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INNOVATION-DRIVEN DEVELOPMENT OF UKRAINE'S AGRICULTURE UNDER COMPLEX THREATS

Introduction. *As a result of Russia's full-scale war against Ukraine, food security at the global level is under threat. Ukraine's agricultural sector suffered losses of USD 2.1 billion because of the destruction or partial damage of agricultural lands and failure to harvest crops. Agricultural land has been damaged by landmine contamination, unexploded ammunition, which poses a mortal threat to farmers, and by direct physical bombardment of agricultural land.*

Problem Statement. *Production and productivity sustainability of agricultural production is one of the most important issues today. A system of knowledge and innovation in the agricultural sector is necessary and important. It includes organizations and cooperatives of farmers, foresters, advisers, researchers, business representatives, and public organizations.*

Purpose. *The purpose is to conduct a correlation-regression analysis of the innovation-driven development of agriculture in Ukraine under conditions of complex threats.*

Material and Methods. *While doing this study we have used methods of multivariate statistical analysis and taxonomy methods to assess the level of individual threats. The center of gravity method is used to select representative indicators of threats to innovation-driven development.*

Results. *In the study, the complex threats to the innovation-driven development of agriculture have been analyzed. The matrix of distances has been calculated for the initial set of indicators characterizing a separate threat. The threat of a decrease in research and development expenditure in the forecast period has the highest impact on the level of innovation-driven development of agriculture. This is evidenced by low pairwise correlation coefficients and the overall level of innovation-driven development.*

Conclusions. *The correlation-regression analysis of innovation-driven development of agriculture has made it possible to determine the highest threat affecting the level of innovation-driven development of agriculture.*

Keywords: innovation-driven development, agriculture, threats, innovation, and agrarian sector.

The agriculture of Ukraine have incurred colossal losses, including the direct losses of USD 4.3 billion and the indirect ones of USD 23.3 billion dollars [1]. Agricultural machinery and equipment are damaged by shelling, airstrikes, and hostilities. The estimated cost of replacing and repairing equipment is USD 926.1 million. In addition, losses due to damage or destruction of granaries are estimated at USD 272 million. As a result of Russia's aggression, the estimated value of the dead livestock has exceeded USD 136 million. According to approximate data, more than 42,000 sheep and goats, 92,000 cows, 258,000 pigs, and more than 5,700,000 poultry have died.

In November 2022, the launch of the *Grain from Ukraine* humanitarian food program was announced. This initiative aimed to provide grain to at least 5 million people by the end of spring 2023. In general, as part of the *Grain from Ukraine* humanitarian initiative, Ukraine plans to send more than 60 ships to Ethiopia, Sudan, South Sudan, Somalia, Congo, Kenya, Yemen, etc. Many European countries and international organizations have supported the Ukrainian grain program by making financial, technical or logistical contributions. In general, more than USD 190 million have been raised for the implementation of this program from various sources.

Only efficient innovation in agriculture will be able to bring the agrarian sector to a new level, through the development of the field of agriculture and deep processing of agricultural products, the expansion of knowledge in agrarian management and marketing, advanced technologies in agriculture, consultations on profitable farming, the formation of a new model of agriculture development consultancy, given Ukraine's and European experience.

Among modern innovation solutions, crucial importance is given to once related to agricultural land, value-added chains, environment, climate, biodiversity, society, consumers, etc. (Fig. 1).

Examples of innovation are the system of GPS supervision and monitoring of fuel consumption. Thanks to the developed system, a household saved USD 15 million for 4 years, which is more than the annual investments in innovation of the seven largest agricultural holdings of the country. Another example: differential introduction of compensatory rates of nitrogen fertilizers allows rationally spreading fertilizers over the field and returning nutrient residues with basic nutrients to the soil. The use of this technology provides savings from USD 120 to 300 per 1 ha, depending on the harvested crop [2]. Soil cultivation with simultaneous differentiated local application of

Table 1. **Number of Specialists Involved in R&D Works in Agriculture [3]**

Year	Researchers	DSc and CSc	Technicians	Support staff	Employed researchers involved in R&D
2016	128	4	58	107	7283
2017	136	6	65	113	7451
Growth rate, %	*106.25*	*150.0*	*112.07*	*105.61*	*102.31*
2018	156	9	61	115	3910
2019	35	9	8	63	3512
Growth rate, %	*22.44*	*100.0*	*13.11*	*54.78*	*89.82*
2020	124	45	43	65	3562
2021	94	46	37	68	3558
Growth rate, %	*75.81*	*102.22*	*86.05*	*104.62*	*99.89*

| Robots and drones | accelerate farm automation by replacing manual farm works such as fruit picking, harvesting, planting, transplanting, spraying, sowing, and weeding or irrigating |

| Sensor-based devices | collect field data in real time, allowing farmers to make decisions based on specific data |

| AI and machine learning | automate the recognition of anomalies and diseases in plants and livestock and, if necessary, take corrective actions |

| Precision farming based on could technology | uses precise quantities of resources such as water, pesticides, and fertilizers to improve crop quality and productivity |

| Biotechnologies | improve the quality of cultivated crops and livestock in terms of desirable properties such as resistance to diseases, drought, pests, and high yields |

| Analytics | used to collect data on weather phenomena, agricultural equipment, water cycle, quality and quantity of harvest |

| Hydroponics and aeroponics | for growing plants without soil in a liquid nutrient medium or in steam |

