and fulvic acids (HA, FA-humic substances, HS) for use in environmental and agricultural research. The authors of this study concluded that HS contains biological molecules and humification products with a molecular weight mostly lower than previously thought. In this case, the decomposition of SOM can occur from the most (oxidised) to the least (reduced) thermodynamically stable form. Consequently, permanganate-oxidised OC (POXC) is a weakly processed (moderately stable), easily oxidised pool of soil OC (SOC). In addition, the fraction of OC extracted with cold water (CWEOC) contained a higher proportion of aliphatic and carboxyl groups, while the fraction extracted with pyrophosphate or NaOH contained more aromatic groups. This means that CWEOC is also poorly treated by microorganisms, while NaOH-HS, on the contrary, is a more "mature" SOC (Culman *et al*., 2021; Fox *et al*., 2017). It is likely that the patterns inherent in CWEOC, at least in part, are also characteristic of hot water-extracted HWEOC. Often, studies use one of the most labile fractions – dissolved OC (DOC), which is collected using lysimeters (Błońska *et al*., 2021), or extracted with K_2SO_4 (Culman *et al*., 2021).

POXC has been shown to be sensitive to agricultural management methods, in particular, to tillage, organic fertilisers, and positively correlated with crop productivity (Culman *et al*., 2021). Straw application caused an increase in HWEOC, but did not affect DOC, while nitrogen addition in fertilisers acted the other way around (Li *et al*., 2019). It is known that the activity of soil enzymes positively correlates with the content of SOM, water-soluble humus WEOC (Lazcano *et al*., 2013). A strong positive correlation between β-glucosidase activity and POXC, HWEOC, has been documented, with an accumulation of 1st due to OC from plant residues and 2nd due to rhizosphere (Hok *et al*., 2018. A strong positive correlation was demonstrated between the activity of β-glucosidase, β-D-cellobiase, xylanase, N-acetyl-β-D-glucosaminidase (based on POXC), and DOC (lysimetric) released from plant litter (Błońska *et al*., 2021). This is mediated by the stimulation of microbial activity under the influence of DOC and subsequent stabilisation of the latter in the "heavy" fraction by binding to minerals. HA and FA are important for providing plants with Fe, Ca, K and are sensitive to land management methods, in particular, ploughing plant residues, organic fertilisers (manure), etc. (Olk *et al*., 2019). In addition, SOM affects yield by improving, maintaining soil quality and health, and providing plants with nutrients (Lal, 2020). At the same time, it was not possible to find in the scientific literature the substantiation and explanation of the interdependencies between C -, N-hydrolysing fermenative activities of the soil, signs of redox microbial activity, and NaOH-extracted labile humus, and productivity.

In connection with the above, indicators of productivity of the ear of winter wheat were determined (Fig. 2) for the purpose of subsequent analysis of the interdependencies between them and the studied signs of biological activity of the soil under the conditions of ecologised fertiliser systems. In variant 2 there was an increase in the number and mass of grains by 1.12 thsd. units/m-2, 0.025 kg/m^{-2}, respectively, compared to variant 1 (control). In variants 3-7, these indicators experienced an increase of 4.28-7.31 thsd. units/m^{-2}, 0.155-0.271 kg/m^{-2}, respectively, with respect to the control. In general, the pattern of changes in the characteristics of winter wheat productivity was similar to the patterns of variation in the experimental variants of CA, PA, DA, and C-LH values.

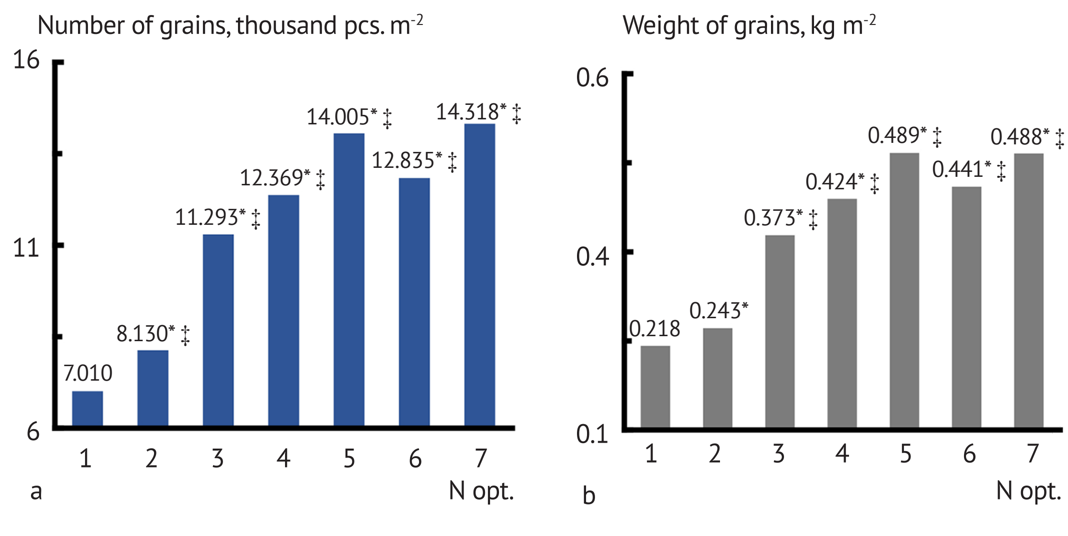

Figure 2*. Influence of ecologised fertiliser systems on the number (a) and weight (b) of grains per crop area of winter wheat (waxy ripeness phase; 2017-2019)*

Note: *Significance level of differences between the average values according to ANOVA data: a, b – P<0.001; symbols *, ‡ – the level of significance of differences relative to variants 1, 2, respectively, P<0.001*

Source: *compiled by the authors*

High and positive Pearson correlation coefficients were obtained between logarithmic values of the number and weight of winter wheat grains per 1 m^2 (NGA, WGA, respectively) and studied signs of soil biological activity (CA, PA, DA, C-LH): 0.901-0.975 (P<0.001-0.01) (Table 1). The Pearson correlation coefficients between C-LH and the enzymatic activity of CA, PA, DA, and between C-LH and NGA, WGA, were significant and amounted to 0.926-0.967(P<0.001-0.01), 0.972-0.975 (P<0.001), respectively. Such results indicate likely significant positive interdependencies between NGA or WGA and CA, PA, DA, C-LH, and between C-LH and CA, PA, DA. At the same time, the partial correlation coefficients between the listed variables in the specified order were significantly smaller and insignificant: -0.389-0.668 (P>0.05), 0.023-0.683 (P>0.05). This, at least to some extent, may be conditioned by the high level of multicollinearity of the original correlation matrix. In particular, the above Pearson correlation coefficients between the characteristics of ear productivity and soil biological activity were accompanied by a significant level of interdependence (r>0.7) between C-LH and CA, PA, DA, and between the listed enzymatic activities. The latter among these regularities determined a significant level of multicollinearity between the studied biological characteristics of the soil. Another reason for the relationships found between the Pearson partial and correlation coefficients was probably the involvement of unaccounted factors in the interdependencies under consideration. In particular, the above-mentioned POXC, CWEOC, HWEOC, DOC can affect the values of CA, PA, DA, and serve as output pools of OC for the formation of a more "mature" C-LH. It is possible that DOC (80°C), dissolved organic nitrogen DON (25, 80°C), and hot water-extracted organic nitrogen HWEON (Li, 2019; Zhao *et al*., 2016) of IN form in fertilisers (Chen *et al*., 2020) and in the soil, easily hydrogenated nitrogen, MBC, N microbial biomass MBN, etc. Notably, the health, quality, productivity, and fertility of the soil are characterised by complex indices, which include enzymatic activities within one or more processes, the content of soluble forms of OC, soil respiration, pH, etc. It is known that there are almost always no direct proportional interdependencies between the potential enzymatic activity of the soil and in situ productivity of agricultural plants (Piotrowska-Długosz, 2019; Nannipieri *et al*., 2012). The determination of *in situ* CA, *in situ* PA did not alleviate this situation in the context of interpretations of partial correlation coefficients, among other things, probably for the following reasons: 1) involvement of many hydrolases specific to the respective biological polymers and oligomers formed from them; 2) complex processes of sorption, desorption of enzymes, intermediate and final products on the respective carriers, etc.; 3) involvement of at least 3 phases – substrate carrier, soil solution, soil colloids; 4) other important enzymatic activities, bio-, physicochemical properties of soil, etc., are not taken into account (Table 1).

Table 1*. Pearson correlation coefficients and partial correlation coefficients between the values of the studied soil characteristics and the productivity of the ear of winter wheat*

Pearson correlation coefficients						
	ln(NGA)	ln(WGA)	ln(CA)	ln(PA)	ln(DA)	ln(C-LH)
ln(WGA)	0.998[a]					
ln(CA)	0.922[b]	0.942[b]				
ln(PA)	0.911[b]	0.901[b]	0.838[c]			
ln(DA)	0.939[b]	0.931[b]	0.902[b]	0.975[a]		
ln(C-LH)	0.972[a]	0.975[a]	0.951[b]	0.926[b]	0.967[a]	
Partial correlation coefficients						
ln(PA)			-0.033			
ln(DA)			0.143	0.816		
ln(C-LH)			0.683	0.023	0.456	
ln(NGA)			0.055	0.249	-0.221	0.615
ln(WGA)			0.281	0.353	-0.389	0.668

Note: *NGA, WGA – the number and weight of grains, respectively, based on the area of sowing; indices a, b, c – significance level of the correlation coefficient P < 0.001, P < 0.01, P < 0.05, respectively; the logarithm sign indicates the logarithmic average values of the calculated values*
Source: *compiled by the authors*

X. Wan *et al*. (2019) cite the results of studies according to which the removal of sediments contributed to an increase in the number of fungi and changed the composition of the bacterial community in favour of species predisposed to use more recalcitrant OC. The authors of this study found that the treatment of trees, their roots, and the removal of precipitation, which lead to a decrease in OC intake in the soil, also cause a decrease in enzymatic activity. At the same time, a significant negative correlation between DOC or NH was found integrally by season$_4$+ and cellobiohydrolase, β-glucosidase, β-1,4-N-acetylglucosaminidase, and acid phosphatase. At the same time, phenol oxidase or peroxidase significantly positively correlated with NH4+ or DON, respectively. These patterns suggest that a certain level of competition between microorganisms and plants for C and N in the experimental variants probably led to a decrease in the values of OC entry into the soil, cursory activation and/or an increase in the number of bacteria and fungi effective in the decomposition of resistant OC. Such a sequence of events may well lead to a decrease in the partial correlation coefficients between C-LH and the studied soil enzymatic activity or plant productivity.

Higher, however insignificant, partial correlation coefficients between C-LH and CA, as well as NGA, WGA and C-LH – 0.683 (P>0.05), 0.615-0.668 (P>0.05), at least to some extent, could be caused by a small sample size: n=number of variants=7. Corresponding coefficients of determination: 0.4665, 0.3782-0.4462. This interpretation suggests that for larger n, the formation of C-LH or NGA, WGA values by at least 46.65% or 37.82-44.62% depends on CA or C-LH, respectively. In turn, this is consistent with the data cited above and interpretations that labile fractions of OC (POXC, DOC) have the ability to stimulate C-hydrolysing fermentative activity of the soil (Hok *et al*., 2018; Błońska *et al*., 2021). At the same time, it is possible that the transition of DOC to the heavy fraction (Błońska *et al*., 2021), and the likely "maturation" of POXC to NaOH-HS, were accompanied by the accumulation of the C-LH under study, including CA. It is reasonable to assume that C-LH is one of the SOC and/or SOM fractions involved in the known effects of the latter on crop yields (Lal, 2020).

In general, the results obtained indicated the presence of complex ambiguous causes that direct changes in the studied features of soil biological activity and, probably, multifactorial interdependencies between C-LH and *in situ* CA, PA, potential DA under the conditions of ecologised fertiliser systems. Obviously, ambiguity and multifactorial nature are also characteristic of the relations between the productivity indicators of winter wheat per sown area and CA, PA, DA, C-LH. In turn, this supports the view that C-, N-hydrolysing fermentative activity of soil should be studied in relation not only to C-LH, but also to other forms of OC and/or ON, in particular, WEOC, NaOH-extracted HA, FA, total SOC, easily hydrolysed nitrogen, probably also IN (NH_4+, NO_3-). It is expedient to involve other potential enzymatic activities in such studies, for example, β-glucosidase, xylanase, invertase, N-acetyl-β-D-glucosaminidase, leucine aminopeptidase.

CONCLUSIONS

The ecologised fertiliser systems under study caused, in general, unidirectional growth *in situ* of cellulolytic, proteolytic, potential dehydrogenase activities of grey forest soil under winter wheat and the content of carbon NaOH-soluble labile humus (average between the phases of spring tillering and earing). The exception is the decrease *in situ* of cellulolytic activity under the conditions of pea straw application, compared to the control. The highest level of the above hydrolytic enzymatic activities of the soil in the specified order was achieved under the conditions of pea straw + $N_{30}P_{45}K_{45}$ + biostimulator + humus fertiliser or pea straw + $N_{30}P_{45}K_{45}$ + biostimulator + microbiological fertiliser, dehydrogenase – in two, while the highest content of labile humus – in the first of these two experimental variants. The smallest values of the studied biological characteristics of the soil among the applied ecological fertiliser systems occurred with the application of pea straw. The largest number and weight of grains per unit area of wheat sowing was observed in the case of using pea straw + $N_{30}P_{45}K_{45}$ + biostimulator + humus fertiliser or pea straw + $N_{30}P_{45}K_{45}$ + chelated fertiliser, the smallest – after applying pea straw.

High, positive and significant Pearson correlation coefficients between the number and weight of winter wheat grains per 1 m^2 and the studied signs of biological activity of the soil, including the carbon content of labile humus and the studied enzymatic activities (0.901-0.975, P<0.001–0.01), significantly smaller and insignificant coefficients of partial correlation between these variables (-0.389-0.683, P>0.05) are caused, in particular, by the multicollinearity and multifactorial nature of such interdependencies.

There is a significant scientific feasibility of substantiating changes in the studied biological characteristics of the soil by the availability of carbon and nitrogen substrates obtained from straw, mineral fertilisers, their impact on biomass, features and intensity of functioning of soil microflora, enzymatic activity, which determines the prospects for further research

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Закономірності формування біологічної активності ґрунту, продуктивності пшениці озимої за екологізованих систем удобрення

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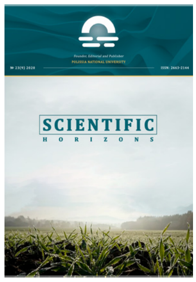
Анотація. Відновлення та оптимізація ґрунтових процесів є важливим завданням сучасного землеробства і одним з резервів збільшення виробництва сільськогосподарської продукції. В існуючих умовах це стає можливим у разі комплексного запровадження екологізованих систем удобрення. Мета досліджень – вивчення закономірностей розвитку біологічних ознак сірого лісового ґрунту, взаємозалежностей між ними та продуктивністю пшениці озимої за екологізовних систем удобрення. У дослідженнях використано такі методи: польові, лабораторно-аналітичні, біохімічні, математико-статистичні. Паттерни змін *in situ* целлюлозолітичної, протеолітичної, актуальної дегідрогеназної активностей ґрунту, вмісту у ньому вуглецю лабільного гумусу, кількості і маси зерен пшениці озимої з розрахунку на одиницю площі посіву були подібними між собою. Відмічено зниження целюлозолітичної активності, найменший приріст решти серед вивчених біологічних ознак ґрунту за умов застосування соломи гороху, порівняно з конролем. Найбільша целюлозолітична або протеолітична активність, мали місце за соломи гороху + $N_{30}P_{45}K_{45}$ + біостимулятор + гумусне добриво або соломи гороху + $N_{30}P_{45}K_{45}$ + біостимулятор + мікробіологічне добриво, відповідно, дегідрогеназна – у 2-х, а вміст лабільного гумусу – у першому з цих 2-х варіантів. Доступність вуглецю і азоту дозволили релевантно пояснити виявлені закономірності. Додатні коефіцієнти кореляції Пірсона між продуктивністю рослин і біологічною активністю ґрунту, вмістом лабільного гумусу і ферментативними активностями, а також незначущі коефіцієнти часткової кореляції між цими змінними частково зумовлені мультиколінеарністю й багатофакторністю взаємозалежностей. У перспективі дослідження дозволять глибше зрозуміти закономірності формування біологічних властивостей ґрунту за екологізованих систем удобрення. Це сприятиме удосконаленню елементів екологізації з метою коригування до оптимуму співвідношень потенційної і актуальної родючості. Наукові результати можуть стати базовою основою розробки ефективних ґрунтоохоронних органо-мінеральних систем удобрення для господарсько-виробничих структур різного рівня інтенсивності та фінансової спроможності

Ключові слова: целюлозолітична і протеолітична активності, дегідрогеназна активність, лабільний гумус, продуктивність пшениці озимої, кореляція

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua

Scientific Horizons, 25(10), 43-52



UDC 630*5:582.475(477.41)

DOI: 10.48077/scihor.25(10).2022.43-52

Thirty-Year Dynamics of the Pine Stand Sanitary Conditions of Boyarka Forestry Research Station

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Article's History:
Received: 09/22/2022
Revised: 11/10/2022
Accepted: 12/05/2022

Suggested Citation:
Puzrina, N., Karpuk, A., Vasylyshyn, R., Melnyk, O., & Tokarieva, O. (2022). Thirty-year dynamics of the pine stand sanitary conditions of Boyarka forestry research station. *Scientific Horizons*, 25(10), 43-52.

Abstract. The drying up of coniferous forests is a problem for both Europe and Ukraine, where drying area of pine stands covered the Polissia region and spread to other natural areas, therefore, the analysis of pathological factors of the reasons for the weakening and deterioration of the sanitary condition is relevant. The purpose of the study provides for generalisation of the reasons for the deterioration of the sanitary condition of pine stands and pathological processes in dynamics over 30 years. The results are based on data from 12 permanent and 10 temporary sample plots established in a separate subdivision of the National University of Life and Environmental Sciences of Ukraine "Boyarka Forestry Research Station". The study used empirical and systematic methods. The predominance of drying of pine stands due to infection with the pathogen *Heterobasidion annosum* ((F.) Bref.) was revealed, at the same time, with the highest infestation coefficient, the dominant species in the stands under study were ash bark beetles *Tomicus piniperda* L. (54%), *Tomicus minor* Hartig (46%) with high and medium infestation rates and *Monochamus galloprovincialis* Olivier with a tree population ratio of 52% and an average degree of population in trunk areas with transitional and rough bark. In the dynamics of observations since 2011, an increase in the index of sanitary condition of pine stands and deterioration of forests due to changes in weather conditions and climate aridity have been established. After the dry growing seasons of 2015-2017, the drying of pine trees with mass reproduction of stem pests was revealed, the infestation coefficient of which indicates the dominance of the sharp-dentated bark beetle *Ips acuminatus* Gyll. and a large ash bark beetle *Tomicus minor* which are aggressive species. Since 2019, there has been a decrease in the number of bark beetles due to exceeding the long-term precipitation rate due to a decrease in the temperature at the beginning of the growing season and unfavourable weather conditions for wintering of these insect species. The results obtained would become an informational component in the development of a strategy for managing damaged forest areas

Keywords: pathological process, forest pathology monitoring, pine stands, forest drying, xylophagous insects

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INTRODUCTION

Reproduction of biologically stable productive forest stands is an important indicator of sustainable forest development, the decrease in the biotic stability of forests is caused by the violation of established links between the components of forest ecosystems, therefore, the sanitary condition of forests is determined by the influence of anthropogenic factors.

There have been significant changes in hydrological and weather conditions, which, in turn, has led to a sharp depletion of pine stands, weakening of trees, deterioration of sanitary conditions and drying of stands (Jaime *et al*., 2022; Meshkova & Borysenko, 2018; Weather archive, n.d.). An increase in the average temperature and a decrease in precipitation leads to a decrease in the groundwater level and creates optimal conditions for the infestation of harmful insects, in particular, bark beetles (Meshkova *et al*., 2017; Porohniach, 2018).

If in the past years drying was characterised by the death of individual trees or their small groups, now there is a dynamic group drying of pine stands in different types of forest-growing conditions, which is characterised by intense yellowing or reddening of needles, followed by the fall of shoots and bark with the exposure of the wood layer. Davydenko *et al*., 2017, Meshkova & Borysenko, 2018, Meshkova *et al*., 2017, noted that earlier pathological processes were mainly inherent in ripening stands at the age of more than 80 years, now rapid drying is observed in young and middle-aged stands. Consequently, the decline in the resistance of Scots pine to the effects of stress factors associated with climate change, and the mass spread of the populations of xylophagous insects caused a large-scale drying of coniferous forests and Scots pine, in particular, in most European countries, where over the past decade it has been registered in Poland, Italy, Germany, and in the Scandinavian countries – Finland and Sweden (Gómez-Pineda *et al*., 2022; Batllori *et al*., 2022; Pineau *et al*., 2017). According to the scientific publications of European researchers (Hajek *et al*., 2022; Batllori *et al*., 2022), the leading role in the weakening of stands and the formation of foci of mass reproduction of harmful insects is played by unfavourable changes in weather and climatic conditions, among which the main role belongs to the level of moisture and temperature regime.

According to the state agency for forest resources of Ukraine, intensive drying caused by xylophagous insects has covered more than 23% of the area of all foci of harmful insects since 2018, and the area of foci has increased 7.7 times in recent years (Agency of Forest Resources of Ukraine, n.d.). The first foci of drying of pine forests in Ukraine were observed in 2011 in the Zhytomyr Oblast, since 2015, such foci have spread to the north-western direction, in 2017, pine drying was observed in the central regions of Ukraine, and in the spring of 2018 – in the Forest-Steppe. The dry and hot summer of 2018-2019 caused the drying of large areas of stands in Central European forests, but since 2020, a sufficient amount of moisture in the summer period has contributed to the restoration of the hydrological regime and the gradual extinction of drying foci.

The purpose of the study is to investigate the main factors of drying of pine stands with the analysis of the species composition of pathogens, phytophagous insects, and their number over a thirty-year period.

MATERIALS AND METHODS

The study was conducted in pine stands of the National University of Life and Environmental Sciences of Ukraine "Boyarka Forestry Research Station". Field studies and information from the Boyarka FRS scientific database for the period since 1990 were used to determine the dynamics of pathological processes and the volume of drying of pine forests. The results are based on data from 12 constant and 10 temporary sample plots.

In particular, in pine forest stands with signs of the presence of pathological processes and drying, reconnaissance and detailed surveys were carried out on permanent and temporary test areas established in stands of different age groups with foci of drying trees. Within the selected sites, the localisation of drying foci, the type of drying, damage by pathogens, and infestation by harmful insects were determined. The type of drying was determined by its area: up to 10 trees – single (group), up to 0.25 ha – block, over 0.25 ha – continuous.

Detailed forest pathological studies of the dynamics of the spread of drying foci in pine stands since 2011 have also been conducted on temporary test areas established around existing group foci of dying trees, according to generally accepted methods (Methodological guidelines..., 2020; Puzrina *et al*., 2021) and in accordance with regulatory reference materials (Standard of organisations of Ukraine, 2007). The state of forest stands was determined by the average index of sanitary condition of trees (Is), the sanitary condition of each tree was determined in accordance with the Sanitary rules in the forests of Ukraine (Sanitary rules in the forests of Ukraine, 2016).

During field work, biotic and abiotic factors of the pathological process and their manifestations in stands (phytophagous insects and pathogens, forest fires, damage by late frosts, animals, etc.) were recorded in test areas.

Sanitary condition (Is) of stands were calculated using the equation (1):

$$I_S = \frac{\sum ki \cdot ni}{N} \tag{1}$$

where I_S – index of sanitary condition of stands; k_1–k_6 – tree condition category (from 1 to 6); ni – number of examined trees of the corresponding condition category; N – total number of trees surveyed.

The level of damage to stands was determined on the scale of values of sanitary condition indices shown in Table 1.

Table 1. Scale of indices of sanitary condition of stands		
Sanitary condition index	**Degree of damage**	**Stand condition**
1.00-1.50	Absent	Healthy
1.51-2.50	Weak	Weakened
2.51-3.50	Medium	Severely weakened
3.51-4.50	Strong	Drying
4.51-6.00	Very strong	Dead wood

Source: *(Methodological guidelines..., 2020; Puzrina et al., 2021)*

The degree of weakening of stands was determined as a weighted average value for estimating the distribution of trees of different conditioned categories. Based on the results of accounting for test areas, the index (average category) of the sanitary condition of the stand as a whole was calculated. Indices of the sanitary condition of stands are characterised by the following indicators: 1.0-1.50 – healthy; 1.51-2.50 – weakened; 2.51-3.50 – severely weakened; 3.51-4.50 – drying; 4.51-6.00 – dead wood.

Population indicators of insects that inhabited trees in drying foci were determined by the pallet method on model Scots pine trees (Methodological guidelines..., 2020; Puzrina, 2020; Puzrina *et al.*, 2021). The state of the population and its impact on forest stands allow assessing the quantitative characteristics of the insect population, in particular: the number, prevalence and harmfulness of insects. In addition, the indicators used to determine the level and dynamics of insect populations include: population, density, and frequency of occurrence.

When studying the species composition of xylophagous insects, each model tree was cleaned of knots, removing a 10 cm wide part of the bark from the base to the top. Within the identified areas of each species, accounting sticks were used, on which the infestation density was determined by the number of uterine passages per 1 dm2 for the subfamily *Scolytinae* and by the number of larvae on the bark-free part of the trunk for families *Cerambycidae* and *Buprestidae* (Table 2).

Table 2. Estimation of xylophagous insect settlement density			
Species	**Settlement density, units*dm^{-2} (uterine passages for bark beetles; number of larvae per 1 tree – for sawyer beetles and jewel beetles)**		
	Low	**Average**	**High**
Phaenops cyanea	0.4 or less	0.5-0.8	0.9 or more
Monochamus galloprovincialis	0.3 or less	0.4-0.8	0.9 or more
Tomicus piniperda	0.7 or less	0.8-1.5	1.6 or more
Tomicus minor	2.9 or less	3.0-5.0	5.1 or more
Ips sexdentatus	0.5 or less	0.6-1.2	1.3 or more
Ips acuminatus	2.0 or less	2.1-5.0	5.1 or more

Source: *(Methodological guidelines..., 2020; Puzrina et al., 2021)*

The relative density was determined by the ratio of the number of individuals of a certain species per unit of accounting (the number of trees surveyed) using the equation (2):

$$Vd = \frac{k}{n}, \tag{2}$$

where Vd – relative density; k – the sum of all individuals of a certain species on the examined trees, units; n – the number of trees surveyed, units.

The density of individuals of a particular species of xylophagous insect is a significant indicator of the accounting of forest biocenosis components; when determining the density it is mandatory to consider data from sample plots where no individuals of that species have been found infesting.

Infestation rate (K_I), which calculates the proportion of trees with the presence of xylophagous insect populations, is calculated by the equation (3):

$$K_I = \frac{m * 100\%}{n}, \tag{3}$$

where m – number of trees with the presence of xylophagous insect settlements, units; n – total number of test areas.

The degree of climate humidity (De Morton aridity index) is calculated to assess the impact of changes in weather conditions for the period 2010-2020 using the equation:

$$V = \frac{R}{t + 10}, \tag{4}$$

where R – amount of precipitation per year, cm; t – average annual temperature, °C.

The complex of methodological approaches provided objective information on the specific features of the dynamics of the sanitary condition of pine stands of the Boyarka Forestry Research Station over a thirty-year period.

RESULTS AND DISCUSSION

The drying of pine stands is chronic, and during the observation period from 1991 to 2020, pathological processes and, as a result, deterioration of the sanitary condition of the studied forest stands occurred unevenly.

As a result of the conducted research, reflecting the generalised research data on the sanitary condition of pine stands of the National University of Life and Environmental Sciences of Ukraine "Boyarka Forestry Research Station" for the period from 1990 to 2010, according to the data of 12 permanent sample plots and according to the author's research for the period 2011-2020, dynamic trends in changes in the index of their sanitary condition were established. The dynamics of the weighted average index of the sanitary condition of pine stands for the period 1991-2000 is shown in Figure 1.

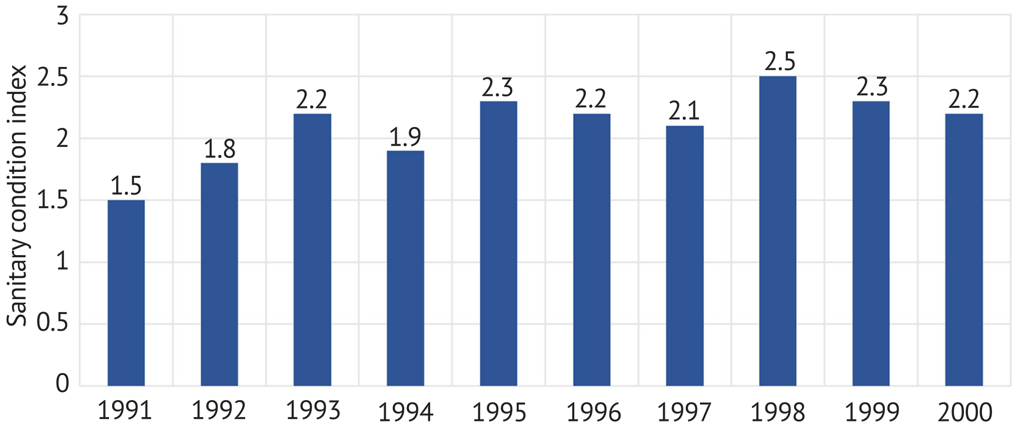

***Figure 1**. Dynamics of the weighted average index of the sanitary condition of pine stands for the period 1991-2000*
***Source:** compiled by the authors*

Comparison of the obtained generalised data on the sanitary condition of the studied pine stands shows that the sanitary condition index (Is) varies between 1.5-2.5 and increases with age (Fig. 2).

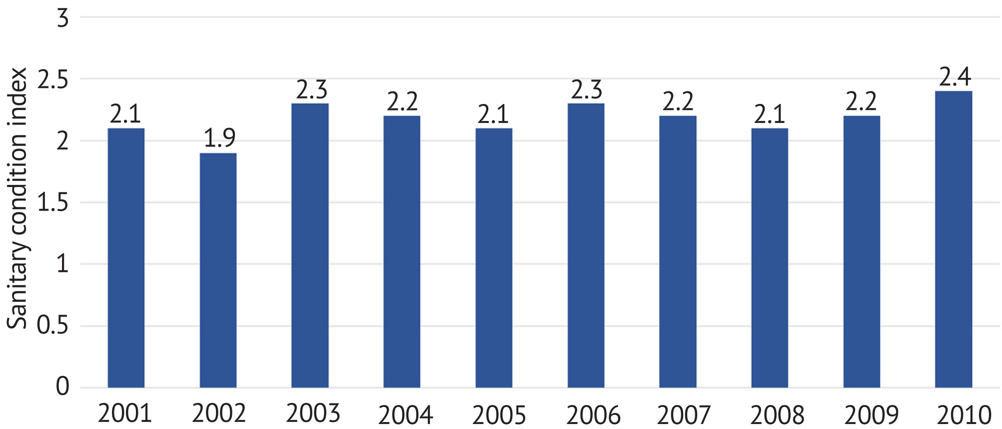

***Figure 2**. Dynamics of the weighted average index of the sanitary condition of pine stands for the period 2001-2010*
***Source:** compiled by the authors*

According to the analysis of information from the database of the Boyarka Forestry Research Station during this period, the main pathological factors of the weakening of pine stands in the region under study were the pine fungus *Heterobasidion annosum* (Fr.) Bref. (detection rate was 60%) and a complex of stem pests (Table 2). Four species of bark beetles (family *Curculionidae*, subfamily *Scolytinae*) most often inhabited viable Scots pine trees: large and small ash bark beetles *Tomicus piniperda* and *T. minor*, pine bark beetle

Ips sexdentatus. A jewel beetle *Phaenops cyaneus* (family *Buprestidae*) and sawyer beetle *Monochamus galloprovincialis* (family *Cerambycidae*) were also found.

The analysis of pine stands damaged by pine fungus indicated that temperature conditions and soil moisture favourable for the development of *Heterobasidion annosum* were formed in pine forests on sandy loamy and sandy soils mainly with the roots in the litter and with the established surface root system. Artificially created pine stands under these growing conditions were in ecological optimum, were highly productive, and were characterised by slow differentiation of trees during growth. Spread of the pathogen *Heterobasidion annosum* contributed to the creation of monocultures of Scots pine on old arable, agricultural, or unsuitable for agriculture lands and the formation of high-growth young trees. Due to the infection with the pathogen *Heterobasidion annosum*, changes in external morphological features were observed in Scots pine trees due to the deterioration of physiological functions. Negative impact of *Heterobasidion annosum* consisted in the accumulation of fresh and old dead wood and deterioration of the sanitary and, as a result, fire safety conditions of pine stands. In the absence of forest fires, pine crops affected by the pine fungus pathogen formed mixed stands with pine fungus-resistant specimens of Scots pine in the first tier and soft-leaved tree species and self-seeding of pine in the second. Analysis of the phytosanitary state of pine forest stands in dynamics indicates that the foci of *Heterobasidion annosum* under favourable conditions for the pathogen, become potential reserves of pathogens and phytophagous insects and can pass into active foci.

The areas and density of xylophagous insect settlements were determined by comparing the number of uterine passages of stem pests (per 1 dm^2) and the number of larvae (per 1 tree) on the rootless side of the trunk with tabular indicators (Table 3), which were used to determine the degree of tree infestation in the test areas.

***Table 3**. Species composition of xylophagous insects (for the period 1991-2010)*

Species	Settlement area	Infestation rate, %	Settlement density, units*dm^{-2} (uterine passages for bark beetles; number of larvae per 1 tree – for sawyer beetles and jewel beetles)	Degree of infestation
Phaenops cyanea	Rough, transitional, thin bark	45	0.3 ± 0.2	Low
Monochamus galloprovincialis	Rough, transitional bark	52	0.7 ± 0.5	Medium
Tomicus piniperda	Rough bark	54	1.9 ± 0.8	High
Tomicus minor	Thin bark	46	3.6 ± 0.7	Medium
Ips sexdentatus	Rough bark	36	1.0 ± 0.4	Low

Source: *compiled by the authors*

It was found that at the highest rate of infestation, the dominant species in the stands under study were ash bark beetles *Tomicus piniperda* (54%) and *Tomicus minor* (46%) with high and medium infestation rates, respectively, and *Monochamus galloprovincialis* with a tree infestation rate of 52% and an average degree of infestation, mainly in areas of the trunk with transitional and rough bark. Moreover, during additional nutrition of ash bark beetles, intensive damage to annual and biennial shoots is noted in the crowns of Scots pine. During the period of monitoring studies since 2011, pine stands on temporary test areas were examined and their sanitary condition was established (Fig. 3).

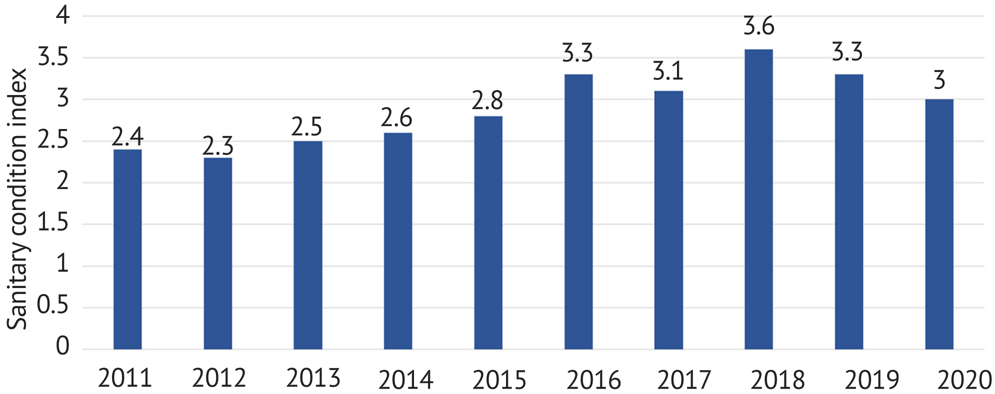

***Figure 3**. Dynamics of the weighted average index of the sanitary condition of pine stands for the period 2011-2020*
Source: *compiled by the authors*

Calculated as the proportion of the distribution of annual precipitation and average annual air temperature, the De Morton aridity index allowed estimating the degree of climate humidity and changes in climatic conditions over the studied years (Fig. 4). The gradual increase in the sanitary conditions index of pine stands, and, consequently, the deterioration of the state of forests during the study period, depended on weather conditions and arid climate.

