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MODELING OF THE DESIGN OF AGRICULTURAL RESOURCE-SAVING CLUSTERS IN THE CONDITIONS OF A THREAT TO NATIONAL SECURITY AND A SPECIAL LEGAL REGIME

Khanlar Makhmudov[1*], Olena Taran-Lala[1], Nelia Volkova[1], Olena Mykhailova[1], Svitlana Pysarenko[1], Oleksandr Sen[1]

[1]Department of Entrepreneurship and Law, Poltava State Agrarian University, Skovorody str. 1/3, 36003 Poltava, Ukraine

[*]e-mail: ocvita-ukr@ukr.net

Abstract

The last decades are characterized by the acceleration of the process of globalization, which requires business entities in the agrarian sphere to adapt to these conditions, in particular, to ensure the appropriate level of efficiency and competitiveness. In the process of improving the efficiency of the competitiveness of agricultural enterprises, it is advisable to introduce resource-saving technologies in the agro-industrial sector, based on the fact that the high efficiency of agricultural enterprises through ensuring the food security is a guarantee of national security. Since the introduction of a special legal regime due to the military aggression of the Russian Federation against Ukraine, provision of the effective functioning of agribusiness has become a critically important task. The construction of resource-saving clusters is one of the approaches that allows obtaining a synergistic effect from the collaboration of agricultural enterprises, thanks to which the efficiency of the respective enterprises and the agricultural sector as a whole will increase. The aim of the research is to develop a methodological approach to modeling of resource-saving clusters of agricultural enterprises.

The research was carried out on the basis of the analysis of empirical data characterizing the activities of 48 economic entities of the agrarian sphere of Ukraine. The analysis of empirical data made it possible to carry out clustering of these economic entities, taking into account the level of introduction of resource-saving technologies into economic practice and the level of the risk of implementing the activities in conditions of a special legal status. To solve the problem of clustering of agricultural enterprises, a neural network, namely Kohonen self-organizing map, was used.

As a result of the carried out research, a methodology for modeling the design of resource-saving clusters was proposed, which involves the analysis of indicators of the activity of agricultural enterprises that allows the distribution of agricultural enterprises by clusters, taking into account the level of implementing the resource-saving technologies in economic practice and the level of the risk of implementing activities in conditions of a special legal status. The analysis of empirical data made it possible to identify six clusters into which the studied agricultural enterprises were divided. Economic entities falling into the same cluster are characterized by similar values of indicators. The use of this approach allows creating an optimal design to develop recommendations for agricultural enterprises regarding collaboration, taking into account the characteristic level of implementation of resource-saving technologies in the production process and the risk of implementing economic activities in conditions of a special legal status.

Ensuring a high level of efficiency and competitiveness of agricultural enterprises becomes a particularly important task in the conditions of a special legal status. It is due to the application of the cluster approach and the proposed cluster design modeling methodology that agricultural enterprises obtain a chance to quickly adjust their functioning according to the requirements of a special legal status and reduce the risks associated with military actions. The application of the proposed methodology made it possible to divide the studied enterprises into six clusters, which are characterized by the corresponding levels of the introduction of resource-saving technologies and the risk of carrying out activities in war conditions, and to develop recommendations for their collaboration.

Key words: *Clusters, Agricultural Enterprise, Resource-saving Technology, Special Legal Status.*