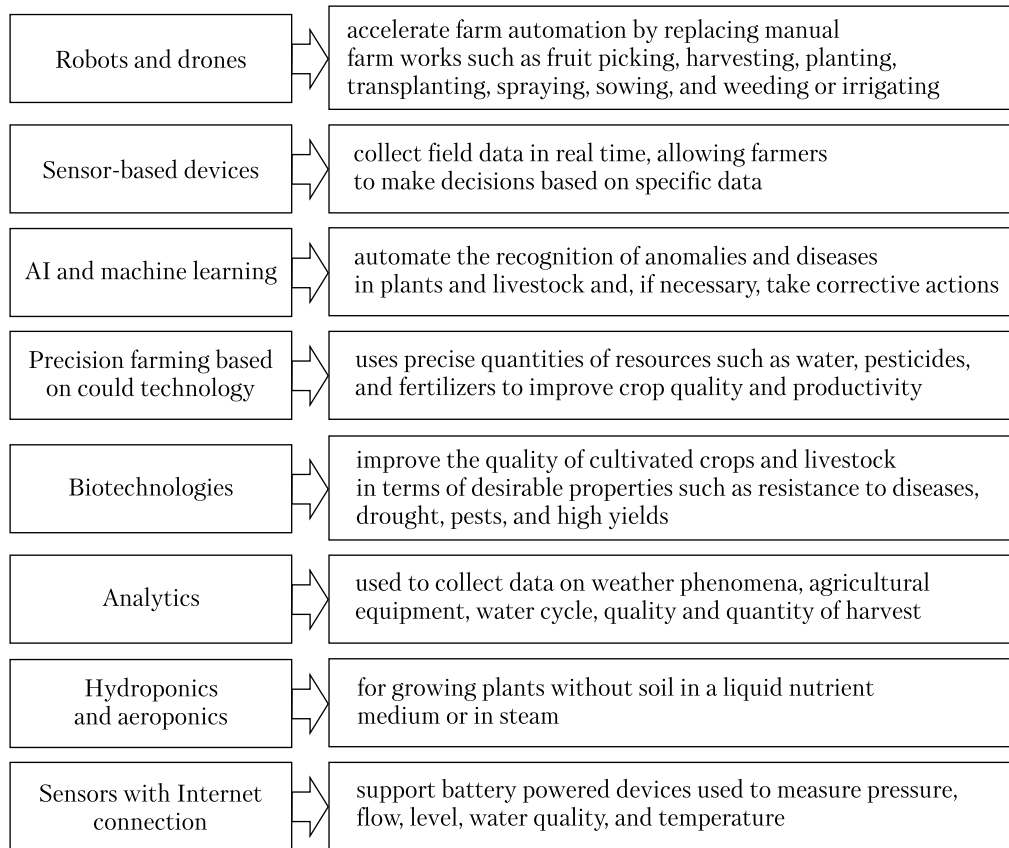| Sensors with Internet connection | support battery powered devices used to measure pressure, flow, level, water quality, and temperature |

Fig. 1. Innovation in agriculture
Source: prepared by the authors.

4 types of fertilizers provides a reduction in the consumption of basic fertilizers by up to 50% as compared with spreading them. Simultaneous cultivation of the soil, application of fertilizers and sowing saves about 40% of fuel and lubricants as compared with conventional methods.

The most important condition for innovation-driven development is the formation and effective use of R&D as an integral structural element of the innovation ecosystem. Therefore, it is extremely important to increase the number of people employed in the field of R&D. They generate new ideas that are embodied in R&D products: patents, prototypes that are a source of innovation.

Table shows that the number of specialists employed in the field of R&D in agriculture has been steadily decreasing, which is connected both with the loss of scientific potential in connection with the occupation of part of the territory of Ukraine and with a permanent reduction in the number of researchers and low funding of R&D. Such conditions do not ensure the possibility of conducting high-quality research and motivation of employees in this field.