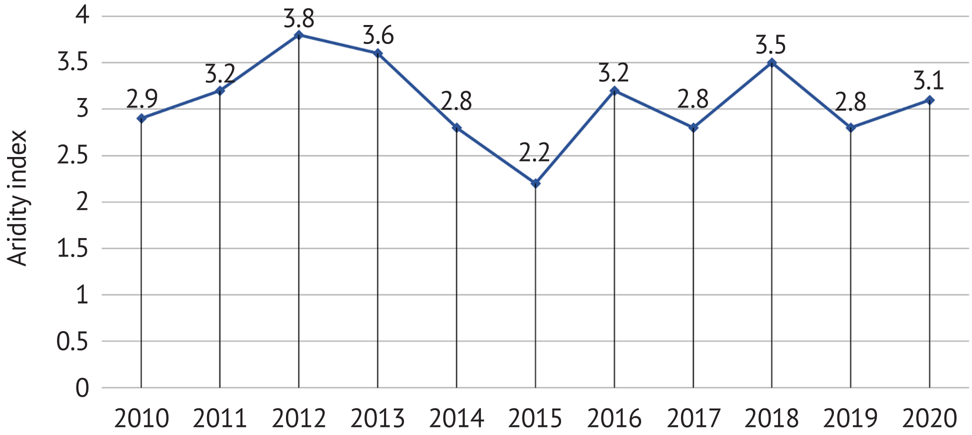

Figure 4. *Climate aridity index of Kyiv Polissia*

Source: *developed by the authors based on the weather archive*

It is revealed that a typical sign of climate change is a persistent tendency to sharp fluctuations in the amount of precipitation. This was especially evident in recent years, as the average amount of precipitation for the growing seasons of 2012-2013 exceeded the norm, and in 2015, 2017, and 2019 there was a sharp shortage of atmospheric moisture. Deviation of the average air temperature for the year from the norm is proof of gradual changes in the thermal regime and climate warming, so the main factor of epiphytotic drying of Scots pine and forest woody plants in Ukraine is hydrothermal stress. Thus, in the last decade, with an annual amount of precipitation in the range of 491-625 mm, up to 115 mm of precipitation fell during the growing season, which is typical for the region under study. Therefore, the deterioration of the sanitary condition of pine stands is associated with their ecological features, in particular, the attitude to humidity and soil fertility. Evidently, under such conditions, there are droughts (atmospheric and soil), and sometimes temperature indicators have abnormally high values throughout the year. There is also a certain deformation of hygrotopes with an increase in the dryness index of forest-growing conditions, which leads to a weakening and deterioration of the condition of pine stands.

During monitoring studies since 2018, a dynamic drying of pine stands has been noted. The largest number of new drying foci in pine stands occurred in 2017-2018, and the predominance of group and single types of drying of pine trees was established. In the resulting foci of drying out, a sharp increase in the population size of *Ips acuminatus* was recorded, including a rapid expansion of existing foci and the establishment of new ones. Notably, an increase in the number of sharp-dentated bark beetles was recorded during 2018, and since 2019, the population has gradually decreased due to unfavourable conditions for wintering in the young beetle phase and climatic indicators, in particular, low temperatures and excessive precipitation at the beginning of the growing season.

During the examination of drying foci and detailed analysis of model trees of the 4th and 5th categories of sanitary condition, chronic damage by the pine fungus pathogen was established according to the characteristic symptoms of root system rot. Notably, the volume of drying of pine stands from the pine fungus has significantly decreased, the degree of damage is weak, but the drying processes have not stopped.

It was also found that a complex of xylophagous insects acts in the focus, which infected the pine tree with fungi of the genus *Ophiostoma* with a predominance of the apical type of lesion, followed by the spread of pathogens along the trunk. The population indicates the dominance of the sharp-dentated bark beetle (inhabiting thin bark) and the large ash bark beetle (inhabiting weakened pines in the zone of thick and transitional bark), which are aggressive species. Most of the identified insect species tended to inhabit weakened trees, preferring trees of category 6 of sanitary condition, pine bark beetle and ash bark beetle also caused damage to trees during additional feeding in the crowns, weakening them (Fig. 5), which increased the susceptibility of trees to infestation by other trunk insects.

***Figure 5**. Additional nutrition of ash bark beetles ("crown cutting")*
***Source:** photographed by the authors*

Big ash bark beetles *Tomicus piniperda* and pine tree beetles *Ips sexdentatus* populated the trunk in the lower part in areas with rough bark (Table 4). In the foci of the sharp-dentated bark beetle, the needles of inhabited trees changed colour from green to light green, and then to reddish within 4-6 weeks.

***Table 4**. Species composition of xylophagous insects (for the period 2011-2020)*

Species	Settlement area	Infestation rate, %	Settlement density, units per 1 dm^2	Degree of infestation
Ips acuminatus	Thin bark	68	6.4 ± 1.4	High
Tomicus piniperda	Rough bark	58	0.6 ± 0.5	Medium
Ips sexdentatus	Rough bark	45	1.5 ± 0.9	High
Tomicus minor	Thin bark	52	4.2 ± 1.1	Medium
Phaenops cyanea	Rough, transitional bark	44	0.6 ± 0.5	Medium
Monochamus galloprovincialis	Rough, transitional bark	37	0.8 ± 0.4	Medium

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

The frequency of detection on the trunk of the surveyed trees was dominated by the sharp-dentated bark beetle (68% of the analysed trees), to a slightly lesser extent there was big ash bark beetle (58%), pine tree beetle (45%), the lowest infestation coefficient of the small ash bark beetle (32%), which does not stand up to the competition with the sharp-dentated bark beetle.

On model trees, the presence of numerous passages of sharp-dentated bark beetles and pine tree beetles was clearly traced, the sharp-dentated bark beetle formed several generations per year, therefore, some individuals overwintered in the adult stage in the litter and under the bark, some – in the larval stage. This explains the long period of departure of adult generations from May to September, since after wintering, imagos that overwintered under the bark first fly out, then imagos that overwintered in the litter and those that overwintered at the larval stage. Notably, with such a rapid increase in the number of natural entomophages, they cannot regulate bark beetle populations, which also contributes to an increase in the number and expansion of the boundaries of existing tree drying foci.

Of particular importance in forest biogeocenoses now are the issues of protecting pine stands from pathogens and phytophagous insects. Global climate change makes research on the biological stability and productivity of Scots pine stands relevant, especially in the context of investigating outbreaks of mass reproduction of xylophagous insects and fungal associations, which is confirmed by the presence of a number of publications (Davydenko *et al.*, 2017; Meshkova & Borysenko, 2018; Gómez-Pineda *et al.*, 2022).

Ustskyi (2011) found that the period 2001-2006 was characterised by a significant deterioration in the sanitary condition of forest stands of Ukraine and scots pine, in particular, the area of pine stands in which pathological processes were recorded, as of 2006, compared with the records as of 1994 and 1997, increased by 1.3-1.4 times, therefore, a steady trend of deterioration of the sanitary condition was also traced in the monitoring observations of the presented study of pine stands in the Boyarka Forestry Research Station. Zhezhkun *et al.* (2021) for the period 2017-2019 in pine stands of Eastern Polissya analysed the dynamics of drying of *Ips acuminatus* foci and noted the apical drying with the mass spread of the sharp-dentated bark beetle, which is consistent with the results of forest pathological monitoring of the dynamics of the number of foci in the sample areas. Based on the conducted studies, the pattern of occurrence of foci of drying of Scots pine was established, and a clear synchronisation of the distribution areas of xylophagous insects with the weakening of pine stands. In the studies by Borodavka *et al.* (2017) in the stands of the Volyn Polissia, rapid drying of Scots pine was diagnosed, namely, the spread of aggressive associations of ash bark beetles in stands aged from 40 years with the presence of active, growing foci of drying with a rapid course of pathological decline, that is, the above-mentioned processes were observed in all regions of Ukraine.

Most natural forest biocenoses have a disturbed structure as a result of forestry activities, so the determining factors for regulating the number of phytophagous insects are health-improving forestry measures, considering the methods of logging and the time of its implementation. According to the authors' observations, drying was observed mainly in middle-aged, ripe and over-mature pine stands of artificial origin of low fullness, clean in composition in all types of forest, which is consistent with studies of the sanitary condition of pine stands in the Rivne Polissia by Andreieva *et al.* (2018), where it is statistically proved that bark beetle foci are confined to pure medium-high pine stands of 5-8 age classes. Meshkova & Borysenko (2018) also note that the age and proportion of Scots pine in the forest are of the greatest importance for the threat of the spread of xylophagous insect populations. However, after continuous logging is carried out in the drying foci due to the restriction of the food supply, bark beetles can later populate young trees. Yukhnovskyi *et al.* (2018), investigating the drying of pine trees on reclaimed land, note that the timely application of the system of measures in young trees will reduce the natural fall and excessive sampling of trees by sanitary condition and, accordingly, will allow compliance with the standards for reducing the fullness and number of trees per unit area. Therefore, conducting selective sanitary logging in the autumn-winter period is a fairly effective forestry measure, since its terms coincide with the period of winter dormancy of insects.

Notably, the adaptation of Scots pine to the so-called "bark beetle drying" under conditions of high ecological plasticity of its genotype can lead to the appearance of stress-resistant specimens (Vysotska *et al.*, 2020), so further monitoring studies would allow tracking dynamic changes in the complex system "environment-plant-pathological factors".

In the conditions of leaving trees freshly populated by xylophagous insects after selective sanitary logging during the current year, they may dry out, which, in turn, will lead to the need for repeated logging. If trees are properly assigned to selective sanitary logging and regularly carried out at the appropriate time, the drying area of pine stands will significantly decrease, and their sanitary condition will improve.

CONCLUSIONS

The drying of pine stands in previous years occurred mainly due to pine fungus damage and covered more than 30% of their total area. Due to changes in weather conditions during 2011-2020, pine stands weakened and stem pests, mainly bark beetles, spread. Artificial pine stands were not always created in accordance with forest-growing conditions, especially in areas after agricultural use, as a result of which significant areas of pine forests were created in unsuitable environments and were unstable to the action of pine fungus and xylophagous insects. With the mass spread of phytophagous insects and pathogens, the death of trees intensified and acquired an epiphytotic character with infectious or pathological disappearance.

In general, the analysis of materials of the forest pathological state of pine stands in the region indicates the establishment of a forest pathological situation cyclically to changes in the age and species structure of forests, the establishment of which is determined by the forestry strategy; the most susceptible to damage by phytophagous insects and pathogens are pure Pine stands created by homogeneous massifs, which are also the most dangerous in terms of fire. Nowadays, in the conditions of martial law, there is a negative impact of the anthropogenic factor on the forest; in particular, partial mining of woodlands, the termination of regular care and economic activities in stands due to military operations will lead to the activation of natural regulatory processes and structural and functional changes in tree stands. Due to the lack of care and sanitary logging in artificial stands, there will be a gradual accumulation of dead wood, and, as a result, disruption of pine stands due to their damage by harmful insects and pathogens. Therefore, to stabilise the ecological and sanitary condition of pine stands, it is necessary to further study the sanitary condition of pine forests in the region, constantly monitor and forecast the dynamics of the development of xylophagous insect populations, considering the current difficult conditions that have developed in the region.

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Тридцятирічна динаміка санітарного стану соснових насаджень Боярської лісової дослідної станції

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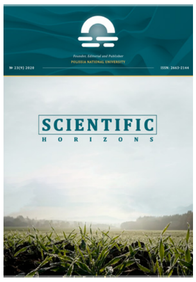
Анотація. Всихання хвойних лісів є проблемою як для Європи, так і для України, де площа всихання соснових насаджень охопила регіон Полісся й поширилася на інші природні зони, відтак, аналіз патологічних чинників причин ослаблення та погіршення санітарного стану є актуальним. Мета дослідження передбачає узагальнення причин погіршення санітарного стану соснових насаджень та патологічних процесів в динаміці за 30 років. Результати базуються на даних 12 постійних та 10 тимчасових пробних площ, закладених у відокремленому підрозділ Національного університету біоресурсів і природокористування України «Боярська лісова дослідна станція». В дослідженні було використано емпіричні та системний методи. Виявлено переважання усихання соснових насаджень внаслідок інфікування збудником *Heterobasidion annosum* ((F.) Bref.), водночас, за найвищого коефіцієнту заселення домінуючими видами в досліджуваних насадженнях були лубоїди *Tomicus piniperda* L. (54 %), *Tomicus minor* Hartig (46 %) з високим і середнім ступенем заселення та *Monochamus galloprovincialis* Olivier з коефіцієнтом заселення дерев 52 % та середнім ступенем заселення на ділянках стовбура із перехідною та грубою корою. В динаміці спостережень з 2011 року встановлено збільшення індексу санітарного стану соснових насаджень та погіршення стану лісів за рахунок зміни погодних умов та аридності клімату. Після посушливих вегетаційних періодів 2015–2017 рр. виявлено всихання сосняків за верховим типом із масовим розмноженням стовбурових шкідників, коефіцієнт заселення якими свідчить про домінування короїда верхівкового *Ips acuminatus* Gyll. та великого соснового лубоїда *Tomicus minor*, які є агресивними видами. З 2019 р. відмічено зменшення чисельності короїдів внаслідок перевищення багаторічної норми опадів за зниження температури початку вегетаційного сезону та несприятливих для зимівлі комах зазначених видів погодних умов. Отримані результати стануть інформаційною складовою формування стратегії поводження з пошкодженими ділянками лісу

Ключові слова: патологічний процес, лісопатологічний моніторинг, соснові насадження, всихання лісів, комахи-ксилофаги

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 25(10), 53-61



UDC 633.11
DOI: 10.48077/scihor.25(10).2022.53-61

Influence of the North Kazakhstan Plains Weather on the Productivity of the Spring Soft Wheat

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Article's History:
Received: 10/18/2022
Revised: 11/24/2022
Accepted: 12/14/2022

Suggested Citation:
Zholaman, R., Fedorenko, E., Savin, T., Aituganov, K., & Shvidchenko, V. (2022). Influence of the North Kazakhstan plains weather on the productivity of the spring soft wheat. *Scientific Horizons*, 25(10), 53-61.

Abstract. Spring soft wheat is a primary agricultural crop of North Kazakhstan, the growing process of which is done in harsh weather conditions due to the fact, that early spring drought and the biggest rainfalls at the end of June and beginning of July, are normal in the region. Due to this fact, scientists and producers have mistakenly believed that in the Northern region, spring wheat should be sown later, adjusting the main phase of plant development "tillering – stem elongation" under the maximum summer rainfalls. The research aims to establish the dependence of spring wheat yield on the amount of spring-summer rainfall at different sowing periods. The following methods were used in the research: field method, methods of clustering, variation, correlation and dispersion analysis. Analysis of observations from 2012-2021 showed that years with an early-spring drought and mid-summer maximum rainfalls were less than one-third of ten and about 60% were years with no spring drought, although the maximum rainfall period was shifted to the June month. However, only one year (10%) was characterized by a severe spring drought and a shift of summer rainfalls to August. The highest yield (26.9 c/ha) of the studied wheat species was observed in years with an atmospheric precipitation shift at the beginning of the summer period and early sowing date. During years of early spring drought with the biggest rainfall in mid-summer, relatively high yields (20.5 cwt/ha) are observed in the later sowing dates. The practical value of the research is determined by the fact, that in Northern Kazakhstan the sowing dates of spring wheat are not closely tied to the calendar dates and depend significantly on the climatic conditions of the region and the weather conditions that prevailed in the spring and summer period of a specific year

Keywords: whether conditions, grain culture, yield, wheat productivity, sowing dates

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INTRODUCTION

Soft (by grain hardness) wheat (*Triticum aestivum L.*) is considered the most widely grown grain in the world (90-95%) and the main source of protein, as stated in a systematic review by P. Giraldo *et al.* (2019). The cultivation of crops is closely linked to their resistance to climate change, the improvement of which is a guarantee of global food security, and at the same time poses tremendous challenges to agricultural production around the world. Many scientists stated that drought, caused by decreased rainfalls and higher temperatures, put significant strain on both wheat and other crop yields. A. Batool *et al.* (2019) argue that nearly half of the world's crop area often suffers from either terminal or prolonged drought, which are drought after flowering and drought throughout the development and growth period, resulting in significant declines in grain yields, respectively. Chinese researchers J. Zhou *et al.* (2019) found that water deficiency leads to a shortened grain filling period, decreased number of grains, grain weight, and grain yield.

S. Fahad *et al.* (2021) provided a comprehensive overview of plant-soil interactions in a climate affected by greenhouse gas and organic carbon emissions and management approaches and strategies to stabilize soil organic matter. A. Sehgal *et al.* (2018) found that under drought conditions due to inadequate water supply, there was a decrease in carbohydrate synthesis by wheat plants and an increase in grain protein content. A. do Nascimento Silva *et al.* (2020) proved that nitrogen fertilizer application mitigated the negative effects of drought on wheat production and, to some extent, increased plant resilience. A. Batool *et al.* (2019) cited results from partial and full drought stresses in the root zone of two pot-grown soft wheat (*Triticum aestivum L.*) genotypes in different decades, which showed that both wheat varieties under the induction of non-hydraulic root signal (*nHRS*) improved water used efficiency and yield index, and improved drought tolerance. N. Mi *et al.* (2018) determined the effects of different duration and stages of progressive drought on corn development, yield formation, and dry matter production, which provided the basis for water management strategies.

Noteworthy are the results of pot experiments with magnetized water irrigation under two levels of spring soft wheat drought stress (75% and 50% field capacity, 100% control) conducted by D.A.F.H. Selim *et al.* (2019) in Egypt at the experimental farm of the Faculty of Agriculture, Menufia University, Shibin El Qom. Artificially created drought stress in the greenhouse negatively affected the growth, physiological, biochemical, and anatomical traits of Saha 93 and Sids 9 wheat species. Magnetic water irrigation during two consecutive winter growing seasons (November 20 to May 5, 2014/2015, and 2015/2016) of spring wheat species Saha 93 and Sids 9 overcame completely or mitigated the adverse effects of drought stress on all studied traits. In addition, the application of magnetic water increased grain yield in both varieties by 100-150% compared to the stressed control. It should also be noted the results of a meta-analysis of data from 48 articles (published up to 2020) conducted by Chinese scientists C. Wan *et al.* (2022), showed that drought significantly reduced wheat yield and grain protein yield by 57.32 and 46.04%. Statistical analysis showed that the responses of grain yield and grain nitrogen content to drought were mainly related to drought type and grain protein yield to precipitation. It was also noted that sandy soils and high doses of nitrogen application most significantly mitigated the negative effects of drought, especially for spring wheat.

The study aims to establish the spring soft wheat levels of variability yield depending on atmospheric precipitation at different sowing periods.

MATERIALS AND METHODS

Experimental studies were conducted for ten calendar years (from 2012 to 2021) at North Kazakhstan Agricultural Experimental Station (North Kazakhstan AXS). Agro-technique in the experiment was generally accepted, namely: forecrop – bare fallow, seeding rate – 3.0 million pcs/ha. Terms of sowing: 1st – 10-15 May; 2nd – 20-25 May; 3rd – 30 May-5 June. As a starting material for research were 10 varieties of spring soft wheat: Astana, Astana 2, Asyl sapa, Shortandinskaya 2012, Shortandinskaya 2014, Semenovna, Shortandinskaya 95 improved, Karabalykskaya 20, Omskaya 35, Omskaya 38 which were placed randomly in four replications. The area of the record plot was 25 m^2. Wheat was sown by AMAZONE DMC 3000 seed drill. Seeding rate – 3.0 mln. pcs. per 1 ha.

The cultivated soils of the farm are mainly carbonate chernozems, which by their mechanical composition belong to the clay variety (56.5% clay, 43.5% sand). The bonitet score is 65. Treatment of crops against weeds was carried out with a tank mixture of herbicides – Ether Extra + Grami Super 100 + Galantny. Analysis of agroclimatic conditions was carried out using data from PessIInstruments weather station (iMETOS) of Austrian production, which provides not only highly accurate local meteorological data, but also a highly accurate weather forecast covering 6 days. As it is known, grain culture vegetation consists of the following phases: germination; sprouting; tillering; stem elongation; earing (panicle earing); blooming; formation and ripening of the grain (Aseeva and Zenkina, 2020).

The initial growth phase of spring wheat was phenologically recorded on the day when it occurred, as in all cereal crops, in about 10% of plants, and the end – for the manifestation of signs in 75-85% of plants. The inter-stage period was defined as the time interval from the full previous phase to the beginning of the next one. The duration of the growing season of the variety was calculated from the date of full sprouts to the date of wax (managemental) maturity. Spring soft wheat was harvested by mowing the accounting plots by the harvester ZhVN-6 to the dump and the subsequent threshing of swaths and considering the yield in terms of standard moisture (14%) and grain purity (100%).

Methods of clustering, variation, correlation, and analysis of variance were used for data processing. The experimental data obtained in the form of analytical-numerical material were subjected to mathematical and statistical processing performed by variance-correlation analysis using Microsoft Excel and Agrostat software applications. The study years differed significantly in terms of weather conditions. In 2012, 2015, 2016, 2017, 2018, and 2019, 105.5 mm of precipitation averaged over the growing season with a multi-year average of 81.3 mm, while in 2013, 2014, 2020, and 2021, drought was present and rainfall in May-June was 38.6, 18.0, 32.1, and 81.3 mm, respectively. Consequently, 2012, 2015, and 2018 were more favorable weather years, and 2013, 2014, and 2021 were less favorable. Such contrasting conditions made it possible to study the influence of weather conditions on the duration of interphase periods and the yield of spring soft wheat.

RESULTS AND DISCUSSION

Table 1 shows the rainfall distribution in North Kazakhstan for 2012-2021. Based on this material analysis, it can be concluded that the May-June drought and the strongly pronounced rainfall maximum in mid-summer are not always typical for the climate of Northern Kazakhstan. If the distribution of precipitation in the last decade of this century was to be analyzed (2012-2021), at the first point of the discussion of this issue it can be noted that 60% of the analyzed years (2012, 2015, 2016, 2017, 2018, 2019) were periods, when rainfall was shifted to the early summer period – the month of June, and only one year (2013) was characterized by a later occurrence of maximum rainfall, which is one percent of the studied years of the research. However, the given year on the character of rainfall cannot be attributed to so-called years with the characteristic occurrence of "July" maximum. In conditions of 2013 maximal rainfall has shifted to August which does not correspond to the classical scheme, which is described in the literature. The analysis of the distribution of rainfall over ten years allows concluding that the climate of Northern Kazakhstan is characterized not only by years with a drought in early spring and "July" maximum rainfall. The climate of this region is characterized by years with relatively sufficient rainfall at the beginning of the summer period – June. In comparison with the average multiyear norm of rainfall, the share of such years within the framework of these studies was a significant advantage (Table 1).

***Table 1**. Rainfall distribution character for 2012-2021*
(North Kazakhstan Agricultural Experimental Station, North-Kazakhstan region)

Years	Number of rainfalls by month, mm					Amount rainfalls in May-June, mm
	May	June	July	August	May-August, total	
2011[2]	38.3	89.4	77.9	55.4	261.0	127.7
2013[3]	25.9	12.7	25.3	59.0	122.9	38.6
2014[2]	10.0	8.0	135.6	27.1	180.0	18.0
2015[1]	54.3	82.0	64.0	33.0	233.3	136.3
2016[1]	9.0	85.0	99.0	35.5	228.5	94.0
2017[1]	52.0	31.7	55.9	9.1	148.4	83.7
2018[1]	47.7	52.6	67.9	147.8	316.0	100.3
2019[1]	35.0	56.8	23.0	43.0	158.1	91.0
2020[2]	28.1	35.9	75.6	21.6	161.2	64.0
2021[2]	10.1	22.0	69.8	29.1	131.0	32.1
Average	33.7	47.6	69.5	46.1	196.9	81.3

***Note:** rainfall shift to [1] – beginning of the summer; [2] – mid-summer period; [3] – end summer period; drought of various intensities in 2013, 2014, 2020, 2021*
***Source:** compiled by the authors*

It should be noted that the long-term average of rainfall distribution in the north of Kazakhstan still reflects the so-called characteristic feature of the climate of this region – the maximum rainfall in the middle of the summer period in late June, or early July. This is because during this period in North Kazakhstan only in some years a significant excess of rainfall is observed, which has a significant impact on the multiyear average. In the studies (Table 1), the climatic conditions of 2014 can undoubtedly be attributed to such years.

In this study on the influence of weather conditions on the productivity of different species of spring soft wheat, the distinctive feature was the fact that the sowing dates were combined into the following groups: the first group – conditionally early sowing date – 10-15 of May; the second group – conditionally optimal sowing date – 20-25 of May; the third group – conditionally late sowing date – 30 of May – 5 of June. During the study of spring soft wheat species sowing dates, commonly used in the production crops of Northern Kazakhstan during the last decade (2012-2022), it was found that high productivity in the studied varieties in some years has been noted in the earlier sowing date. In these years (2012, 2015, 2016, 2017, 2018, 2019), a decrease in the productivity of spring wheat varieties was observed when sowing them later. According to the data of Table 2, such years include those in which the rainfall season was shifted to the early summer period, which can be seen from the data of the abovementioned Table 1.

***Table 2**. Influence of the weather conditions and sowing dates (May-June) on the productivity of the spring soft wheat (North Kazakhstan Agricultural Experimental Station, North Kazakhstan region, 2012-2021)*

Climate conditions characteristic by years	Rainfall		Amount of analyzed species, pcs.	Average yield (cwt/ha), acquired from three different sowing periods		
	Average	Average multiyear norm		1st 10...15 May	2nd 20...25 May	3rd 30 May...5 June
No drought: 2012[1] 2015[1] 2016[1] 2017[1] 2018[1] 2019[1]	105.5	81.3	10	26.9	24.9	21.9
Drought: 2014[2] 2020[2] 2021[2]	38.0	81.3	-//-	14.4	18.5	19.4
Drought: 2013[3]	32.1	81.3	-//-	9.8	14.7	20.5

***Note:** rainfall shift to [1] – beginning of the summer; [2] – mid-summer period; [3] – end-summer period*
***Source:** compiled by the authors*

As such, in the years of a drought of different intensity (2013, 2014, 2020, 2021), when rainfall relative to calendar dates was shifted to the middle of the summer period, the productivity of the analyzed varieties of spring soft wheat increased from early to later sowing date.

Due to climate changes and the variable periodicity of cyclonic rainfalls, and the increased number of heavy rains, there is an excess of moisture when half a month's worth of rainfall occurs in a short period. As a result, moisture cannot fully enter the soil. It either escapes or intensifies erosion processes in rugged parts of the landscape. Therefore, one of the problems of the agro-ecosystems is insufficient soil absorption of rainfalls, significant evaporation of moisture from soil surface during vegetation of crops, and its large losses per unit yield, which is caused by high transpiration coefficient, the consequence of which is underharvesting of crops. At the same time, high atmospheric temperature and reduced rainfall also lead to a decrease in the hydrothermal coefficient and eventually to drought, which negatively affects the agroecosystem: plant growth is sharply reduced, and the development of diseases and pests increases. As suggested by S.S. Baysholanov *et al.* (2018), to measure the level of drought intensity in Kazakhstan, used for many years, a generally accepted indicator in agriculture – Selyaninov's hydrothermal coefficient (HTC), which is calculated for the spring-summer period (May-August) according to the formula:

$$HTC_{5-8} = \frac{\Sigma R_{5-8}}{0.1 \Sigma t_{5-8}} \quad (1)$$

where: $HTC_{5\text{-}8}$ – a value of the hydrothermal coefficient for May-August; $\sum R_{5\text{-}8}$ – overall rainfalls in May-August; $\sum t_{5\text{-}8}$ – the overall temperature on average per day from the beginning of May to the end of August.

In the environment of Kazakhstan, the values of HTC criteria (Table 3) given in S.S. Baysholanov *et al.* (2018) are used to assess the atmospheric drought in the period from May to September.

Table 3. Drought evaluation criteria per HTC

HTC_{5-8}	Drought intensity
<0.40	Severe drought
0.40-0.59	Moderate drought
0.60-0.79	Slight drought
⩾0.80	No drought

***Source:** based on S.S. Baysholanov et al. (2018)*

It is because of the increase in temperature and decrease in rainfall that climatic zones may shift, for example, a moderately humid moderately warm zone will move to a slightly humid moderately warm zone (Baysholanov *et al*., 2018). Thus, the assessment of agro-ecosystems on soil moisture supply per the growing season of crops allows for predicting the level of their yield, assessing the reduction of ecological load through a rational selection of crop varieties, optimization of soil treatment methods to reduce moisture loss in the technology of their cultivation, increase the efficiency of the application of fertilizer and plant protection system against diseases and pests, aimed at reducing the ecological load on agro-ecosystems. The process of rainfall in the North of Kazakhstan is very unstable both in time and quantity. During the research on the weather condition influence on the productivity of spring soft wheat species, it was found that in this region of Kazakhstan in some years the rainfall can be shifted to the period of early summer. The number of such cases (number of years) in the North of Kazakhstan can be quite high. At the same time, it should be noted that such years have a significant impact on the overall grain balance of the region.

For a more detailed analysis of the North Kazakhstan weather conditions impact on the productivity of spring soft wheat species, cluster analysis, i.e., division of the studied objects was used, which are characterized by common features, into homogeneous groups (clusters) in one or another sense from the researcher's point of view. S.S. Kukoleva (2021) notes the identification of the presence of the connection between individual sources of information within the population under study as an important property of cluster analysis. In this research, the study years differing from each other in the character of atmospheric precipitation (Table 1) have been divided into three clusters. Cluster "A" is represented by a series of years with a characteristic shift of rainfall to the early summer period – the month of June. Cluster "B" is represented by the years with early spring drought and the maximum rainfall in the mid-summer period – July. Cluster "C" included only one year, which was characterized by the occurrence of early spring drought and a shift of the maximum summer rainfall to August (Table 4).

Table 4. Comparative evaluation of spring soft wheat productivity in dependence on rainfall patterns and sowing dates (North Kazakhstan Agricultural Experimental Station, North Kazakhstan region, 2012-2021)

Year groups with similar weather conditions	Amount of analyzed species, pcs.	Yield (cwt/ha), acquired from three different sowing periods			± Against the first sowing period	
		1st 1…15 May	2nd 20…25 May	3rd 30 May…5 June	2nd 20…25 May	3rd 30 May – 5 June
Cluster "A"	10	26.9	24.9	21.9	- 2.0	- 5.0
Cluster "B"	-//-	14.4	18.5	19.4	+ 4.1	+ 5.0
± against the "A" cluster	-//-	-12.5	- 6.4	-2.5		
Cluster "C"	-//-	9.8	14.7	20.5	+ 4.9	+ 10.7
± against the "A" cluster	-//-	- 17.1	- 10.2	- 1.4		

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

According to the experimental data presented in Table 4, the highest productivity of spring soft wheat of the ten varieties studied was observed in years with a shift of rainfall to the early summer period when sowing them at the conditional early date – 10-15 May. At later sowing dates (20-25 May) productivity of spring wheat species compared with the first sowing date decreased by 2.0 c/ha, and at sowing 30 May – 5 June by 5.0 c/ha (cluster "A"). In a series of years characterized by the drought in early spring and rainfall in the middle of the summer period (cluster "B"), the opposite pattern was observed. Under climatic conditions of such years, spring wheat species sown at a conditionally early date – 10-15 May – had the lowest productivity. At sowing in a later period – 20-25 May, the yield capacity of spring wheat varieties compared with the first sowing period increased by + 4.1 c/ha, at sowing 30 May – 5 June by + 5.0 c/ha. The cluster "B" represents the year with the occurrence of acute drought in the spring-summer period and rainfall at the end of the summer period – August. Yields of spring wheat species in climatic conditions this year increased from early sowing to later sowing. At the same time, a yield of the wheat species under study in comparison with the conditionally early sowing date – 10-15 of May at sowing in 20-25 of May was higher by 4.9 c/ha and by + 10.7 c/ha at sowing in 30 of May – 5 of June. It should be noted that in the conducted studies, the highest productivity had varieties of spring wheat in a series of years characterized by a shift of rainfall at the beginning of the summer period.

Most of Kazakhstan's export grain is spring wheat grown in the north of the country, where the sown area under this crop reaches 85%, which amounts to about 10 million acres. The main factors influencing the high variability of yields of this crop in this region and limiting its productivity over the past fifteen to twenty years are moisture deficit (average annual rainfall of 320-350 mm) on the background of a drought of various intensity, as the most common and dangerous agrometeorological phenomenon in Kazakhstan, as well as heavy rainfall, hail, frost (Babkenov *et al.*, 2020; Karatayev *et al.*, 2022). From 2005-2010 in the territory of Kazakhstan, the crops were almost destroyed. The number of cases of extreme climatic conditions and weather phenomena showed that atmospheric and soil drought accounted for about 80%, heavy rainfall and hail accounted for 14%, overwatered soils, frost, severe frost with winds – 2% each. Agroclimatic zoning of the territory of Northern Kazakhstan conducted in 2018 by a group of authoritative experts and scientists on heat and moisture availability showed that the bioclimatic potential of spring wheat yield, i.e., the criterion that characterizes the level of crop yield under natural field moisture and calculated using the computer simulation application "climate-soil-yield", is used in this region by about half (the yield is from 30 to 50 c/ha). Consequently, the level of farming in Kazakhstan is not high enough, especially in comparison with Western European countries, where this figure can reach 85% (Baysholanov *et al.*, 2018).

Obviously, in these years, under the conditions of late sowing, the attitude of farmers towards more effective use of rainfall by wheat plants by using agronomic techniques for crop care is quite justified. Numerous literature sources indicate that the main climate feature of Northern Kazakhstan is the nature of rainfall distribution (Zheksenbayeva, 2016; Rysbekova & Sultanova, 2022). The maximum atmospheric rainfall in the region occurs in the middle of the summer period – late June – early July (Sommer *et al.*, 2013; Schierhorn *et al.*, 2020). In the North of Kazakhstan, the drought occurs in early spring, then sharply interrupted in the middle of summer, and continues in autumn. Such distribution of rainfall forces farmers in Northern Kazakhstan to sow spring wheat later, thus adjusting the critical phase of development of spring wheat plants to the maximum of summer precipitation.

In the XX century, after the development of virgin and fallow lands and the introduction of the soil-protective system of agriculture in North Kazakhstan, there was a strong opinion, which now exists as an indisputable official doctrine. The climate of Northern Kazakhstan is characterized by the May-June drought and the occurrence of sudden rainfall peaks in the middle of the summer (Suleymenov, 2020). M.K. Suleymenov (2020) and S. Eliby *et al.* (2022) believe that under the climate conditions prevailing at that time, the later the sowing date of spring wheat strains, the better they use rainfall in the second half of summer and the higher the yield. However, modern research, conducted for the first time, somewhat refutes these statements, which refer to the second half of the twentieth century and have lost relevance in the current time, especially due to the occurred significant changes in climatic conditions, as confirmed in the articles of A.K. Zheksenbayeva (2016), I.I. Zhumagulov *et al.* (2021).

As an illustrative example, it can be cited the study of the impact of rainfall on the yield of spring wheat in the dry-steppe zone of Northern Kazakhstan, which was carried out in 2016-2019 on the production crops in the scientific and experimental farm S. Seifullin Kazakh Agrotechnical University. Due to the analysis of rainfall in the years of research and their impact on the yield, it was concluded that during the vegetation period of spring wheat, the amount of rainfall was not more than 41% of the required average annual rate. The dependence of grain crop productivity on the timing of rainfall was determined, as well as the accumulation of snow on the fields in winter and the reserves of productive moisture in the meter layer of soil in the spring period. It was found that under the conditions of seasonal irregularity of rainfalls during the year in the most demanding moisture phases of grain crops development "stem elongation – earing", the precipitation that fell out in June had a determining influence on the crop yield. The correlation between spring wheat yield and rainfalls in June was 0.61; barley's (for comparison) yield was only 0.41. It was concluded that both spring wheat and barley yields differed significantly from year to year, but annual rainfall amounts did not differ significantly. Contrary to the opinion that years with rainfall in June-July, i.e., mid-summer, are favorable, as it was considered earlier, the average yield of spring wheat obtained in these studies was low and amounted to 14.7 c/ha. It was shown that with insufficient average annual rainfall, especially during the critical phases of spring wheat development, the yield decreased fourfold and was only 3.3 cwt/ha (Zhumagulov *et al.*, 2021; Kurmanbayeva *et al.*, 2021).