1. Introduction

In the modern world, processes are taking place that have a bilateral nature, on the one hand, there is an intensification of competition on the global market of agricultural products, and on the other hand, the problem of the food crisis is becoming actualized, which became even more acute in the first half of 2022 due to the war between the Russian Federation and Ukraine as far as due to: military actions agribusiness lost the opportunity to safely deliver its products to customers, the impossibility of conducting field work in the war zone, the deterioration of the material and technical support of agricultural enterprises, the destruction of the production infrastructure. An example of such a situation can be the grain crisis. In connection with the military aggression of the Russian Federation against Ukraine, the Decree of the President of Ukraine No. 64/2022 of February 24, 2022 introduced Martial Law in Ukraine. For Ukrainian agricultural enterprises, this situation is extremely difficult and requires management to make non-standard decisions quickly in conditions of uncertainty. In order to ensure the food security of the state and a high level of competitiveness of the products of national agricultural enterprises on international markets, it is advisable to form a strategy that provides for the implementation of innovative resource-saving technologies in the economic practice of agricultural enterprises. The level of development of integration mechanisms in the field of agribusiness is also important, because it is due to the effective interaction of business entities that it is possible to achieve a synergistic effect in overcoming the challenges faced by Ukrainian agribusinesses in the conditions of a special legal regime. However, in addition to the specific problems caused by the war, agricultural enterprises have to solve other problems that were and remain characteristic of the national agricultural sector, namely: soil degradation, dependence on mineral fertilizers and agrochemicals, slow pace of implementation of resource-saving technologies, loss of biodiversity, climate change. Thus, in 2020, the national agribusiness suffered heavy losses due to the significant dependence of agribusiness on natural conditions, and therefore the insufficient use of agrotechnology. Therefore, Ukrainian agricultural enterprises will have to solve these problems despite the extremely difficult conditions of wartime.

The concept of resource-saving agribusiness involves the use of modern technologies to improve production and soil protection of land plots, rational use of water resources, minimization of the use of pesticides, herbicides, fungicides, and preservation of biodiversity. It is thanks to the identification of sources of losses or places of suboptimal use of resources and their elimination that it is possible to increase competitiveness and increase profitability.

The analysis of scientific works indicates a significant interest of scientists in various aspects of the development and implementation of resource-saving technologies in the agricultural sector. For example, Farooq and Siddique, [1], Giller *et al.,* [2], Stanojevic*,* [3], and many other authors consider the general principles of resource-saving agriculture, emphasizing the importance of using innovative agricultural technologies for more efficient use of natural resources and reducing the negative impact on the environment. Singh and Meena*,* [4], in their study pay special attention to the economic aspects of resource-saving agribusiness. The authors emphasize that the preservation of resources and the environment is the foundation of sustainable productivity growth. And they also draw attention to the fact that the process of implementing resource-saving technologies is demanding not only in the context of financial resources, but also requires highly qualified knowledge and suggest organizing a close partnership between scientists and farmers.

The feasibility of resource-saving agriculture is considered and analyzed by Palm *et al.,* [5], in their work and note the peculiarities of management using resource-saving technologies in the tropics and subtropics. Globalization aspects of the application of the agribusiness resource-saving concept are investigated by Kassam *et al.,* [6], in their work.

The work of Berger-Tal and Lahoz-Monfort [7], is interesting, considering the paradigm shift and public perception of innovative technologies as a tool for environmental protection. They emphasize that it is thanks to the introduction of innovative technologies that it is possible to achieve significant success in preserving the environment and resources. The authors also came to the conclusion that the success of the introduction and use of resource-saving technologies largely depends on the coordinated work of all business entities.

Some psychological aspects of the implementation of resource-saving technologies, namely water conservation, on the example of farmers who grow strawberries in Florida, are considered by Lynne *et al.,* [8], in their work. The authors analyze the application of the theory of planned behavior, and also pay attention to the perception of control in the decision-making process regarding the implementation of resource-saving technology and investments in it. They emphasize that in the process of evaluating the prospects for the implementation of resource-saving technology, it is important to take into account both the actual control over the implementation and the imaginary one.

Also, in the context of ensuring the high competitiveness of agricultural enterprises on global food markets, it is advisable to develop integration ties in the field of agribusiness. Back in the late 70s of the 20th century scientists began to investigate the role of agrarian clusters in the development of the agro-industrial complex and came to the conclusion that clustering has a positive effect on competitiveness. Modeling of agrarian clusters is an element of an innovative model of the development of the national economy agro-industrial sector.

Clustering involves achieving a synergistic effect, due to which the following outcomes can occur: increasing the competitiveness of products, reducing logistics costs, accumulating resources for the implementation of cost-effective projects, etc.

Within the framework of the research, the agro-industrial cluster is considered as an innovative association of enterprises, focused on increasing the competitiveness of products, productivity and the actualization of increasing resource efficiency.