During the war, the field of science and innovation suffered losses that significantly affected its subjects, infrastructure, and mechanism of functioning. The number of organizations involved in R&D in agriculture fluctuated over the years: 16 organizations, in 2016; 14, in 2017; 15, in 2018; 7, in 2019; and 12, in 2020. In 2022, about 15% of the research infrastructure, including higher education establishments and R&D institutions, in paticular unique scientific equipment, research lab-

oratories, centers for collective use of scientific equipment,was damaged by military actions [4].

In recent years, agricultural enterprises spent 75% of funds from the state budget and 25% of their own funds on innovation (Table 2). The largest general fund expenditure in 2021 accounted for promising technologies of the agro-industrial complex and processing industryas the priority direction. The share of expenditure on the priority field made up 40.8% of the total funding; the share of *Technology* in the R&D products in the priority field came to 73.3% of the total number of products, that of *Materials* accounted for 55.6%, that of *Varieties of plants and animal breeds* made

up 33.3%, that of *Methods, theories*was 27.4%, and that of *Types of products*was 20.9% [5].

Important conditions for ensuring the effective development of agricultural enterprises are the strengthening of their innovation and investment potential, which contributes to the production of high-quality and competitive products; technical and technological upgrade of the industry; the enhancement of the effectiveness of innovation and investment management in the agricultural sector, and the ensuring of the country's food security.

Table 3 shows that the capital investments in agriculture were decreasing from 2016 to 2020. The main reason for this was the expectation of

Table 2. **In-House Expenditure on R&D in Agriculture, UAH thousand [3]**

Year	Fundamental research	Applied research	R&D works	Expenditure from budget	In-house expenditure
2016	321458.2	402589	148643	13457	859234
2017	276084.9	388187	157679	11274	810676
Growth rate, %	*85.89*	*96.42*	*106.08*	*83.78*	*94.35*
2018	327045.9	460565	188341	9547	966405
2019	262636	489090	211543	425	7652.3
Growth rate, %	*80.31*	*106.19*	*112.32*	*4.45*	*0.79*
2020	12074.4	19933.4	2183.5	25477	8714.3
2021	15562	36521	1874.2	32856	9547
Growth rate, %	*128.88*	*183.22*	*85.83*	*128.96*	*109.56*

Table 3. **Investment Support of Innovation Processes in Agriculture, UAH thousand [3]**

Year	Capital investments by assets, total	Including investments in tangible assets	Including investments in intangible assets	Investments in trademarks and title to industrial property	Investments in software and databases
2016	55323733	54521368	802365	7523	32568
2017	52939146	52146582	792564	7945	34258
Growth rate, %	*95.69*	*95.64*	*98.78*	*105.61*	*105.19*
2018	44018119	43256874	761245	8725	32548
2019	40458233	39745687	712546	9526	35698
Growth rate, %	*91.91*	*91.88*	*93.60*	*109.18*	*109.68*
2020	36442059	35756668	685391	9955	33886
2021	49127383	48198605	928778	–	85208
Growth rate, %	*134.81*	*134.80*	*135.51*	*0.00*	*251.45*

the opening of the land market and the corresponding accumulation of financial resources by farmers in order to preserve the current land bank in the event of significant trade activity, high land value or other unforeseen circumstances. Even the poor harvests of most agricultural crops in 2020 did not have a positive effect on capital investments.

In recent years. the total capital investments per 1 ha of land have been varying from USD 70 to USD 100. However, only with capital investments over USD 150/ 1 ha we may consider that the country is developing in the direction of innovation-driven modernization. As the war continues, many households and family farms, individual agricultural producers, small businesses, traders, and processors of agricultural products have been experiencing difficulties with accessing production resources, financing, and investment to sustain and expand production.

From 2021 till now, Ukraine has been receiving significant assistance from the Food and Agriculture Organization of the United Nations (FAO), which actively supports farmers. So far, they have received winter wheat seeds to ensure production needs for the 2023 harvest; grain sleeves (over 30,000 plus 105 sets of special equipment for loading/unloading) to ensure storage and protection of the crop this season; animal feed; multi-purpose cash assistance and vouchers for the purchase of other means of production. In particular, in 2022, FAO allocated USD 2.4 million for the purchase of vegetable seeds, grain seeds, and potatoes for Ukrainian farmers. In addition, more than USD 3 million have been assigned to the modernization of phytosanitary and veterinary laboratories in Izmail [6].

In terms of investments, the agrarian sector falls behind the IT sector, construction, real estate, and metallurgy, while in terms of the number of transactions, the agricultural sector takes the second place.

It is appropriate in this research to conduct a correlation-regression analysis of the integral assessment of complex threats that create danger for innovation-driven development of agriculture and form the uncertainty of outcomes.