Ensuring optimal moisture for crops is one of the most important prerequisites for high yield. The ability of the soil to provide enough moisture to the crop is one of the primary factors of fertility. Famous hydrologist, pedologist, and professor A.A. Rode (1965) states, that knowledge of soil moisture characteristics is needed for the solution of complex issues in agriculture, as moisture, that emerged to the surface, transforms into the ground and is one of the primary nature factors, that influence the mineralization of the organic moisture of the rainfalls. Thus, the soil joint in this chain is one of the most important in the moisture cycle. Other researchers also value these parameters, such as water penetration, moist capacity, and moist keeping abilities of soil as well as moist accessibility for crops. Soil moisture also influences the amount and activity of microorganisms, controls microorganism oxygen access, predetermines the creation of water microorganism stress periods, and may destabilize organic element contents, which leads to the improvement of surface carbon. V.A. Golubtsov *et al*. (2021) determined that the content and composition of soil carbon are not much affected by the ratio of heat and moisture in the growing season compared with the amount of precipitation.

The vast experience in the cultivation of spring soft wheat in Northern Kazakhstan is currently accumulated, although in some years there are quite severe conditions, which are related to the characteristics of the climate and unfavorable unregulated environmental factors. A very short growing season, the systematic nature of cold weather in spring and early summer, large ranges of temperature fluctuations, uneven distribution of precipitation during the growing season, and the onset of early frosts in autumn significantly limit the productivity of spring wheat varieties cultivated in the North of Kazakhstan. It is important to note that rainfall in the middle of the summer period in the North of Kazakhstan is usually followed by relatively high and stable temperatures. This characteristic feature of the local climate is very beneficial for the development of spring wheat, as in the arable soil layer during this period microbiological processes are actively developing, contributing to good plant growth and development of their root system.

CONCLUSIONS

The research results determined that in Northern Kazakhstan, the sowing dates of spring wheat were not closely tied to the specific calendar dates and depend significantly on the climatic conditions of the region and the weather conditions that prevailed in a specific year in the spring and summer period. It was proven that the years with occurrences of severe drought at the beginning of the spring period and rainfall in the middle of summer did not fully characterize the climate of the North of Kazakhstan. Analysis of weather conditions of the past decade (2012-2021) shows that years with occurrences of spring-summer drought and rainfall in the middle of the summer period in this region are not represented by the vast majority. In this regard, the climate of Northern Kazakhstan cannot be characterized as a climate with stable occurrences of drought in early spring and maximum rainfall in the middle of summer. Along with this, given the previously obtained confirming experimental data, it should be recognized that it is in these years acceptable later sowing dates of spring soft wheat, and therefore the orientation of farmers to the predominant use of rainfall by wheat crops, including through agronomic techniques, is quite justified.

In some years, when rainfall shifts to the early summer period, it is advisable to sow spring wheat in earlier terms. In this case, the distinctive feature of rainfall in early and mid-summer accompanied by relatively high and stable temperature is used, which is very advantageous for the development of spring wheat, as the arable soil layer at this time intensively develop microbiological processes that promote favorable development of the root system and plant growth. This provision on sowing dates presents a rather complex scientific and production problem in the cultivation of spring wheat species in the conditions of Northern Kazakhstan. Finding a solution for the issue would help farmers in Northern Kazakhstan to make the right decision when choosing the sowing dates of spring wheat. On this basis, it is worth continuing research on this topic.

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Вплив погодних умов Північно-Казахстанської рівнини на продуктивність ярої м'якої пшениці

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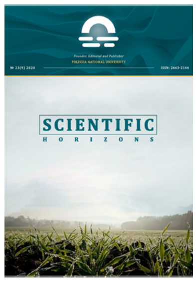
Анотація. Яра м'яка пшениця є основною сільськогосподарською культурою Північного Казахстану, процес вирощування якої проходить в суворих погодних умовах, обумовлених тим, що для регіону характерна ранньовесняна посуха і найбільші опади в кінці червня і на початку липня. У зв'язку з цим науковці та виробники помилково вважали, що в Північному регіоні яру пшеницю слід висівати в більш пізні строки, підганяючи основну фазу розвитку рослин «кущіння – витягування стебла» під максимальні літні опади. Мета досліджень – встановити залежність урожайності пшениці ярої від кількості весняно-літніх опадів за різних строків сівби. У дослідженнях використовували такі методи: польовий метод, методи кластеризації, варіаційного, кореляційного та дисперсійного аналізу. Аналіз спостережень за 2012–2021 рр. показав, що роки з ранньовесняною посухою та середньорічним максимумом опадів становили менше третини з десяти і близько 60 % – роки без весняної посухи, хоча період максимальної кількості опадів змістився на червень місяць. При цьому лише один рік (10 %) характеризувався сильною весняною посухою та зміщенням літнього максимуму опадів на серпень. Найвища врожайність (26,9 ц/га) досліджуваних сортів пшениці спостерігалася в роки зі зміщенням атмосферних опадів на початок літнього періоду та ранніми строками сівби. У роки ранньовесняної посухи з найбільшою кількістю опадів у середині літа відносно висока врожайність (20,5 ц/га) спостерігається за більш пізніх строків сівби. Практична цінність досліджень визначається тим, що в умовах Північного Казахстану строки сівби ярої пшениці не мають тісної прив'язки до календарних дат і суттєво залежать від кліматичних умов регіону та погодних умов, що склалися у весняно-літній період конкретного року

Ключові слова: погодні умови, зернова культура, урожайність, продуктивність пшениці, строки сівби

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
***Scientific Horizons*, 25(10), 62-70**



UDC 338
DOI: 10.48077/scihor.25(10).2022.62-70

Diversification Through Promotion of Export-Oriented Production and "Green Transformation" in Azerbaijan

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Article's History:
Received: 10/01/2022
Revised: 11/21/2022
Accepted: 12/11/2022

Suggested Citation:
Guliyev, M., & Azizov, T. (2022). Diversification through promotion of export-oriented production and "green transformation" in Azerbaijan. *Scientific Horizons*, 25(10), 62-70.

Abstract. Diversification is an important component of the development of any economy. The reason for this is the increase in the country's resilience to external stimuli, which makes progress more gradual, constant and predictable. Thus, the study of the possibilities of diversifying the economy is very relevant, especially in today's geopolitical conditions. The purpose of the work was to analyse some methods of diversifying the economy of Azerbaijan, namely the development of export-oriented production and the implementation of the "green transformation". Analysis became the main method in writing the article, but historical, modelling, deduction, abstract-logical methods also played an important role. Thus, the work examined and analysed the export of Azerbaijan, during which a significant dependence of the country on oil sales to foreign markets was revealed. Since such a prospect is dangerous for the sustainable development of the country, it is important to carry out certain measures aimed at increasing the diversification of its exports. First of all, they are associated with public-private partnerships, but they also take other forms, such as attracting investments and building infrastructure. In addition, the paper describes how the "green transformation" of the country can help achieve the goals of economic diversification and at what stage is the level of "greening" of the state economy; the paper also describes the prospects for the state in achieving these goals. The article brings new knowledge to understand the features of the functioning of the Azerbaijani economy, as well as to the theory of economic and sustainable development, as well as trade

Keywords: economy of Azerbaijan, sustainable development, export concentration, export diversification, "green transformation" of business

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INTRODUCTION

The economic diversification is an important aspect of sustainable development as it enhances macroeconomic stability and promotes long-term social, political and other transformations (Jolo *et al*., 2022). Indeed, the ability of the state not to be dependent on the supply of a single type of product is a relevant component of development. Difficult times for the global economy began with the spread of the pandemic, the unstable situation in the global economy, due to the volatility of the global oil market. This became especially relevant in connection with the consequences of the conflict in Ukraine, after which European countries began to experience significant problems in the energy sector due to a decrease in russian gas and oil supplies (Prohorovs, 2022; Caldara *et al*., 2022). It should be noted that it would be quite possible to avoid this if the countries of Europe paid more attention to their energy security and economic diversification (Elbassoussy, 2019; Rodríguez-Fernández *et al*., 2022). In this paper, two main types of achieving economic diversification are considered. The first is the development of export-oriented production: its essence is that, with the development of several export-oriented industries, the country's economy cannot function without funds when problems affect one of them; in the conditions of a global crisis (Matezo *et al*., 2021; Swathi & Perumal, 2021). The second is the "green transformation", the essence of which is to achieve cleaner production methods, their full cycle of consumption within the country, which allows countries to achieve higher levels of independence in some sectors, such as energy (Soderholm, 2020).

A significant number of scientists have been engaged in the analysis of this and related problems. Thus, in particular, it is worth noting A.M. Jolo *et al*. (2022), who studied the role of economic diversification for its healthy and sustainable development. Scientists single out a special role for the positive components of this phenomenon, but they lose sight of the negative ones, which also exist, albeit on a much smaller scale. In turn S. Jednak *et al*. (2016) described the role and importance of the economic diversification based on empirical data from Serbian enterprises. The role of promoting export-oriented production in Azerbaijan was actively studied by R.M. Jabiev (2018), who describes in his work the features and mechanisms for the development of export-oriented production, especially with the help of state assistance. However, during the study, the scientist paid little time to the existing problems in this type of enterprise support. It is also worth noting some of the authors who studied the current conditions for the development of "green transformation". Among them, it is worth mentioning P. Soderholm (2020), who wrote about future changes and challenges from the introduction of environmentally friendly technologies, as well as methods for their implementation. R.A.O. Aliev and G.F.K. Ismailova (2015). In the paper, they consider the goals already achieved, and also describe the likely prospects for future changes, but they devote little time to the possibilities of creating state policy in this area.

Thus, *the aim of the paper* was to analyse how to develop export-oriented production and implement a "green transformation". The object of the study was the methods mentioned above, namely the possibility of their development in the country. The novelty of the work lies in detailed consideration of Azerbaijan's exports and proposals for solving problems with its concentration.

MATERIALS AND METHODS

When conducting statistical studies, the Herfindahl-Hirschman indicator was used in the work. Its essence lies in finding the company's share (in percent) in the market and bringing this indicator to the square: if there is only one company on the market, then the indicator will be equal to 10000; if their number tends to infinity, which is more than a theoretical assumption, then the indicator will tend to zero. Most often, it is used to assess the level of monopolization of a particular market, the role of certain companies in it (Laine, 1995), however, in this work, it was decided to use it to assess the level of export concentration, since the essence of both indicators is quite similar (the company's share in the market and the share of the product/country in exports (imports or foreign trade)). Thus, the value of the indicator the Herfindahl-Hirschman Index (HHI) is calculated as follows:

$$\mathrm{HHI} = \sum_{i=1}^{n} S_i^2 \quad (1)$$

where: HHI – Herfindahl-Hirschman index; S_i^2 – (within the framework of this study) expression (in percent) of the share of the i-th product/country in exports;

$\sum_{i=1}^{n} S_i^2$ is the sum of the squared shares of n goods/countries in total exports.

When assessing the level of market monopolization, it is considered that with an indicator HHI<1000 the market is low concentrated, with 1000<HHI<1800 – moderately concentrated, with 1800<HHI<10000 – highly concentrated.

The main sources of information in the article were the works of other scientists. However, significant volumes of statistical data were also used, in particular, on Azerbaijan's exports (both in terms of products and countries). The source for such information in the article was the Trade Map (2022) database. In addition to it, some official documents such as Decree of the President of the Republic of Azerbaijan "On Measures to Create a "Green Energy" Zone in the Territories of the Republic of Azerbaijan Liberated from Occupation" (2021) were mentioned in the article, and also Decree of the President of the Republic of Azerbaijan "On Approval of the

"National Priorities of Social and Economic Development: Azerbaijan 2030" (2021).

The basis of the work was the theoretical abstract-logical methods of research. Among them, it is worth noting the analysis, given the significant amount of statistical data processed. An important way of examining the problem was the historical method, with the help of which the development of exports in the country over a certain amount of time was studied. In addition to it, modelling was used in the work to form and determine the general principles of work to promote export-oriented production in Azerbaijan. With the help of deduction, the general state of export-oriented production and "green transformation" in the country was assessed, based on separate data on these areas of activity.

All work can be divided into several stages. At the first stage, a brief review of Azerbaijan's foreign trade was carried out to form a possible future direction of its development: in particular, the concentration of exports by goods and countries was assessed using the HHI indicator. At the second stage, the level of implementation of the "green transformation" in Azerbaijan is considered, the potential benefits that the country can receive in the event of the development of environmentally friendly technologies and the production of "green" products are described. At the end of the work, a comparison was made of the results obtained from data from similar or related articles by other scientists.

RESULTS

In order to assess the opportunities for the development of a country's export products, it is worth studying the structure of its exports. The data for 2002-2021 were selected for analysis. These data are provided in Table 1.

***Table 1**. Share of certain types of export products of Azerbaijan in some years, %*

Group	Year						
	2002	**2007**	**2012**	**2017**	**2019**	**2020**	**2021**
Mineral fuel; oil and products of its distillation; bituminous substances; mineral waxes	88.92	81.40	93.42	90.60	90.65	87.25	88.40
Plastics, polymeric materials and products from them	1.03	1.17	0.46	0.66	0.91	1.20	1.99
Edible fruits and nuts; peels of citrus fruits or melons	1.06	2.06	0.87	1.91	1.85	2.57	1.85
Cotton	1.06	0.66	0.10	0.34	0.81	1.14	1.23
Vegetables, some edible roots and tubers	0.13	0.65	0.23	1.37	1.24	1.85	0.99
Natural or cultured pearls, precious or semi-precious stones, precious metals, metals clad with precious metals and articles thereof; bijouterie; coins	0.00	0.00	0.00	0.83	0.89	1.45	0.93
Aluminum anditsproducts	0.03	1.51	0.40	0.77	0.65	0.83	0.85
Fertilizers	0.01	0.00	0.00	0.01	0.10	0.08	0.55
Organic chemical compounds	0.52	0.35	0.17	0.44	0.34	0.42	0.45
Black metals	0.64	0.74	0.25	0.25	0.20	0.22	0.40

***Source:** compiled by the authors taking into account the Trade Map database (2022)*

As can be seen from Table 1, the main type of product that is exported in Azerbaijan is oil and its refined products: other types of exports occupy a very low share in foreign trade, not exceeding 2%. It is also important to estimate the share in exports of the first several groups of goods, the data of which are shown in Table 2.

***Table 2**. Share of the first n goods in the structure of Azerbaijan's exports in some years, %*

Year	2002	2007	2012	2017	2019	2020	2021
One item	88.92	81.40	93.42	90.60	90.65	87.25	88.40
First three	91.01	84.62	94.75	93.17	93.41	91.02	92.24
First five	92.20	85.93	95.08	94.88	95.46	94.01	94.46
First ten	93.39	88.53	95.90	97.19	97.64	97.00	97.63

***Source:** compiled by the authors taking into account the Trade Map database (2022)*

As can be seen from Table 2, the specialization of Azerbaijan's exports as a whole is increasing in all indicators, except for the first one (that means, the shares of the first 3, 5, 10 goods have changed in 2021 compared to 2002). However, the overall picture has not changed and oil remains the country's main export. It is important to analyse the diversification of Azerbaijan's exports also in the context of countries. These data are provided in Table 3.

***Table 3**. Share of the top ten largest countries in Azerbaijan's exports in some years, %*

Countries	Year						
	2002	**2007**	**2012**	**2017**	**2019**	**2020**	**2021**
Italy	49.95	15.53	23.28	34.97	28.72	30.38	41.63
Turkey	3.85	17.44	2.52	9.11	14.58	18.92	12.69
Russian Federation	4.41	8.70	4.03	3.84	3.69	5.17	4.15
Israel	7.11	6.10	6.99	4.17	6.78	3.19	4.04
Croatia	0.34	0.66	1.39	1.39	2.22	3.43	3.38
Georgia	3.73	5.68	2.40	3.19	2.99	3.36	2.98
Germany	1.33	0.33	4.05	2.94	4.74	1.70	2.93
India	0.10	2.39	7.93	2.64	4.87	3.33	2.68
Portugal	0.14	0.00	1.02	3.28	1.80	1.75	2.65
Tunisia	0.00	0.00	1.04	1.19	0.00	2.27	2.60

***Source:** compiled by the authors taking into account the Trade Map database (2022)*

As can be seen from Table 3, Italy remains the main trading partner of Azerbaijan during the analysed period of time; however, a significant part of the countries is also regularly occupied by Turkey. For a more detailed assessment of the level of concentration of exports by countries, they were also formed into groups of 3; 5 and 10 countries. These data are shown in Table 4.

***Table 4**. Share of the top n countries in the structure of Azerbaijan's exports in some years, %*

Year	2002	2007	2012	2017	2019	2020	2021
One country	49.95	15.53	23.28	34.97	28.72	30.38	41.63
First three	58.21	41.67	29.83	47.91	46.99	54.46	58.46
First five	65.66	48.43	38.21	53.48	55.99	61.08	65.89
First ten	70.96	56.83	54.65	66.71	70.39	73.49	79.72

***Source:** compiled by the authors taking into account the Trade Map database (2022)*

Table 4 shows that the concentration of the country's exports has changed quite a lot from year to year: for example, comparing 2002 and 2021, it is possible to see that the share of the first country has significantly decreased, while at the same time as the top 10 it has increased. In order to accurately assess the level of concentration of exports in the context of countries and goods, it was decided to use the Herfindahl-Hirschman indicator described in the methodology. The performance of this index is shown in Table 5.

***Table 5**. Share of the top n countries in the structure of Azerbaijan's exports in some years, %*

Year	2002	2007	2012	2017	2019	2020	2021
Countries	2699.50	857.96	901.27	1457.85	1225.02	1413.58	2002.58
Products	7915.22	6648.27	8730.46	8216.30	8226.29	7628.28	7827.33

***Source:** compiled by the authors taking into account the Trade Map database (2022)*

As can be seen from Table 5, the indicator for countries decreased, while for products it remained at almost the same level. And although they are all quite large, indicating a high concentration of exports in the country, the indicator of concentration by product is much higher. Thus, increasing the diversification of a country's exports is a very important component of its future development, especially to protect against unexpected changes in the price of petroleum products.

Basically, the policy aimed at increasing the diversification of exports through the promotion of export-oriented production is carried out through the support of individual enterprises through the provision of financial privileges: deferrals or exemptions from paying taxes, providing cheap loans, etc. At the moment, there is an organization in Azerbaijan "Azerbaijan Export and Investment Promotion Foundation", which is engaged in the development of the non-oil sector of the economy by attracting international investment and encouraging the export of non-oil products (Frappiand & Pashayeva, 2012). The Foundation cooperates with many other organizations around the world, conducts regular export missions and events both in the country and abroad, thereby developing the brand "Made in Azerbaijan". Until 2026, the "Azerbaijan Export and Investment Promotion Foundation" plans to increase the level of exports of non-oil sector products to the level of 3.6 billion dollars (Nasirzade, 2020). According to the data for 2021, the level of exports of this sector was slightly more than 2.5 billion dollars: thus, reaching the level of 3.6 billion dollars seems quite realistic (TradeMap, 2022). Among other methods for the development of export-oriented enterprises, it is worth noting the construction of techno parks, which allows increasing the level of investment in the country: as studies show, the development of such facilities can really improve the level of industrial development in the country and increase the export potential of enterprises (Guliyev, 2016).

In Azerbaijan, within the framework of the legal framework, there are direct decrees that are aimed at developing and helping to promote export-oriented products: such, in particular, is the Presidential Decree "On additional measures related to the promotion of exports of non-oil products", which provides for payments from the state budget in the amount of 3 to 6% of the actual customs value of the exported goods, depending on the number of components manufactured in the country and resources of local production or origin (Jabiev, 2018). In addition, the rules and mechanisms for issuing payments were described, as well as lists of exported products to which export promotion is applied: they, in particular, include various types of vegetables and fruits, alcoholic beverages, clothing, some chemical products and many other goods.

It is worth considering the prospects and opportunities for Azerbaijan to introduce "green transformation" technologies and diversify the economy with its help. The very concept of "green transformation" means a combination of economic growth with concern for the environment in order to ensure a high quality of life for present and future generations at a level achievable through civilizational development, as well as the efficient and rational use of available types of resources. However, there are several possibilities in view of which it allows for the diversification of the economy. Firstly, due to the current trend towards "green technologies", it should be expected changes in global markets, in which the trend towards environmentally friendly products will gradually increase. Therefore, the countries that are the first to be able to take places in the newly created market will have a more advantageous position; in other words, the transition to green technologies is likely to change the global competitive environment in favour of these countries (Mealy & Teytelboym, 2020). Thus, Azerbaijan will be able to achieve an increase in the export of these types of products, and thus achieve a higher level of diversification. Secondly, the creation of "green" products will probably provide an opportunity to increase the level of competitiveness of their own Azerbaijani enterprises in the domestic market, which will reduce the level of the state's import dependence on certain types of goods.

The most promising for the subsequent development of the "green economy" in Azerbaijan are probably energy, transport and agriculture. In terms of energy, solar, wind, hydropower, biogas and thermal potentials have been found in the country, which are quite significant (Mustafayev *et al.*, 2021). The development of solar energy is facilitated by a significant number of hours of sunshine per year: its introduction would solve some problems with energy supply in certain regions of the country. The mountainous terrain contributes to the development of wind energy, allowing the installation of wind turbines in some regions, in particular, in Baku, Sumgayit, the Absheron Peninsula, the Caspian Sea Zone and the right bank of the Kura. The development of hydropower is helped by significant water resources, in particular, numerous rivers in the lower reaches of the Kura; although there are large hydroelectric power plants (HPPs) operating in the country, there is still untapped water potential. The use of biomass in the country is facilitated by the high level of development of the agricultural sector (Mustafayeva & Jafarli, 2022), and in terms of geothermal energy, it is promising to use thermal water reserves in the Greater and Lesser Caucasus, on the Apsheron Peninsula, on the slopes of the Talysh Mountains, in the valley of the Kura River and some other places (Aliev & Ismailova, 2015).

For the development of "green" energy, Azerbaijan received assistance from the European Bank for Reconstruction and Development (EBRD); the country continues to cooperate with the organization, developing and implementing new projects every year; in addition, there is interaction with other organizations (The EBRD, 2022). As for the country's policy in this industry, the State Agency for Alternative and Renewable Energy Sources of Azerbaijan can be considered the main body responsible for its development, and from the latest documents describing the strategy for its development and regulating it, Decree of the President of the Republic of Azerbaijan "On Measures to Create a "Green Energy" Zone in the Territories of the Republic of Azerbaijan Liberated from Occupation" (2021) can be mentioned, the attention should also be paid to Decree of the President of the Republic of Azerbaijan "On Approval of the "National Priorities of Social and Economic Development: Azerbaijan 2030" (2021), which also mentions the development of the alternative and renewable energy industry.

As for the "green transformation" in agriculture, the main environmental problem of the industry is "semi-nomadic extensive animal husbandry", as animals eat more green cover than the land can subsequently produce (Hajiyeva, 2018). In areas where large livestock were grazed, the land is subject to trampling, resulting in erosion. The reason for this is the economy of enterprises on feed, which creates the need to develop new types of feed in order to increase nutritional value, without increasing the cost, or reducing the price of them. A serious problem is the inefficient use of water resources, for the solution of which the sector requires the introduction of resource-saving technologies for irrigation. Also, an important modern goal for environmentally friendly development of agriculture is the transition to intensive principles of development. The state should encourage such activities through financial or any other mechanisms.

The role of the introduction of "green" technologies in the transport industry is justified by its high level of pollution. For Azerbaijan, this is especially true, since the number of cars has increased significantly in the country, which poses a threat to its environmental safety. It is worth noting that not only cars as such, but also gas stations with roads cause harm. Naturally, the functioning of the economy in modern conditions without these attributes is impossible, however, in order to carry out a "green transformation", a country must pursue a policy of minimizing the harm from such pollutants. The country has taken some measures to reduce pollution, in particular, it has adopted the use of unleaded gasoline exclusively, which helps to reduce the rate of pollution of the external environment. To solve the existing problems in the transport industry in terms of its environmental friendliness, some recommendations can be made: to increase the efficiency of organizing management activities in the field; promote the renewal of the vehicle fleet, the technical base, as well as the modernization and application of modern technologies at enterprises; develop environmental training among transport professionals, etc.

DISCUSSION

The role of economic diversification for its healthy development is studied by A.M. Jolo *et al.* (2022). In their paper, the scholars mentioned that empirical studies showed a correlation between economic performance, structural factors, and diversification. In addition, scientists noted that the factors affecting the level of economic diversification were still not fully understood, which meant that each country would have its own characteristics of achieving it based on economic, political and even social factors. In turn, S. Jednak *et al.* (2016) also praised the role of economic diversification in the development of the country, as it allows making the economy more resilient in relation to various shocks and imbalances. In other works, scholars have also supported the role of export diversification in economic development. So, V. Sarin and S.K. Mahapatra (2020) that export diversification has a positive impact on economic growth regardless of the nature of the economy (with the exception of a few studies that have shown mixed results). In addition to it, they noted that the subsequent achievement of diversification will allow them to achieve better financial results, especially for developing countries.

It was shown above that Azerbaijan is a country that has a huge dependence on oil exports. Indeed, among economists it is generally accepted that trade liberalization, and hence the specialization of the country in the production of one or more types of products, leads to an increase in the level of general economic welfare. However, as it was noted by J. Lee (2011) in his work on the interaction of export specialization and economic growth, the specialization brings the most benefits to countries that produce high-tech products that create more value added. Thus, although Azerbaijan received super profits from the sale of oil, however, in the long term, it should be focused on the non-oil sector. In addition to it, the resource specialization can become dangerous for future economic development due to the trend towards more "green" development methods (Pickl, 2019). In this regard, there is a popular hypothesis of "peak demand for oil" described in T.V.D. Graaf & A. Verbruggen (2013). Its essence is that in the future the price of oil will reach its peak value, after which it will only begin to decline. The reason for this may be several factors: the massive transition of countries to "green" energy sources, the reduction in energy consumption by newer technologies, as well as the development of energy saving technologies. Thus, for the main oil exporting countries, achieving diversification of the economy and exports should become one of the main long-term strategic development goals.

One of the most effective tools for promoting export-oriented products is public-private partnership, which is actively used in Azerbaijan as well. J. Mota *et al.* (2021) confirm the effectiveness of this method; in their work on evaluating the effectiveness of the impact of programs to promote the production of enterprises for export, the authors wrote that receiving such financing from the state really allowed companies more effectively promoting their own products for sales abroad, but subjected to the formation of the correct investment, financial and management strategy of the company. Thus, it can be effective from the point of view of the state only if there is a quality selection of enterprises to provide such financing. S.H. Jajail (2012) also comes to similar conclusions in his work on evaluating the effectiveness of programs to promote export-oriented products based on Iranian companies, where the scientist described the existing relationship between export promotion programs and its level directly. Furthermore, the author noted that these programs are useful both in the short term (due to a temporary increase in the productivity of enterprises) and in the long term (by increasing the competitiveness of the products of this sector).

Thus, the public-private partnership, which plays an important role in the diversification of Azerbaijan's exports, the essence of which is to support non-oil exporters by making payments from the budget, was considered in their works by R.M. Jabiev (2018), describing the mechanisms and features of interaction between the state and export-oriented enterprises in the country, as well as some other features of the development of non-oil companies in the country. According to the scientist, such activities, carried out since the beginning of 2000, have brought significant benefits to the development of the Azerbaijani industry. However, in order to significantly reduce the share of oil products in the structure of exports, the state should allocate more funds and act more actively. Also, R.M. Jabiev (2018) proposes to replace oil products in exports through innovative technologies, which, in fact, is a fairly effective method of diversifying the economy and exports, which Kazakhstan has already proved by its own example (Sadyrova *et al.*, 2021). Indeed, a qualitative substitution of oil products in the country's exports is possible by increasing the export of products with a large added value, which includes certain types of industry and innovative products. In such a context, it would be effective to locate a site with a low level of taxes on the territory of the country to increase the attractiveness of the state for investment by transnational corporations (Shaqiri *et al.*, 2019). For the same purpose, the subsequent construction of techno parks, as well as the development of existing ones, is perfect.

The concept "green transformation" in the current conditions of world development is very common. The reason for this is the general trend towards sustainable development, that is, one in which economic development is carried out without the depletion of natural resources (Ruggerio, 2021). It is believed that such a development methodology will solve many existing economic and environmental problems, as well as create new sources for growth (Lavrinenko *et al.*, 2019). As P. Soderholm noted (2020), further challenges that economic, environmental and social problems may bring will still require a deeper introduction of "green technologies".

The above work described how achieving a "green transformation" can help a country increase its level of economic diversification. Definitely, the subsequent "greening" of the economy will help consolidate the position of Azerbaijani companies on the world stage in the coming years, which, among other things, will lead to the diversification of the economy. For this, the state pursues an appropriate policy, but the question remains how effective it is. The EaPGREEN (Greening Economies in the Eastern Neighbourhood) report can help (Green Transformation, 2019). It draws the following important conclusions: there is political will in government to ensure green growth; the existing working group has proved useful in opening up a dialogue in government and sharing information to further improve the principles of green development; cooperation with GGI Global Alliance can be a starting point for future policy development in this area, as it provides a framework for individuals to evaluate their green growth decisions on the government agenda. It can be concluded that, according to the results of the study, there are prospects for subsequent "green" development in Azerbaijan. If the current trend continues, it should be expected significantly better results in this area, and hence achieving an increase in the level of diversification of the country's economy.

CONCLUSIONS

The work analysed the foreign trade of Azerbaijan, namely its export. The study showed that this aspect of foreign trade was very concentrated both in terms of countries and types of products. The reason for this is a significant share of oil in the country's foreign trade. In addition, this makes the state more vulnerable in the event of an economic (or other) crisis that negatively affects the price of energy. In the long term, it is necessary to improve the business climate and diversify non-oil exports. For an export breakthrough, it is necessary to expand the range and quality of goods to enter new regional markets. In this regard, modern methods used in the Republic of Azerbaijan were considered to achieve a higher level of export diversification, among which public-private partnership programs are mainly used, namely, encouraging the production of products for export by non-oil companies through payments. Among other methods of export diversification, one can note the attraction of investments in the industry and the construction of technology parks (development of the appropriate infrastructure).

In addition to it, the article analyses the possibilities of achieving diversification of the Azerbaijani economy through the "green transformation". One of these is the creation of more environmentally friendly products in production through the use of "clean" materials. In addition, the article describes the current state of achieving the goals of "green" economic development in the country. Since the main sectors for this are energy, agriculture and transport, the existing problems are described in them, and also indicates the prospects for their development. Although the existing methods of achieving "green" principles of the functioning of the economy may not be effective enough, however, as studies and assessments show, the country has significant potential in the subsequent development of environmental friendliness. A promising direction for further research could be a more detailed description of the state policy to increase the diversification of the Azerbaijani economy, as well as the search for other opportunities, in addition to conducting a "green transformation" and promoting export-oriented production, to achieve this goal.

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Диверсифікація через сприяння експортоорієнтованому виробництву та «зеленій трансформації» в Азербайджані

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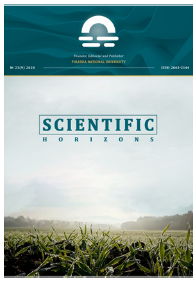
Анотація. Диверсифікація є важливою складовою розвитку будь-якої економіки. Причиною цього є підвищення стійкості країни до зовнішніх подразників, що робить прогрес більш поступовим, постійним і передбачуваним. Отже, дослідження можливостей диверсифікації економіки є дуже актуальним, особливо в сучасних геополітичних умовах. Метою роботи було проаналізувати деякі методи диверсифікації економіки Азербайджану, а саме розвиток експортоорієнтованого виробництва та здійснення «зеленої трансформації». Основним методом при написанні статті став аналіз, але важливу роль також відіграли історичний, моделювання, дедукції, абстрактно-логічний методи. Так, у роботі було розглянуто та проаналізовано експорт Азербайджану, під час якого було виявлено значну залежність країни від продажу нафти на зовнішні ринки. Оскільки така перспектива є небезпечною для сталого розвитку країни, важливо здійснити певні заходи, спрямовані на підвищення диверсифікації її експорту. Насамперед, вони пов'язані з державно-приватним партнерством, але можуть набувати й інших форм, таких як залучення інвестицій та розбудова інфраструктури. Крім того, в роботі описано, як «зелена трансформація» країни може допомогти досягненню цілей диверсифікації економіки та на якому етапі знаходиться рівень «озеленення» економіки держави; в роботі також описані перспективи держави в досягненні цих цілей. Стаття привносить нові знання в розуміння особливостей функціонування азербайджанської економіки, а також в теорію економічного та сталого розвитку, а також торгівлі

Ключові слова: економіка Азербайджану, сталий розвиток, концентрація експорту, диверсифікація експорту, «зелена трансформація» бізнесу

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 25(10), 71-78



UDC 664:663.8
DOI: 10.48077/scihor.25(10).2022.71-78

Comparative Analysis of the Amino Acid Composition of Beverages Based on Plant Raw Materials and Cow's Milk

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Article's History:
Received: 10/12/2022
Revised: 11/28/2022
Accepted: 12/13/2022

Suggested Citation:
Merzlov, S., Tsebro, A., Rol, N., Nadtochii, V., & Kachan, A. (2022). Comparative analysis of the amino acid composition of beverages based on plant raw materials and cow's milk. *Scientific Horizons*, 25(10), 71-78.

Abstract. Knowledge of the peculiarities of technological processes for the production of cow's milk analogues, optimal parameters for production, the chemical composition of raw materials and the resulting finished product, in particular the amino acid composition, plays an essential role in the development of new types of functional products, improvement of their stability, taste, and nutritional properties, and allows them to be enriched with additional components through various modifications. The purpose of the study is to compare the amino acid composition and balance of amino acids of various types of beverages based on plant raw materials: almond, rice and coconut, oatmeal with respect to the amino acid composition of cow's milk protein. The following methods were used: capillary electrophoresis – to determine the amino acid composition of the protein in analogues of milk and cow's milk, mathematical – to calculate the amino acid score and utility coefficient. The composition, organoleptic quality indicators, main technological stages, and safety of production of plant-based analogues of animal milk are presented. Three types of plant-based beverages were used for the study: almond with a mass fraction of fat of 1.5%; oatmeal with a mass fraction of fat of 2.5%; rice and coconut with a mass fraction of fat of 1.8%; and cow's milk with a mass fraction of fat of 2.5%. A comparative estimate of the mass fraction of amino acids valine, isoleucine, leucine, lysine, methionine, threonine, and phenylalanine in the protein of beverages based on plant raw materials is presented relative to the mass fraction of amino acids in the milk protein, and the reference protein. The limiting amino acid in the protein composition of the studied analogues of cow's milk is methionine. The highest amino acid protein scores were observed in oatmeal drink; however, they did not exceed those of pasteurised milk. To assess the balance of the amino acid composition, the utility coefficient was determined. The findings are of practical importance, because they can be used in the production of functional products, in particular, analogues of cow's milk, to improve the composition, increase biological value, and enrichment with nutrients and additional components

Keywords: cow's milk analogues, plant-based drink, oatmeal drink, almond drink, rice and coconut drink, amino acid score, utility coefficient

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INTRODUCTION

Nowadays, in the processing industry, there is a tendency to increase the segment of natural products for healthy nutrition, accompanied by a continuous expansion of protein processing, the search for new, potentially suitable raw materials. Skripnichenko *et al.*, (2020) found that for this purpose, raw materials of plant origin are often used, which can increase the nutritional and biological value of products and have therapeutic properties, etc.

Studies by Min *et al.* (2018), Merzlov *et al.* (2021) indicate that one of the priority areas of research in the field of nutrition is the production of Non-Dairy Milk – a drink based on plant raw materials, which was created as an alternative to animal milk, including to solve the problem of protein deficiency in economically undeveloped countries. However, such drinks are becoming increasingly popular today.