In the scientific literature, a number of works are also devoted to the issues of clustering and innovations [9-10]. So Bargoni *et al.,* [11], examine the competitive strategies of agribusinesses in the context of the COVID-19 pandemic. In the work, the authors analyze the data of 123 enterprises, divide them into four clusters and develop strategies for individual clusters. Sudhanshu *et al.,* [12], investigate agritourism clusters, the main advantages and problems of building agritourism clusters.

Some works are devoted to the study of logistical aspects of clustering of agricultural enterprises, for example, Boudahri *et al.,* [13], analyze the application of a location routing model based on clustering in order to improve the quality of perishable supply chain planning. Also Halatsis *et al.,* [14], propose the development and use of export-logistics agroclusters, analyzing the effectiveness of such an approach on the example of specific clusters.

Perez-Mesa and Galdeano-Gomez [15], consider the impact of individual factors on the agro-industrial cluster. The authors note that three factors are interrelated, namely: the creation and spread of technology, the degree of development, and the presence of multinational companies.

The introduction of the concept of development of agroclusters aims to:

- increasing the competitiveness of agricultural companies on global markets;
- introduction of innovative and resource-saving technologies;
- ensuring sustainable development of the agricultural sector.

The role of agricultural clusters in general is to create conditions for the development of all cluster participants. That is, a specific environment of competition and cooperation is formed in agrarian clusters due to the co-optation of companies of various scales. Usually, technologically successful companies act as drivers of development in a cluster, while less developed ones create a competitive environment.

The analysis of scientific works indicates that scientists pay attention to the study of clustering, in particular in the agricultural sphere, but the problem of the methodology of forming resource-saving clusters remains relevant. Therefore, the purpose of the research is to form a methodology that will allow modeling the design of resource-saving agroclusters and provides for the analysis of indicators of the agricultural enterprises activity, taking into account the level of resource-saving technologies implementation in economic practice and the level of risk of the activities implementation in conditions of a special legal status.

Having all of this in mind, the aim of the research is to develop a methodological approach to modeling of resource-saving clusters of agricultural enterprises.

2. Materials and Methods

In order to conduct a cluster analysis of the studied enterprises, a set of indicators was chosen that characterizes the economic activity of an agribusiness, in particular, investments in resource-saving technologies, and the probability of realizing risks that enterprises may face under the conditions of a special legal regime. The indicators that were selected for the cluster analysis and their notation (G_1,...,G_14) are shown in Table 1. Data for the cluster analysis were obtained from the results of the activities of 42 enterprises in the agrarian sector (E_1,...,E_m).

Table 1. Indicators that characterize the economic activity of an agro-enterprise and their notation

Indicator	Indicator conditional notation
Volume of sold products	G_1
Index of agricultural products	G_2
Crop production index	G_3
Index of livestock products	G_4
Costs of implementing resource-saving measures for land	G_5
Costs of implementing resource-saving measures for water resources	G_6
Costs for the implementation of resource-saving measures in relation to others	G_7
Costs of implementing innovative technologies	G_8
The level of use of effective agricultural technologies	G_9
The probability of a decrease in soil fertility	G_{10}
Probability of climate change	G_{11}
Probability of deterioration of the demographic situation	G_{12}
Probability of destruction of logistics infrastructure	G_{13}
Probability of loss of control	G_{14}

Source: developed by the author.

Clustering involves grouping observations into classes consisting of objects with similar characteristics. A cluster is formed from objects that meet two conditions:
1) The object is similar to the objects of the corresponding cluster;
2) The object is not similar to the objects of other clusters.

The fundamental difference between clustering and classification is that the clustering algorithm involves the segmentation of data into homogeneous clusters in which the similarity between objects is maximal, while the similarity with objects of other clusters is minimal.

The formation of clusters is a preliminary step, because the next step will be the development of recommendations for individual clusters. The general clustering algorithm includes the following stages:
1) Formation of a list of indicators that will characterize the objects under observation;
2) Collection of data characterizing objects under surveillance,
3) Analysis of the pattern and differences between objects;
4) Definition of groups of objects belonging to a separate cluster.

In the next steps, a development strategy is developed for a separate cluster and the effectiveness of its functioning is evaluated.