The assessment starts with choosing representative indicators for each threat studied. It is followed by an integrated assessment of the level of innovation-driven development of the industry based on the representative indicators and an integrated assessment of the level of threats based on the initial indicators, excluding the representative indicators, which are made in parallel. Then, based on a retrospective series of observations, a model of the relationship of an individual risk can be built. This makes it possible to track the dynamics of changes in the system of threats and the dynamics of changes in the degree of influence of each individual threat on the overall level of innovation-driven development of the industry.

Let us consider the algorithm for choosing the risk representative indicators based on the center of gravity method. When evaluating and analyzing complex threats to the innovation-driven development of agriculture, there is a problem of reducing the initial number of indicators that describe each of them. One of the options for solving the given problem can be choosing the representative indicators for each analyzed threats, based on the use of the center of gravity method.

In this case, for each s-th threat to innovation-driven development of the industry out of the totality of the indicators that describe it, $X_1^s, X_2^s, ...,$ X_{qs}^s, where q_s is the number of the indicators describing the s-th threat is chosen as representative indicator $U_s = X_k^s*$. In this case, the indicator of initial totality is considered as point T in space, where T is the number of steps. Distances between points $X_1^s, X_2^s, ..., X_{qs}^s$ are analyzed as criteria for choosing optimal point X_k^s*.

The block diagram of the center of gravity method algorithm that is used to choose the indicators representing the threats to the innovation-driven development of agriculture is presented in Fig. 2. Below, there is a description of each block.

Block 1. Based on the preliminary analysis, a list of threats to the innovation-driven development of agriculture and a list of the indicators describing each threat is determined.
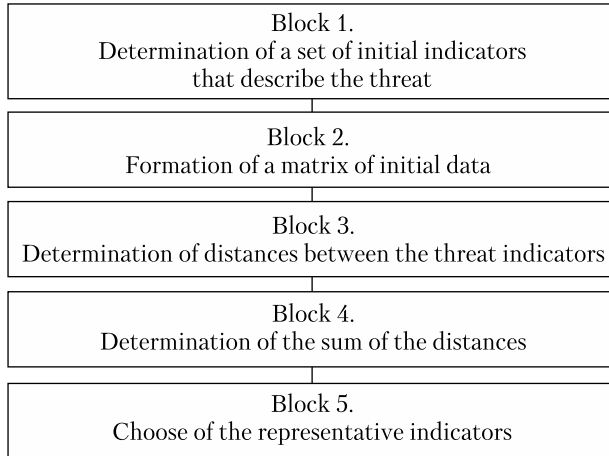
| Block 1.
Determination of a set of initial indicators
that describe the threat |
| Block 2.
Formation of a matrix of initial data |
| Block 3.
Determination of distances between the threat indicators |
| Block 4.
Determination of the sum of the distances |
| Block 5.
Choose of the representative indicators |

Fig. 2. Block diagram of the algorithm of the center of gravity method

Source: prepared by the authors.

Block 2. For each threat, a matrix of the initial data is formed $X^s = \{x_{tj}^s\}_{T \times Ns}$, where x_{tj}^s is the value of j-th indicator in t-th period of development, which describes threat s; $s = [1, p]$, where p is the number of threats considered, N_s is the total number of the indicators that describe s-th threat, T is the number of steps.

Block 3. The matrix of distances is written as follows:

$$C = \{C_{ij}\}_{Ns \times Ns}, \ C_{ij} = \sqrt{\sum_{k=1}^{T}(x_{ik} - x_{jk})^2}. \qquad (1)$$

Block 4. The type of formula for calculating the sum of distances is determined depending on the number of initial indicators that describe the threat.

If the number of the initial indicators characterizing the threat is more than two, then for each indicator, the sum of the distances d_{ik} to other indicators that describe given threat is calculated by the formula:

$$d_{ik} = \sum_{\substack{j=1 \\ j \neq i}}^{N_s} C_{ij}, \qquad (2)$$

where C_{ij} is the distance between the i-th indicator to j-th indicator of s-th threat;

N_s is the number of the indicators that describe s-th threat.

If the number of the initial indicators characterizing the threat is equal to two, then the sums of the distances of each of these two indicators from the representative indicators chosen for other threats in the previous step are calculated:

$$d_{ik} = \sum_{j=1}^{p} C_{ij}, \qquad (3)$$

where p is the number of the representative indicators previously chosen for threats in which the number of initial indicators is greater than two or equal to one.

Block 5. The representative indicator of the threat is chosen depending on the number of the initial indicators characterizing the threat. If the number of the initial indicators characterizing the threat is more than two, then we choose as representative indicator the indicator for which:

$$d_{mk} = \min_{i} d_{ik}, \ i = [1, N_s], \qquad (4)$$

where N_s is the number of the indicators that describe s-th threat.

If the number of the initial indicators characterizing the threat is equal to two, then the indicator for which:

$$d_{mk} = \max_{i} d_{ik}, \ i = [1, 2]. \qquad (5)$$

is chosen as representative indicator.