According to the authors of Khalupa-Krebzdak *et al.* (2018) the advantages of consuming such a drink are the absence of cholesterol, low caloric content, high content of fibre, isoflavonoids, antioxidants, monounsaturated, and polyunsaturated fats, which is important, especially when following a diet. R. Bocker *et al.* (2022), J. Poore *et al.* (2022), C. Short *et al.* (2021) found that the technological process for the production of beverages based on plant raw materials is environmentally friendly and contributes to reducing carbon emissions into the environment compared to the technology for the production of cow's milk.

With the constant consumption of plant analogues of milk, there is a possibility of a nutritional imbalance associated with protein and trace element composition. McClements *et al.* (2021) showed that such products are characterised by low digestibility of essential substances, and instability of the amino acid composition, compared with animal products, contain many antinutrients, such as trypsin inhibitors, phytic acid, and inositol phosphates.

Sarangapany *et al.* (2022), Silva *et al.* (2020) investigated various technologies for the production of plant-based beverages and found that for the stability of the amino acid composition and increasing the nutritional value of the final product, minerals, vitamins, various food additives are additionally applied to the product, for example, flavourings, dyes, stabilisers (guar gum, gellan gum, xanthine gum, etc.) or, as indicated in studies by Kundu *et al.* (2018), several types of raw materials can be used simultaneously. Sarangapany *et al.* (2022), Bocker *et al.* (2022) studying the mass fraction of protein and amino acid composition of beverages based on plant raw materials proved the dependence primarily on the production technology, in particular, the use of innovative processing technologies (ultrasound, high-pressure processing, the use of pulsed electric field, ultraviolet and microwave radiation), which affects the nutritional, organoleptic quality indicators and product safety, but no less important were the quality indicators of the raw materials used (variety, climatic conditions and geographical area of cultivation).

Studies by Han *et al.* (2021) and Sarangapany *et al.* (2022) showed that a mandatory stage in the production of cow's milk analogues is the extraction of water- and salt-soluble protein fractions from raw materials. First, pre-grinding of raw materials is carried out, followed by the preparation of a suspension and filtering it, to obtain a consistency similar to cow's milk. This technological operation ensures the colloidal stability of the product. McClements and Grossmann (2021) and Short *et al.* (2021) proved the importance of using technological operations of homogenisation and pasteurisation to increase microbiological stability, inactivation of enzymes, increase the storage time of the product, in addition to providing pleasant sensory properties of the product for the consumer. Pasteurisation is performed by heat treatment, but Aydar *et al.* (2020) suggest that the use of high temperatures (from 60°C to 130°C) changes the physical, chemical, and organoleptic properties and nutritional value of beverages. Analysing research data by Han *et al.* (2021), an extremely important step in the production of beverages based on plant raw materials is the choice of technological parameters, which is associated with the need to block or break down anti-nutrients: protease inhibitors, lectins (for example, during the use of legumes) specific alkaloids or other substances that can cause protein deposition. McClements and Grossmann (2021) investigated the technological operations of steaming, calcination, and soaking in slightly alkaline solutions, which can increase the efficiency of protein and dry matter extraction in beverages, increase the colloidal stability of the obtained emulsions in the production of beverages from various types of legumes and nuts.

Silva & Smetana (2022) found that one of the main factors influencing the quality of a plant-based drink is the temperature regime. During the production of animal milk analogues from legumes, the use of ultra-high temperatures allows inactivating trypsin, but the use of such modes at the stages of blanching and roasting affects the fractional composition of proteins, reducing their solubility and extraction indicators. The main criterion in assessing the biological value and physiological role of amino acids is their ability to provide protein synthesis in the body.

The purpose of the study is to investigate the amino acid composition of the protein of plant-based milk analogues: almond, rice and coconut, and oatmeal, and to conduct a comparative analysis of amino acid balance in relation to cow's milk protein. To achieve this goal, the following tasks were set: to investigate the amino acid composition of cow's milk analogues: rice and coconut, almond, and oatmeal; to compare the amino acid composition of beverages with the amino acid composition of cow's milk; to determine the amino acid score of the products under study and compare it with the amino acid score of cow's milk; to calculate the utility coefficient.

MATERIALS AND METHODS

For the study, samples were taken in accordance with DSTU 4856:2007 (2008) of three types of plant beverages: rice and coconut with a mass fraction of fat of 1.8%, almond and oatmeal with a mass fraction of fat, respectively, 1.5 and 2.5 %, and cow's milk with a mass fraction of fat of 2.5% in accordance with DSTU ISO 5538:2004 (2005).

The mass fraction of amino acids in the products was determined in the laboratory for the control of feed additives and premixes of the State Scientific Research Control Institute of Veterinary Medical Products and Fodder Additives in Lviv by capillary electrophoresis according to the method of I.Y. Kotsyumbas (2013). Capillary electrophoresis is based on electrokinetic phenomena – electromigration of ions and other charged particles and electroosmosis. The study was carried out using the Kapel-105/105M capillary electrophoresis system, equipped with special software based on a personal computer. The method is based on the hydrolysis of samples by the acid method (hydrochloric acid for 16 hours) with the transition of amino acids to free forms of phenylisothiocarbamyl derivatives (PTC derivatives), their further separation and quantitative determination by capillary electrophoresis. This method was used to determine the mass fraction of amino acids: lysine, phenylalanine, leucine and isoleucine, methionine, valine, and threonine. The obtained indicators were compared with the amino acid composition of cow's milk.

The biological value of proteins in beverages based on plant raw materials and cow's milk was determined using the method described by Peshchuk & Nosenko (2011) comparing the composition of products with the composition of the "ideal" protein and calculating the score by determining the ratio of the amount of each amino acid (g) in 1 g of protein of the studied product to the amount of the same amino acid in 1 g of the "ideal" protein. The amino acid with the lowest amino acid score is an amino acid that limits the biological value of protein.

Using the methods developed by academician N.N. Lipatov (2001), which are based on the development of the Mitchell-Block principle and allow estimating the amino acid composition, its balance and the degree of digestibility of amino acids. The ratio of the lowest amino acid score to the highest was determined (the utility coefficient was established) according to the method described by M. Hayes (2020).

RESULTS AND DISCUSSION

The amino acid composition of plant-based beverages was studied: oatmeal with a mass fraction of fat of 2.5%, almond with a mass fraction of fat of 1.5%; rice-coconut with a mass fraction of fat of 1.8 %; and cow's milk with a mass fraction of fat of 2.5%. It was found that the protein of pasteurised milk has a higher mass fraction of the amino acids leucine, valine, isoleucine, lysine, and threonine, respectively, by 39.7%; 15.6%; 42.7%; 43.1%, and 15.2%. The mass fraction of phenylalanine and methionine in cow's milk was 13.8% and 25.1% lower, respectively, compared to the reference protein index (Table 1).

***Table 1**. Amino acid composition of cow's milk and beverages based on plant raw materials M ± m, n = 12*

Name of amino acid	Mass fraction of amino acid, mg/1 g of protein				FAO/WHO reference protein, mg/1 g of protein
	Product name				
	Pasteurised milk	Oatmeal drink	Rice and coconut drink	Almond drink	
Valine	57.8 ± 4.41	32.4 ± 0.02	8.1 ± 0.03	20.0 ± 0.01	50.0
Isoleucine	57.1 ± 3.31	26.7 ± 0.01	5.7 ± 0.02	17.0 ± 0.03	40.0
Leucine	97.8 ± 6.26	53.0 ± 0.09	11.3 ± 0.01	35.0 ± 0.01	70.0
Lysine	78.7 ± 6.08	19.0 ± 0.03	5.4 ± 0.03	10.0 ± 0.02	55.0
Methionine, mg	26.2 ± 2.36	9.8 ± 0.005	3.5 ± 0.02	4.9 ± 0.02	35.0
Threonine, mg	46.1 ± 2.66	21.7 ± 0.02	7.5 ± 0.02	16.0 ± 0.01	40.0
Phenylalanine, mg	51.7 ± 4.64	36.5 ± 0.02	8.5 ± 0.04	26.9 ± 0.015	60.0

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

Comparing the amino acid composition of plant-based beverages with the amino acid composition of pasteurised milk and reference protein, there is a low mass fraction of amino acids: valine, isoleucine, leucine, lysine, methionine, threonine, and phenylalanine, which is associated with the low content of these amino acids in the composition of plant proteins and the technological stage of production of this product (soaking and extraction process). In all the studied analogues of cow's milk, the predominance of the mass fraction of the amino acid leucine in comparison with other amino acids was noted. Thus, in oatmeal drink, the mass fraction of leucine exceeds the indicator of almond and rice and coconut drinks by 1.5 and 4.7 times, respectively, but its amount is significantly less than in pasteurised milk by 1.84 times.

In rice and coconut drink, the mass fraction of the amino acid leucine exceeds the mass fraction of valine by 39.5%, isoleucine by 98.2%, lysine by 2.09 times, methionine by 3.2 times, threonine by 1.5 times, and phenylalanine by 32.9 %. The mass fraction of the amino acid leucine in almond drink exceeds the mass fraction of valine by 75.0%, isoleucine by 2.06 times, lysine by 3.5 times, methionine by 7.1 times, threonine by 2.2 times, and phenylalanine by 30.1%.

The findings indicate that the limit for all the studied analogues of milk is the amino acid methionine, the smallest mass fraction of which is in the rice and coconut drink. Compared to oatmeal and almond drinks, the amount of it in this product is less by 2.8 and 28.5%, respectively. In oatmeal drink, the mass fraction of this amino acid exceeds other indicators of plant-based beverages and amounts to 9.8 mg/1 g of protein and remains 2.6 times less compared to cow's milk. The amino acid score of pasteurised milk according to the following indicators: valine, isoleucine, leucine, lysine, and threonine exceeds 100, respectively, by 15.6%; 42.7%; 39.7%; 43.1% and 15.2%, which indicates the completeness of protein (Table 2).

***Table 2**. Amino acid protein score of pasteurised milk and plant beverages M ± m, n = 12*

	Amino acid score, %			
Name of the amino acid	**Pasteurised milk**	**Oatmeal drink**	**Rice and coconut drink**	**Almond drink**
Valine	115.6 ± 19.2	64.8 ± 0.024	16.2 ± 0.06	40 ± 0.011
Isoleucine	142.7 ± 21.3	66.7 ± 0.02	14.2 ± 0.068	42 ± 0.11
Leucine	139.7 ± 22.1	75.7 ± 0.027	16.1 ± 0.12	50.0 ± 0.13
Lysine	143.1 ± 23.5	34.5 ± 0.018	9.8 ± 0.031	18.2 ± 0.12
Methionine	74.9 ± 12.3	28.0 ± 0.017	10.0 ± 0.022	14.0 ± 0.07
Threonine	115.2 ± 19.1	54.2 ± 0.03	18.7 ± 0.06	40.0 ± 0.09
Phenylalanine	86.2 ± 14.5	60.8 ± 0.02	14.2 ± 0.072	44.8 ± 0.01

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

Drinks based on plant raw materials have a significantly lower amino acid score of all the amino acids under study. Analysing the obtained data, it is worth noting that the amino acid score of pasteurised milk protein is limited by the amino acid methionine and phenylalanine, the amino acid score of which is the smallest (<100%) and is 74.9% and 86.2%, respectively. Deviation of the indicator both below and above 100% is undesirable, since this indicates an inefficient use of amino acids by the body for the synthesis of its own proteins.

The first limiting amino acid is methionine. The difference in amino acid score was less than valine by 40.7%, isoleucine by 67.8%, leucine by 64.8%, lysine and threonine by 68.3% and 40.7%, respectively. The amino acid score of the second limiting amino acid phenylalanine is 29.4% less than valine, 56.5% less than isoleucine, 53.5% less than leucine, 56.9% less than lysine, and 29.4% less than threonine.

Analogues of animal milk – rice and coconut, almond, and oatmeal drinks have a low amino acid score compared to pasteurised milk, which is associated with a lower mass fraction of amino acids in these products. Lysine and methionine in the rice and coconut drinks have the lowest amino acid score, which is 8.4% and 4.0% less compared to the almond analogue, respectively, and 3.5 and 2.8 times less compared to oatmeal, respectively.

Oatmeal drink is characterised by the highest amino acid score in leucine and surpasses the analogues of rice and coconut and almond by 4.66 times, by 51.4%, respectively. The leucine index in oatmeal is 10.9% higher than the amino acid score of valine, 9.0% higher than isoleucine, 2.2 times higher than lysine, 2.7 times higher than methionine, and higher than threonine and phenylalanine by 21.5% and 14.9%, respectively.

Rice and coconut drink has the highest amino acid score of threonine, exceeding valine by 2.5%, isoleucine by 4.5%, leucine by 2.6%, lysine by 8.9%, methionine by 8.7%, phenylalanine by 4.5%. In the almond drink, the highest amino acid score was observed for leucine, which exceeds the index of valine, isoleucine, lysine, methionine, threonine, and phenylalanine by 10.0; 8.0%, 2.75 and 3.57 times and by 10.0; 5.2%, respectively. The utility coefficient was calculated to assess the balance of the amino acid composition (Table 3).

***Table 3**. Utility coefficient*

Product name	**Utility coefficient, %**
Rice and coconut drink	9.8
Almond drink	13.9
Oatmeal drink	27.9
Pasteurised milk	74.7

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

The higher the value of the utility coefficient, the better the balance of the amino acid composition, and the more efficiently amino acids can be used to synthesise the body's own proteins. The highest utilitarianism coefficient was observed in the studied pasteurised milk. This figure is 74.7%. Drinks based on plant raw materials have a lower utility coefficient relative to cow's milk. Thus, the lowest coefficient of rice and coconut drink is 9.8%, the indicator is less than that of almond and oatmeal by 4.1 and 2.85 times, which indicates a low level of protein digestibility of this product. In an almond drink, the utility coefficient is lower compared to pasteurised milk and oatmeal drink by 5.4 times and 2.0 times, respectively. Oatmeal drink is characterised by the highest utility coefficient among plant-based beverages compared to rice and coconut and almond analogues of cow's milk by 2.85 and 2.0 times, respectively.

Analysing the results obtained, it can be concluded that the studied plant-based drinks oatmeal, almond and rice and coconut in the protein composition have a lower mass fraction of the amino acids valine, isoleucine, leucine, lysine, methionine, threonine, and phenylalanine compared to cow's milk. The amino acids limiting for all the studied milk analogues are methionine and lysine, the smallest mass fraction of which is found in rice and coconut drinks.

Plant-based oatmeal drink contains the largest mass fraction of the amino acids valine, isoleucine, leucine, lysine, methionine, threonine, phenylalanine compared to rice and coconut and almond drinks, however, the indicators are lower compared to cow's milk. The largest mass fraction of the amino acid leucine, this indicator is higher compared to almond and rice and coconut drinks by 54.4% and 4.7 times, respectively, but its amount is less than in pasteurised milk by 84.5 %. In addition, oatmeal drink is characterised by the highest utility coefficient in comparison with rice and coconut, and almond plant-based analogues of milk.

Singhal *et al.* (2017) and Atalar (2019) found that a rice-based drink is rich in vitamins A, B12, and D and is high in dietary fibre, contains more selenium and manganese compared to other types of beverages. But compared to cow's milk, almond, rice and oatmeal drinks have a lower mass fraction of protein, amino acids, calcium and argentum. Comparing the amino acid composition of plant-based beverages with the amino acid composition of pasteurised milk and reference protein, there is a low mass fraction of amino acids: valine, isoleucine, leucine, lysine, methionine, threonine, and phenylalanine.

Munekata *et al.* (2020), Han *et al.* (2021) and Paul *et al.* (2020) suggest that a key role is played by essential amino acids, which are not synthesised by humans and animals, and are found in very small amounts in plant products (limited or deficient). The researchers have proven that lysine and methionine are the limiting amino acids for most milk analogues. The study results indicate that the first limiting for all the studied analogues of milk is the amino acid methionine, the smallest mass fraction of which in the rice and coconut drink – 3.5 mg in 1 g of protein of the drink, the second limiting amino acid is lysine, the smallest mass fraction of which in the rice and coconut drink – 5.4 mg in 1 g of protein.

Jeske *et al.* (2017) and Fawzi *et al.* (2022), comparing the obtained data, prove that the protein of a drink made from soy is similar in composition to cow's milk protein, and the protein of an oatmeal drink is the most complete in amino acid composition. Analysing the data of this study, it is found that the plant-based oatmeal drink also contains the largest mass fraction of the amino acids valine, isoleucine, leucine, lysine, methionine, threonine, phenylalanine compared to rice and coconut and almond drinks, however, the indicators are lower compared to cow's milk.

Pua *et al.*, (2022), Raikos *et al.* (2020), Vagadia *et al.* (2018) prove that an important indicator of raw materials used in the production of plant drinks and analogues of dairy products, which characterises the nutritional and biological value is not only the chemical composition and ratio of nutrients, but also the composition and balance of amino acids. There is a certain relationship – the higher the value of the utility coefficient, the better the balance of the amino acid composition. According to the results of the conducted studies, it was noted that oatmeal drink has the highest indicator of the utility coefficient relative to the indicator of rice and coconut and almond analogues of milk. The value was 2.85 and 2.0 times higher, respectively.

Analysis of the obtained data shows that oatmeal drink is more complete in terms of amino acid composition of protein compared to rice and coconut and almond drinks, because it differs from analogues by a larger mass fraction of amino acids valine, isoleucine, leucine, lysine, methionine, threonine, and phenylalanine, has the highest indicators of amino acid score and utility coefficient. Comparing the amino acid composition of the studied milk analogues with the amino acid composition of cow's milk, there is a low mass fraction of the amino acids valine, isoleucine, leucine, lysine, methionine, threonine, and phenylalanine. Limiting amino acids are methionine and lysine, the smallest mass fraction of which is found in rice and coconut drink.

CONCLUSIONS

It was researched that the development of insurance of the subjects of the closed cycle technology sphere would depend directly on the participation of the state and Insurers in this process. It was noted that for development of this type of insurance, efforts of all participants of the insurance market should be attracted. On the part of the state there should be the most incentive to insurance for enterprises working in the sphere of closed cycle technologies. Such an incentive may look like compensation of the part of the insurance cost for these enterprises. Therefore, enterprises will be able to ensure their risks and have a better chance of successful existence and development, and the state will get another developed branch in the economy, which can become a significant part of the state's gross domestic product. Also, it was confirmed that under the condition of the consumer's awareness of insurance services under the conditions of the Contract of insurance the trust to Insurers would increase considerably.

It was established that the insurers themselves should develop new insurance products, which might be interested in terms of the subjects of the closed cycle technology sphere and significantly increase competition in the market of this type of insurance. However, to motivate Insurers first, it is necessary to increase the demand due to the compensation of part of the insurance cost. It was determined that in the long-term period of insurance of the subjects of the closed cycle technology sphere has all chances for successful development taking into account the development of the entire insurance market of Ukraine. All this will significantly improve the development of the closed cycle technologies and insurance in Ukraine. Thus, it is possible to confirm that under the condition of global insurance of subjects of the closed cycle technologies sphere and further development of such technologies, in the future the nature of risks of individual and legal persons, and accordingly the insurance sphere as a whole, will change considerably.

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Порівняльний аналіз амінокислотного складу напоїв на основі рослинної сировини та коров'ячого молока

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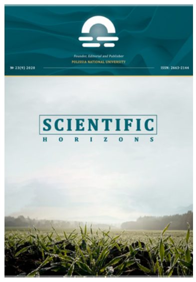
Анотація. Знання особливостей технологічних процесів виробництва аналогів молока коров'ячого, оптимальних параметрів за виробництва, хімічного складу сировини та одержаного готового продукту, зокрема амінокислотного складу, все це відіграє важливу роль під час розроблення нових видів продуктів функціонального призначення, а також для покращення їх стабільності, смакових та поживних властивостей, та дозволяє збагачувати їх додатковими компонентами шляхом різних модифікацій. Мета роботи – порівняльний аналіз амінокислотного складу та збалансованості амінокислот різних видів напоїв на основі рослинної сировини: мигдального, рисово-кокосового, вівсяного відносно амінокислотного складу білка коров'ячого молока. Були використані такі методи: капілярного електрофорезу – для визначення амінокислотного складу білка аналогів молока та коров'ячого, математичні – для розрахунку амінокислотного скору та коефіцієнту утилітарності. Наведено склад, органолептичні показники якості, основні технологічні етапи та безпечність виробництва аналогів молока тваринного походження. Для дослідження було використано три види напоїв на рослинній основі: мигдальне з масовою часткою жиру 1,5 %, вівсяне та рисово-кокосове з масовою часткою жиру 2,5 та 1,8 %, а також молоко коров'яче з масовою часткою жиру 2,5 %. Представлено порівняльну оцінку масової частки амінокислот валіну, ізолейцину, лейцину, лізину, метіоніну, треоніну, фенілаланіну у складі білка напоїв на основі рослинної сировини відносно масової частки амінокислот у складі білка молока, а також еталонного білка. Лімітуючою амінокислотою у складі білка досліджуваних аналогів молока коров'ячого є амінокислота метіонін. Найвищі показники амінокислотного скору білка напою вівсяного, проте, вони не перевищували показники молока пастеризованого. З метою проведення оцінки збалансованості амінокислотного складу визначали коефіцієнт утилітарності. Результати досліджень мають практичне значення, адже можуть застосовуватися за виробництва продуктів функціонального призначення, зокрема аналогів молока коров'ячого з метою покращення складу, підвищення біологічної цінності, збагачення поживними речовинами та додатковими компонентами

Ключові слова: аналоги молока коров'ячого, напій на рослинній основі, вівсяний напій, мигдальний напій, рисово-кокосовий напій, амінокислотний скор, коефіцієнт утилітарності

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 25(10), 79-86



UDC 602.6:582.28:546.56
DOI: 10.48077/scihor.25(10).2022.79-86

Growth Intensity of *Trichoderma Viride* at Different Doses and Sources of Copper in the Medium

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Article's History:
Received: 09/15/2022
Revised: 11/10/2022
Accepted: 12/01/2022

Suggested Citation:
Mitiohlo, L., Merzlov S., Merzlova, H., Dudnyk, O., & Rozputnii, O. (2022). Growth intensity of Trichoderma Viride at different doses and sources of copper in the medium. *Scientific Horizons*, 25(10), 79-86.

Abstract. The biological properties of Trichoderma Viride fungi allow them to be effectively used in the technologies of crop waste disposal, production of organic, environmentally friendly fertilisers, and prevention of soil diseases of plants. The growth and development of these fungi depend on a number of trace elements that are found in the medium. Copper is of great importance among trace elements. The establishment of the ability to use copper as a stimulator of biomass accumulation of Trichoderma Viride fungi is of scientific and practical interest for national economic needs, which indicates the relevance of the study. The purpose of the study is to establish the effectiveness of the effect of various copper compounds on the growth and development of Trichoderma Viride. To investigate the effect of the metal-biotic on the growth of microorganisms, 0.5 to 10.0 mg/100 cm^3 of the element in the form of copper sulphate, mixed ligand complex and copper glycinate were added to the medium with potato dextrose agar (PDA). In the control variant, the element was not added to the nutrient medium. The media were inoculated with the Viridin preparation. Trichoderma Viride growth was recorded on days 4 and 7 of the experiment. It has been experimentally established that the fungal population is affected by the content and source of copper in the medium. It was found that the presence of a biotic metal in the medium in mineral or chelated form is up to 1.0 mg/100 cm^3 stimulates the build-up of fungal biomass. It was proved that on the 4^{th} day of cultivation for the introduction of copper into the medium in the amount of 1.0 mg/100 cm^3 in the mixed-ligand form, the population of Trichoderma Viride increased by 75.0%. On the 7^{th} day, the increase in the number of fungal cells was 58.3%. It was found that with the introduction in the medium of more than 5.0 mg/100 cm^3 copper in any form, the population growth of Trichoderma Viride fungi decreased. The higher the copper content in the medium, the greater the inhibition of fungal cell reproduction. It was generalised that comparing the action of the mixed ligand complex copper, copper glycinate, and copper sulphate, it was found that the latter compound is the most toxic against Trichoderma Viride

Keywords: fungal growth, mixed ligand complexes, copper glycinate, copper sulphate, metal biotic

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INTRODUCTION

Among the wide variety of fungi, Trichoderma Viride is widely used in crop production and bioconversion technologies. Trichoderma Viride promotes the control of plants against soil diseases and to a certain extent stimulates their growth and yield. The effect of fungal action on the accumulation of chlorophyll and carotenoids in onions has been established (Aleksandrova & Velikanov, 2000; Metwally & Al-Amri, 2020).

Trichoderma is one of the microorganisms that are promising for biological control, as it has different mechanisms of action on plant pathogens (Aleksandrova *et al*., 2004; Aleksandrova *et al*., 2006). This includes competition for nutrients, antibiosis by hydrolytic enzymes (β-glucanases, chitinases, and proteinases) and mycoparasitism. Fungal preparations are used to accelerate the utilisation and bioconversion of organic waste (straw, chaff, damaged silage, haylage, sawdust, shavings, sunflower and corn crop residues) into organic fertiliser. Trichoderma spp. is one of the methods of controlling phytopathogenic fungi (Reino *et al*., 2008). This is possible due to the fact that Trichoderma species have lytic activity against phytopathogens, synthesise antibiotics, and transmit plant resistance to phytopathogenic fungi (Mendez-vilas, 2010; Valencia *et al*., 2011).

Currently, biotechnological studies are being conducted to develop effective methods for growing Trichoderma Viride fungi and obtaining stable preparations from them that are convenient for use in various sectors of the economy. The biological properties of biotic metals, including copper, in the fungal medium, can affect the course of metabolic processes in Trichoderma Viride. The amount of copper in the medium depends on the increase in the biomass of the fungus, its development and reproduction. With large doses of biotic metal in the medium, the growth of the fungus and even its death can stop. Low doses can stimulate the processes of anabolism in cells (Sidorenko, 2012; Tiwari *et al*., 1989). However, currently in the available literature, there are no clear data on the use of organic compounds of copper (compounds with amino acids, compounds with organic acids, compounds with vitamins, compounds in combination with vitamins and amino acids) as stimulants of fungal biomass growth, including Trichoderma Viride. By investigating the optimal doses of biotic metal in the medium, it is possible to activate the metabolic processes in Trichoderma Viride, thereby, accelerating the growth of fungal biomass, increasing the efficiency of using a unit of mass of the medium and obtaining stable preparations for further bioconversion technologies.

The purpose of the study is to establish the optimal source and optimal doses of organic compounds of copper in the medium for the cultivation of Trichoderma Viride.

LITERATURE REVIEW

A number of researchers (Tiwari *et al*., 1989; Samuels, 2006; Gonzalez *et al*., 2010) proved that most species of the genus Trichoderma accelerate the fermentation time of organic parts in compost due to the ability to synthesise a significant amount of cellulolytic enzymes that hydrolyse lignin-cellulose complexes of plant residues. This leads to the enrichment of the finished compost with nutrients. In soils and compost, Trichoderma Viride persists as long as there are nutrients for it. On plant residues there is a significant amount of culture getting into the soil fungi continue the process of hydrolysis of this waste (Tiwari *et al*., 1989; Druzhinina *et al*., 2011).

The process of growth and development of fungi, including Trichoderma Viride, in the medium is affected by the concentration and shape of trace elements (heavy metals). A number of researchers (Sidorenko, 2012; Benitez *et al*., 2004; Chaverri *et al*., 2003) proved that a significant amount of mineral elements inhibit the growth rate of fungi that cause plant diseases (Hanada *et al*., 2009). These elements include heavy metal – copper (Sidorenko, 2012; Hryhora *et al*., 2003).

Copper as a biotic metal is an important trace element found in organisms of all life forms from microorganisms to mammals. According to the computational algorithm, about 0.3% of bacterial proteomes are copper-binding proteins (especially metalloenzymes). Linder & Hazegh-Azam, 1996; Andreini *et al*., 2008).

Copper and its various complexes are an effective agent for inhibiting the growth of fungi and yeast (Aspergillus fumigates, Candida albicans, Aspergillus niger, Aspergillus fumigates, Saccharomycesel cerevisiae, Aspergillus carbonarius, Cryptococcus neoformans, Aspergillus oryzae) (Kumbhar *et al*., 1991; Zatcoff *et al*., 2008).

New copper compounds – metal nanoparticles – are also used to fight fungal diseases. It has been experimentally proven that the antifungal effect of copper nanoparticles on Saccharomycesel cerevisiae (baker's yeast) depends on its concentration in the medium (Cioffi *et al*., 2004; Sydorenko, 2012). The harmful effect of nanomaterials was also found in relation to fungi Candida sp. (Lipovsky *et al*., 2011; Monteiro *et al*., 2011).

The effect of copper (II) ions on the growth and development of white and brown rot fungi was established (Guillén & Machuca, 2008). N. Poitou and J.M. Olivier investigated the effect of various copper salts on the mycelium growth of several species of edible ectomycorrhizal fungi: Lactarius deliciosus, Suillus granulates, and truffle. It was found that with an increased dose of metal in the medium, the growth of fungal mycelium significantly decreases and the absorption of potassium, calcium, and magnesium is disrupted (Poitou & Olivier, 1990). In addition to inorganic compounds (chlorides, sulphates), and metal-biotic nanoparticles, chelated copper complex is widely used in the national economy (Merzlov, 2009; Merzlov & Gerasymenko 2005). Currently, the effect of various compounds and doses of copper on the growth rate of Trichoderma Viride in the nutrient medium has not been investigated.

MATERIALS AND METHODS

Potato dextrose agar (PDA) medium was used for the study. The medium was pre-autoclaved (temperature 122-124°C for 25 minutes). Penicillin – sterile benzylpenicillin sodium salt (Benzylpenicillin 1,000,000 OD O.L.KAR.) 0.5 g/dm^3 and streptomycin sulphate 0.4 g/dm^3 were added to the PDA medium 5 minutes before bottling to suppress possible bacteria that may have entered the drug and copper sources. Various doses and sources of copper were added to the nutrient medium. Copper mixed ligand complex, copper glycinate, and copper sulphate were used as a source of biotic metal. In the control variant, no metal was introduced to the nutrient medium. The experimental nutrient media contained copper according to Table 1.

***Table 1**. Application of copper to the medium, mg/100 cm^3, n = 5*

Group	Copper source		
	Copper sulphate	Copper mixed ligand complex	Copper glycinate
Control	–	–	–
I experimental	0.1	0.1	0.1
II experimental	0.5	0.5	0.5
III experimental	1.0	1.0	1.0
IV experimental	2.5	2.5	2.5
V experimental	5.0	5.0	5.0
VI experimental	10.0	10.0	10.0

Nutrient media were poured into Petri dishes of 15 cm^3. Each petri dish was labelled considering the number of the experimental group and the dose of copper added. The media were inoculated with the Viridin preparation. Incubation was carried out in a thermostat at a constant temperature of 26 ± 0.5°C for 7 days. Counting was performed on the 4th and 7th days of incubation. The experimant was repeated three times.

RESULTS AND DISCUSSION

Experimentally, it was found that the development of Trichoderma Viride is affected by both the dose of copper in the medium and the form of its compound. On the 4th day of cultivation on a medium without additional application of copper (control group), the indicator of colony-forming units (CFU) of the fungus was 2.0*104. With the additional application of copper to the medium in mixed ligand form and glycinate form in the amount of 0.1 mg/100 cm^3, the amount of fungi increases by 10.0% relative to the control. At this dose of metal biotic, there was no difference in the growth of Trichoderma Viride between the variants where copper was used in mineral and organic form. Increase in the copper content in the medium to 0.5 mg/100 cm^3 promoted the growth of CFU of Trichoderma Viride in the experimental groups, respectively, by 20.0% (medium containing copper sulphate), 45.0% (medium containing copper mixed ligand complex), and 50.0% (medium containing copper glycinate) compared to the control (2).

***Table 2**. Amount of Trichoderma Viride in the medium at the 4th day of cultivation, CFU/g*

Group	Medium without adding copper	Copper source		
		Copper sulphate	Copper mixed ligand complex	Copper glycinate
Control	$2.0 * 10^4$	–	–	–
I experimental	–	$2.1 * 10^4$	$2.2 * 10^4$	$2.2 * 10^4$
II experimental	–	$2.4 * 10^4$	$2.9 * 10^4$	$3.0 * 10^4$
III experimental	–	$2.4 * 10^4$	$3.5 * 10^4$	$3.2 * 10^4$
IV experimental	–	$0.7 * 10^4$	$2.8 * 10^4$	$2.4 * 10^4$
V experimental	–	$0.5 * 10^3$	$5.5 * 10^3$	$4.9 * 10^3$
VI experimental	–	$3.5 * 10^2$	$1.0 * 10^3$	$9.5 * 10^2$

The greatest stimulating effect of copper was found when adding this metal in mixed ligand form at a dose of 1.0 mg/100 cm^3. In terms of the number of CFU, the difference with the control was 75.0%. The addition of cobalt glycinate to the medium at the same dose increased the amount of fungi by 60.0%. The use of a mineral form of biotic metal at a dose of 1.0 mg/100 cm^3 of the medium also had a positive effect on the growth and development of the fungus relative to the control data, but for the variants with copper, the CFU index of Trichoderma Viride was lower, respectively, by 31.4 and 25.0%. The reduced effect of copper exposure in the form of copper sulphate is conditioned by the lower bioavailability of the metal to biotics and its inclusion in the metabolic processes of fungi compared to its organic complexes.

According to the dose of copper in mixed ligand form 1.0 mg per 100 cm^3 of the medium, the fungus biomass absorbs the optimal amount of metal, which is included in metabolic processes, thereby stimulating growth and development. Redox processes and the virulence property of Trichoderma Viride are optimised. The virulence of fungi depends on the action of a number of copper-containing proteins synthesised by their own body. This biotic metal is a critical determinant of their optimal functions. Cuproproteins associated with fungal virulence and redox processes have been identified in these processes, including superoxide dismutase (SOD) and laccase. Laccase (EC 1.10.3.2, para-benzenediol: oxygen oxidoreductase, *P* – diphenol oxidase) is an enzyme that belongs to oxidases and performs a number of oxidation reactions of aromatic and non-aromatic compounds in fungal biomass and contains copper bound to imidazole groups of histidines. SODFC 1.15.1.1) is an enzyme belonging to the group of antioxidant biocatalysts. Together with other antioxidants, it protects against highly toxic oxygen radicals. The active centres of the enzyme include copper. Due to the mixed ligand complex of copper at a dose of 1.0 mg per 100 cm^3 of medium, the metal-biotic assimilated in an accessible biological form in Trichoderma Viride stimulates the synthesis of laccase and SOD and increases their catalytic activity, thereby improving metabolic processes in fungi.

In addition, when the metal is optimally absorbed from the mixed ligand complex, copper affects transcription regulators (transfer of genetic information, as a result of which RNA is synthesised from DNA as a matrix) of Trichoderma Viride, thus activates protein synthesis and fungal reproduction (Ding *et al*., 2011; Ding *et al*., 2013; Strong & Claus, 2011).

Increase in the metal content in the medium in the form of copper sulphate to 2.5 mg/100 cm^3 had a negative effect on the growth of Trichoderma Viride. The CFU score was 2.85 times lower than in the control. At this dose of biotic metal in the fungal medium, the greatest negative effect of copper was found in the variant where the element was in mineral form. Compared to the variants where the mixed ligand complex and copper glycinate were added to the medium, the CFU rate was 4.0 and 3.4 times lower, respectively.

Application of metal in the form of sulphate, mixed ligand form, and glycinate at a dose of 5.0 mg/100 cm^3 helped to reduce the increase in the amount of fungus in the medium, respectively, by 40.0, 3.6, and 4.1 times relative to the control. At this dose of copper, the medium continued to maintain a pattern regarding the toxic effect of the biotic metal on Trichoderma Viride. The growth and development of the fungus was preferable in the variant where a mixed ligand complex of copper was used in relation to samples of the medium where copper sulphate was introduced 11 times. The obtained experimental data confirm the lower toxicity of the copper mixed ligand complex against Trichoderma Viride.

The copper content in the form of sulphate 10.0 mg/100 cm^3 of the medium maximally reduced the growth of Trichoderma Viride on the 4th day of cultivation. At this dose, the mixed ligand form of copper had the least negative effect on the growth of Trichoderma Viride. The CFU index was 2.85 times higher than in the variant with the sulphate content (VI experimental group).