The efficiency of cluster activity can be determined using the following indicators:
• The share of the produced products of the cluster in the total volume of the regional product;
• Dynamics of labor productivity;
• The amount of tax revenues in the budgets;
• Costs of implementing innovative technologies;
• Volume of involved investments.

Usually, neural networks are used to obtain estimates and forecasts, which are associated with the processing of large amounts of information, which allows for faster management decisions. The use of neural networks allows you to model nonlinear processes and make predictions based on these models. Another advantage is the ability to work with noisy data. In particular, the Kohonen network allows modeling, forecasting, searching for relationships in large data sets, and determining independent characteristics.

In order to implement cluster analysis, the Kohonen neural network, which is a type of self-organizing map or topology-preserving map, is used in the study. The purpose of the self-organizing map is to convert a complex multidimensional input signal into a simpler low-dimensional output layer. The use of this tool is appropriate, because this type of neural network allows you to identify the main hidden regularities among the objects that are being monitored.

The architecture of the self-organizing map incorporates two levels - input and output levels. Under these conditions, every neuron in the input layer is connected to every neuron in the output layer.

That is, each neuron at the output level represents a cluster of a given input signal. At the same time, each neuron represents an n-dimensional vector $v = [v_1, v_2, \dots, v_n]^\tau$, where n is determined by the dimension of the input signal. It is important that neurons interact with each other. At the same time, the strength of this interaction determines the distance between them on the map.

The clustering algorithm using Kohonen's self-organizing map involves several stages.

The first stage is initialization. Weights are initialized by assigning the values of random observations from the array of input data to the vector of weights.

At the second stage, an arbitrary observation $g(t)$ is selected from the array of input data. Next, the distance between $g(t)$ and the neuron weight vectors is determined, and the nearest neuron $C_c(t)$ in terms of weight is determined - the "winner". This neuron must meet the following condition (1):

$$C_c(t) \in \|g(t) - v_c(t)\| \leq \|g(t) - v_j(t)\| \quad (1)$$

Where: $v_j(t)$ - the vector of weights of neuron $C_c(t)$.

The next step is to determine the neighborhood function for the neighbors C_c and adjust their weight vectors. The neighborhood function is calculated according to the following formula (2):

$$Y_{cj}(t) = \sigma(t) \cdot P_{cj}(\mathrm{t}) \cdot (g_c - v_j) \quad (2)$$

Where: $0 < \sigma(t) < 1$ - a learning parameter monotonically decreasing for each iteration, which determines how much the weights will be changed; $P_{cj}(\mathrm{t})$ - a neighborhood parameter that determines the degree of adjustment of the update of the weighting coefficients in accordance with the distance from the neuron to the winning neuron.

It is determined by formula (3):

$$P_{cj}(\mathrm{t}) = \exp\left(-1 \cdot \|\rho_c - \rho_j\|^2 \cdot 2\beta(t)^{-2}\right) \quad (3)$$

Where: $\beta(t)$ - Is the radius parameter, which has a decreasing character at each iteration.

To determine the map error, the following formula can be used (4):

$$Err = N^{-1} \sum_{j=1}^{N} \|g_j - v_c\| \quad (4)$$

Where: N - the number of elements of the input data set.

In the context of the study, after the moment when the input vector of the selected indicators values enters the model, the weights of the output layer are adjusted. The adjustment occurs in such a way that the weights of the winning neuron are closest to the input vector, while the neighboring neurons are adjusted much less depending on their distance to the winning neuron. That is, the neuron adjusts less if the neuron is more distant from the winning neuron. Thus, after many iterations, a topological structure is formed on the original layer.

Based on the fact that the selected indicators are characterized by a heterogeneous nature, therefore, in order to bring them to a homogeneous form, it is advisable to conduct a standardization procedure according to formula (5):

$$s_i = (a_i - \bar{a}) \cdot \left(\sqrt{(m-1)^{-1} \cdot \sum_{i=1}^{m} (a_i - \bar{a})^2}\right)^{-1} \quad (5)$$

Where: s_i - the standardized value of a separate indicator i; a_i- the value of a separate indicator i; $\bar{a}$ - the average arithmetic value of a separate indicator; m - the number of observations.