Thus, the use of the algorithm of the center of gravity method to determine the representative indicators of threats to innovation-driven development of agriculture allows significantly reducing the dimension of the information space of indicators of threats, as well as determining a set of the most significant indicators characterizing threats.

The set of representative indicators of threats, which is obtained with the help of this algorithm, serves as initial information for calculating the integral index of the level of innovation-driven development of agriculture.

Let us consider the algorithm for building models of the relationship of an individual threat based on the method of the level of development. For this purpose, it is proposed to use the methods of multivariate statistical analysis, namely, the taxo-

nomy methods. These methods are used to identify regularities in statistical populations, the units of which are characterized by a relatively large set of the indicators. Therefore, their use expands the possibilities of performing various comparisons on multidimensional objects. This algorithm is also used to assess the level of individual threats.

Each level of innovation-driven development of the industry is considered a point in the multidimensional space of threats:

$$X_t = (x_{t1}, x_{t2}, ..., x_{tj}), \qquad (6)$$

where x_{tj} is the value of j-th indicator that describes t-th state, $t = [1, T], j = [1, m]$.

Division of the indicators into stimulators and destimulators in the considered set. These types of indicators are introduced in order to take into account their economic content: the stimulators raise the level of innovation-driven development, while the destimulators, accordingly, cause a slump in it. In general, the indicator type is defined as follows:

the stimulators: $(x_{sj} \geq x_{rj}) \Rightarrow (w_s \succ w_r) \qquad (7)$

the destimulators: $(x_{sj} \geq x_{rj}) \Rightarrow (w_s \prec w_r) \qquad (8)$

Condition (7) means that object w_s dominates over object w_r, which formally is described as $w_s \succ w_r$, if $x_{sj} \geq x_{rj}$. Condition (8) characterizes the sign of the opposite operation. For this type of signs, the object w_r dominates over object w_s, if $x_{sn} \geq x_{rm}$. All the signs used in the study should be reduced to one type, for example, turned into stimulators. Thus, the destimulators are replaced by the stimulators through the following transformations:

$$x_{tj} = 1 - x'_{tj}, \qquad (9)$$

where x'_{tj} — is t-th realization of j-th destimulator indicator.

Determination of the index of innovation-driven development $M = (M_1, M_2, ..., M_T)$.

$$M_t = \frac{d_t}{c_0}, t = [1, T], \qquad (10)$$

$$c_0 = \overline{d} + a * S_d, \overline{d} \frac{1}{T} \sum_{t=1}^{T} d_t,$$

$$S_d = [\frac{1}{T} \sum_{t=1}^{T} (d_t - \overline{d})^2]^{\frac{1}{2}}, \qquad (11)$$

where a is a certain positive number chosen in such away that M_t ranges from 0 to 1.

At the last stage, the obtained results are interpreted from economic point of view. For M to take high values at large values of stimulators and low values at small values of stimulators, it is converted to the form:

$$M^* = 1 - M. \qquad (12)$$

Thus, the result of the considered algorithm is a number of values of the integral index of the level of innovation-driven development of agri-

Table 4. **Indicators That Describe the Treat of Reducing the R&D Efficiency**

Indicator	Code	Type
Researchers	x_1	stimulator
DSc and CSc	x_2	stimulator
Technicians	x_3	stimulator
Support staff	x_4	stimulator
Employees involved in R&D	x_5	stimulator

Table 5. **Matrix of Distances for the Risk of Reducing the R&D Efficiency**

	T_{2016}	T_{2017}	T_{2018}	T_{2019}	T_{2020}	T_{2021}	d_{ik}
X_1	0.0125	0.0139	0.1256	0.0036	0.0101	0.0098	3.3756
X_2	0.0047	0.0058	0.0094	0.0094	0.0587	0.0561	**1.2540**
X_3	0.0164	0.0198	0.0185	0.0095	0.0136	0.0107	2.8492
X_4	0.0112	0.0110	0.0128	0.0098	0.0092	0.0145	3.3258
X_5	1.1458	1.1421	1.0987	1.0925	1.0754	1.0687	4.2587

Source: prepared by the authors.

culture, which allows us to organize the studied set of its levels.

The task is solved within the framework of correlation-regression analysis by developing a model of the dependence of the level of innovation-driven development of agriculture on the level of threats:

$$M = f(U_1, U_2, ..., U_p) \qquad (12)$$

where M is the level of innovation-driven development, $U_1, U_2, ..., U_p$ are threat levels.