On the 7th day of the experiment, the number of microorganisms in the control increased to 1.2*109. The increase in Trichoderma Viride in the first group with copper sulphate content in the medium was 8.3% higher than in the control group. For using copper at a dose of 0.1 mg/100 cm^3 in organic forms, the increase in culture was higher relative to the variant where copper sulphate was added to the medium by 7.7%. There is a pattern of increasing the increase in the amount of fungus with an increase in the content of copper in sulphate form in the medium to a concentration of 1.0 mg/100 cm^3 compared to the control. A similar phenomenon was observed with the use of copper in the mixed ligand form and glycinate form. Copper doses of 0.5 and 1.0 mg/100 cm^3 of the medium in the form of a mixed ligand complex and glycinate stimulated the increase in the mass and amount of Trichoderma Viride better than its mineral form. The CFU index in these variants was higher than in the medium with copper sulphate, respectively, by 21.4 and 14.3%, and 18.7 and 12.5 % (Table 3).

***Table 3**. Amount of Trichoderma Viride in the medium for 7 days of cultivation, CFU/g*

Group	Medium without adding copper	Copper source		
		Copper sulphate	Copper mixed ligand complex	Copper glycinate
Control	$1.2*10^9$	–	–	–
I experimental	–	$1.3 * 10^9$	$1.4 * 10^9$	$1.4 * 10^9$

Table 3, Continued

Group	Medium without adding copper	Copper source		
		Copper sulphate	Copper mixed ligand complex	Copper glycinate
II experimental	–	$1.4 * 10^9$	$1.7 * 10^9$	$1.6 * 10^9$
III experimental	–	$1.6 * 10^9$	$1.9 * 10^9$	$1.8 * 10^9$
IV experimental	–	$0.1 * 10^9$	$0.5 * 10^9$	$0.6 * 10^9$
V experimental	–	$0.3 * 10^3$	$5.8 * 10^3$	$5.3 * 10^3$
VI experimental	–	$3.2 * 10^2$	$1.2 * 10^3$	$9.7 * 10^2$

The highest CFU of fungi was found in the group where the medium contained 1.0 mg/100 cm^3 of mixed ligand complex of copper. The indicator was higher than in the control group by 58.3%. Comparing the effect of organic forms of copper on the growth of the fungus with each other, it is proved that the mixed ligand complex of the metal is more effective against glycinate by 5.6%.

On the 7th day of cultivation, with the content of copper at a dose of 2.5 mg/100 cm^3 (copper glycinate and mixed ligand form), a decrease in the population growth activity of Trichoderma Viride was observed. The content of microorganisms in the medium was 2.0 and 2.4 times lower compared to the control group, respectively. The presence of copper sulphate in the medium (IV experimental group) led to a 12-fold decrease in the CFU of Trichoderma Viride compared to the control. In addition, a decrease in the amount of Trichoderma Viride was observed for the action of copper at a dose of 2.5 mg/100 cm^3 in mineral form, a mixed ligand complex and copper glycinate were used as part of the medium in relation to the variants. The difference was 5 and 6 times, respectively.

According to the content of copper, in the amount of 5.0 mg/100 cm^3 of the medium in mineral and organic form, the CFU index of Trichoderma Viride was lower compared to the control group. For the use of biotic metal in a mixed ligand complex, the difference with the control was more than 206 thousand times. The presence of a high dose of copper in the form of glycinate also led to almost suspension of growth and development of the fungus. In comparison with the values for the 4th day of cultivation, the CFU indicator increased by only 8.1%.

A significant inhibition of the reproduction of the fungus and its neutralisation was found when using a mineral form of metal-biotic in the medium. Comparing with the data obtained on the 4th day of fungus cultivation, the CFU index of Trichoderma Viride on the 7th day for the action of copper sulphate decreased by 40.0%.

Comparing different sources of metal, it was found that copper sulphate at a dose of 10.0 mg/100 cm^3 has the most toxic effect on Trichoderma Viride compared to chelated metal compounds. The CFU index (VI experimental group) for cultivating the fungus on a medium containing copper sulphate was 3.75 and 3.0 times lower, respectively, compared with the variant where the metal biotic was in mixed ligand form and in the form of glycinate. It was found that due to the accumulation of copper by fungi from the medium, the toxic effect of metal increases over time. This phenomenon is confirmed by the data obtained at the end of the experiment. Thus, on the 7th day of cultivation, the CFU indicator in the variant with copper sulphate decreased by 8.6% compared to the indicator obtained on the 4th day.

Thus, it was found that copper at a low dose of up to 1.0 mg/100 cm^3 of the medium stimulates the growth of the fungus Trichoderma Viride. The most effective source of copper was its mixed ligand form. The explanation for this may be that the metal biotic in this form has a high bioavailability and actively enters into a compound with the corresponding proteins (metalloenzymes), which take an active part in the metabolism of the fungus (Linder & Hazegh-Azam, 1996). The stimulating effect of copper on the growth of microorganisms in low doses has also been established (Ding *et al*., 2011; Ding *et al*., 2013). The authors state that the expression of the CTR1 and CTR4 genes responds to a copper-deficient medium. At critically low levels of copper in the medium, the growth of microbial cells slows down (Ding *et al*., 2013; Ding *et al*., 2011).

Increase in the content of copper in the medium to 10.0 mg/100 cm^3 in mineral and organic form has a negative effect on the growth and reproduction of Trichoderma Viride, because copper in mineral form is more toxic to microorganisms. The negative effect of copper on fungal cells is explained by the generation of free radical stress due to the Fenton reaction. In addition, excess metal biotics alter the structures and metabolic functions of fungal cells. Copper can also affect the DNA of microorganisms and disrupt its replication and transcription, which, in turn, leads to partial and complete death of fungal organisms (Cioffi *et al*., 2044; Garcia-Santamarina *et al*., 2017).

Data (Druzhinina *et al*., 2011) argue that Trichoderma fungi have the biological property of interacting with other fungi, bacteria, plants, and animals, the ability to counteract plant-pathogenic fungi and stimulate plant growth and protective reactions confirm our claim of the feasibility of finding ways to stimulate the accumulation of Trichoderma Viride biomass for use for national economic purposes.

The results obtained by the authors regarding the detection of the stimulating effect of copper on the growth and development of Trichoderma at low doses of metal biotic in the form of copper sulphate, mixed ligand complex, and copper glycinate are confirmed by other researchers (Benitez *et al*., 2004; Hanada *et al*., 2009, Kalatehjari *et al*., 2015), who argue that different types of Trichoderma, although found almost everywhere and not very demanding of the medium, still prefer quite different substrates and are exposed to different ranges of temperature, humidity, and copper content in the medium.

The study found that an increase in the content of copper to 2.5 mg/100 cm^3 of the medium and above in mineral and organic form leads to inhibition of the growth and development of Trichoderma Viride. These results are supported by data (Cioffi *et al*., 2004), where it is noted that the possible mechanisms of action of various copper compounds are based on changes in the structure and function of fungal cells. In addition, the metal can affect DNA and disrupt its replication and transcription, which can eventually cause the death of fungal microorganisms (Cioffi *et al*., 2004).

CONCLUSIONS

Addition of copper sulphate, copper mixed ligand complex, and copper glycinate at the rate of 0.1 mg of the active substance per 100 cm^3 of the medium did not significantly affect the growth and development of Trichoderma Viride fungi on both the 4th and 7th days of cultivation. For increasing the metal content in the medium due to its mineral and chelated forms to an amount of 0.5 mg/100 cm^3, the CFU index of the fungus increases by 16.7-41.7% relative to the variant where copper was not added to the medium (control group). The lowest indicator was observed in the variant with copper sulphate in the medium.

Use of mineral and chelated forms of biotic metal at a dose of 1.0 mg/100 cm^3 of the medium contributed to the best activation of the growth and development of the fungus Trichoderma Viride. The optimal source of copper at this dose was found to be a mixed ligand complex of the metal. In this form, copper is optimally absorbed and has a positive effect on increasing the amount of fungus, being included in the synthesis of metalloenzymes and activating the metabolic processes of Trichoderma Viride cells. For applying copper to the medium at a dose of 1.0 mg/100 cm^3 in the mixed ligand form, on the 7th day of cultivation, the CFU index of the fungus increased by 58.3% relative to the control and by 18.7% and 5.6% relative to variants where, respectively, the medium contained copper sulphate and copper glycinate.

Introduction of metal into the medium in the form of copper sulphate at a dose of 2.5 mg/100 cm^3 negatively affected the growth and development of Trichoderma Viride. Fungal CFU score was 12 times lower than in the control. Increase in copper content in the medium to 5.0 mg/100 cm^3 due to the mixed ligand complex of copper and copper glycinate negatively affects the growth of the Trichoderma Viride population.

The most toxic compound for the fungus is copper sulphate at a dose of 10.0 mg/100 cm^3 of the medium. The CFU index, in this case, was 3.0 and 3.75 times lower, respectively, compared with similar doses of the biotic metal in the form of glycinate and the copper mixed ligand complex. For a dose of copper in mineral or organic form from 2.5 mg/100 cm^3 of the medium and higher, metal is absorbed by the fungus in excessive amounts, thereby causing disruption of oxidative processes (free radical stress) and the processes of replication and transcipation of fungal DNA.

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Інтенсивність росту *Trichoderma Viride* за вмісту різних доз і джерел Купруму в середовищі

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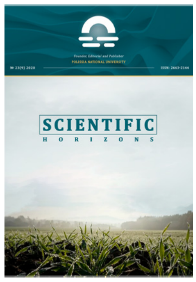
Анотація. Біологічні властивості грибів Trichoderma viride дозволяють їх ефективно використовувати за технологій утилізації відходів рослинництва, виробництва органічних, екологічно чистих добрив та профілактування ґрунтових хвороб рослин. Ріст і розвиток цих грибів залежить від ряду мікроелементів, які знаходяться у середовищі. Важливе значення серед мікроелементів має Купрум. Науково-практичний інтерес має встановлення здатності використання Купруму як стимулятора нарощування біомаси грибів Trichoderma viride для народно-господарських потреб, що зумовило актуальність дослідження. Метою роботи є встановлення ефективності впливу різних сполук Купруму на ріст і розвиток Trichoderma viride. Для вивчення впливу металу-біотику на ріст мікроорганізмів до середовища із картопляним декстрозним агаром (PDA) вносили від 0,5 до 10,0 мг/100 см^3 елементу у формі купрум сульфату, змішанолігандного комплексу та гліцинату купруму. У контролі до поживного середовища елемент не вносили. Середовища засівали підготовленим препаратом «Viridin». Облік росту Trichoderma viride проводили на 4 та 7 добу експерименту. Експериментально встановлено, що на популяцію грибів впливає вміст і джерело Купруму у середовищі. Було встановлено, що присутність у середовищі металу-біотику у мінеральній чи хелатній формі до 1,0 мг/100 см^3 стимулює нарощування біомаси гриба. Було доведено, що на 4 добу культивування за внесення у середовище Купруму у кількості 1,0 мг/100 см^3 у змішанолігандній формі популяція Trichoderma viride підвищується на 75,0 %. На 7 добу збільшення кількості клітин грибів становило на 58,3 %. Було досліджено, що за включення до середовища Купруму у будь якій формі більше 5,0 мг/100 см^3 нарощування популяції грибів Trichoderma viride знижувалось. Виявлена тенденція чим вищий вміст Купруму у середовищі тим гальмування розмноження клітин грибів більше. Було узагальнено, що порівнюючи дію змішанолігандного комплексу Купруму, гліцинату купруму та купрум сульфату виявлено, що остання сполука є найбільш токсичною щодо Trichoderma viride

Ключові слова: ріст грибів, змішанолігандні комплекси, гліцинат купрум, купрум сульфат, метал-біотик

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 25(10), 87-98



UDC 631.333.92
DOI: 10.48077/scihor.25(10).2022.87-98

Energy and Ecological Prerequisites for the Choice of Technologies for Processing Organic Livestock Waste

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Article's History:
Received: 09/05/2022
Revised: 10/20/2022
Accepted: 11/15/2022

Suggested Citation:
Shevchenko, I., Golub, G., Skydan, O., Tsyvenkova, N., & Marus, O. (2022). Energy and ecological prerequisites for the choice of technologies for processing organic livestock waste. *Scienti ic Horizons*, 25(10), 87-98.

Abstract. For modern Ukraine and European countries, the issues of soil restoration after intensive cultivation and reducing the cost of agricultural products by including energy from alternative sources in the energy supply of technological processes are relevant. Therefore, considerable attention is paid to the development of biogas technologies and the production of organic waste. The purpose of the study is to improve the efficiency of the manure processing system with subsequent production of biogas and compost by consistently implementing anaerobic and aerobic fermentation technologies. Economically feasible ways of using organic animal waste are presented. It is proved that the introduction of biogas technologies is economically feasible only in the conditions of functioning of closed systems for the production of crop and livestock products. The most effective combination was the consistent implementation of anaerobic digestion technology and accelerated biothermal composting. Anaerobic methane fermentation, in contrast to the process of composting bio-raw materials, allows more than 55% of carbon to be disposed of in the form of high-calorie methane gas, due to which nitrogen losses are reduced from 20-25% to 1.5-3%. Analytical studies show that as a result of processing 1 tonne of cattle manure, 23.22 g^3 of biogas with an energy equivalent of 510 MJ can be obtained. It is also shown that by making changes made by accelerated biothermal composting energy costs for the production of an equivalent (according to NPK) amount of mineral fertilisers are reduced by 895 MJ. However, it should be borne in mind that in the conditions of construction and maintenance of a biogas system, the high start-up and operating costs leads to the use of accelerated biothermal composting technology at the first stage of processing bio-raw materials. The results obtained can be used as the basis for a modern methodology for calculating the expediency of application of a particular technology depending on the operating conditions of the agricultural enterprise and the technological task regarding the volume of production of finished products. This would allow determining the rational parameters of the bioenergy system and increase the energy and ecological efficiency of biogas and high-quality compost production processes from organic raw materials

Keywords: anaerobic methane fermenztation, accelerated biothermal composting, bioenergy conversion, organic raw materials

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INTRODUCTION

The agro-industrial sector is one of the most important links in the economic system of most countries of the world with a market economy (Grechko *et al.*, 2020). The production of agricultural products is associated with the buildup of a significant amount of organic raw materials, the useful disposal of which is not given enough attention (Shevchenko & Lyashenko, 2012). The European legislative framework provides for a number of regulatory documents on waste management, the basic of which are the Nitrates Directive (Council Directive 91/676/EEC, 1991) and the Industrial Emissions Directive (Directive 2010/75/EU, 2010). These documents provide for: the implementation of a comprehensive assessment of the negative impact on the environment with the identification of affected areas; environmental monitoring; the use of highly effective available technologies; prevention measures and an action plan to minimise risks at both local and national levels. This approach reduces environmental risks and promotes the development of technologies for further processing of waste, including biological ones. Modern Ukraine, which is integrating into the European Economic Area, is adapting its regulatory framework to the European one, including in the context of bio-waste management.

A powerful source of bio-waste from the agro-industrial sector in the vast majority of countries of the world is animal husbandry, partly – pig and poultry farming (Yoshizaki *et al.*, 2013). In these industries, organic raw materials such as milk, meat, and eggs are a commodity – organic fertiliser, which, unfortunately, is almost not applied to the soil to maintain its fertility (Shevchenko *et al.*, 2009). In Ukraine, of all types of bio-waste, cattle manure is the most prevalent, which can be used both for the production of energy (biogas) and bio-fertilisers (Shevchenko *et al.*, 2011). In Ukraine, in contrast to the EU countries, where small and medium-sized farms with a focus on organic production are developing, more than 50% of livestock farms are industrial facilities with significant volumes of bio-waste. In animal husbandry, about 100 million tonnes of manure is accumulated, in crop production – more than 50 million tonnes of biomass, with manure accounting for more than 60%.

Singapore researchers (Deng *et al.*, 2020) note that a promising method of processing bio-waste is the production of biogas, which contains 60-75% CH4 with a calorific value of 20-25 MJ/m^3. In particular, biogas plants are capable of processing manure of pigs and cows, poultry droppings, plant waste, sewage sludge, waste from animal slaughtering shops, etc. The most effective bioreactors are the BRK-100 cassette type of cyclic action with an average daily biogas capacity of 1.5-2 m^3 with 1 m^3 of bioreactor working volume. Biogas production waste mixed with plant biomass is a raw material for fertiliser preparation.

According to Kudria *et al.*, 2020), although Ukraine has rich scientific and production potential, unfortunately, it has not been implemented. In Ukraine, the first experimental biogas plant was built in 1954 and successfully operated on the premises of the CNIPTIMET experimental farm (Khortytsia Island, Zaporizhzhia) (Shevchenko *et al.*, 2009). In the 1970s, teams of researchers from DEIAMC, ILM NAAS (Zaporizhzhia), UkrNDIagroproekt, UkrCTM and others designed and put into operation bio-installations on the basis of the poultry farm "Kyivska", in the state farm "rosiya", Zolotonosha district, Cherkasy Oblast, in the Doslidnytske village of the Kyiv Oblast (Shevchenko *et al.*, 2011). In 2003, at the pig farm of the Agro-Oven company in the Olenivka village, Magdalynivskyi district, Dnipropetrovsk Oblast, within the framework of the Dutch government's technical assistance project to Ukraine with the participation of the Dutch company BTG Netherlands, STC Biomasa (Kyiv) and UkrNDIagroproekt (Kyiv), a large biogas plant for processing manure effluents from 15 thousand pigs was put into operation (Shevchenko & Lyashko, 2012). The plant's biogas capacity reached 3,300 m^3/day. Capital investments in the project amounted to about USD 400 thousand with a payback period of more than 10 years. However, the construction and operation of biogas plants in Ukraine and in European countries require significant investment, which, at least partially, should be covered by appropriate state or regional programmes.

For the purpose of partial self-sufficiency of biogas projects, the researchers (Ning *et al.*, 2021) propose to combine the production of biogas and biofertilisers. As part of the study, biogas production residues were sequentially processed by thermophilic composting and vermicomposting. This combination allowed eliminating heavy metal inclusions and producing high-quality organic fertilisers in accordance with existing requirements for microbiological indicators. The disadvantage of the proposed solution is the duration of production of biofertilisers, which was 37 days. Reducing the duration of fertiliser production would increase the efficiency of this process and increase the volume of processed raw materials.

Researchers (Meng *et al.*, 2020) also sought to investigate the feasibility of using full-scale composting based on biogas fermentation residues. The use of *Anaerolineaceae* and *Limnochordaceae* bacteria and Chaetomium fungi reduced the duration of the process to 30 days. The resulting compost had the following composition as a percentage of absolutely dry matter: nitrogen $N_{tota}l$=2.04%; P_2O_5=1.89%; K_2O=1.68%; S_{total}= 21.88%; ash content – 14.8%; humidity – 57%. The humidity of the original substrate was 61%.

Bai *et al.* (2020) investigated the effect of different proportions of cattle manure and biogas production residues on the degree of degradation of lignocelluloses and humification during composting. An increase in the content of cattle manure extended the duration of the thermophilic phase of the process, contributing to the degradation of organic matter in the substrate and increasing the degree of humification during composting. Depending on the content of cattle manure in the substrate, the cellulose content in the finished compost was 3.9-22.81% less than the cellulose content in the compost from the base substrate (waste from biogas production). Moreover, the addition of cattle manure to the base substrate increased the content of humic acids by 17.21-26.02%. The decision to add 6.7% of cattle manure to the original substrate was optimal in terms of compost quality. The study also raises the question of determining the priority for each farm (region, state) – energy production or restoration of the humus layer of the soil.

Chadwick *et al*. (2015) present solutions to research, infrastructure, socio-economic, and communication problems to ensure the integration of animal husbandry bio-waste into the restoration of soil fertility at the level of fields, farms, regions, etc. This is necessary to protect the environment, reduce the need for the production and use of inorganic fertilisers, and increase farmers' incomes. Practical solutions for the efficient processing of cattle manure in the practice of Chinese enterprises are also presented. The existing barriers to the introduction of green technologies are evaluated, future challenges for rational waste management in this industry are outlined, and the role of the state in this issue is indicated.

The degradation of arable land in Ukraine and the growing energy needs of industry and the population pose a challenge to society to find the best ways to solve these problems. Therefore, the issue of finding engineering and technological solutions for the introduction of various technologies, calculating the economic efficiency of the proposed solutions, and the ability to meet both environmental (recycling of agricultural waste with fertiliser production) and energy (production of heat and electric energy) needs simultaneously remains relevant.

Therefore, *the purpose of the study* is to increase the efficiency of the manure processing system with the subsequent production of biogas and compost by consistently implementing anaerobic and aerobic fermentation technologies.

Object of study – cattle manure processing systems.

Subject of study – interrelation of the sequence of operations for processing cattle manure and the energy and ecological efficiency of such systems.

Hypothesis – the use of aerobic fermentation (composting) after anaerobic digestion would increase the energy and ecological efficiency of the cattle manure processing system.

To achieve this goal, it is necessary to solve the following tasks: 1) analyse closed systems for the production of crop and livestock products; 2) determine the shares of organic livestock waste that should be used for the production of fertilisers and energy; 3) establish the energy and ecological efficiency of the cattle manure processing system with simultaneous production of biogas and compost.

MATERIALS AND METHODS

Methods of scientific search, analysis and synthesis, comparison, statistical methods of analysis and forecasting were used to solve the tasks set. The block diagram of biomass transformation in a closed cycle is developed on the basis of analysis of data from studies by Ukrainian and foreign researchers. The table of energy potential of biogas in Ukraine was compiled based on statistical data for 2010-2021 on the number of livestock at enterprises of the agricultural sector of Ukraine, the amount of waste from the livestock industry, the physical and chemical characteristics of waste from this industry, etc. (Ukraine in numbers 2021, 2022; Animal husbandry of Ukraine 2020, 2021). Based on these data, a schedule of the annual production of cattle manure in Ukraine was also built. The diagram of anaerobic processing of organic waste with the production of biogas and fertiliser and the scheme of technological aspects of manure processing, depending on its moisture content, compiled based on the authors' own developments and practical data obtained at the experimental farm CNIPTIMET (Khortytsia Island, Zaporizhzhia) and the Agro-Oven enterprise (Olenivka village, Dnipropetrovska Oblast).

The scheme of energy balance of feed costs in the cattle body, considering the mineralisation of its waste, was developed on the basis of data obtained by the authors of this study.

Comparative indicators of anaerobic digestion technology and accelerated biothermal composting technology during cattle manure utilisation are presented on the basis of statistical data of the Agro-Oven enterprise (Olenivka village, Dnipropetrovsk Oblast).

The block diagram of transport costs in the implementation of organic waste disposal technology was developed considering the technical and economic performance indicators of the enterprise Agro-Oven for 2010-2020, analysis of biogas and fertiliser production technologies used at the enterprise, and consumer needs. The needs of consumers for fertilisers and energy were determined by a questionnaire (550 forms).

RESULTS AND DISCUSSION

On June 24, 2022, in Kyiv and July 13, 2022, in Prague (Czech Republic), an agreement was signed on Ukraine's accession to the LIFE Programme to address climate change and environmental issues, including air, soil, and water pollution, biodiversity conservation through demonstration of innovative solutions and methods and capacity building of the actors involved (EU LIFE programme, 2022). In addition, on 03.09.2014, the Cabinet of Ministers of Ukraine has submitted Decree No. 791-r

"On Approval of the Action Plan for the implementation of Directive 2009/28/EC of the European Parliament and of the Council" (2014) developed in accordance with the norms of Directive 2009/28/EC of the European Parliament and of the Council on the promotion of the use of energy produced from alternative sources (2010). According to these documents, Ukraine undertakes to develop technical and technological solutions to replace natural energy sources with alternative ones and reduce the harmful impact on the environment.

However, the question of the feasibility of producing energy (biogas) or restoring the state of soils (production of organic fertilisers) should be considered in the context of each individual enterprise, taking into account the state of its economic activity, location, financial capabilities, etc. To understand the needs of enterprises and find optimal energy, environmental and technological solutions in each individual case, a block diagram of biomass conversion in a closed cycle was developed (Fig. 1).

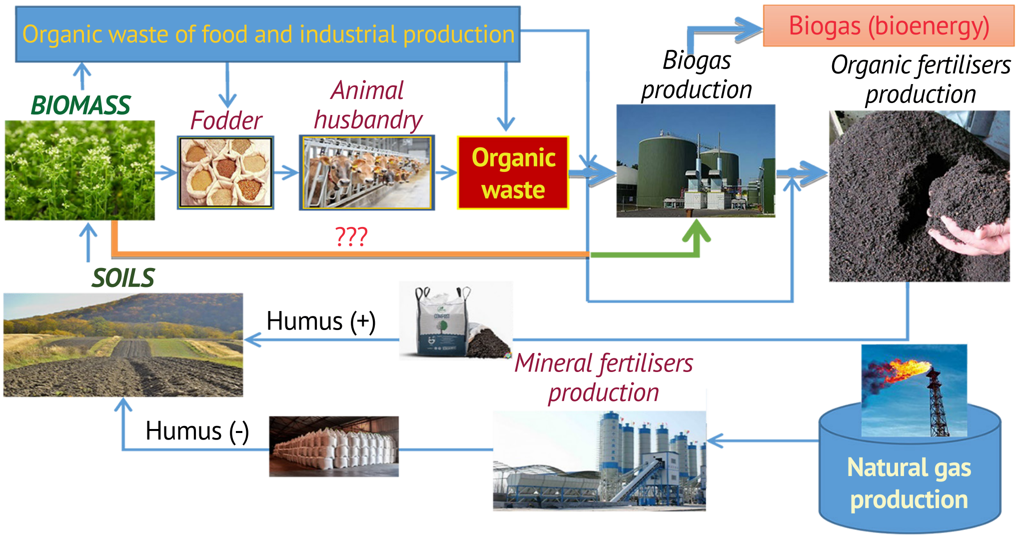

***Figure 1**. Block diagram of biomass conversion in a closed cycle*

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

The diagram includes the production of animal feed from biomass, followed by the production of organic fertilisers and biogas. The conventional technology of producing mineral fertilisers and applying them to the soil is also presented. As an alternative that helps restore the humus layer of soils, it is proposed to replace synthetic fertilisers with organic ones.

According to Kudria *et al.* (2020), despite the fact that animal husbandry in Ukraine is in decline, the total potential for biogas production remains significant and amounts to up to 2 billion m^3/year. However, the lack of a plan for the development of the livestock industry without a certain number of cattle per 100 hectares of arable land (at least 40 animal units) would lead to the loss of fertile soils in Ukraine. An increase in the number of cattle per 100 hectares implies an increase in the yield of organic material (manure), which would contribute to the growth of the potential of biogas production by 2-3 times. If manure is used in a mixture with other organic residues of agricultural production (silage, grass, food waste), the potential for biogas production can increase up to 20 times. Under such conditions, the increase in the technical potential of biogas production would reach 1,790 million m^3/year (1.3 million tonnes of fuel equivalent/year). To understand how much of the conventional energy of Ukraine can be replaced by energy obtained during the utilisation of biogas, Table 1 has been developed based on statistical data for 2010-2021.

***Table 1**. Energy potential of biogas in Ukraine*

Type of biogas	Theoretical potential, mln tonnes of fuel eq.	Coefficient of technical accessibility	Technical potential, mln tonnes of fuel eq.	Energy utilisation rate	Economic potential, mln tonnes of fuel eq.
Biogas from animal husbandry waste	3.27	0.7	2.45	0.3	0.76
Biogas from poultry farming waste	2.69	0.7	2.02	0.3	0.61
Biogas from corn as an energy crop	1.59	0.7	1.11	1.0	1.11

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

Based on the data in Table 1, Ukraine has sufficient potential for the production of biogas from all types of bio-raw materials, but high initial investments and significant payback periods for projects negate the advantages of this technology. The situation is gradually changing with the increase in tariffs for the main types of energy resources in Ukraine. In proportion to their increase, interest in implementing such projects is also growing. New biogas plants will be built in Ukraine in the near future. Analysing the long-term activity of the Agro-Oven enterprise, it can be concluded that it is possible to reduce the payback period of a biogas project by successfully combining several technologies. The most efficient biogas technologies should combine the use of anaerobic digestion and accelerated biothermal composting technologies sequentially (Fig. 2).

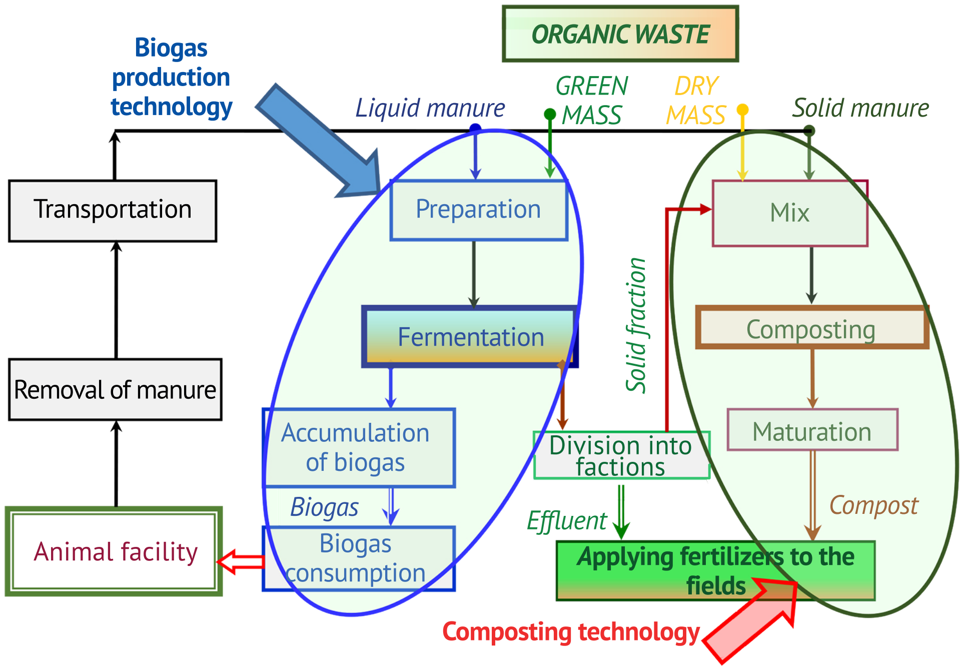

***Figure 2**. Anaerobic processing of organic agricultural waste with the production of biogas and fertilisers*
***Source:** (Shevchenko & Lyashenko, 2012)*

Based on Figure 2, biogas systems should be designed together with composting and organic fertiliser production systems, considering the physical and chemical properties of manure, in particular, humidity (Fig. 3).

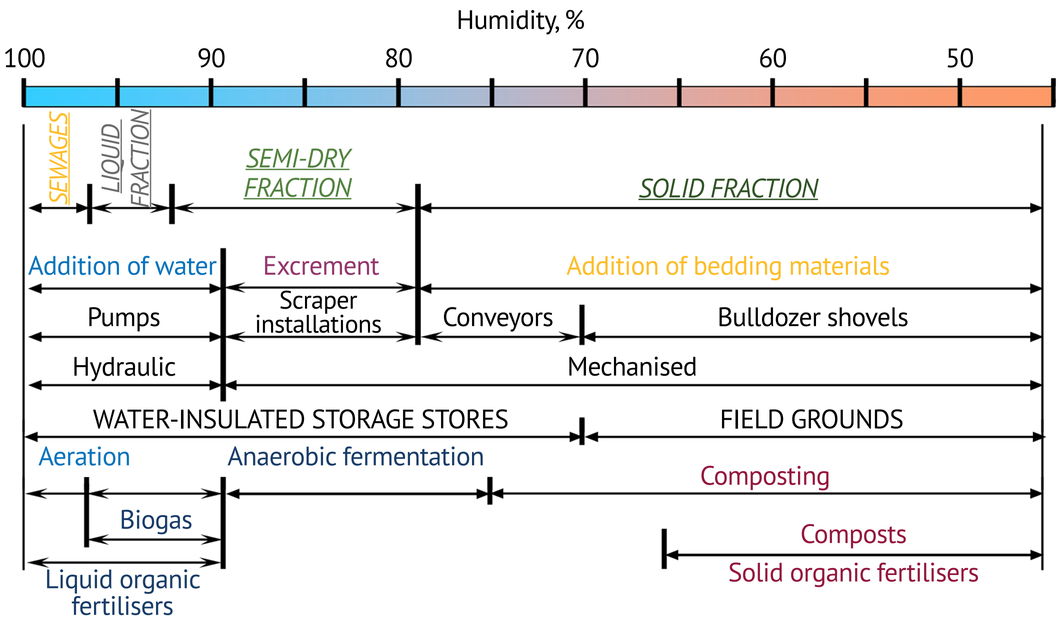

***Figure 3**. Scheme of technological aspects of manure processing depending on its humidity*
***Source:** compiled by the authors*

Over the past 10 years in Ukraine, the vast majority of cattle manure was litter and came from households (Fig. 4). Admittedly, the energy balance of feed costs in the body of cattle allows determining the energy of "fuel" biogas at the level of 17% and the energy of solid fertiliser – at the level of 35.5%. Setting up organic waste processing equipment for a specific technological process should take place in accordance with the volume of bio-raw materials that can be used for the production of one (biogas) or another (fertiliser) final product. Technologies, in turn, must consider the degree of decomposition of organic matter depending on the final product – biogas or organic fertilisers.

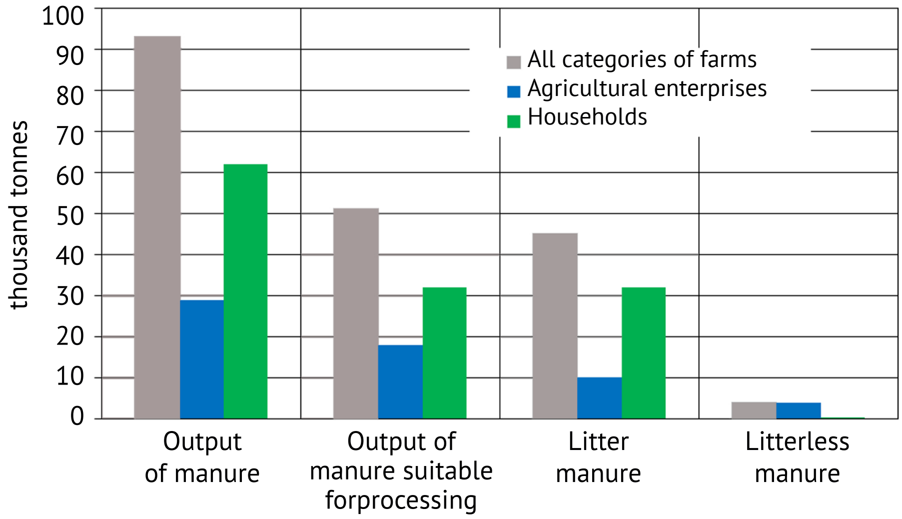

Figure 4. *Annual production of cattle manure in Ukraine during 2010-2020*
Source: *calculated by the authors*

According to the authors' calculations, to meet Ukraine's needs for biogas, it is necessary to build about 3,000 biogas plants with an average volume of 1,000 m^3, including: 295 installations at pig farms; 130 installations at poultry farms; 2,478 installations in other livestock farms and processing enterprises.

However, despite the prospects, the widespread introduction of biogas technologies is hindered by a number of factors, in particular, the most significant are technological ones:

– lack of tested Ukrainian technologies for solid-phase methane fermentation of litter manure, which accounts for more than 80% of the country's manure biomass (Fig. 4);

– lack of modern highly efficient installations for the production and use of biogas;

– lack of multi-tonnage agricultural waste processing plants for the production of biologically active and highly efficient fertilisers to accelerate energy-saving reproduction of soil fertility;

– lack of coordination between research and development activities in this area and specialised design institutions and equipment manufacturers.

Researchers (Deng *et al*., 2020; Chadwick *et al*., 2015) note the similarity of technological factors that hinder the introduction of biogas technologies in Singapore and China.