3. Results and Discussion

Using the selected indicators and the described methodology, 42 enterprises of the agrarian sector are clustered. The chosen methodology involves the architecture of a neural network - Kohonen's self-organizing map, which consists of 2 layers - input and output. There are 14 neurons in the input layer, and 6 in the output layer.

As a result of clustering, the neural network divided agricultural enterprises into clusters. Thus, 4 agro-enterprises got into the first cluster, 5 enterprises into the second, 8 enterprises into the third and fourth, 6 enterprises got into the fifth cluster, and 11 got into the 6th cluster - the largest one in terms of size. The frequency of distribution of agro-enterprises by clusters is presented on Figure 1.

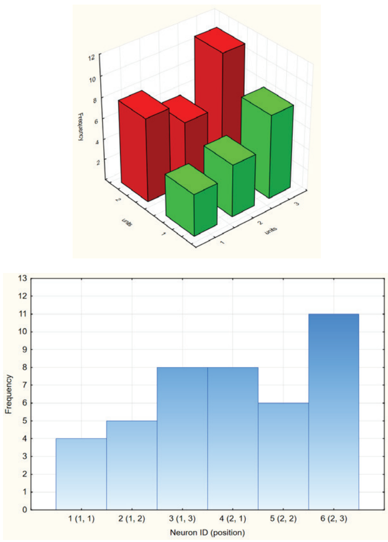


Figure 1. Frequency of distribution of agricultural enterprises by clusters
Source: author's development

Agricultural enterprises that took part in the research were divided into clusters as shown in Table 2.

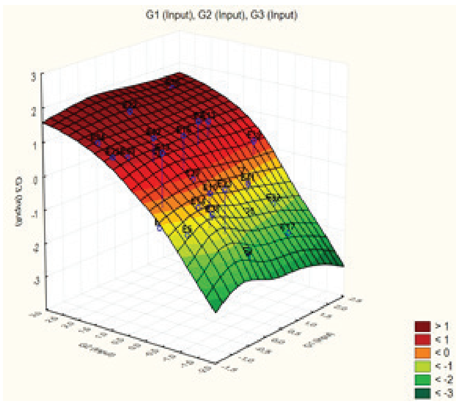
Table 2. Distribution of agricultural enterprises into clusters

Cluster	Enterprises
Cluster 1	E2, E11, E30, E41
Cluster 2	E6, E14, E21, E29, E35
Cluster 3	E1, E5, E10, E16, E19, E23, E25, E39
Cluster 4	E8, E12, E17, E20, E26, E27, E32, E38
Cluster 5	E7, E9, E13, E15, E31, E36
Cluster 6	E3, E4, E18, E22, E24, E28, E33, E34, E37, E40, E42

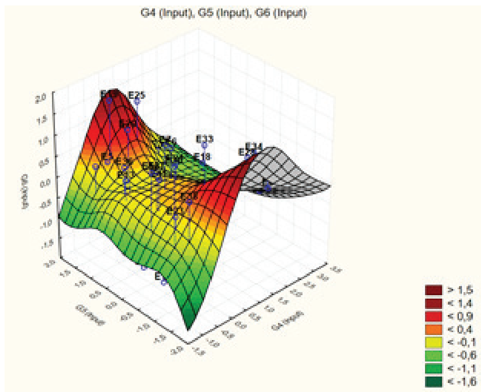
Source: author's development.

Figure 2 and Figure 3 visualize the distribution of agricultural enterprises according to the indicators that were used in the process of implementing the Kohonen self-organization map algorithm. Each map shows the distribution of agricultural enterprises according to three separate indicators. The color of the zones on the maps corresponds to the levels of the values of the selected indicators. So, the higher the value of the indicator, the more saturated red the zone is painted. The smaller the value, the more richly green the area is painted. These maps clearly characterize the formed clusters.

The analysis of the results indicates that the first cluster is characterized by almost no enterprises with large production volumes and low production growth rates. Enterprises of the first cluster invest financial resources in resource-saving technologies, and most of the cluster participants implement innovative technologies. The management of most companies foresees the possibility of a decrease in soil fertility, but the risks of climate and demographic changes are not high. Risks associated with military actions - the probability of loss of control over assets - according to the management of agricultural enterprises are low, but the probability of destruction of the logistics infrastructure is higher. Therefore, for this cluster, it is important to increase the rate of growth of production volumes, and it is also advisable, taking advantage of the cluster, to develop a plan of joint measures to eliminate the negative consequences of military actions, in particular, to create backup elements of the logistics infrastructure and develop alternative logistics flows.



