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MATHEMATICAL METHODS OF RISK ASSESSMENT OF AGRICULTURAL ENTERPRISES

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Methods. The results are obtained through the use of methods: abstraction – in determining the nature of the category «risk»; analysis and synthesis – in highlighting the nature of the risks of agricultural enterprises; logical and historical – in the study of the evolution of approaches to determining the risks of agricultural enterprises; method of classifications – when summarizing the existing approaches to mathematical methods of risk assessment in groups; general and special - in establishing the unity of existing methods of risk assessment; comparison – to determine the advantages and disadvantages of the types of mathematical assessment of the magnitude of risks; abstract-logical analysis – to generalize and formulate conclusions.

Results. It is established that against the background of a large number of definitions of risk in the scientific literature there is no established understanding of it. The essential features of agricultural production are analyzed and their influence on the formation of risks of agricultural enterprises is determined. The essential signs of risks of agricultural enterprises and their features are revealed. There is analyzed the essence of the main modern methods of risk assessment and modeling in relation to agro-industrial enterprises (deterministic method, statistical method, probabilistic-statistical method, theoretical-probabilistic method, logical-linguistic method, simulation method, expert method, especially fuzzy sets method). The advantages of using fuzzy logic methods to assess the risks of agricultural enterprises are shown. An algorithm for risk assessment based on the fuzzy logic method is presented.

Novelty. On the basis of theoretical and analytical generalizations on mathematical methods of risk assessment of agricultural enterprises, there is substantiated the possibility of using the mathematical apparatus of fuzzy logic and logical-linguistic modeling to assess the source information, which has a fuzzy, uncertain and probabilistic nature.

Practical value. The development of methods for identifying and describing sources of danger, as well as the conditions of their manifestation during the operation of these facilities is crucial to the development and implementation of measures to prevent risks on agricultural sites. The limitations of available scientific and methodological materials does not meet practical needs. Therefore, the use of logical-linguistic modeling to assess risks seems promising. This assessment of the presentation of fuzzy information is the most acceptable, as it allows to formalize the knowledge of experts in a convenient semantic form.

Keywords: agricultural enterprise, risk, assessment, identification, mathematical methods of risk assessment, fuzzy sets.

Statement of problem. The agricultural sector occupies a strategic position in the economy of any country, as agriculture acts as the main production system, forming an uninterrupted supply of food and basic necessities, without which it is impossible to live, as well as increasing the number of jobs for rural residents. In essence, the sustainable development of the agricultural sector is the key to economic security of the state. Agricultural production is characterized by a high degree of risk, which is explained primarily by the management of open space and its high dependence on weather conditions. The inelastic supply of agricultural products in relation to changes in market prices is an equally important problem and explains the high price risks of agricultural producers. In addition, changes in the regulatory framework for business regulation also create significant sources of risk in agricultural production. Meanwhile, if in the past agricultural production was subsidized by the state, now the enterprises of the agro-industrial complex are forced to solve problems caused by high risks. The development of a system for identifying, assessing and managing risks in the agricultural sector is an essential tool to anticipate and respond in a timely manner to shocks, create a favorable market environment and support investment in the industry.

Analysis of recent papers. Currently, a significant number of scientists are studying the risk of business. Theoretical, methodological and practical aspects of risk assessment, for example, covered in the works of scientists, including in the agricultural sector [1–6]. Traditionally, in scientific research of theoretical and practical problems of risk identification and classification, the formation of applied principles of risk systems and, in particular, risk insurance management. However, the issues of risk assessment of agricultural enterprises are insufficiently studied and require additional attention from the scientific community. This is what led to the choice of tasks and objectives of this study, which are to improve the classification of risks and deepen the theoretical and mathematical foundations of definition and analysis in order to further overcome them in the agricultural sector.

Aim of the paper. The purpose of this article is to study the generalization of approaches to determining the risks of agricultural enterprises and their features, analysis of mathematical methods for their determination, as well as substantiation of the possibility of using fuzzy logic tools to strengthen risk assessment capabilities in order to further develop mechanisms to prevent risks and combat their consequences in the activities of agricultural enterprises.

Materials and methods. Risks are inherent in any sphere of human activity, which is associated with many conditions and factors that lead to a positive or negative outcome of decisions. The uniqueness of the agricultural sector is due to its ability to generate public goods (food), demand for which almost always has a positive trend and depends on natural resources, socio-economic, environmental, demographic, migratory and other factors of social transformation. But its essential nature is related to such concepts as uncertainty, probability and risk.