As the experience of functioning of the Agro-Oven enterprise shows, the efficiency and use of the potential of biogas technologies and bioenergy installations largely depends on the main purpose of their creation, because this determines their technical equipment, complexity, completeness, and hence the cost of capital structures and maintenance. In particular, the introduction of such installations provides for:

– rational use of biomass energy of agricultural waste (animal, plant, municipal origin, etc.) with the production of biofuels and attracting additional non-conventional and renewable energy sources in the form of biogas to the energy balance. The real potential for obtaining biogas in the agro-industrial complex of Ukraine only from the processing of livestock waste (manure) is 0.3-0.5 billion m^3/year, while the total biogas potential in animal husbandry is 2.5 billion m^3/year;

– obtaining high-quality biofertilisers (more than 10-20 million tonnes/year) and thus increasing the yield of agricultural crops by 10-20%, and most importantly – meeting the requirements for preserving the humus composition and fertility of significantly depleted soils in Ukraine in recent years;

– diversification of agricultural production through trade in new products (bio-phytopreparations, vitamins), quotas and reduction of greenhouse gas emissions (carbon dioxide and methane), which make up 96% of the biogas composition. The average profit from the sale of greenhouse gas emission quotas can reach more than EUR 4 billion per year in animal husbandry alone;

– environmental protection: reducing or preventing environmental pollution by secondary products (waste) of agricultural production; improving the environmental, sanitary, and hygienic situation in the region (by deodorisation, devitalisation, disinfection, treatment of wastewater from organic substances);

– more complete involvement of chemical elements in the natural cycle, in particular biogenic ones – C, N, P, K, including in the cycle "soil environmen – farm – soil environment", restoration and stabilisation of soils and their fertility. During anaerobic methane fermentation, more than 55% of carbon is not only not lost, as as a result of manure decomposition during composting, but is disposed of in the form of high-calorie methane gas. Accordingly, nitrogen losses are reduced from 20-25% to 1.5-3%. In general, during fermentation, the total content of the main biogenic elements of manure does not change, with the exception of ammonia nitrogen, an increase in the content of which up to 15% increases the digestibility of agrochemical (biogenic elements) substances by plants, especially in the first year of application;

– reduction of the cycle, energy and capital costs in the treatment systems of "secondary" waste media and wastewater in comparison with standard solutions.

As part of the study, the distribution of the potential of animal husbandry bio-waste across historically formed natural and economic zones and administrative territories of Ukraine is analysed. According to the results of the analysis, the first place – more than 43% belongs to the forest-steppe zone, followed by the steppe zone located in the southern part of the country, which accounts for 30% of possible biogas production. In the north-western zone of Polissia, the potential of biogas is 27%. Thus, rural residents of the steppe zone should be considered the most potentially provided with biogas, and residents of Polissia should be considered the least provided. Notably, in the steppe zone, there is a significant scientific and industrial potential for Ukraine, sufficient for the production and equipping all regions with modern equipment for processing manure to obtain environmentally friendly biofertilisers and biogas. Areas with significant opportunities for biogas production due to developed animal husbandry (more than 100 million m^3/ year) include Vinnytsia, Khmelnytskyi, Lviv, Poltava, Zhytomyr, Chernihiv oblasts, etc.

It is possible to increase the efficiency of bio-waste processing and increase the profits of enterprises by developing a manure processing system with simultaneous production of biogas and compost. For this purpose, the technology of accelerated biothermal composting is analysed (Fig. 5).

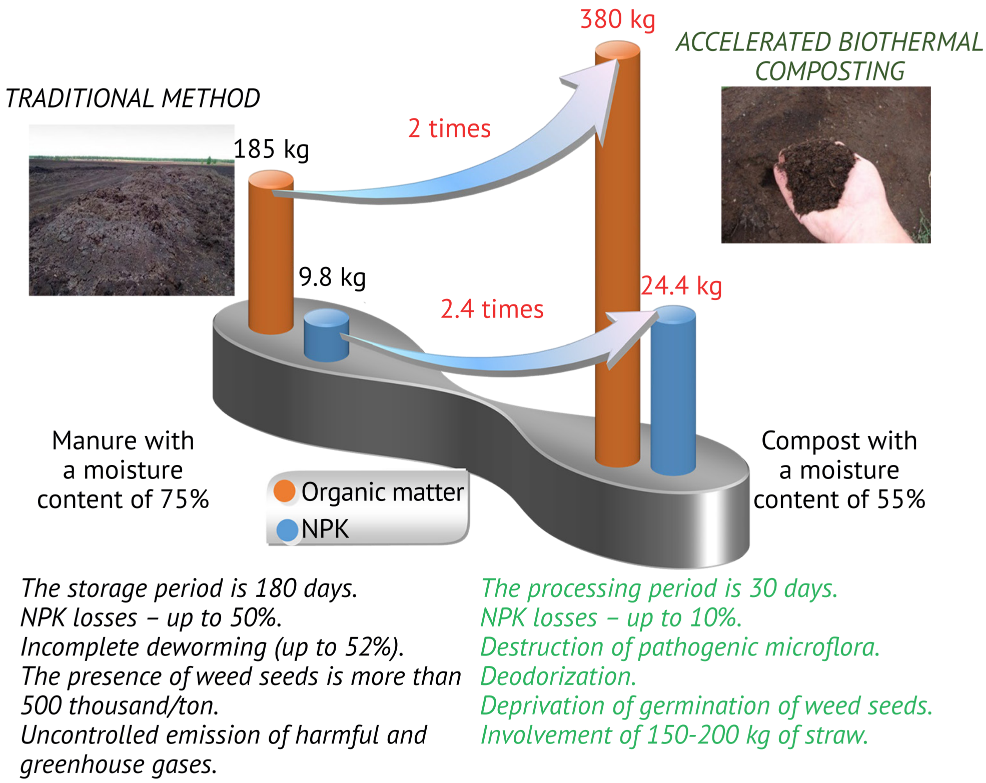

Figure 5. *Efficiency of accelerated biothermal composting in the calculation of processing 1 tonne of cattle manure*
Source: *compiled by the authors*

This type of composting can be not only an application to biogas technologies, but also an independent technological solution to the problem. Accelerated biothermal composting – is a controlled process that allows setting and maintaining optimal conditions necessary for the flow of microbiological processes (humidity, temperature, structure, physicochemical composition, the presence of biogenic substances) and minimises the time of waste processing into high-quality compost. This type of composting can be used: directly at livestock facilities of various sizes with litter and non-litter keeping of animals; during the reconstruction of existing sites for compost production, including as part of biological manure processing facilities; in all climatic zones of Ukraine. For example, 1 tonne of cattle manure processed using accelerated biothermal composting allows increasing the production of organic matter by 2 times and NPK by 2.4 times (Shevchenko *et al*., 2011). For comparison, according to studies (Bohacz, 2018) using the same technology, the production of organic matter from 1 tonne of cattle manure increases by 1.78 times, and NPK – by 2.19 times. Accelerated biothermal composting technology requires preliminary preparation of mixtures for composting and creation of optimal conditions for the passage of microbiological processes in the prepared mixtures. This technology provides for the completion of the process with the minimisation of necessary technological and resource costs; quality assurance of the final product – compost as an organic fertiliser; sanitary and environmental safety of both the production itself and the resulting compost.

For a comparative analysis of the use of two technologies for the disposal of cattle manure, the algorithm and calculation method developed as part of the study were used (Table 2). For anaerobic digestion, 450 kg of water was added per 1,000 kg of cattle manure, and for accelerated biothermal composting – 220 kg of straw.

***Table 2**. Comparative indicators of anaerobic digestion technology and accelerated biothermal composting technology during cattle manure recycling*

Name	Designation	Unit of measurement	Anaerobic digestion technology	Accelerated biothermal composting technology
Volume of processing of cattle manure	M_g	kg	1,000	
Chemical properties of manure (by dry matter)				
Nitrogen		%	3.2	
Phosphorus		%	1.8	
Potassium		%	5	
Introduced components:				
Water	M_w	kg	450	–
Straw	M_{str}	kg	–	220
Volume of prepared mass	M_{prp}	kg	1,450	1,220
Humidity	W	%	92	75
Organic matter content:	R_{orm}	kg	98.60	291.78
Energy potential depending on the degree of decomposition of organic matter, E:				
10%		MJ	–	525.20
15%		MJ	–	787.80
20%		MJ	390.46	1,050.39
25%		MJ	–	1,312.99
30%		MJ	585.68	1,575.59
40%		MJ	780.91	
50%		MJ	1,015.19	
Equivalent consumption of energy produced for own technological needs				All the released thermal energy is used to evaporate moisture
15%		MJ	–	787.80
20%		MJ	230.03	1,050.39
25%		MJ	–	1,312.99
30%		MJ	287.54	1,575.59
40%		MJ	345.04	
50%		MJ	–	
10%		kg	–	-175.07
15%		kg	–	-262.60
20%		kg	1,109.35	-350.13
25%		kg	–	-437.66
30%		kg	1,132.35	-525.20
40%		kg	1,155.36	

Table 2, Continued

Name	Designation	Unit of measurement	Anaerobic digestion technology	Accelerated biothermal composting technology
50%		kg	1,182.97	
Solid fraction (compost) transportation volumes			Solid fraction after separation of the fermented mass	Compost
10%		kg	–	1,015.48
15%		kg	–	913.36
20%		kg	320.93	811.23
25%		kg	–	709.11
30%		kg	288.07	606.99
40%		kg	255.20	
50%		kg	215.76	
Transportation costs (conditional, for the degree of decay of 30%):			Fermentation	Composting
manure to sewage treatment plants (0.5 km)		t*km	0.50	0.50
water (0.5 km), straw (5 km)		t*km	0.23	1.10
liquid fraction (5 km)		t*km	5.66	0.00
solid fraction/compost (5 km)		t*km	1.44	3.03
Total		t*km	7.83	4.63
Vehicles				
Liquid fertilisers			Tractor + tanker	–
Solid fertilisers			Tractor + spreader	Tractor + spreader
Properties of solid fertilisers				
Dry matter content		kg	34.57	217.43
Organic matter content		kg	23.78	149.59
Macronutrient content:				
N		kg	1.11	6.96
P		kg	0.62	3.91
K		kg	1.57	10.87

Source: *compiled by the authors*

It is evident that the results of calculations for the disposal of pig manure or bird droppings will be different, but the algorithm and methodology of these calculations will remain unchanged. Figure 6 shows the calculation of transport vehicles costs for typical implementation conditions for each of the technologies.

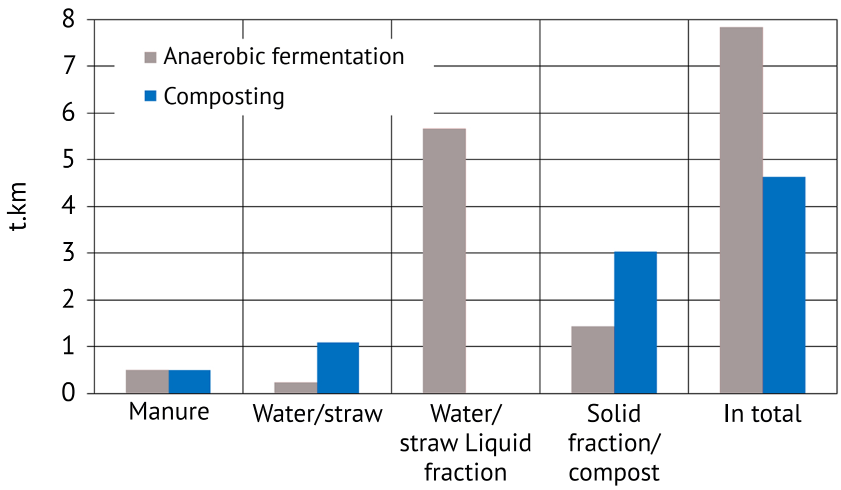

Figure 6*. Structure of transport costs in the implementation of comparative technologies for organic waste disposal (t.km)*
Source: *calculated by the authors*

The results of calculations are the basis for analysing the economic feasibility of using various technological solutions for organic waste disposal. The structure of calculations, depending on the realities of the agricultural activity of a given enterprise, allows determining which area of organic matter processing should be preferred and at what stage of development. Calculations show that as a result of processing 1 tonne of cattle manure, 23.22 g^3 of biogas can be obtained (with an energy equivalent of 510 MJ), and by applying the obtained organic fertilisers to reduce energy costs for the production of an equivalent (according to NPK) quantity of mineral fertilisers by 895 MJ. However, the cost of building and maintaining a biogas system is such that at the first stage of cattle manure recycling, it is more expedient to apply accelerated biothermal composting technology.

Zhou *et al*. (2012) note that it is advisable to process cattle manure in the form of mixtures with the addition of plant residues of agricultural production, and the operation of preliminary microbial treatment of these residues should be included in the anaerobic digestion technology. For example, the addition of pre-treated corn plant residues to cattle manure increased the yield of biogas during anaerobic digestion by 23.2%-40.7%. In turn, the researchers (Kudria *et al*., 2020) also note the need for preliminary preparation of mixtures for composting and the creation of optimal conditions for the passage of microbiological processes in the prepared mixtures in the process of accelerated biothermal composting during the recycling of cattle manure. This should be considered when performing further calculations for the effective disposal of cattle manure and bird droppings.

Researchers (Ji *et al*., 2022) note that the development of pig farming can also be a powerful source of bio-waste for the production of biogas and compost. In particular, in the structure of the energy potential of bio-waste of the people's Republic of China, pig farming occupies more than 50% in terms of the volume of manure yield. Thus, potentially the share of biogas from pig waste can be 17% or more. In addition, pig manure effluents are the largest environmental pollutants and their processing into compost or biogas will contribute to compliance with mandatory environmental protection measures.

The cost of biogas, in turn, will be economically substantiated when the ratio of the cost of biogas production and the unit cost of other energy carriers is adequate to the ratio of the corresponding energy values in units taken during their implementation. According to researchers from the EU countries (Bai *et al*., 2020; Deng *et al*., 2020), energy costs for the implementation of the technological process of biogas production in countries with warm climates are minimal, and the share of commercial biogas is quite high – from 80 to 100%, while in temperate and cold climates (for example, in Germany, Ukraine) this share is in the range from 30 to 50%. For farms in Denmark, the Netherlands, and Germany, the return on investment in biogas technologies for cattle from 180 to 200 cows is 5-7 years old.

Thus, biotransformation of biomass energy into biogas by methane fermentation allows comprehensively solving a number of important tasks – energy, social, agrochemical, and environmental (Channarayappa *et al*., 2018; Yoshizaki *et al*., 2013). An important component of the efficiency of biogas technology is the existence, along with direct effects (obtaining biogas and high-quality fertilisers), of a number of indirect effects, the significance of which is based on both economic indicators and national priorities. The latter include: reducing the energy consumption component in the cost of production; saving energy resources in the rather expensive production of mineral fertilisers; reserving energy for the purpose of continuous implementation of the main technological processes in the production of livestock products; reducing the load on the soil from the use of herbicides.

CONCLUSIONS

The introduction of biogas technologies is economically feasible in full only within the framework of the functioning of closed systems for the production of crop and livestock products. Organic waste of animal origin is the main source of soil fertility renewal. Organic fertilisers with biogas should become a highly marketable product.

The main source of biogas production is cattle manure, which accounts for more than 84%. At the same time, the share of the potential energy of biogas reaches 85% (from the number of cattle – 63%). The use of bio-waste from the livestock industry for the production of biogas should be limited to the level of 25 to 30% of organic decomposition. The full use of organic waste from this industry for energy purposes is impractical.

The efficiency of the manure processing system with simultaneous production of biogas and compost is, depending on the economic condition of the enterprise, 10 to 35% higher compared to the production of only biogas or only compost. As a result of processing 1 tonne of cattle manure, 23.22 g^3 of biogas can be obtained (with an energy equivalent of 510 MJ), and by applying the organic fertiliser produced, the energy inputs for producing an equivalent (at NPK) amount of mineral fertiliser can be reduced by 895 MJ. Due to the high costs of building and maintaining a biogas system, it is advisable to use accelerated biothermal composting at the first stage of waste disposal.

Further study will be aimed at developing the basic principles of organic farming based on an economically and environmentally sound level of bioconversion of organic biomass in artificial conditions to provide nutrition to the soil environment and field crops.

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Енергоекологічні передумови вибору технологій переробки органічних відходів тваринництва

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Анотація. Для сучасної України та країн Європи актуальними є питання відновлення ґрунтів після інтенсивного обробітку та зниження собівартості аграрної продукції шляхом включення в енергозабезпечення технологічних процесів енергії на основі альтернативних джерел. Тому значна увага приділяється розвитку біогазових технологій та виробництву органічних відходів. Метою дослідження є підвищення ефективності системи переробки гною з подальшим виробництвом біогазу і компосту шляхом послідовного виконання технологій анаеробного та аеробного зброджування. Представлено економічно доцільні шляхи використання органічних відходів тваринництва. Доведено, що впровадження біогазових технологій є економічно доцільним лише за умов функціонування замкнених систем виробництва продукції рослинництва і тваринництва. Найбільш ефективним виявилося поєднання послідовної реалізації технології анаеробного зброджування та прискореного біотермічного компостування. Анаеробне метанове зброджування, на противагу процесу компостування біосировини, дозволяє понад 55 % вуглецю утилізувати у вигляді висококалорійного газу метану, за рахунок чого втрати азоту знижуються із 20–25 % до 1,5–3 %. Аналітичні дослідження дозволяють стверджувати, що в результаті перероблення 1 тони гною великої рогатої худоби можна отримати 23,22 м^3 біогазу з енергетичним еквівалентом 510 МДж. Також показано, що за рахунок внесення вироблених шляхом прискореного біотермічного компостування органічних добрив енерговитрати на виробництво еквівалентної (за NPK) кількості мінеральних добрив скорочуються на 895 МДж. Проте, слід враховувати, що за умов побудови та обслуговування біогазової системи висока вартість стартових і поточних витрат зумовлює на першому етапі перероблення біосировини використовувати технологію прискореного біотермічного компостування. Отримані результати можуть бути покладені в основу осучасненої методології розрахунків доцільності застосування тієї чи іншої технології залежно від умов функціонування аграрного підприємства та технологічного завдання щодо обсягів виробництва готової продукції. Це дозволить визначати раціональні параметри біоенергетичної системи та підвищити енергоекологічну ефективність процесів виробництва біогазу та високоякісних компостів з органічної сировини

Ключові слова: анаеробне метанове зброджування, прискорене біотермічне компостування, біоенергоконверсія, органічна сировина

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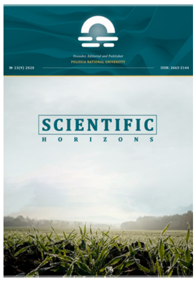
Scientific Horizons, 25(10), 99-106



UDC 539.1.04

DOI: 10.48077/scihor.25(10).2022.99-106

The Influence of the Radiation Background of City-Forming Settlements with NPPs on Public Health and the Environment

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Article's History:
Received: 09/13/2022
Revised: 11/02/2022
Accepted: 11/29/2022

Suggested Citation:
Bolotnikova, A., & Malyshevska, H. (2022). The influence of the radiation background of city-forming settlements with NPPs on public health and the environment. *Scientific Horizons*, 25(10), 99-106.

Abstract. The radioactive decay of elements as a result of a nuclear reaction is a powerful source of energy used in the production of electricity and heat in cities close to NPPs. The problem of using this kind of energy is the danger of radiation exposure. The production of nuclear energy has many advantages, including the profitability of the final product and its low cost; on the other hand, the half-life products of radionuclides in the composition of gas-aerosol emissions from ventilation pipes settle in the environment on the territory of city-forming nuclear power plants. The duality of the problems of the impact of radiation background on the urban areas near NPPs has become the purpose of this study. It is necessary to investigate the negative effect of radioactive waste emissions during the normal operation of nuclear power plants. For this purpose, the method of a project experiment was used, during which, using laboratory monitoring of external radiation safety and an automated radiation monitoring system, indicators of exposure dose capacities were collected from points in the 30-kilometre zone around the NPP. As a result of the monitoring of radiation samples from soil, atmospheric air and precipitation, and reservoirs, it was revealed that the natural radiation background is insignificant; the probability of harm from radiation exposure is small and insufficient for the development of radiation sickness. However, potentially unsafe sources of radiation exposure have been identified, such as natural radiation – the consumption of contaminated food, solar and cosmic radiation from radioactive elements present in the bowels of the earth; radionuclides, whose emissions uncontrollably occur into the atmosphere; radioactive waste, the disposal and storage technology of which is economically costly. Therefore, it is justified to conduct regular design experiments to check the operability of automated radiation monitoring systems. The materials of the study are of practical value for chemists, environmentalists, and ecotechnologists working at NPPs that monitor safety for human health and environmental protection in the field of atomic energy use

Keywords: nuclear energy, nuclear power plants, radiation, exposure dose indicators

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INTRODUCTION

Ionising radiation enters the environment from various sources – streams of photons or other elementary particles capable of ionising matter. In the process of a nuclear chemical reaction, radioactive elements are released, the energy of which is converted into other types of energy, such as heat or electricity. The background radiation can come from both natural and artificial sources. Unfortunately, the half-life products of artificial nuclei, when ingested into the human body, replace living cells, destroying tissues from the inside (Environmental Safety Report, 2020).

P. Pereira *et al.* (2022) in their study provide reports on how some radionuclides affect the human body. Thus, the radionuclide Caesium-137 causes sarcoma, Strontium-90 replaces calcium, causing leukaemia, bone and breast cancer; Krypton-85 leads to skin cancer. The main organs and parts of the human body that take on radiation in the first place: skin, bone tissue, bone marrow, lungs, stomach, intestines, inguinal zone; the thyroid gland and spleen are the next to be exposed to radiation; the trachea and liver are the last. The changes in the environment that the radiation background produces are caused, firstly, by the extraction of raw materials, during which the ecosystem of soil and vegetation is destroyed, the atmosphere and the aquatic environment are polluted by radioactive and chemical products. Secondly, the reproductive capacity of flora and fauna is reduced, and species mortality and morbidity are increased. The risks lie in the fact that environmental pollution by city-forming nuclear power plants entails an accelerated process of extinction of mankind, since by consuming contaminated food and water, humans and animals expose themselves to radiation from the inside, thereby accelerating the process of spreading the radiation background.

The amount of the dose received, the duration of exposure to radiation, and the state of human health and wildlife are the factors that affect the nature of the course of radiation sickness or death. The power of the absorbed dose of 10,000 rad on the human body is fatal within a few hours or days (depending on the degree of damage). The indicator of natural radiation that a person acquires from terrestrial radiation is 0.1 rad (Pereira *et al.*, 2022).

Modern studies by Ukrainian (Hromyka, *et al.*, 2020; Zabulonov, *et al.*, 2021) and Western European researchers (Partanen *et al.*, 2020; Oe *et al.*, 2021; Boldsaikhan, & Juyoul, 2021) indicate that nuclear power has been firmly embedded in the industry of the world economy. V. Burtniak *et al.* (2018) and O. Trofymchuk *et al.* (2021) cite the following statistics in their papers. To date, 31 countries of the world produce electricity and heat with the help of nuclear power plants, and 73 energy facilities are being developed in another 15 countries. 140 surface and submarine ships use nuclear reactors, and in the last century, Soviet and American design engineers used nuclear reactors in spacecraft that are still in Earth orbit. In connection with the facts presented, the thesis that humanity will soon abandon nuclear energy is questionable. Moreover, the search for alternative energy sources is a complex and lengthy process with high resource costs and low performance forecasts. Therefore, the preservation of wildlife and the reduction of human morbidity associated with the effects of radiation on the body is a promising plan for the development of energy technologies of international atomic protection organisations (Shielding radiation…, 2020; Gender + Radiation Impact Project, 2022). The World Nuclear Association (WNA, 2020), analysing trends in the global nuclear industry, notes that compliance with technological standards for the operation of nuclear power plants reduces the risks of environmental pollution, in turn, opponents of such an energy source cite evidence of a threat to human life and natural resources.

This study is aimed at investigating the indicators of the automated radiation monitoring system (ARMS) using the indicators of EDR (exposure dose rate). *The purpose of the study* is to investigate the influence of the radiation background of city-forming nuclear power plants on public health and the environment.

MATERIALS AND METHODS

The study was conducted from January 2020 to December 2021. The following methods were used in the process. The theoretical ones include the analysis and synthesis of academic literature on ecology, biology, chemistry, physics, and nuclear energy. The concretisation and synthesis of theoretical data showed the relevance of the problem under study and allowed setting a goal and objectives. A comparative analysis of the achievements of world scientists in the nuclear power industry was carried out using the method of analogies. An approach to investigating the influence of NPP radiation on the adjacent territories of settlements and wildlife is theoretically modelled. For this purpose, a diagnostic evaluation of the determination of the exposure dose rate was carried out. The empirical study started with the analysis of the experience of energy generating companies of the present and past years, regulatory and educational documentation, and reports on environmental safety. The main experiment took place in three stages: ascertaining, formative, and control. Methods of mathematical statistics and graphical representation (figures, tables, diagrams) were used to summarise the results and generate conclusions. The experimental base of the study was the Scientific and Production Association "Typhoon".

During the first, ascertaining stage, after analysing the necessary scientific and methodological literature, it was decided to investigate the annual indicators of the results of determining the exposure dose rate. A laboratory experiment to control the radiation situation was carried out on the territory of the Khmelnytskyi NPP, on the shore of the Netishinskyi reservoir of the Hnylyi Rih river. The industrial site of the Khmelnytskyi NPP accommodates 2 departments of reactor power units and workshops of construction and installation organisations. The city-forming settlements of residential areas of the Khmelnytskyi NPP form the territories of the Khmelnytskyi (part of the Shepetivskyi district) and Rivne (part of the Rivnenskyi district) oblasts. The release of radionuclides is carried out through ventilation pipes as part of gas-aerosol waste coming from each power unit.

Soil sampling was carried out 1 time a year at 8 radiation monitoring stations. Using the envelope method, 5 soil samples 5 cm deep were excavated in each square with 10 × 10 m sides. Water samples were taken from the nearby Hnylyi Rih river water reservoir. Several samples were taken: one from the basin of the cooling reservoir of the Khmelnytskyi NPP and the second from the water area of the fishing station.

During the next, formative part of the study, in the 30-kilometre zone of the Khmelnytskyi NPP, exposure dose indicators were taken from sensors of the automated radiation monitoring system located at radiation monitoring points at different distances from the NPP. With the help of dosimeters, the indicators of annual dose absorption in settlements were measured. Summing up the above indicators, conclusions were drawn about the state of the radiation background in the atmosphere, soil, and reservoirs. The EDR measurement was carried out with a DRG-01 T dosimeter.

At the final, control stage, after analysing all the data obtained from the annual survey of radiation background indicators from all points on the territory of the 30 km zone of the NPP, it turned out that the indicators of radionuclide emissions increased, but are within acceptable limits. As in general, the data of the dosimeter of the calculation of the EDR, which ranged from 0.09 to 0.16 mSv/h. The sums of all other sample indicators are presented in the following sections using mathematical and graphical methods of providing information.

RESULTS AND DISCUSSION

The industrial site of the Khmelnytskyi NPP is a sanitary zone where any economic activity and permanent residence of people are prohibited, but temporary stay of workers of category A (personnel who work directly with artificial sources of ionising radiation) and B (personnel who do not work directly with artificial sources of ionising radiation, but their workplaces are located in the zone impacts) is allowed. The time spent at the industrial site is limited to 180 days per year. The dose loads on the territory of the sanitary protection zone were estimated from external (emissions of radioactive clouds and their deposits in the soil) and internal (inhalation of atmospheric air and consumption of contaminated food) exposures. Outside the 30-km zone, the radiation background in residential areas of the Khmelnytskyi NPP is determined by the values of the total safety factor on the ground, equal to the ratio of the annual radiation dose to the permissible dose limit.

The population density near nuclear power plants within a radius of 3 km to 10 km is very high and is about 316 people/km^2 at the expense of the urban population, and the density of the rural population in this radial interval is 70 people/km^2. In general, in the 30-km zone around the Khmelnytskyi NPP, the population density is 134 people/ km^2. Currently, the NPP region is densely populated with a fairly high level of industrial and agricultural development, where industrial and transport companies are located. In agriculture, the 30-kilometre zone is an area of intensive agriculture with developed animal husbandry, dairy, and vegetable growing areas.

During the formative experiment, the authors of the study investigated the contribution of various radiation sources to the collective radiation dose of the population of the Netishynskyi district in the vicinity of the NPP (Fig. 1). It can be seen that the main dose of radiation the population of the district receives from enterprises with sources of ionising radiation (65%) and from natural sources (35%). These indicators are different for each of the regions and are not constant over time.

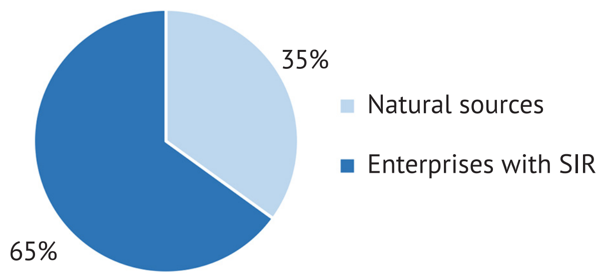

***Figure 1**. The results of the study of the general effect of background radiation from various sources on the regions adjacent to the NPP territory*

Proponents of nuclear energy claim that the described radiation doses are too low to cause any "proven" harm, however, the results of research (Arguments against nuclear energy, 2020) indicate that among children and pregnant women, leukaemia diseases and disorders of the nervous system are associated with doses that are within the levels "background" radiation, which is claimed by the industrial industry. Low doses of radiation can cause serious oncological diseases, including blood diseases (leukaemia) and diseases not related to oncology, for example, diseases of the cardiovascular system, genetic damage to the DNA of reproductive cells, deterioration of the development of the nervous system, and many other diseases that may manifest several years after exposure. This phenomenon has been called the "delayed action" of radiation.

Table 1 shows the average monthly values of EDR indicators of surface and atmospheric air, soil and water samples obtained during the formative stage of the experiment.

***Table 1**. The results of the study of the average monthly and average annual indicators of the radiation background samples of the residential area of the city-forming Khmelnytskyi NPP*

Month	EDR indicators (mSv/h)	Ground air (10^{-5}Bq/m^3)	Atmospheric precipitation (Bq/m^3)	Soil samples (kBq/ m^3)	Water samples (mBq/l)
January	0.09	27	0.47	0.12	88
February	0.12	20	0.54	0.15	78
March	0.12	22	0.50	0.17	69
April	0.13	13	0.49	0.19	245
May	0.10	10	0.46	0.18	264
June	0.11	26	0.52	0.13	235
July	0.15	15	0.45	0.11	246
August	0.17	17	0.56	0.24	267
September	0.11	21	0.84	0.10	92
October	0.09	12	0.73	0.20	152
November	0.12	18	0.82	0.22	105
December	0.11	16	0.67	0.21	211
Average for the year	0.85	18.9	0.58	0.16	171

After analysing the data on the ARMS of the reception and transmission points of the average monthly values of EDR in the 30-km zone for 2021, the authors of this study note that there were no significant deviations from the radiation background in the surveyed area. The average annual rate of 0.85 mSv/h is within the fluctuations of the global background and does not exceed the normative indicators for the territory. The average annual radioactivity of the surface layer of air is $18.9 \cdot 10^{-5}$ Bq/m^3, which is 2.9 times lower compared to the surveys for 2020, which were analysed by P. Pereira *et al.* (2022). High precipitation rates are observed for the period from September to November, which affected the average annual value of 0.58 Bq/m^3. Table 1 shows that the average annual value of the background radiation in these territories is 0.16 kBq/m^2. The average background radiation in the cooler basin is 3 times higher than in the riverbed – 171 mBq/l. It follows from this that the increased content of radionuclides in cooling basins does not affect their content in rivers.

The state of radiation activity in samples of agricultural products is significantly lower than the permissible specific activity of radionuclides: meat – 0.70 Bq/kg, milk – 0.35 Bq/kg, vegetables and cereals – 0.35 Bq/kg. Meat and milk sampling was carried out 1 time a year in the summer. Vegetables, root crops, and grains were sampled during the seasonal harvest. The planned catch of fish was carried out to take samples to study the activity of radionuclides in fish products. The samples were also taken once a year, the indicator is 0.70 Bq/kg per year. The number of radionuclides identified on the territory of the Khmelnytskyi NPP and adjacent territories included: ^{51}Cr, ^{59}Fe, ^{58}Co, ^{64}Zn, ^{89}Sr, ^{95}Zr, ^{103}Ru, ^{131}I, ^{141}Ce, ^{144}Ce. The data indicators collected on the territory of the Khmelnytskyi NPP are 0.91 mGy. As a result, it can be argued that the average annual total risk of radiation exposure for the population in the area near the NPP is equal $8.6 \cdot 10^{-7}$, directly on the territory of the Khmelnytskyi NPP it is equal $5.6 \cdot 10^{-7}$, which is 65% of the total percentage of radiation occurring in the surveyed area.

In addition, according to the authors, the use of new equipment, the closure of reactors and the abandonment of nuclear power facilities that have exceeded their service life can reduce the dose of human radiation exposure, and avoiding the consumption of food produced in contaminated areas naturally leads to a decrease in collective radiation doses. However, according to J. Perkins, *et al.* (2019), many people carry artificial radiation in their bodies as a result of the work of nuclear technologies, especially emissions that occurred as a result of atomic bomb tests and accidents at nuclear power plants. The largest of them are: the accident at the Mayak plant, 1967 (Chelyabinsk Oblast, Russia); Windscale, 1957 (Scotland, UK); Three Mile Island, 1979 (USA); the accident at the Chornobyl NPP, 1986 (Ukraine); and in 2011, Fukushima (Japan) (Nuclear reactors..., 2020; Fukushima catastrophe at 6..., 2019). The consequences of these accidents have caused irreparable harm to the world's population and their natural environment (Rowlatt, 2020).

J.F. Barquinero *et al*. (2021) noted that changes in radiation emissions into the environment should be made considering comprehensive assessments of the risks existing in the region, and the mandatory establishment of appropriate priorities. This approach allows focusing only on those problems that require attention. However, M. Partanen *et al*. (2020) consider the transition to an ecocentric approach in the field of ethics of relationships with nature, which are not found or very rarely found in the industrial sector, to be a priority. Having investigated the experience of Western European countries (Kosovets, 2015; Chumak et al, 2016) on the assessment of background radiation control in (Table 2), the authors of this study presented the main observations obtained from this information.

Table 2*. Examples of automated radiation monitoring systems in some countries of the world*

Country	Controlled territories	Technological support of NPPs	Features of the application of ARMS	Availability
Finland	Scandinavian countries, 20 stations in the Leningrad NPP district	290 stations across the country	The results are entered into the National Data Bank.	To the authorities. In real time
Bulgaria	Monitoring centre indicators from 35 stations across the country	Gamma background control system	The indicators are transmitted to the control and response centre	To the authorities. In real time
United Kingdom	94 posts across the country (with a large location in the coastal area)	RIMNET – national network for analysing the dose rate of gamma radiation in the atmosphere	It mainly tracks the consequences of foreign nuclear accidents.	UK National Nuclear Database
Belgium	212 measuring posts across the country	TELERAD – a system of 4 rings around nuclear power plants	Automatic registration of artificial radioactive isotopes, consisting of 10-30 m. masts of stations for mobile measurement	Official website, freely available
Japan	19 prefectures and 217 posts	Computerised dose determination system	The system of forecasting the radiation situation, observing weather conditions near radiation-hazardous enterprises	On the official website, freely available

The studies by O. Hromyka *et al*. (2020) and J. Rowlatt (2020) show that mainly developed countries define ensuring safety from radiation catastrophe as a priority area of policy (Table 2). ARMS will not protect from radiation, but it will allow taking timely measures to prevent a man-made disaster. Adopting the experience of developed countries, it is possible to organise a single automated network with the countries of the second and third world at the international level. F. Krasnogorova (2015) has revealed that on the territory of the city-forming enterprises of the Khmelnytskyi NPP there are radionuclides that are of natural origin and can be isolated as a result of chemical reactions at an industrial site. By their nature, such radionuclides are unpredictable and, without constant monitoring and compliance with safety measures, can cause harm even during normal operation of power plants. For example, the main radionuclides are presented in Table 3.