The accuracy of the regression analysis is assessed with the use of coefficients of multiple correlation, multiple determination, pairwise correlation and partial correlation. The coefficient of multiple correlation R characterizes the degree of joint influence of threats on the aggregate level of innovation-driven development:

$$R = \sqrt{1 - \frac{\sum_{i=1}^{n}(M_i - M_i)^2}{\sum_{i=1}^{n}(M_i - \overline{M})^2}}. \qquad (13)$$

Table 6. **Indicators That Describe the Risk of Reducing Expenditure on the R&D**

Indicator	Code	Type
Fundamental research	x_1	stimulator
Applied research	x_2	stimulator
R&D	x_3	stimulator
Budget expenditure	x_4	stimulator
In-house expenditure	x_5	stimulator

So, from the above research, to determine the level of innovation-driven development of agriculture, we consider the main three threats:
- the risk of reducing the R&D efficiency;
- the risk of reducing expenditure on the R&D;
- the risk of decreasing investment support for innovation processes in the industry.

We have made out an integral retrospective assessment of the level of threats based on the construction of the index of the level of development. Preliminary, the representative indicator chosen by the center of gravity method was excluded from the set of indicators describing each threat.

The results of the implementation of the specified algorithms for each threat are presented below. When assessing the threats to the innovation-driven development of agriculture, we propose the following interpretation of the types of initial indicators: an increase in the stimulator indicator leads to a decrease in the level of the corresponding threat, a low indicator means an increase in the level of the threat. The level of threats has beenforecasted with the use of the Kalman-Busy adaptive filtering method.

1. Let us consider the risk of a slump in the R&D. Table 4 shows the initial indicators, their conventional designations, and the type of indicators.

For the initial set of the indicators characterizing the threat of reducing the R&D efficiency, the obtained matrix of distances is presented in Table 5. It shows minimum sum of distances d_{ik} that corresponds to indicator X_2. Therefore, it is this indicator that acts as a representative indicator for the specified threat.

Table 7. **Matrix of Distances for the Risk of Reducing Expenditure on the R&D**

	T_{2016}	T_{2017}	T_{2018}	T_{2019}	T_{2020}	T_{2021}	d_{ik}
X_1	0.8796	0.7554	0.8948	0.7186	0.0330	0.0426	1.6858
X_2	1.1015	1.0621	1.2602	1.3382	0.0545	0.0999	1.4982
X_3	0.4067	0.4314	0.5153	0.5788	0.0060	0.0051	**1.1402**
X_4	0.0368	0.0308	0.0261	0.0012	0.0697	0.0899	6.3954
X_5	2.3510	2.2181	2.6442	0.0209	0.0238	0.0261	1.4735

Source: prepared by the authors.

X_2 is the lowest index of the number of DSc and CSc in the research field. It is this indicator that is further considered as representative indicator of the risk of reducing the R&D efficiency. One of the reasons that causes this threat is remote work of researchers, which, according to many organizers of science, negatively affects the efficiency of research activity and does not contribute to maintaining a positive creative and psychological climate in teams. A significant part of the R&D potential of Ukraine is located in the temporarily occupied territory. As a result of the hostilities, the infrastructure of many institutes has been damaged, some institutions and design bureaus in the front-line regions have been seriously destroyed. Many researchers had to evacuate from the zones affected by the war to the western regions of Ukraine or go abroad. Despite the efforts of top officials of R&D institutions on establishing effective communication with their employees who are abroad or forced to work remotely, the institutions still have not fully regained their once-achieved efficiency [7].

A significant reduction in budget funding for science, as well as an increase in the costs of maintaining and restoring its infrastructure have a negative impact on the R&D. Under such conditions, R&D institutions are often forced to introduce part-time employment of researchers, to put part of the staff in the forced downtime, or even to reduce the staff.

Let us consider the risk of reducing expenditure on the R&D. Table 6 lists the initial indicators describing the threat, their designations, and the type of indicators.

For the initial set of the indicators characterizing the risk of reducing expenditure on the R&D, the matrix of distances has been determined and is presented Table 7, according to which the minimum sum of distances d_{ik} corresponds to X_3 that is the index of R&D.

This indicator is further considered the representative indicator of the risk of reducing expenditure on the R&D.

The growing risk of low funding of the R&D restrains the growth of economic efficiency in the agricultural sector, the introduction of resource-saving solutions and the optimization of technology levels (choice of optimal technology, requirements for innovativeness of agricultural technology and saving of material and other costs). Therefore, it is extremely necessary to enhance the efficiency of budget and in-house expenditure for the timely application of agricultural innovation, which allows agricultural producers to optimize up to 35% of their in-house expenditure and to

Table 8. **Indicators that Describe the Risk of Decreasing Investment Support for Innovation in the Industry**

Indicator	Code	Type
Capital investments by type of assets	x_1	stimulator
Investments into tangible assets	x_2	stimulator
Investments into intangible assets	x_3	stimulator
Investments into trademarks and titles to industrial property	x_4	stimulator
Investments into software and databases	x_5	stimulator