(a)



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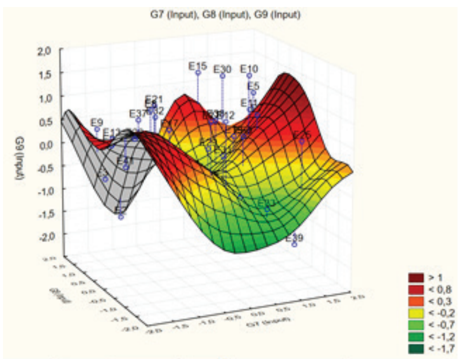

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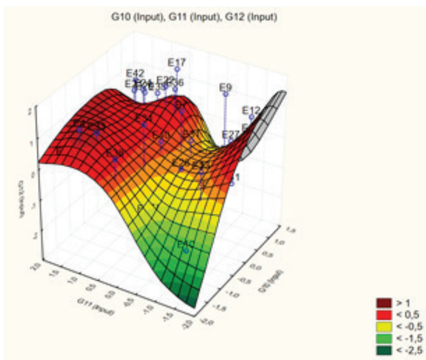

(d)

Figure 2. Distribution of enterprises according to the indicators that were used in the process of implementing the Kohonen self-organization map algorithm
Source: author's development

Enterprises of the second cluster are characterized by relatively small volumes of production, moderate growth rates of production, both in livestock and crop production, enterprises implement resource-saving technologies, some invest in soil conservation, others in water resources conservation. Some enterprises implement other resource-saving and innovative technologies. The management of most enterprises considers the probability of a decrease in soil fertility to be quite high, as well as the probability of worsening climatic conditions and difficulties with the demographic situation. Also, according to the management, the probability of infrastructure destruction is high and the probability of loss of control over assets is low, only one company assessed the risk of loss of control as quite high. For the second cluster, it is advisable to attract various financial resources, which will allow to expand and accelerate the implementation of resource-saving technologies aimed at soil protection, and will also allow to preserve the existing personnel. For an enterprise that may be under the threat of occupation, the company's management may consider the temporary transfer of material assets to other members of the cluster.

The third cluster includes enterprises that produce a small or medium volume of products and have very low growth rates of production volumes. Agricultural enterprises implement resource-saving technologies aimed at preserving water resources to a greater extent. Also, most enterprises invest in innovative agricultural technologies. The companies define the risk of soil degradation as insignificant. Therefore, for the third cluster, it is appropriate to implement measures aimed at increasing production volumes and finding ways to enter foreign markets, in particular, European ones.

The fourth cluster includes both small and large enterprises with low growth rates. Enterprises invest in resource-saving technologies heterogeneously, that is, one enterprise pays almost no attention to it. Agribusiness does not invest enough in innovation. Companies define the probability of demographic problems as quite high. For this cluster, first of all, it is necessary to balance the structure of production, to achieve an increase in the profitability of capital investments and land yield, and the next step is to implement the wide implementation of resource-saving technologies.

The fifth cluster includes mostly large-scale enterprises with moderate growth rates. Agricultural enterprises invest heavily in resource-saving and innovative technologies. They determine the probability of soil degradation as quite high. Also, according to company management, the risk of demographic problems is increasing. The fifth cluster can increase its efficiency due to the formation of reserves of fuel and lubricants, as well as directing resources to support personnel.

The sixth cluster co-opts various enterprises in terms of production volumes with high growth rates. Enterprises invest in resource-saving agricultural technologies. This cluster is also characterized by insignificant investments in innovation. They determine the probability of soil degradation as quite low. The risk of negative climatic and demographic changes for the enterprises of this cluster is increasing. In order to increase the efficiency of the cluster, it is advisable to pay attention to the introduction of innovative technologies, which in the future will reduce the negative impact of climatic and demographic changes.