The concepts of certainty, uncertainty and risk play a huge role in the world around us and in economic relations in particular. They are used in game theory and dynamic programming, and also in management theory, economics, politics, law and insurance.

The concept of certainty is associated with the conditions for making management decisions, when the manager knows the potential outcome of each of the possible scenarios with sufficient reliability for this situation. It should be noted that complete certainty is quite rare. The notion of uncertainty is perceived as a condition of a situation in which the probability of a potential outcome cannot be estimated. This situation often occurs when reliable factors cannot be obtained from the factors influencing the situation. Therefore, the consequences of decision-making in such conditions are difficult to predict, especially in rapidly changing conditions.

Of course, the concept of risk has several meanings. Vlek and Stallen list the six most common definitions of risk in the scientific literature:1) risk is the possibility of loss; 2) risk is the amount of possible damage; 3) risk is a function that is mainly the result of the probability and magnitude of damage; 4) risk is equivalent to variation in the distribution of probabilities of all possible consequences of the risky course of the case; 5) risk is a semi-variation of the distribution of all results, taken only negative consequences and in relation to a certain set baseline; 6) risk is a weighted linear combination of variation and expected value (mathematical expectation) of the distribution of all possible results [7].

According to mathematical definitions, if uncertainty occurs when the result is a set of possible alternatives, the probability of which is unknown, the risk (resulting from uncertainty) occurs if the action leads to a set of alternatives, the probability of each is known.

In the economic sense, the risk of the results of the action provides two options: 1) determination of losses and damages, the probability of which is associated with the presence of uncertainty (lack of information, inaccuracy); 2) obtaining benefits and profits that are possible only with actions weighted by risk. The founders of economic doctrine recognize risk as one of the main conditions of economic activity, but only in 1921 F. Knight [3] identified a special category of economic risk derived from uncertainty.

There are also special works on business, economic, financial risks, as well as risk management. Their review allows us to identify the following postulates of entrepreneurial risk: risk is associated with estimates (expectations) and decisions of the subject and does not exist regardless of them; risk reflects the decisions by which time is connected, although the future may not be sufficiently known; there is no risk-free behavior. Risk classification helps to comprehensively identify risk. To develop a risk register, all existing types of risks can be analyzed to understand what each of them means to the organization.

Considering agricultural production, we can note the presence of various risks (climatic, socio-institutional, economic, environmental, etc.), which pose a threat to the cyclical process of production and processing of agricultural products. In general, agro-industrial production is most exposed to the factors that lead to risks. The production and sale of agricultural products are associated with the likelihood of situations that could lead to loss of profits or even resources by producers, and possibly to the failure of a particular enterprise or even its bankruptcy.

To understand the causes of risks, it is necessary to take into account the fact that agriculture differs from other industries in the composition of the means of production, its social structure and purpose of the products supplied.

The main feature of agricultural production is that its structures are both producers and suppliers of food necessary for human life and reproduction of labor, and raw materials for production and other types of non-productive consumer goods. In agriculture land is used as a means of production. To maintain and nurture its fertility, it is necessary to invest additional financial resources over time, which increases the term of capital investments.

A characteristic feature of agriculture is the seasonal nature of activities, which directly affects the use of resource potential of enterprises in the industry, the efficiency of their work and the course of production processes. Even advanced technologies and a high level of agricultural technology do not allow to smooth out the dependence on weather conditions. Therefore, it is difficult to accurately predict the size of income of agricultural enterprises. But due to the objective nature of risks, agriculture has more opportunities to adapt to market conditions. Their presence is due to the fact that food products are characterized by low elasticity of demand, as they are essential goods. Therefore, the production of raw materials for food production is not subject to significant fluctuations, even in the face of declining incomes or rising prices for consumer goods.

It should be remembered that the change in the efficiency of the agro-industrial complex may also be due to changes in the state's economic policy on agricultural production. Thus, the risk essentially includes adverse effects, reduced yields and income, and may include catastrophic events such as financial bankruptcy, food insecurity and human health problems. Risk outcomes can have cascading effects when one type of risk contributes to another type, for example, excessive rainfall during harvest is an event that may lead to a different set of risks, such as financial risks associated with the inability to repay loans. Therefore, agricultural enterprises have to deal with many risks at the same time. Ideally, new initiatives to promote and support holistic risk management should be supported by evidence of how agricultural enterprises cope with multiple risks.