Table 3*. The main radionuclides formed as a result of the operation of nuclear power plants*

Source of radiation	Main features	Radiation doses
Tritium	Hydrogen isotope	Beta particles have an energy charge of 18.6 keV 65 % – in the world ocean 27 % – in the biosphere 8 % – in the atmosphere 0.01 % – in the human body
Carbon – 14	Beta particles with emitted energy	Particle energy – 155 keV
Potassium – 40	Natural mixtures of potassium isotopes 30 Bq	Content in marine biota – 90-100 Bq/kg The human body contains 0.23% of the total body weight
Radon	Half-life products	50-60 Bq/m^3 indoors

O. Trofymchuk *et al.* (2021) argue that technogenic tritium formed as a result of nuclear fuel reprocessing at nuclear power plants depends on the type of reactor and its parameters. Tritium fills the biosphere as a by-product of the use of atomic energy, the isotope actively affects natural processes, genetic structures, as it is easily assimilated in water, turning it into tritiated water. Its half-life is 12.3 years. Thermonuclear explosions led to an increase in the concentration of tritium in the stratosphere for 1 year, most of which settled in the Northern hemisphere, since almost all tests were conducted in this area. Concentrating in atmospheric precipitation, tritium decay products began to move closer to the equator (Krasnogorov, 2015). This is conditioned by the process of global warming. Tritium ions enter the human body in a matter of minutes, assimilating with the liquid in the human body, they are also quickly excreted. In this regard, this radionuclide does not pose a danger to public health and the environment. Technogenic Carbon-14 is formed as a result of nuclear weapons tests at the enterprises of the nuclear complex. It takes 5,730 years for the decay products to fully decompose.

The third largest radionuclide-causing radiation in the Earth's biosphere is Potassium-40. A. Chumak, *et al.* (2016) noted that the presence of this radionuclide is concentrated mostly on the Earth's surface. The accumulation of Potassium-40 in the bowels of the Earth leads to an increase in the natural heat of the planet. As already noted, radionuclides increase their concentration when they enter water. Thus, in the waters of the world ocean, the concentration of Potassium-40 is 12 Bq/kg, and in the cells of the body, its amount is 30 times higher than outside the cells. With age, its concentration decreases. Of all the listed radionuclides, Radon has the shortest half-life – 92 days. During its half-life, it is able to irradiate the largest number of living organisms. Its concentration in the atmosphere is 5,200 PBq, which is 5 times higher than the concentration from nuclear tests. The greatest amount of radiation a person receives in residential premises. Assimilating with water, the Radon concentration is 0.05 Bq/l. In production, when generating 1GW of electricity, the Radon background radiation is 0.03%. Thus, the safety of emissions does not exceed the values of the norm obtained by radiation exposure. In fact, the emissions of all controlled radionuclides are 4.0% of the permissible. The release of radionuclides with wastewater at the Khmelnytskyi NPP is carried out in cooling reservoirs and spray pools located on the territory of the NPP industrial site. The cooling pond is used at the Khmelnytskyi NPP for the organisation of technical circulating water supply. The maximum values of radiation indicators were recorded at the northern border of the sanitary protection zone. When calculating the concentration of radionuclides, all pathways of infection, including food chains, were considered. The distribution of emissions of ionising radiation sources outside the industrial sites does not exceed 1 m^3/year. The heterogeneous nature of local maxima near the sanitary protection zone is associated with changes in climate, wind direction, precipitation, changes in these factors are beyond human control.

Only 3% of the world's population receives a radiation dose of 1 mSv/year, another 1.5% – 1.4 mSv/year, the remaining 95% – 0.3-0.6 mSv/year. Low radiation dose rates and short-time influence reduce the likelihood of serious consequences. Being near a radiation source with low indicators for a long period of time increases the risk of diseases that may manifest themselves in years and decades (Arguments against nuclear energy, 2020). The likelihood of such risks increases for children, adolescents, pregnant women and their unborn children. According to the World Nuclear Association (2020), from 1 to 8, and from 25 to 40 weeks of pregnancy, there is no risk of radiation to the fetal brain even with indicators of 100 mSv and higher. However, the risk of developing cancer in the foetus is equivalent to the risk of developing cancer in an early child. Terrestrial animals receive the most external radiation. The dose of internal radiation depends on the content of radionuclides in the local components of the environment. The increased radiation dose of terrestrial plants in comparison with animals is most likely due to a number of the following factors: the presence of 40K in the plants themselves; dust and fragments of rock settle on the leaves; rhizome and young shoots are in close contact with the soil. Accordingly, invertebrates and microorganisms, in contact with the settled half-life products in the soil, receive high doses of radiation. A. Chumak, *et al.* (2016) claim that simple microorganisms, unicellular plants, animals, and bacteria are also sensitive to radiation doses. However, they are also more stable, as they are adapted to aggressive environmental conditions. For example, bacteria form spores, in this state their metabolism stops, and they withstand lethal doses of radiation. Invertebrates are also resistant to ionising radiation 1,000 times higher than the lethal dose for humans. For example, the DNA of water bears contains the Dsup protein, which forms the protection of genes from various damages.

CONCLUSIONS

The analysis of the influence of the radiation background in residential areas of settlements of city-forming NPPs on public health and the environment showed that with the normal technical condition of the system and elements of nuclear power plants important for safety, the risks of radiation contamination are reduced – 0.85 mSv/h (65%). While natural radiation (30%) and medical radiation (5%) are no less dangerous for the population and the environment.

Radiation acting on a living organism from the outside can be harmful because it affects DNA, cells, tissues, and organs of a person. Ionising radiation leads to the formation of free radicals and ions, which, in turn, destroys the structure of cells and tissues of the body. Such processes usually take place irreversibly, without the possibility of regeneration of the systems of a living organism, and improper restoration of cells leads to various diseases. However, it is possible to stop the harmful effects by protecting from external radiation or avoiding its effects. However, if a person consumes radioactively contaminated food or inhales radioactive air, radionuclides still enter the body. This is a serious problem because the human body mistakenly perceives these radionuclides as natural elements. Thus, radioactive isotopes are deposited in bones and muscles, irradiating a person from the inside, for a long time. This process is called internal irradiation. It is more dangerous than external exposure due to the long period of exposure. Summarising the results of the study of the impact of atomic radiation on the environment, the authors came to the conclusion that nuclear energy is not capable of causing serious harm if handled reasonably.

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Вплив радіаційного фону міських поселень з атомними електростанціями на здоров'я населення та навколишнє середовище

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Анотація. Радіоактивний розпад елементів в результаті ядерної реакції є потужним джерелом енергії, що використовується при виробництві електричної та теплової енергії в містах, наближених до АЕС. Проблемою використання такого виду енергії є небезпека радіаційного опромінення. Виробництво ядерної енергії має багато переваг, серед яких рентабельність кінцевого продукту і його низька собівартість, з іншого боку, продукти напіврозпаду радіонуклідів у складі газоаерозольних викидів з вентиляційних труб осідають в навколишньому середовищі на території містоутворюючих АЕС. Двоїстість проблеми впливу радіаційного фону на міські території поблизу АЕС стала метою даного дослідження. Необхідно дослідити негативний вплив викидів радіоактивних відходів при нормальній експлуатації атомних електростанцій. Для цього було використано метод проектного експерименту, під час якого за допомогою лабораторного контролю зовнішньої радіаційної безпеки та автоматизованої системи радіаційного моніторингу були зібрані показники експозиційних дозових потужностей з точок 30-кілометрової зони навколо АЕС. В результаті моніторингу радіаційних проб ґрунту, атмосферного повітря та атмосферних опадів, водойм встановлено, що природний радіаційний фон незначний, ймовірність шкоди від радіаційного опромінення невелика і недостатня для розвитку променевої хвороби. Разом з тим, визначено потенційно небезпечні джерела радіаційного опромінення, такі як природне випромінювання - споживання забруднених продуктів харчування, сонячне та космічне випромінювання від радіоактивних елементів, присутніх в надрах землі; радіонукліди, викиди яких неконтрольовано відбуваються в атмосферу; радіоактивні відходи, технологія захоронення та зберігання яких є економічно затратною. Тому проведення регулярних розрахункових експериментів з перевірки працездатності автоматизованих систем радіаційного моніторингу є виправданим. Матеріали дослідження мають практичну цінність для хіміків, екологів та екотехнологів, що працюють на АЕС, які здійснюють контроль за безпекою для здоров'я людини та охороною навколишнього середовища у сфері використання атомної енергії

Ключові слова: ядерна енергетика, атомні електростанції, радіація, показники експозиційної дози

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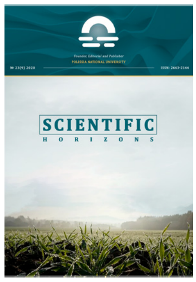
Journal homepage: https://sciencehorizon.com.ua
***Scientific Horizons*, 25(10), 107-118**



UDC 368.5:338.43
DOI: 10.48077/scihor.25(10).2022.107-118

Mission of International Agribusiness Insurance: Modern Challenges and Opportunities for Ukraine

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Article's History:
Received: 09/20/2022
Revised: 11/04/2022
Accepted: 11/23/2022

Suggested Citation:
Vilenchuk, O., Nedilska, L., Kurovska, N., Vikarchuk, O., & Klapkiv, Yu. (2022). Mission of international agribusiness insurance: Modern challenges and opportunities for Ukraine. *Scientific Horizons*, 25(10), 107-118.

Abstract. An urgent problem today is the reproduction of a sustainable ability to meet the demand for food products in different countries of the world. The solution to this global problem lies in the search for optimal financial and economic tools for timely counteraction to agricultural risks. Many years of international experience prove that such a tool is insurance. The purpose of the study is to conceptualise the mission of international agribusiness insurance, specify modern challenges, and identify opportunities for Ukraine. The methodology of this study was based on the use of various methods, in particular: abstract and logical, epistemological, comparative, structural and functional, modelling, formalisation, induction and deduction, regression and system analysis. The uniqueness of insurance lies in its ability to accumulate the necessary financial resources and distribute them to the needs of compensation for losses in the case of insurance events distributed in space and time. Consequently, the conducted research is aimed at substantiating the mission of international agribusiness insurance, identifying current challenges and existing opportunities in Ukraine. The main advantages and disadvantages of various models of interaction of stakeholders in the international agricultural insurance market are established. The paper highlights the world experience in positioning classic and index insurance products on the market. It was found out that the current level of agribusiness insurance in Ukraine does not correspond to its potential opportunities. Based on the parameters of the constructed regression model, it is established that the basis for further expansion of insurance coverage of agricultural risks is an increase in the number of concluded and renegotiated agricultural insurance contracts, an increase in the liability limit (insurance amounts) of companies, ensuring actuarial balance, and an increase in the amount of state subsidies. The practical implementation of these measures should be considered in the context of food security at the regional, national, and global levels

Keywords: agricultural insurance, agricultural risks, market stakeholders, insurance interests

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INTRODUCTION

One of the fundamental, vital needs of humanity is the consistent provision of broad access to high-quality food products. The solution to this problem depends on the ability to increase productivity while reducing the risk of agricultural production. The relevance of this study is based on deep awareness and comprehensive assistance to the processes of timely counteraction to various risks with extensive application of potential opportunities of agricultural insurance. The scientific originality of the study consists in: conceptual substantiation of the mission of international agribusiness insurance; disclosure of optimal forms, methods, and tools of interaction between stakeholders of the insurance market; modelling of probable scenarios for further development of increasing the share of insured areas of agricultural crops in the total area of crops; development of proposals for further functioning of the agricultural insurance market in Ukraine on the basis of balancing financial and economic interests and increasing social responsibility of participants in the insurance process.

As of 2020, agricultural insurance is successfully developing in 125 countries around the world (Vyas *et al*., 2021). A significant variety of available opportunities for obtaining insurance coverage has become more accessible due to the expansion of the insurance field and the diversification of services. Agricultural insurance is perceived in the international community as a creative tool for countering real and potential risks in the agricultural sector.

The European Union countries use a variety of insurance tools for risk management. According to the decision of the European Commission, the amount of state support is limited to 70% of premiums or annual payments to mutual funds (European Commission, 2017). Three-quarters of EU countries allocate subsidies from 45% to 65% for agricultural risk insurance (Schwarze & Sushchenko, 2022).

For Ukraine, which positions itself as one of the guarantors of food security in the world, agricultural risk insurance is becoming particularly relevant from the standpoint of balancing the financial and economic interests of insurance market stakeholders. In the war and post-war period, there are new threats associated with the timely production, processing, and sale of agricultural products. Obviously, the solution of these problems requires additional scientific substantiation of the process of interaction between insurance companies, policyholders, and the state, based on innovative agricultural insurance technologies that are used in different countries of the world.

Hypothesis of this study assumes that the accelerated process of integration of the national insurance market into the global insurance environment would contribute to a significant increase in the level of insurance protection for agricultural producers. *The purpose of this study* is a theoretical and methodological reflection of modern guidelines for the functioning of international agribusiness insurance and substantiation of the conditions for Ukraine's adaptation to the global insurance space.

LITERATURE REVIEW

A review of literature sources indicates that global climate changes occurring around the world have a significant impact on agricultural production. The group of international experts on climate change (*Intergovernmental Panelot Climate Change*) notes that over the past 20 years, the number of natural disasters has increased 2-fold, thereby causing multibillion-dollar losses to the agricultural sector of the economy. At the same time, it is noted that the continuation of negative trends threatens to increase the number and duration of manifestations of extreme weather events (IPCC, 2020).

During the period 1980-2019, extreme natural and climatic events caused more than 80% of total economic losses in the countries of the European Economic Area totalling EUR 446 billion. Cumulative losses amounted to almost 3% of the GDP of these countries (Schwarze & Sushchenko, 2022).

A sharp fluctuation in atmospheric temperature conditions is considered a significant factor in the instability of agricultural systems and, as expected, an increase in the frequency and intensity of risks in many regions of the world (Vyas *et al*., 2021). In the scientific literature, various judgments have been formed regarding the likely threats associated with climate change, in particular, it is noted that extreme weather conditions cause significant food shocks to the globe (Cotrell *et al*., 2019), abnormal weather processes reduce the quantity and quality of food products (Lesk *et al*., 2016), and the caloric content of consumer food is reduced by 1% annually (Ray *et al*., 2019).

Modern realities of agricultural business require management decisions in an aggressive environment under the influence of various dangerous factors, namely: biological (diseases, insects, pests, weeds), environmental (weather conditions, water quality, soil condition), institutional (legislation, market conditions) (Raimondo *et al*., 2021). The studies by American researchers from the University of Oregon (USA) warn about a sharp increase in extreme climatic conditions in the world (Ripple *et al*., 2019).

According to the Global Sustainable Development Goals until 2030 declared by the UN, it is planned to overcome poverty (*Sustainable Development Goal* – SDG 1), hunger (SDG 2), and the consequences of climate change (SDG 13), the solution of this problem is carried out, among other things, through the use of the agricultural risk insurance mechanism (Siwedza & Shava, 2020). Agricultural insurance is becoming increasingly important as an instrument of agricultural policy (Rural insurance around the world…, 2021).

The positive impact of insurance on the development of the agricultural sector of the economy and the protection of farmers' property interests in the event of unforeseen events is mentioned in many studies. In particular, the objects of research are processes related to the formation of insurance's ability to combine and neutralise risks (Komadel *et al.* 2018), demand for insurance services, (Santeramo *et al.*, 2016), financial and economic relations between the insurance market stakeholders (Ivashkiv *et al.*, 2021) pricing and subsidies (Lusk, 2017), government regulation and institutional support (Shibaeva & Baban, 2020).

The world economic literature focuses on reflecting the role of insurance in promoting the safety and continuity of the agricultural sector. The defining mission of insurance is to neutralise risks in conditions of extreme weather events, in particular, such as drought, flood, etc. (Eze *et al.*, 2020), stabilise farm incomes, promote conditions for the growth of investment inflows to the industry, increase the competitiveness of agricultural products (Mârzaa *et al.*, 2015), reduce unforeseen expenses in conditions of uncertainty of results (Russo *et al.*, 2022), and promote sustainable land use (Goodwin & Hungerford, 2015, Claassen *et al.*, 2017).

Among many economic scientists, there is a constant discussion about options for improving the types, forms and methods of agricultural risk insurance (Nguyen & Jolly, 2019). In this context, attention is focused on the feasibility of additional substantiation for the process of coordination of insurance interests between insurance market stakeholders (Yanuarti *et al.*, 2019), the problems of legal and institutional support for participants in the insurance process (Aleskerova, 2015), the development and use of modern information technologies in the insurance sector (Yanyshyn *et al.* 2019), there is a need to further adapt the agricultural insurance market of Ukraine to the international system of insurance relations (Nesterchuk *et al.*, 2018). Consequently, a critical review of literature sources gives grounds to assert the expediency and necessity of further research in a given line.

MATERIALS AND METHODS

The methodology of research is based on a systematic combination of principles, methods, and approaches in the process of identifying the most important triggers in the organisation and functioning of international agribusiness insurance. The establishment of mutually beneficial insurance relations in the agricultural sector should be based on compliance by all market stakeholders with the fundamental principles of agricultural insurance. These principles include: insurance risk, insurance interest, concentration of funds in the insurance fund, maximum integrity, reality, completeness and availability of insurance coverage, compensation. Compliance with the above principles creates the basis for balancing financial and economic interests between participants in the insurance process.

The process of scientific knowledge requires the consistent use of various research methods. Combination of *abstract and logical, structural and functional methods* formulated the mission of international agribusiness insurance, determined the evolution of its development, and substantiated the role and necessity of strengthening and diversifying insurance protection of agricultural producers at the national and global levels. The application of *epistemological and logical methods* contributed to the substantiation of the terminology of the presented study.

The study uses general scientific methods, in particular, *induction and deduction* – to compare features of positioning of insurance services in different countries of the world; *concretisation* – to investigate the innovative foreign experience of organising an agricultural insurance system; *formalisation* – to reveal the existing advantages and disadvantages of existing models of interaction between stakeholders in the international agricultural insurance market; *system analysis* – to substantiate dynamic changes in key parameters of agricultural insurance development; *structural and functional method* – to reflect the conceptual provisions of the development of agribusiness insurance in Ukraine in the post-war period; *comparative studies method* – to summarise the multifaceted phenomena and processes that are currently taking place in the national and international markets of agricultural insurance; *graphical method* – to visualise the main results of the study.

To achieve the purpose of this study, the prospects of increasing the share of insured agricultural crops in their total volume were modelled by the linear regression equation using the *regression analysis method*. The initial data of the forecast model were the indicators of the size of crop areas, the number of concluded contracts, the amount of insurance payments and subsidies for the period 2005-2020. The choice of these parameters is determined by their objective reflection of existing trends in the field of agricultural insurance.

The regression model was built using the Data Analysis tool in Microsoft Excel software suite, and the validity of the inclusion of absolute indicators using logarithmisation was checked in the R-Studio environment. The simulation results allowed: first, to confirm the hypothesis about the existence of a relationship between the key indicators of the agricultural insurance market and establish a mathematical relationship between them; second, to present promising scenarios for the possible expansion of insurance coverage in relation to agricultural acreage.

The development of the methodological core of the study determines the need to reveal modern approaches to organising interaction between agribusiness insurance stakeholders. Their essence is to increase the motivation of potential market participants to be jointly responsible for possible risks, using microinsurance, insurance, and reinsurance mechanisms, diversify the opportunities of farmers to access insurance coverage, expand the range of insurance services, minimise the likely risks of agricultural production and increase food security guarantees in Ukraine. The expected results of the implementation of these approaches should be recognised as the expansion of insurance coverage of agricultural risks and the use of the existing potential for the development of agricultural insurance in Ukraine.

The information base of the study is established from official data, in particular, the World Bank (Disaster Risk Financing for Agriculture, 2020), the Ministry of Agrarian Policy and Food of Ukraine in cooperation with the project "Development of financing of the agricultural sector in Europe and Central Asia", which is implemented with the help of the World Bank and the International Finance Corporation (IFC) (Agrarian Union of Ukraine, 2018), reporting on the development of the national insurance market of Ukraine in the agricultural insurance segment (TOP-10, 2020; TOP-10, 2021). In addition, scientific publications of American, Italian, German, Ukrainian researchers and scientists from other countries of the world were used, including analytical, review, and research materials from the Internet.

RESULTS AND DISCUSSION

The very idea of insurance originated as a form of mutual assistance to farmers during crop failures, natural disasters, and unforeseen circumstances. The first organisational and legal form of insurance relations in the company is mutual insurance companies. Their professional activity was based on the principles of non-profit, solidarity, and unity of financial and economic interests of its participants. Starting in 1720, Germany provided insurance services in case of animal deaths due to diseases, and later insurance extended to various agricultural crops (Roth, 1960).

Since the late 1930s and until now, agricultural insurance has been considered from the standpoint of an integral infrastructure element of the functioning of many national market-type economies. Its key mission is to implement a balanced distribution (redistribution) of risks and responsibilities among all stakeholders of the insurance process. In international practice, various options for interaction of agricultural risk insurance participants are used, in particular, "providing insurance services by private insurance companies without state assistance (Sweden), state participation in reinsurance pools (Spain), subsidising insurance premiums for certain insurance risks, for example from hail (France, Austria), providing financial assistance to cover catastrophic losses (Germany, Italy, USA, Canada), creating a special state institution for implementing the policy in the field of agricultural insurance (Spain, Canada, USA)" (Slobodyanuk, 2016).

Each country has a specific model (or combination of several models) of the organisation of the agricultural risk insurance system (Table 1). The differences in the presented models lie in the levels of state intervention in the insurance process. Admittedly, each of the models has its own advantages and disadvantages. But the development of a system of insurance relations based on public-private partnership in the agricultural sector is the most adequate and acceptable from the standpoint of the need for timely and effective counteraction to possible risks in the agricultural sector.

***Table 1**. A set of advantages and disadvantages of existing models of interaction between stakeholders on the international agricultural insurance market*

Key advantages and disadvantages of basic organisational and legal models of agricultural insurance functioning in the world	
Advantages	**Disadvantages**
A liberal model based on the principles of market competition	
Australia, Argentina, Germany, Netherlands, New Zealand, South Africa, Uruguay, Sweden	
– development of commercial insurance in the agricultural economy; – pricing is formed solely under the influence of supply and demand for insurance services; – absence of fiscal expenditures from the state and municipal budgets	– insufficient level of agricultural risk insurance coverage; – high cost of insurance services; – lack of a centralised system of state subsidies
A model based on the principles of public-private partnership	
Austria, Brazil, Israel, Spain, Italy, Canada, Luxembourg, South Korea, Poland, Portugal, USA, Turkey, France, Chile, Sweden, Switzerland	
– diversity of sources of insurance coverage; – expansion of the insurance field for agricultural risks; – increase in accumulated insurance premiums and corresponding formed insurance reserves; – joint social responsibility of state and non-state institutions for the consequences of insurance events	– additional burden on state and municipal budgets; – complexity of combining the financial and economic interests of all PPP participants; – probability of new risks that are not coordinated with PPP participants
Compulsory insurance model (under full state control)	
Greece, India, Iran, Cyprus, Philippines	
– comprehensive insurance coverage of agricultural risks; – broad involvement of potential policyholders (farmers) in the insurance process	– lack of competition in the insurance market; – rigidity of insurance services to the needs of potential policyholders

***Source:** (Slobodyanuk, 2016; Jisang Yu et al., 2018; Russo et al., 2022)*

The combination of financial resources of state and non-state institutions allows increasing the volume of accumulated insurance payments, and therefore, the possibility of making insurance payments in the case of insurance events. Such cooperation between stakeholders in the insurance market contributes to improving the reliability and safety of the insurance system as a whole. In addition, the use of the public-private partnership model provides for the possibility of reducing the cost of insurance services, which is a significant motivational factor for potential policyholders to conclude and renegotiate agricultural insurance contracts.Despite the diametrically opposite approaches that are used in world practice regarding the forms and methods of organising agricultural insurance, the volume of accumulated payments in the global dimension increases annually. For the 2019-2020 underwriting year, the amount of insurance premiums amounted to USD 35 billion, which is more than 2 times higher than in 2007 (Table 2). However, there is a rather high concentration of payments on the global agricultural insurance market: 10 countries of the world account for more than 90% of collected payments.

***Table 2**. Indicators of accumulated insurance payments and allocated subsidies in the top 10 countries of the world for the 2019-2020 underwriting year*

Countries	Total amount of insurance premiums, (billion USD)	Share globally, (%)	Total amount of subsidies, (billion USD)	Share of subsidies in insurance premiums, (%)
USA	11,063	32	7,191	65
China	10,200	29	8,160	80
India	4,000	11	3,400	90
France	1,509	4	0.906	60
Canada	1,400	4	0.840	60
Japan	1,200	3	0.600	50
Spain	0.910	3	0.287	32
Italy	0.665	2	0.399	60
Brazil	0.571	2	0.166	29
South Korea	0.468	1	0.383	82
Top 10 countries	31,986	91	22,331	70
Other countries of the world	3,014	9	n.a.	–
Total	35,000	100	–	n.a.

Source: *(Disaster Risk Financing for Agriculture, 2020)*

The undisputed leaders of the global agricultural insurance market are the United States, China, and India, the share of these countries in the global distribution of insurance premiums is 32%, 29%, and 11%, respectively. Among the countries of the European Union, it is worth highlighting the agricultural insurance markets of France, Spain, and Italy, their payment contribution was in the range of 2%-4% of the total amount of accumulated insurance premiums in global terms. The high level of concentration of insurance payments is conditioned by the different financial capabilities of farmers to invest in insurance coverage. The solution to this problem lies in expanding the access of agricultural producers to various insurance products. The key features of insurance services used in various countries around the world are shown in Table 3.

***Table 3**. Key features of insurance services used in the global agricultural insurance market*

Types of insurance services (insurance products)	Key features (characteristics) of insurance services	Countries where insurance services are positioned
Classic	Provides the ability to choose insurance coverage for agricultural risks depending on the effective demand of consumers of insurance services. The variable series is formed from anthropogenic, natural and climatic, industrial and economic, institutional, financial and economic, and other risks. Under the terms of the insurance contract, protection can extend in a wide range from 1 to 15 risks	Austria, Belgium, Great Britain, Canada, China Luxembourg, Portugal, Romania, Slovakia, Slovenia, USA, France, Sweden, Japan
Index	Insurance coverage is provided in case of changes in a certain index (namely: weather indices, regional yield and income Index). Payment of insurance indemnities is made in case of changes in the indicators of the specified indices	India, Spain, Canada, USA, countries of South America and Africa
Microinsurance	Insurance coverage applies to a limited range of risks (natural and climatic). This insurance coverage is mainly designed for private peasant and family-type farms	India, countries of Africa, Central Asia, and South America

Source: *(Slobodyanuk, 2016; Jisang Yu et al., 2018; Russo et al., 2022)*

In the international practice of agricultural insurance, three groups of insurance services are used, namely: classical, index, and microinsurance. Among the classic types, it is worth highlighting the following available insurance options: against one or several risks at the same time, that is, it becomes possible to combine different insurance coverage options. The advantages of classic types of agricultural insurance are the wide possibilities (in particular, insurance terms, insurance rates, insurance coverage, etc.) of choosing the best option for insurance protection and the objective solvency of policyholders. Usually, the cost of these services is quite high, which somewhat narrows the availability of insurance for low-and middle-income farmers.

The solution to this problem is possible due to the introduction of index insurance. The conceptual foundations of this insurance product are based on the establishment of a certain parameter (index) from its threshold value. An index, as a rule, is the yield of agricultural crops in the region, the amount of precipitation for a certain period, the number of days with a certain air temperature, wind speed, humidity level, and the sufficiency of sunlight during the growing season (Samoshkina, 2019). Deviation from the maximum pre-determined value of the index is considered an insured event, and then the insurance company pays compensation regardless of whether the damage was caused to the policyholder or not.

The innovative direction of index insurance should be considered from several positions. First, the process of forming insurance coverage for agricultural producers is simplified. Second, access to agricultural insurance is being expanded by reducing the cost of services and simplifying the mechanism for recording the occurrence of an insured event. Third, the problem of information asymmetry is solved. Fourth, the range of insurance services is expanding, and therefore, there are additional arguments in favour of further development of agricultural insurance in the international context.

Microinsurance services are increasingly in demand among small-scale agricultural producers. This insurance instrument is considered as "a type of civil law relationship to protect the property interests of low-income individuals in exchange for low insurance premiums under the conditions of small insurance amounts, a simplified insurance system, a high share of insurance indemnities and a low profit of the provider of such services" (Shirinyan, 2012). Thus, positioning in the market of microinsurance services expands the range of insurance coverage for agricultural risks, creates additional opportunities for insurance protection of farmers, especially those with low and middle-income levels.

Modern international agribusiness insurance is in the conditions of constant transformational processes of search and adoption of innovative solutions to counteract potential agricultural risks. Its defining mission is to balance the financial and economic interests of market stakeholders by combining microinsurance, insurance, and reinsurance tools to achieve food security goals at the regional, national, and global levels. It is in this context that it is worth exploring the existing challenges and potential opportunities for the development of the agricultural insurance business in Ukraine.

The analysis of the functioning of the national agricultural insurance market for the period 2005-2020 provided certain conclusions and generalisations. The insurance amount (the insurer's liability limit) per 1 ha has increased almost 7-fold, which indicates the readiness of companies to bear joint responsibility for risks in the event of insurance events. An objective criterion for assessing the state of development of insurance relations in the agricultural sector is the indicator of the ratio of insured areas to sown areas. This indicator for the study period was in the range from 1.5% to 9.1% (Fig. 1). Definitely, the presented parameter indicates the untapped potential for the development of agricultural insurance in Ukraine.

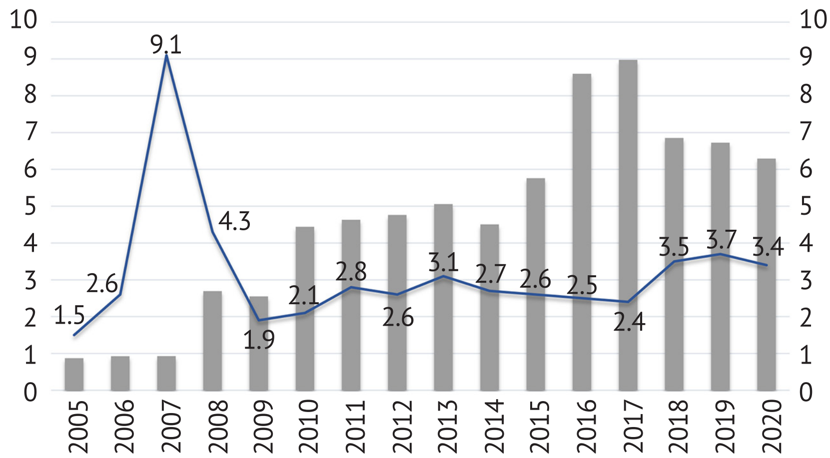

***Figure 1**. Ratio of insured to sown areas in Ukraine*

Note: *insurance amount per 1 ha, mln UAH; ratio of insured areas to sown areas, %*

Source: *(Agrarian Union of Ukraine, 2018; TOP-10, 2020; TOP-10, 2021)*

But it is worth noting that during the study period, almost all indicators of business activity of the insurance market as a whole had positive dynamics of changes (Fig. 2). First of all, this applies to the amounts of accumulated insurance premiums, the number of insurance contracts concluded, and payments of insurance indemnities upon the occurrence of insurance events. Analysing the cyclical nature of changes in the agribusiness insurance, it can be argued that the most productive years in terms of attracting payments by insurance companies were: 2007, 2009, 2011 (Chvertko *et al.* 2019). The increase in the volume of agricultural risk insurance was carried out due to the presence of favourable factors, namely: the availability of state subsidies (2005-2008 and 2012), improvement of the system of positioning services in the market, establishment of communication between participants in insurance relations, awareness by agricultural producers of the need for insurance coverage, etc.

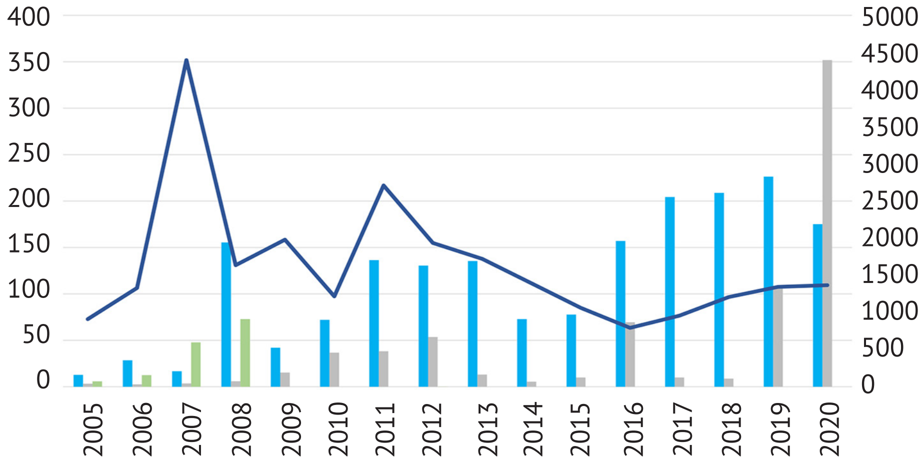

Figure 1. *Ratio of insured to sown areas in Ukraine*

Note: *amount of bonuses, mln UAH; subsidy, mln UAH; insurance payments, mln UAH; bumper of contracts, units*

Source: *(Agrarian Union of Ukraine, 2018; TOP-10, 2020; TOP-10, 2021)*

The level of the ratio of insurance payments to premiums for the study period was in the range of up to 50%, which is quite acceptable from the standpoint of regulating financial and economic relations of market participants. However, in 2020, this ratio was 200%. This level of payments indicates the need to use a risk management system aimed at ensuring the solvency of insurance companies, that is, fulfilling their financial obligations under existing agricultural insurance contracts.

The urgency of taking anti-crisis measures is compounded by the military aggression of the Russian Federation against Ukraine and certain risks (fire, crop shortages, occupation of territories, etc.) that it can entail. However, in the war and post-war periods, the need for food will not disappear, but on the contrary, will only increase. Hence, there is a scientific need to substantiate possible options for strengthening the insurance protection of national agricultural producers.

The logic of further research is based on the assumption that the activation of agricultural insurance, which can be expressed through the indicator of increasing the share of insured crops in the total area of crops, is possible with a synergistic combination of the influence of a number of direct factors, such as an increase in the volume of insurance amounts, insurance payments and subsidies, an increase in the number of concluded contracts. Based on this hypothesis, the necessary parameters for the development of agricultural insurance in Ukraine are modelled. The basic indicator of the forecast model is the ratio of insured areas to the total volume of sown areas (Y – dependent variable in %), the determining factors of which are:

– number of insurance contracts concluded (x_1), in connection with the assumption that the expansion of agricultural insurance depends directly on the activity of concluding new contracts for certain types of crops;

– insurance amount per 1 ha, thous UAH (x_2), as a result of the assumption that the larger the insurance amount per 1 ha, the higher the interest of agricultural producers to conclude insurance contracts due to the full expected coverage of possible risks;

– insurance payments, mln UAH (x_3), due to the assumption that the larger payments were made by insurance companies in previous periods, the higher the confidence of potential policyholders in them;

– subsidy volumes, mln UAH (x_4), which is associated with the possibility of state support both for the development of the insurance market and agricultural production in general through partner financing of expenses of agricultural producers.

The matrix of paired correlation coefficients (Table 4) shows that such indicators as the number of concluded contracts and the volume of state subsidies for compensation of insurance costs have a noticeable and strong influence of direct (+) action on increasing the share of insured acreage in their total aggregate. The other two indicators – the insurance amount per 1 ha and the total amount of insurance payments – do not have a significant reverse (-) impact on the expansion of the share of insured areas.

***Table 4**. Matrix of paired correlation coefficients (r)*

–	y	x_1	x_2	x_3	x_4
y	1	0.8027	-0.2623	-0.00394	0.6418
x_1	0.8027	1	-0.4683	-0.1199	0.4544
x_2	-0.2623	-0.4683	1	0.3204	-0.4867
x_3	-0.00394	-0.1199	0.3204	1	-0.2106
x_4	0.6418	0.4544	-0.4867	-0.2106	1

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

The expediency of including these factors in this model is justified by the results of the analysis of their logarithmised equivalents in the R-Studio environment (Table 5), which confirm the significance of existing relationships.