In the conditions of martial law, agribusiness in Ukraine faces many challenges - starting with a lack of fuel, mineral fertilizers, in particular nitrogen fertilizers, and ending with the threat of being blown up by a mine or coming under fire during work. Entrepreneurs are concerned about general mobilization and its consequences for business. Two indicators were chosen for the study, which partially reflect the concerns of agricultural enterprises and their management, namely: the probability of losing control over assets and the probability of destruction of the logistics infrastructure (Figure 3).

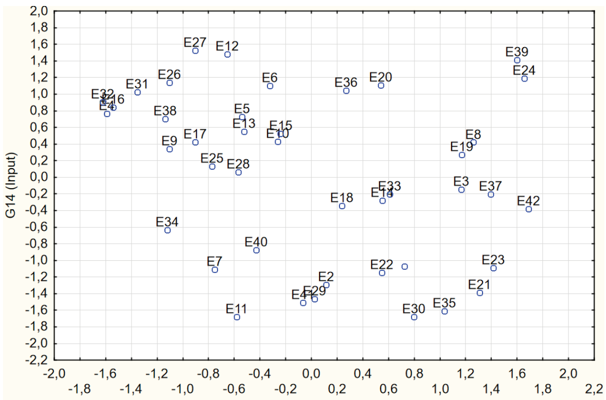

Figure 3. Distribution of enterprises according to indicators characterizing the risks associated with military operations
Source: author's development

Unfortunately, the analysis indicates that the management of almost all enterprises expresses concern about these issues - there are no surveyed enterprises that do not feel threatened by military actions. Only the management of E34, E7 and E11 enterprises believes that the probability of these events occurring is extremely small. However, enterprises E39 and E24 feel a direct threat.

The clustering of the studied enterprises made it possible to identify six agroclusters, in turn, for a separate cluster it is possible to formulate more adapted recommendations for the implementation of economic activity in conditions of a special legal status.

It is important to note that the following aspects are of great importance for the formation and effective functioning of agricultural clusters: integration and cooperation with research institutions; existence of a regional development strategy; availability of investment financing.

4. Conclusions

- In recent years, Ukraine has confidently taken a place in the top five world leaders in the export of agricultural products. In part, such success was achieved thanks to the concept of the development of the agricultural sector, which was based on scale effects and a deformed structure. However, the full-scale military invasion of the Russian Federation into Ukraine highlighted the shortcomings of this concept and prompted agribusiness to look for new approaches that would ensure the high adaptability of agrarian business to functioning in conditions of a special legal status. Effective development and implementation of such a concept can be a guarantee of ensuring food security of the state and a high level of competitiveness of the products of national agricultural enterprises on international markets.
- Despite the fact that the introduction of new technologies in the period of martial law seems too risky and difficult, it is the implementation of resource-saving technologies that can improve production and protect the soil of land plots, ensure the rational use of water resources and minimize the use of pesticides, herbicides, fungicides, and preserve biodiversity. It is thanks to the identification of sources of losses or places of suboptimal use of resources and their elimination that it is possible to increase competitiveness and increase profitability.
- In order to implement cluster analysis, the Kohonen neural network was chosen for the study, which is a type of self-organizing map or map with topology preservation. Thanks to the self-organizing map, a complex multidimensional input signal is converted into a simpler low-dimensional output signal. The use of this tool is expedient, because this type of neural network made it possible to reveal the main hidden regularities among the objects under observation.
- As a result of clustering, the neural network divided agricultural enterprises into clusters. Thus, 4 agricultural enterprises were included in the first cluster, 5 enterprises in the second, 8 enterprises in the third and fourth, 6 enterprises in the fifth cluster, and 11 enterprises in the 6th cluster - the largest in size.
- As a result of the conducted research, a methodology for modeling the design of resource-saving agroclusters was proposed, which involves the analysis of indicators of the agro-enterprises activity, which allows the distribution of agro-enterprises by clusters, taking into account the level of implementation of resource-saving technologies in economic practice and the level of risk of the activities implementation in conditions of a special legal status.
- The search for the optimal set of indicators that characterizes the functioning of agricultural enterprises and can be used in the process of implementing the proposed algorithm can become a subject for further research.

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