Table 9. **Matrix of Distances for the Risk of Decreasing Investment Support of Innovation in the Industry**

	T_{2016}	T_{2017}	T_{2018}	T_{2019}	T_{2020}	T_{2021}	d_{ik}
X_1	7.0078	6.7058	5.5758	5.1248	4.6161	6.2229	1.6858
X_2	6.9062	6.6054	5.4793	5.0346	4.5293	6.1053	1.4982
X_3	0.1016	0.1004	0.0964	0.0903	0.0868	0.1176	1.1402
X_4	0.0010	0.0010	0.0011	0.0012	0.0013	0.0000	**1.0255**
X_5	0.0041	0.0043	0.0041	0.0045	0.0043	0.0108	1.4735

Source: authors' calculations.

increase income by USD 150—250 per 1 ha (due to increasing yield and gross collection).

Let us consider the risk of a decrease in investment support for innovation in the industry (Table 8).

For the initial set of the indicators characterizing the threat, the obtained distance matrix is presented in Table 9, according to which the minimum sum of distances d_{ik} corresponds to X_4, i.e. coefficient of investments into trademarks and titles to industrial property, which is further considered the representative indicator for the risk of decreasing the investment support of innovation.

During the period under review, the threat level has decreased, as indicated by growing investment activity in the industry due to the active involvement of foreign investments in the recovery of the Ukrainian economy in recent years.

Table 10 summarizes the forecast trends in all the above-mentioned threats to the innovation-driven development of agriculture, according to which, when making management decisions, the decision makers shall pay special attention to the threats of reducing the efficiency of the use of the R&D and reducing expenditure on the R&D in agriculture, because for the forecast period they show upward trends.

The annual change in the index of the level of innovation-driven development of agriculture for the retrospective period from 2016 to 2021 and for the forecast period of 2023, as obtained by the Kalman-Busy method, is 0.587. The obtained forecast indicates a decrease in the level of innovation-driven development of agriculture by 0.037 points, as compared with 2021.

Table 10. **Forecast Trends in the Risks to Innovation-Driven Development of Agriculture**

Risk	Trend
Efficiency of the R&D	Upward
Expenditure on the R&D	Upward
Investment support of innovation in the industry	Downward

Let us build a model of the relationship between threats and the level of innovation-driven development of the industry:

$$M = f(U^1, U^2, ..., U^p, a_0, a_1, ..., a_p),\qquad(14)$$

where M is the level of innovation-driven development; U^k is the level of k-th threat, $k = [1, p]$; a_0, a_1, ..., a_p are the model coefficients.

The model analysis has shown that within the period of forecast, the risk that forms the main component, namely, the risk of reducing expenditure on the R&D (U^2) has the highest influence on the level of innovation-driven development of agriculture. This has been confirmed by the low pairwise correlation coefficient for the mentioned risk and the general level of innovation-driven development: $cor(M, U_2) = 0.1$. The factors that cause this are low funding of the R&D in agriculture and the exchange rate that affects the profits and innovation in agro-industry, since all operations are made in foreign currency. Prices, for example, for maize fertilizer, fuel, and logistics have more than doubled, which has led to an increase in the cost of crops.

Although the budget for 2023 is focused on defense, with 43% of all funds assigned to the army, the budget includes expenditure on grants for the creation and development of businesses (UAH 1.37 billion) and for the Fund for the Elimination of the Consequences of Armed Aggression (UAH 19.3 billion). This expenditure also applies to agriculture. The government plans to expand the financing of soft loans through the Entrepreneurship Development Fund. In 2023, the expenditure on it amounts to UAH 16 billion. Raising additional funds to support the industry is planned only at the expense of international aid programs.

Within this research we have made a correlation-regression analysis of the integrated assessment of complex threats to the innovation-driven development of agriculture in Ukraine. The main three risks that affect innovation in the industry have been identified: the risk of reducing the efficiency of the R&D; the risk of reducing expenditure on the R&D, and the risk of decreasing investment support of innovation. From the set of

the indicators describing each threat, representative indicators have been chosen by the center of gravity method. For each threat, matrixes of initial data $X^s = \{x_{tj}^s\}_{T \times Ns}$ have been formed. From the forecast trends, the threat that forms the main component, namely the threat of reducing expenditure on R&D, has been identified. In the forecast period, it has the highest influence on the level of innovation-driven development of agriculture. This has been evidenced by the low pairwise correlation coefficient and the overall level of innovation-driven development.