***Table 5**. Substantiation of the feasibility of including the selected indicators in the model*

Coefficients:	Estimate	Std. Error	t value	Pr (>|t|)	
(Intercept)	1.651726	0.613885	2.691	0.019648	*
Sum insured	0.001242	0.000355	3.499	0.004392	**
Amount of bonuses	-0.032272	0.010133	-3.185	0.007850	**
Subsidies	0.069127	0.013790	5.013	0.000303	***
Signif. codes:	0 ‘***’	0.001 ‘**’	0.01 ‘*’	0.05 ‘.’	0.1 ‘ ’ 1

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

Based on the results of regression analysis of the selected factors influencing the development of agricultural insurance (Table 6), linear equations are constructed: $Y=-0.4424+0.00144x_1+0.187x_2+0.00185x_3+0.03823x_4$ with Fischer's criterion F=11.921. On this basis, it can be argued that the coefficient of determination of the constructed model of agricultural insurance development ($R^2=0.901415$) is statistically significant, and the equation is statistically reliable.

***Table 6**. Estimation of parameters and main characteristics of the regression equation*

Indicator	Y	X_2	X_2	X_2	X_2
Coefficients	-0.4425	0.00144	0.18701	0.00185	0.03823
Standard error	0.84282	0.0003	0.11041	0.00276	0.01295
t-statistics	-0.525	4.73496	1.6938	0.67078	2.95107
P-Value	0.61003	0.00061	0.1184	0.5162	0.01318

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

Thus, the coefficient of determination of the obtained regression equation $R^2=0.901415$ and the weighted coefficient of determination R=0.812549 confirm the hypothesis about the close dependence of agricultural insurance on the factors included in the model, and the constructed equation reflects the following regularities: $a_0=-0.4425$ – if the selected factors are constant, the share of insured agricultural areas in Ukraine will decrease by -0.4425 percentage points annually, starting from 2022.; $a_1=0.00144$ – if an increase in the number of contracts is achieved, each of them will provide an increase in the share of insured areas by 0.00144 percentage points, and every 100 additional contracts will contribute to an increase in the share of insured areas by 0.14 percentage points, while other signs remain unchanged; $a_2=0.18701$ – if the volume of insurance amounts per 1 ha increases by UAH 1,000, then the share of insured areas will increase by 0.187 percentage points; $a_3=0.00185$ – if the amount of insurance payments increases by UAH 1 million, the share of insured areas will grow by 0.00185 percentage points; $a_4=0.03823$ – if the volume of subsidies for insurance of agricultural producers in Ukraine is increased, then every UAH 1 million will increase the share of insured areas by 0.03823 percentage points.

Based on the parameters of the constructed regression model for expanding the scale of agricultural insurance in Ukraine and focusing on world experience, it is possible to form probable scenarios for achieving the required level of the ratio of insured areas to sown areas (Table 7). Further expansion of insurance coverage of agricultural risks is based on increasing the number of concluded and renegotiated agricultural insurance contracts, increasing the liability limit (insurance amounts) of companies, adhering to the principle of actuarial balance when forming the tariff policy for insurance services.

***Table 7**. Scenarios of prospects for increasing the share of insured agricultural areas in the total sown areas*

Indicators	Designation	Options for increasing the share of insured crop areas in the total sown area			
Ratio of insured area to sown area, %.	Y	15%	25%	40%	50%
Number of contracts	X_1	5,000	9,500	18,000	24,000
Insurance amount per 1 ha, thous UAH	X_2	30	45	55	60
Insurance payments, mln UAH	X_3	100	170	230	270
Subsidy, mln UAH	X_4	65	80	100	110

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

An important argument for further activation of insurance relations in the agricultural sector is the availability of state subsidies, which is provided for by the current legislation (in particular, the resolution of the Cabinet of Ministers of Ukraine "On Approval of the Procedure for Providing State Support for Insurance of Agricultural Products" dated December 9, 2021 No. 1342) (2021). If the share of insured persons in the structure of sown areas increases, the probability of occurrence of insurance events will increase, which is associated with the need to increase payments under agricultural insurance contracts.

The generation of optimistic forecasts for the development of agribusiness insurance requires the adoption of systematic, interrelated measures of an institutional, legal, financial, economic, moral, and ethical nature. Undoubtedly, military operations in Ukraine significantly complicate the process of managing agricultural risks and transferring them to insurance. However, the relevance of food security at the local, national, and global levels is constantly becoming more acute, which determines the need for reliable insurance protection of agricultural producers.

With Ukraine acquiring the status of an associate member of the European Union in 2022, it obliges Ukraine to gradually adapt to pan-European requirements and traditions in organising and conducting insurance activities. First of all, this refers to compliance with basic values in the interaction of agribusiness insurance stakeholders, among which it is worth highlighting: transparency of insurance activities, solvency of insurance companies, and corporate governance. A significant step to this was the adoption in 2021 of the new version of the Law of Ukraine "On Insurance" (Law of Ukraine, 2021). This Law significantly increases the requirements for insurance and reinsurance activities in the market, while strengthening the protection of consumer rights to insurance services.

The vast majority of researchers (agricultural economists) share the identity of positions regarding the expediency of using the agricultural insurance system as an effective tool for countering agricultural risks. This opinion is shared by Aleskerova (2015); Siwedza & Shava (2020); Ivashkiv (2021); Raimondo (2021). Paying tribute to the best practices of researchers from different countries of the world, the authors of the study support the scientific position on the validity of a gradual increase in the amount of state subsidies in the field of agricultural insurance (Slobodyanuk, 2016; Lusk, 2017; Russo, 2022), the need to diversify services in the insurance market (Yanyshyn, 2019; Siwedza & Shava, 2020). At the same time, issues related to the scientific substantiation of the role of insurance in the system of ensuring sustainable land use remain controversial (Goodwin & Hungerford, 2015; Claassen *et al*., 2017). Since the achievement of "sustainability" in the production and processing of agricultural products in the context of the establishment of insurance relations in the agricultural sector provides for maximum insurance coverage of natural, anthropogenic, economic, environmental, social, and other risks. Admittedly, such a development is the most desirable from the standpoint of the development of agricultural insurance, although it is unlikely in the medium term for Ukraine.

However, the results of the conducted research indicate the objective possibility of a gradual expansion of insurance coverage of agricultural risks. The driving force for the development of agricultural insurance should be the growth of the institutional capacity of participants in the insurance process. For insurance companies, this concept is associated with the development and implementation of innovative insurance products (classical and index) that can fully meet the needs of agricultural producers in insurance protection; the use of creative management and marketing technologies in the field of purchase and sale of insurance services; ensuring the solvency, liquidity, and profitability of insurance operations. At the same time, for policyholders, the process of increasing their institutional capacity is based on awareness of the role of agricultural insurance in the process of minimising agricultural risks; mastering the necessary array of knowledge and forming an insurance culture among potential consumers of insurance services, and increasing effective demand for insurance coverage. The growing institutional maturity of key stakeholders in the agricultural insurance market will indicate an increase in their integration capabilities into the pan-European insurance space.

In the scientific literature, insufficient attention is paid to the issues of increasing social responsibility by all participants in the insurance process. Although it can obviously be argued that moral, ethical, and socio-psychological factors acquire special weight in the process of distributing risks and responsibilities between agricultural insurance entities. The formulated statement is based on the position that social responsibility increases trust, and therefore, increases the business and investment activity of interested parties in the insurance process. The authors of this study agree with the thesis that "the driving force of the development of insurance relations in society on the basis of corporate social responsibility should be considered the reproduction of a high level of trust, the manifestation of insurance culture, ensuring information awareness and actuarial balance of consumers and sellers of insurance services" (Skydan *et al*., 2022). Thus, the growth of social responsibility should be considered an innovative factor in the intensive development of insurance relations in the agricultural sector in the medium and long term.

Summarising the results of the study, it is worth focusing on the key positions of further development of agricultural insurance in Ukraine. This refers to the establishment of broad access (in terms of the price and volume of insurance coverage) of agricultural producers to classical and index insurance services. Separately, it is necessary to emphasise the expediency of activating the process of insurance and reinsurance of risks associated with: food exports to international agricultural markets, production of organic products, and increase of ecological and economic responsibility for land pollution. Consequently, the continued use of microinsurance, insurance, and reinsurance tools allows minimising agricultural risks and maintaining an appropriate level of food security at the national and global levels.

CONCLUSIONS

For the vast majority of civilised countries of the world, agribusiness insurance is an integral element of an integral system of financial and economic relations in rural areas. The fundamental advantage of the insurance system lies in its ability to effectively distribute risks and liability among interested market stakeholders and provide a mechanism for compensation of losses in the case of an insured event. The success of implementing insurance relations in the agricultural sector largely depends on the ability to accumulate funds in the insurance fund in a timely manner and direct them to insurance payments distributed in space and time.

Against the background of the widespread use of agricultural insurance in many countries of the world, this financial instrument is not used sufficiently in Ukraine to neutralise possible risks. The achievement of the set mission of development of agribusiness insurance is seen in a significant expansion of coverage of agricultural risks by insurance, strengthening, and diversification of options for property protection of producers, while strengthening the guarantees of financial security of insurance companies. Balancing the insurance interests of market stakeholders is possible in conditions of increasing their institutional capacity, stimulating effective demand with the parallel establishment of a competitive supply for insurance services.

The functioning of the modern model of agribusiness insurance requires a significant concentration of intellectual, technological, and financial resources aimed at consistently neutralising the risks of agricultural production. In the post-war period, more advanced methods of cooperation between agricultural insurance market participants should be used to increase business and investment activity. This refers to organising the insurance process on the basis of public-private partnerships, spreading the practices of mutual insurance companies in the agricultural sector, etc. Consequently, the establishment of joint liability for agricultural risks in the coordinate system of insurance relations in society creates safe conditions for the production, transportation, and sale of products in the domestic and foreign agricultural markets. Prospects for further study are aimed at substantiating strategic guidelines and modelling the processes of implementing the potential of agricultural insurance in Ukraine.

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Місія міжнародного страхового агробізнесу: сучасні виклики та можливості для України

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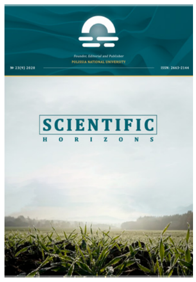
Анотація. Актуальною проблемою сьогодення є відтворення стійкої спроможності задовольнити попит на харчові продукти у різних країнах світу. Розв'язання даної глобальної проблеми перебуває у площині пошуку оптимальних фінансово-економічних інструментів своєчасної протидії сільськогосподарським ризикам. Багаторічний світовий досвід доводить, що таким інструментом виступає страхування. Метою дослідження є концептуальне обґрунтування місії міжнародного страхового агробізнесу та конкретизація сучасних викликів й визначення можливостей для України. Методологія даного дослідження базувалася на використанні різноманітних методів, зокрема: абстрактно-логічного, гносеологічного, компаративістики, структурно-функціонального, моделювання, формалізації, індукції та дедукції, а також регресійного та системного аналізу. Унікальність страхування полягає у його здатності акумулювати необхідні фінансові ресурси та розподіляти їх на потреби відшкодування збитків у разі настання страхових подій, розподілених у просторі й часі. Відтак, проведені дослідження спрямовані на обґрунтування місії міжнародного страхового агробізнесу, окреслення сучасних викликів і виявлення наявних можливостей в Україні. Встановлено основні переваги та недоліки різних моделей взаємодії стейкхолдерів на міжнародному ринку аграрного страхування. Висвітлено світовий досвід у позиціонуванні класичних та індексних страхових продуктів на ринку. З'ясовано, що сучасний рівень страхового агробізнесу в Україні не відповідає його потенційним можливостям. Базуючись на параметрах побудованої регресійної моделі, встановлено, що в основі подальшого розширення страхового покриття сільськогосподарських ризиків є нарощування кількості укладених та переукладених договорів аграрного страхування, збільшення ліміту відповідальності (страхових сум) компаній, забезпечення актуарної збалансованості, зростання сум державних субсидій. Практичну реалізацію окреслених заходів варто розглядати у контексті формування продовольчої безпеки на регіональному, національному та глобальному рівнях

Ключові слова: аграрне страхування, сільськогосподарські ризики, стейкхолдери ринку, страхові інтереси

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 25(10), 119-126



UDC 368.1
DOI: 10.48077/scihor.25(10).2022.119-126

Peculiarities of Insurance of Subjects of the Closed Cycle Technology Sphere

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Article's History:
Received: 09/30/2022
Revised: 11/18/2022
Accepted: 12/11/2022

Suggested Citation:
Shebanina, O.V., Kormyshkin, Iu.A., Kliuchnyk, A.V., Reshetilov, G.O., & Allakhverdiyeva, I.V. (2022). Peculiarities of insurance of subjects of the closed cycle technology sphere. *Scientific Horizons*, 25(10), 119-126.

Abstract. The urgency of the declared subject of scientific research is conditioned by the existence of many problems in the protection of property interests at realization of technologies of a closed cycle. This is especially important for Ukraine, where closed cycle technologies are only introduced into the national economy and do not comprise the significant part of the state's gross domestic product. The purpose of this research is to study the prospects of protection against adverse risks, which may arise during the implementation of the closed cycle technology, due to the transfer of risks to insurance. The basis of methodological approach in this research article is a qualitative combination of methods of system analysis of the possibility and expediency of risk insurance at realization of the technology of closed cycle and research of the quality of insurance protection, assortment of available insurance products, which can cover risks inherent to subjects of realization of closed cycle technologies, and thus prospects of development of such kind of insurance. The main results obtained in this scientific research are the determination of the possibility and quality of insurance protection for the subjects of closed cycle economy, as well as the formulation of problems, logistics and ways of improving insurance of subjects of sphere of realization of closed cycle technologies. The results of this research, as well as the conclusions drawn from them, are significant both for the employees of the closed cycle technology sphere, who will be able to assess the possibility and process of insurance risks that may arise during the period of their activity and for insurance companies on the basis of this research, that have the desire to diversify the insurance portfolio and to add Agreements with representatives of the sphere of realization of closed cycle technologies

Keywords: closed cycle technology subjects, green technologies, insurance, prospects for the development of closed cycle technology subjects, insurance products

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INTRODUCTION

Today, there is a need to increase the share of closed cycle technologies in the general production both in Ukraine and in the whole world, since the constant use of natural resources has a negative impact on the environment (Babbitt *et al.*, 2021). Already in Ukraine are identified such ecological problems as increase of risks for human health, connected with almost all kinds of hydrometeorological phenomena; significant decrease of harvest of the main agricultural crops; aggravation of problems with water supply not only in Southern and South-Eastern regions; intensification of soil degradation and desertisation; reduction of productivity, viability and sustainability of forests; accelerated degradation of ecosystems; occurrence of accidents and unstable functioning of electric networks and centralized heating systems, other infrastructure facilities, and many others (Ministry of Energy and Environmental…, 2020). There are already some steps made by the state to develop a legal and regulatory framework for the operation of closed cycle technologies in Ukraine. One of the most important normative legal documents is the Law of Ukraine "On the Electricity Market" dated April 13, 2017 (Hamburg, 2020). This Law changed the state's approach to green energy and gave the impetus to open a number of enterprises specializing in the processing of different kinds of waste energy resources, which is already consumed by the population of our country.

According to Y. Geng *et al.* (2019), insurance is one of the components for the introduction of any green technologies in the national economy all over the world, and Ukraine is not an exception. In order to procure a loan to create a closed cycle production, any bank or other financial institution will require the conclusion of an insurance contract to protect against risks that may occur in the production of green energy or processing of raw materials. In the paper by I. Markevich and V. Sidenko (2019), the researchers asserted that insurance was required for different kinds of risks, both from political uncertainty of the state, which could cause break in production or decrease financing of the enterprise, and to have been responsible for damage to the environment, as a result of use of dangerous substances and materials. A. Herrera *et al.* (2021) believed that the main type of insurance that was necessary for the implementation of closed cycle technologies was property insurance, since enterprises engaged in processing raw materials, producing green electricity and other green economy often operated the expensive equipment. According to D. Bogdanov *et al.* (2021), in order to find optimal insurance protection, it is necessary to analyze the range of available insurance products offered for protection against risks inherent in closed cycle technologies. The results of their research claim that the main criteria should be a list of risks under which the Insurer assumes obligations, exclusion from insured accidents and other limitations of insurance, the price of insurance (or insurance tariff), reliability and reputation of the Insurer.

V.V. Dima (2020) admitted that insurance could become one of the most important financial instruments that would promote the development of closed cycle technologies. Z.-A. Ismail (2020) thinks that due to insurance, the risks of adverse events that may occur during the production period can be significantly reduced and thus stimulate enterprises to develop their activities in this field without looking at risks that may negatively affect their economic status, and investors will invest in the development of closed cycle technologies. The results of this scientist's research show that all of this can help to develop the sphere of closed cycle technologies in Ukraine considerably. According to B. Lin and R. Bai (2022), insurance gives a large number of advantages for the development of enterprises, including those working in the sphere of closed cycle technologies. However, these researchers believe that a few such companies in Ukraine apply to Insurers with the aim of protecting themselves from risks because of unwillingness to spend spare money.

The results of A.V. Thakor's (2020) research confirm the fact that insurance offers protection to companies that are not prone to risk taking from a wide range of risks, including damage to property, liability risks and financial risks inherent in closed cycle technology. However, despite its theoretical and practical utility, according to the opinion of individual and legal persons, Insurance contracts may not fulfill their duties, and the money spent on insurance protection will only be calculated in the expenses of the enterprise. According to D.H.B. Phan *et al.* (2020), the reasons of distrust include the inability of some Insurers to fulfill their obligations as a result of the low financial stability of many Insurers in Ukraine. One of the Ukrainian scientists who studied the problems of the insurance market of Ukraine, C. Haddad, L. Hornuf (2019) defines the financial stability of an insurance company as its ability to improve or not worsen the value of its performance indicators for changing factors. Therefore, the financial situation will be stable if the company can improve or not worsen the value of its performance indicators for the change of factors. At present, not all Insurers of Ukraine meet this point, because their financial condition and capacity to fulfill their obligations raise questions in any unsatisfactory situation on the market for the company. That is why the problem of insurance of closed cycle technology subjects should be raised to prove the effectiveness of insurance and the development of the correct insurance culture in enterprises working in this field.

The purpose of this research is to study the prospects of protection against adverse risks, which may arise during the implementation of the closed cycle technology, due to the transfer of risks to insurance.

MATERIALS AND METHODS

The basis of methodological approach in this research is a qualitative combination of methods of system analysis of insurance products that can cover risks of enterprises working in the sphere of technologies of closed cycle. The basis of such analysis is the insurance tariff, insurance conditions, exclusion and limitation of insurance, which is offered in accordance with insurance product documentation and reliability and reputation of the Insurer offering the insurance product. The theoretical basis of this research is the results of the carried-out researches of a number of Ukrainian and foreign researchers aimed at studying a number of problems connected with the possibility of protection of enterprises working in the sphere of closed cycle technologies against risks that may occur during the operation of such an enterprise.

The research was presented in three main stages. At the first stage of the scientific research, its theoretical base was prepared, which described the specifics of closed cycle technologies to explain the risks inherent in this type of production, and the specifics of closed cycle technology subjects' insurance, namely, the sources of risk, the method of tariff calculation and possible limits of insurance inherent for this type. At the second stage of scientific research, the analysis of prospects of insurance of closed cycle technology subjects is carried out. Analyzed insurance products that can meet the insurance interests of closed cycle technology subjects, their insurance conditions, exclusion and limitation of insurance. After analysis of insurance products, the product is chosen, which can be considered the most qualitative and effective for protection against risks inherent to the subjects of the closed cycle technology sphere. Each product is separated by both its positive and negative sides, which may influence the final choice of the Insurer.

At the final stage of the research, on the basis of the results obtained during its study, final conclusions of the scientific research, which form the aggregate picture, concerning the market of insurance of the closed cycle technology subjects were formulated. In particular, there are list of problems that prevent the growth of this segment of the insurance market and protection of closed cycle technology subjects from the risks inherent in this sphere. After the formulation of the problems, ways that could change the state of the insurance market of closed cycle technology subjects and improve the protection of enterprises working in this sphere were proposed.

RESULTS AND DISCUSSION

Closed cycle technology is a concept based on the idea to reuse materials to create new products. If in the usual, linear economy the majority of the natural resources extracted are passed into wastes which are recovered soon, then in the cyclic – any resources are used as long as possible, after which they are recycled. One of the teachers of the University of Maryland (United States of America – USA), T. Cao and Y. Hwang (2020) argue that interest in the closed cycle economy has increased due to oil crises, the depletion of open-access natural resources and environmental pollution. The concept of closed cycle technologies is combined with green and low-carbon technologies, where the central idea is to avoid fossil fuels and develop new technologies. However, in contrast to green technologies, closed cycle technologies are more specific and decide how less and more efficient to use different kinds of resources, not only those connected with electric power generation. As noted in the work written by M.T. Brouwer *et al.* (2020), the task of closed cycle technologies is to use renewable resources more widely, to carry out transition to non-waste production, to minimize damage and economic losses, which are caused to the environment through uncontrolled exploitation of mineral sources.

Closed cycle technologies are trying to introduce governments and business representatives all over the world, the most systematic – in Germany (Jiang *et al.*, 2022). For example, in Germany, one third of the total waste is for thermal utilization. The current level of development of closed cycle technologies is insufficient. They make up an average of 8.6% in world production. However, according to L. Cherchyk *et al.* (2019), to remain within the ecological potential of Earth, it is necessary to increase this indicator to 50-70%. In the production of one of the most developed countries in this sphere, Germany, the share of closed cycle technologies is only 10.4% – that is, only 10.4% of the resources were recycled materials. At the same time, progress in this direction is moving slowly. Over the past six years, growth in Germany has been only 0.1% per year. Even if the country is twice as fast, it will be able to reach 50% only by 2215. The group of scientists D. Aloin *et al.* (2020) to the good of closed cycle technologies, the arguments of both ecological and economic nature are presented. For the production of goods and services, and finally for the creation of a joint-stock value, the economy needs resources. If companies do not start using secondary raw materials radically more often, they will meet with lack of availability of resources, which will prevent their operations in the midterm and long term.

It follows that in order to maintain the ecological and economic state of the Earth, new levers of influence on the development of the closed cycle technology sphere are required. One of such levers should be insurance of the subjects of this sphere. During its activity, enterprises that introduce closed cycle technologies into their production meet with the number of risks, which are inherent both to the subjects of closed cycle technologies and in general, to all branches of economy of any state. J. Kaczmarek (2019) believes that closed cycle technology subjects can suffer from various risks, including the political uncertainty of the state, which may cause interruption in production or decrease in financing of the enterprise, and possible liability for environmental damage, as a result of the use of unsafe substances and materials. Equally important are property risks, which may occur with equipment or real estate, which is in use of enterprises. According to D. Asteriou *et al.* (2021), the most effective and simple way to protect against the above risks is insurance, which allows covering financial consequences from any unfavorable events. Nevertheless, insurance is not always in demand among any enterprises, including representatives of the closed cycle technology sphere. The question is particularly acute in Ukraine, where the insurance culture in the population and enterprises has always been low and voluntary types of insurance are more likely rarity than a mandatory step in the course of their activities.

According to R. Kaplinsky and E. Kraemer-Mbula (2022), one of the main problems of the insurance industry, which needs to be solved is planning of long-term development of insurance companies in the conditions of increase of their reliability. This statement once again emphasizes the need to increase the reliability of Ukrainian Insurers for greater trust from potential clients. No less important reason for distrust of Insurers is the ambiguity of Agreements for consumer's part, who may not have enough financial awareness to fully understand the essence of the Agreement and its operation. This factor of mistrust was investigated by scientist R. Peter and J. Ying (2020), and concluded that most of the regulation of the insurance product is focused on the exceptions in the Contract, which are not always aware of the consumer of the insurance service, because of which there are disputes and distrust to the Insurer. Although most of the existing disputes between Insurance Companies and their clients focus on the consequences of non-fulfillment of Insurance Contracts, the probability of non-fulfillment of the Contract should be considered primarily because of insufficient awareness of the consumers of insurance services. A. Belke *et al.* (2019) asserted that knowledge in the conditions of the Contract of insurance considerably increases the probability of proper functioning of such Contract, because under conditions of awareness the Insured is able to fulfill its obligations in accordance with the conditions of the Contract and thus not to prevent the Insurer from paying a possible insurance indemnity. In addition, if realizing the exceptions and limitations that may prevent payment of insurance indemnity, the Insured will be able to avoid risks on its own, which will not be paid insurance indemnity.

Analyzing the work of M. Tanninen (2020), who has studied the prospects of insurance development on the basis of social behavior of consumers of insurance services, it can be concluded that under the conditions of greater trust, demand for insurance products, which are aimed at protection of subjects of the closed cycle technology sphere, which is beneficial for both Insurers, and for the subjects of the closed cycle technology. In addition to the problem of trust in Insurers, there is also one of unwillingness to spend spare money on conclusion of insurance contracts. An insured event may or may not occur, it is an accidental event that cannot be influenced to a certain extent, and it is therefore impossible to predict in advance whether the conclusion of the Agreement will be justified itself or not. Thus, the enterprise risks paying a considerable amount of funds for transfer of risks to insurance, and instead get nothing. But A. Ajello *et al.* (2019) noted that in most cases, the subjects of the closed cycle technology sphere would not receive any insurance indemnity, and the insurance expenses would look like burden in the articles of expenditure of the enterprise. However, if an event could be considered as an insurance and not conclude an insurance contract, the enterprise risks receiving the number of losses that may be more significant than the insurance premiums for several years that the enterprise could pay. This problem of decision making or attempts to avoid risk was investigated by T. Heinrichand and J. Shachat (2020), and on the basis of their research it is possible to understand, that the way of avoiding risk by the enterprise should not be a norm, because on probability of hypothetically losing more significant amount of funds in the future, or to spend less significant amount of funds here and now both individual and legal persons have to choose the second option.

Analyzing one of works written by J. Knighton *et al.* (2020), interesting regularity can be seen: when the development of technologies of a closed cycle (an important instrument of its implementation should be insurance) significantly reduces the risks of natural disasters arising from ecological problems of our planet. By allowing this regularity, it makes sense to study the National flood insurance program (NFIP) records in the USA about flood insurance that provide information about historical risks of floods and the relationship between danger and risks. Over the past few decades, participation in the NFIP has steadily increased to approximately 5 million houses, with an annual record of an average of 60000 insured cases from floods, which is a significant indicator, since almost every 80-th house suffers from flooding. The problem of frequent realization of risks of flooding is just to solve the development of technologies of a closed cycle, according to the discovered regularity which was investigated by J. Knighton *et al.* (2020). However, it should be taken into account that economic barriers and failure to perceive the risk of housing owners may reduce the participation of housing owners in the NFIP, which may change the reliability of insurance indemnity statistics as an unbiased picture of historical data (Song & Wang, 2020).

Thus, for example, regarding the statistics of flooding in the USA, it can be argued that the number of insured events associated with such risks can be significantly reduced. Scientists from the USA, L.A. Bakkensen and L. Ma (2020) confirm this assumption in one of their scientific works, which also confirms the risk mitigation of natural phenomena worldwide. This, in turn, will reduce the loss of such types of insurance, which will positively affect the financial results of Insurers all over the world. Also, if environmental risks are reduced, insurance tariffs for many types of insurance, such as property insurance, vehicle insurance, environmental liability insurance, etc. will be significantly reduced (Beirne, 2020). This will affect the price reduction of insurance services worldwide, because insurance, as a method of risk avoidance, will become more accessible and thus more common for both individual and legal entities. However, with a significant reduction in environmental risks in the world, such types of insurance as flood insurance and other types of insurance associated with environmental risks may become unnecessary to the population and enterprises, although now insurance is used as the main method of covering risks in the flood, as noted by Australian scientists C.H. Lucas and K.I. Booth (2020).

It is necessary to evaluate those insurance products that can protect against risks inherent to the subjects of the closed cycle technology sphere and developed by Ukrainian Insurers. It makes sense to evaluate their insurance conditions, exclusion and limitation of insurance and choose a product that can be considered the most qualitative and effective for protection against risks inherent to the subjects of the closed cycle technology sphere. For analysis the best choice will be insurance of objects of green energy. In Ukraine there are 2 main products developed specifically for the insurance of green energy objects, namely the products "Insurance of solar power stations" from insurance company "Persha" and "Insurance of green energy objects" from insurance company "INGO". It is necessary to note that if the first product is specialized only on solar power, the second product is more universal and more suitable for the subjects of the closed cycle technology sphere. In general, it is possible to ensure objects of green energy and at another insurance companies of Ukraine, but on the terms of insurance products on property insurance, because the special insurance products for green energy objects insurance were not developed by these Insurers. In the product "Insurance of solar power stations" from insurance company "Persha" Insurance consists of four blocks:

1. Block A – insurance of building and construction works for solar power station construction. The insurance coverage begins with "zero cycle" or erection of foundation blocks and continues until the plant is put into operation.
2. Block B – third party liability insurance.
3. Block C – shipment insurance of solar panel. Solar panels are very fragile commodity; therefore, the Insurer strongly recommends to additionally insure their transportation on the whole way of shipment.
4. Block D – insurance of the solar power station as a property complex, after completion of construction and putting into operation (property insurance).

This product has no limitations of insurance or exclusions, therefore it can fully protect the subjects of green energy at all stages of their activity from the beginning of construction of solar "farm", from the moment of erection of foundation blocks, to the stage of main activity of "farm", i.e., electric power generation. At the same time, it is quite convenient that insurance consists of four blocks, and the Insurer can personally choose protection from those risks that he/she considers necessary. For example, if the Insurer is sure that the risks of damage or destruction of solar panels during shipment are minimal, and the course of shipment of expensive equipment is fully controlled by them, they can refuse from this block and save money and thus will reduce the cost of insurance for the enterprise. Insurance company "INGO" offers to the Insurer some other conditions. Insurance is divided into four blocks:

1. Block 1 – insurance of building and construction works at any stage of building activity.
2. Block 2 – liability insurance, which may arise during the basic activity of the enterprise, to third parties.
3. Block 3 – interruption insurance.
4. Block 4 – risk insurance against damage or destruction of property, which may occur during the enterprise activity.

In general, both products have a convenient system of choice of insurance program by blocks, which improve quality. However, each product does not have at least one important insurance block. The product "Insurance of green energy objects" from insurance company "INGO" has no block on the property insurance of the green energy subject against damage or destruction during shipment, and the product "Insurance of solar power stations" from insurance company "Persha" has no block on the interruption insurance. However, interruption insurance is more important for enterprises working in the sphere of closed cycle technologies, as it was noted by representatives of this sphere there are political risks in this sphere, especially in Ukraine. The problem is that at present, green electricity generation has a higher cost. Accordingly, due to the high price of green electricity compared to the prices for electricity generation, the traditional methods may be limited at any moment. That is why the product "Insurance of green energy objects" from insurance company "INGO" can be considered more qualitative and more appropriate for protection of property interests of the subjects of the closed cycle technology sphere. Also, in favor of this product is its universality, thanks to which it is possible to ensure objects of enterprises, which use any green technologies for production of pure electric power, not only electric power generation due to operation of solar panels.

The scientists S. Giglio *et al.* (2021) note the problems that caused the undeveloped insurance of closed cycle technology of the subjects in Ukraine. The main problem of this type of insurance development is extremely low demand for it. In general, almost all types of insurance are in low demand and this situation is observed during the entire period of existence of the insurance market in Ukraine. However, such kind of insurance as insurance of the subjects of the closed cycle technology sphere that demand is minimal, which can be evidenced by the extremely low number of developed insurance products for this type of insurance. Research group K. Hu *et al.* (2021), assume that the main problem for the development of all types of insurance existing in Ukraine, including insurance of closed cycle technology subjects, is extremely low solvency of both individual and legal persons. Enterprises working in the sphere of closed cycle technologies do not have enough funds to spend them on additional methods of protection against risks, one of which is insurance. According to Y.-B. Chiu and C.-C. Lee (2019), the very important problem is the low offer for this type of insurance, namely the small amount of insurance products developed for the subjects of the closed cycle technology. All this makes the unreliability of many Insurers of Ukraine even more difficult due to the offer look like too weak for closed cycle technology subjects to have a high desire to insure their risks. For this purpose, insurers should develop more insurance products for this prospective type of insurance. However, due to the low level of development of closed cycle technologies in Ukraine, Insurers do not expect to receive a large number of insurance premiums, so they do not want to spend human and financial resources on development of new insurance products. Therefore, due to the low development of this sphere in Ukraine, the growth of the offer of such kind of insurance as insurance of the subjects of the closed cycle technology sphere is unlikely.

CONCLUSIONS

It was researched that the development of insurance of the subjects of the closed cycle technology sphere would depend directly on the participation of the state and Insurers in this process. It was noted that for development of this type of insurance, efforts of all participants of the insurance market should be attracted. On the part of the state there should be the most incentive to insurance for enterprises working in the sphere of closed cycle technologies. Such an incentive may look like compensation of the part of the insurance cost for these enterprises. Therefore, enterprises will be able to ensure their risks and have a better chance of successful existence and development, and the state will get another developed branch in the economy, which can become a significant part of the state's gross domestic product. Also, it was confirmed that under the condition of the consumer's awareness of insurance services under the conditions of the Contract of insurance the trust to Insurers would increase considerably.

It was established that the insurers themselves should develop new insurance products, which might be interested in terms of the subjects of the closed cycle technology sphere and significantly increase competition in the market of this type of insurance. However, to motivate Insurers first, it is necessary to increase the demand due to the compensation of part of the insurance cost. It was determined that in the long-term period of insurance of the subjects of the closed cycle technology sphere has all chances for successful development taking into account the development of the entire insurance market of Ukraine. All this will significantly improve the development of the closed cycle technologies and insurance in Ukraine. Thus, it is possible to confirm that under the condition of global insurance of subjects of the closed cycle technologies sphere and further development of such technologies, in the future the nature of risks of individual and legal persons, and accordingly the insurance sphere as a whole, will change considerably.

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Особливості страхування суб'єктів сфери технологій замкнутого циклу

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Анотація. Актуальність заявленої тематики наукового дослідження зумовлюється наявністю безлічі проблем у захисті майнових інтересів при реалізації технологій замкнутого циклу. Особливо актуально це є для Україні, де технології замкнутого циклу лише впроваджуються в національну економіку та ще не є вагомою часткою у ВВП держави. Метою даної науково-дослідної роботи є вивчення перспектив захисту від несприятливих ризиків, що можуть виникати при реалізації технології замкнутого циклу, завдяки передачі ризиків на страхування. Основу методологічного підходу в цій науково-дослідній роботі складає якісне поєднання методів системного аналізу можливості та доцільності страхування ризиків при реалізації технології замкнутого циклу та дослідженням якості страхового захисту, асортименту наявних страхових продуктів, що можуть покрити ризики, притаманні суб'єктам реалізації технологій замкнутого циклу, а отже й перспектив розвитку такого виду страхування. Головними результатами, які були отримані в рамках цього наукового дослідження, є визначення можливості та якості страхового захисту для суб'єктів економіки замкнутого циклу, а також формулювання проблематики, логістики та шляхів покращення страхування суб'єктів сфери реалізації технологій замкнутого циклу. Результати цього наукового дослідження, а також сформульовані на їх основі висновки, мають суттєву значимість як для працівників сфери технологій замкнутого циклу, які на основі цього дослідження матимуть змогу оцінити можливість та процес страхування ризиків, що можуть виникнути в період їх діяльності, так і для страхових компаній, що мають бажання диверсифікувати страховий портфель та додати в нього Договори, укладені з представниками сфери реалізації технологій замкнутого циклу

Ключові слова: суб'єкти сфери технологій замкнутого циклу, зелені технології, страхування, перспективи розвитку страхування суб'єктів сфери технологій замкнутого циклу, страхові продукти

Журнал
«НАУКОВІ ГОРИЗОНТИ»

Том 25, № 10
2022

(Англійською мовою)

Редагування англомовних текстів:
С. Воровський

Відповідальний редактор:
Д. Кокра

Редагування бібліографічних списків:
Д. Кокра, К. Сосєдко

Комп'ютерна верстка:
К. Сосєдко

Підписано до друку з оригінал-макета 28.12.2022
Ум. друк. арк. 15

Видавництво: Поліський національний університет
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Journal
"SCIENTIFIC HORIZONS"

Volume 25, No. 10
2022

Editing English-Language Texts:
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Editing Bibliographic Lists:
D. Kokra, K. Sosiedko

Desktop Publishing:
K. Sosiedko

Signed to the print with the original layout 12/28/2022
Conventional Printed Sheet 15

Publisher: Polissia National University
10008, 7 Staryi Bvld., Zhytomyr, Ukraine
Tel. (0412) 22-04-17;
E-mail: info@sciencehorizon.com.ua
www: https://sciencehorizon.com.ua/en