Therefore, innovation-driven transformations in the agricultural sectorare urgently necessary and shall be accompanied by financial support from the state, significant investments, preferential lending, subsidies, and state programs for the transition from raw material exports to exports of products with high added value; for the transition to sustainable agriculture (precision agriculture, minimum tillage, electronic map of fields, use of GPS technologies); for the establishment of export relations with Asia, Africa, the EU, and the USA; for the improvement of food safety standards; for energy independence of the sector due to the use of alternative types of energy; for the implementation of infrastructure projects that allow increasing the production and reducing its cost, losses of raw materials and finished products during storage and transportation; and for the enhancement of the efficiency of agricultural enterprise management systems.

REFERENCES

1. Word and deed analytical portal: website. URL: https://www.slovoidilo.ua/2022/06/15/novyna/ekonomika/yaki-zbytky-vijna-zavdala-silskomu-hospodarstvu-ukrayini-doslidzhennya (Last accessed: 13.01.2023) [in Ukrainian].
2. Activities of business entities: statistical collection. URL: http://www.ukrstat.gov.ua/druk/publicat/kat_u/2020/zb/11/DSG_2019.pdf (Last accessed: 10.01.2023) [in Ukrainian].
3. Why you should not lose faith in the innovative agricultural future. Dnipropetrovsk Investment Agency: website. URL: https://dia.dp.gov.ua/chomu-ne-potribno-vtrachati-viru-v-innovacijne-agrarne-majbutnye/ (Last accessed: 18.01.2023) [in Ukrainian].
4. Main achievements in the field of science and innovation 2020—2022. Ministry of Education and Science of Ukraine: website. URL: https://mon.gov.ua/ua/news/golovni-dosyagnennya-u-sferi-nauki-ta-innovacij-2020-2022 (Last accessed: 16.01.2023) [in Ukrainian].
5. Pisarenko, T., Kuranda, T. (2022). Implementation of priority areas of development of science and technology and the results obtained in 2021: analytical reference.URL: https://mon.gov.ua/storage/app/media/nauka/informatsiyno analitychni/2022/07/27/Analitych.dov.Real.priorytet.napr.rozv.nauky.tekhniky.2021-08.08.2022.pdf (Last accessed: 10.01.2023) [in Ukrainian].
6. The impact of the war on agriculture: the UN presented an assessment of the urgent needs of the agricultural sector and the rural population. Agro-elite: website. URL: https://agroelita.info/vplyv-viyny-na-silske-hospodarstvo-oon-predstavylo-otsinku-nahalnykh-potreb-ahrosektoru-ta-silskoho-naselennia/ (Last accessed: 16.01.2023) [in Ukrainian].
7. National Academy of Sciences of Ukraine: website. URL: https://www.nas.gov.ua/UA/Messages/Announcements/Pages/View.aspx?MessageID=9463 (Last accessed: 18.01.2023) [in Ukrainian].

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ІННОВАЦІЙНИЙ РОЗВИТОК СІЛЬСЬКОГО ГОСПОДАРСТВА УКРАЇНИ В УМОВАХ КОМПЛЕКСНИХ ЗАГРОЗ

Вступ. Унаслідок повномасштабної війни Росії проти України продовольча безпека опинилася під загрозою на світовому рівні. Через знищення або часткове пошкодження сільськогосподарських угідь та втрату врожаю було зафіксовано збитки у розмірі 2,1 млрд доларів. Землі сільськогосподарського призначення пошкоджено мінним забрудненням через нерозірвані боєприпаси, що створюють смертельну загрозу для аграріїв, та загалом зафіксовано пряме фізичне бомбардування на сільськогосподарських угіддях.

Проблематика. Виробничо-продуктивна стійкість сільськогосподарського виробництва — одне з найголовніших питань сьогодення. Необхідною та важливою виступає система знань та інновацій у сільськогосподарській галузі, де охоплено організації та кооперативи фермерів, лісівників, дорадників, дослідників, представників бізнесу, громадські організації.

Мета. Проведення кореляційно-регресійного аналізу інноваційного розвитку сільського господарства України в умовах комплексних загроз.

Матеріали й методи. Використано методи багатовимірного статистичного аналізу, методи таксономії для оцінки рівня окремих загроз, метод центра ваги — для вибору показників-репрезентантів загроз інноваційного розвитку.

Результати. Проведено аналіз комплексних загроз інноваційного розвитку сільського господарства. Для вихідної сукупності показників, що характеризують окрему загрозу, розраховано матрицю відстаней. Загроза зниження витрат на науково-дослідні роботи у прогнозному періоді здійснює найвищий вплив на рівень інноваційного розвитку сільського господарства. Про це свідчать низькі значення коефіцієнтів парної кореляції та сукупного рівня інноваційного розвитку.

Висновки. Кореляційно-регресійний аналіз інноваційного розвитку сільського господарства дає можливість визначити найвищу загрозу, що здійснює вплив на рівень інноваційного розвитку сільського господарства.

Ключові слова: інноваційний розвиток, сільське господарство, загрози, інноваційні розробки, аграрний сектор.