In world practice, researchers identify the following types of risk in agriculture: production, market, institutional, personal (also called human or idiosyncratic) and financial. The first four of these risks are business risks and are largely independent of the financial risks associated with how the business can be financed.

Production risks stem from the uncertainty of the natural growth processes of crops and livestock, with typical sources of these risks related to weather and climate (temperature and precipitation), as well as pests and diseases. Other factors that limit or reduce yields are production risks, such as excess heavy metals in the soil or soil salinity.

Market risks are mainly focused on uncertainties in prices, costs and market access. Sources of price volatility in agricultural products include weather shocks and their impact on yields, energy price shocks and asymmetric access to information. Other sources of market risk include international trade, liberalization and protectionism, as they can increase or decrease market access on different spatial scales.

Decision-making develops in a context where multiple risks arise, such as weather variability and price spikes, or limited market access. Institutional risks are associated with unpredictable changes in policies and regulations that affect agriculture, and these changes are generated by formal or informal institutions. The government, an official institution, can create risks due to unpredictable changes in policies and regulations, factors over which farmers have limited control.

Sources of institutional risk may also arise from informal institutions, such as unforeseen changes in the actions of informal trading partners, rural organizations, or changes in social norms that affect agriculture.

Personal risks are specific to the individual and relate to human health problems or personal relationships that affect the business or household. Some sources of personal risk include injuries from agricultural machinery, death or illness of family members from disease, adverse effects on human health from the use of pesticides and the transmission of disease between livestock and humans.

Health risks are a major source of income fluctuations and concerns for agricultural enterprises, which often deal with the relationship between personal and institutional risks. In the literature, the words «personal», «human» and «idiosyncratic» usually refer to the same type of «personal» risks we considered.

Financial risk refers to the risks associated with how a farm is financed and is defined as additional variability in the farm's operating cash flow through fixed financial liabilities inherent in the use of credit. Some sources of financial risk include changes in interest rates or the availability of credit, or changes in lending terms.

The cumulative effect of the impact of industrial, market, institutional and personal risks should be defined in the general term «business risk». Business risk is the aggregate effect of the impact of all uncertainties that affect the economic efficiency of management. It affects the economic performance of the enterprise, such as production costs, sales, profits, cash flow and others.

Risk management is carried out using specific tools. According to AS/NZS Standard 4360:1999, the risk management process can be defined as the systematic use of methods and techniques available to managers to address risk-related tasks: contextualization, analysis (detection and evaluation), impact, monitoring and communication.

One of the most important stages of risk management is its assessment and identification. The assessment of the peculiarities of an agricultural enterprise, identification of external and internal risks, determination of the specifics of identified risks, studying of the probability and magnitude of economic damage, determination of the degree of relationship between risks, changes over time, studying of the factors affecting risks, etc. are carried out.

Risk assessment means an assessment of the size and probability of possible damage, i.e., deviation of the actual result (in the direction of deterioration) from its expected value. Most production and economic indicators in agriculture have a statistical distribution of their values, close to normal. Therefore, risk assessment is most often performed on the basis of such statistical characteristics as standard deviation. In addition, a statistical indicator such as the coefficient of variation is often used to assess the degree of sustainability of production. In contrast to the standard deviation, it provides information not only about the variation of the studied feature, but also compares it with the expected value.

However, systems theory, which is based on the procedures of decomposition (analysis) and aggregation (synthesis), has a specific formal apparatus focused on solving various scientific and practical problems. This apparatus provides a mathematical justification for the procedure of multi-criteria strategy selection, which provides, for example, the optimization of business risk and the use of expert judgment and logical formal approaches. In other words, for each subject area there is a set of acceptable means of formal expression of the essence of the studied real object.

At the same time, the most important is the choice of an adequate model that reflects the purpose of the study and limitations, the degree of completeness of knowledge about the system and processes to be simulated, as well as characteristics of the environment and parameters of outrageous influences.

It should be remembered that the use of strictly formalized approaches leads to the loss of semantic expression of the subject of study. In this case, the modeling should include a multi-step procedure from verbal portrait of the system to logical-linguistic representations and analytical mathematical descriptions, including simulation.

In the framework of the formulated research objectives, we will consider the main approaches and methods of risk analysis of agricultural enterprises. The essence of the deterministic method is that the object of study is not uncertain, but strictly deterministic, which is based on the causal scenario of an accident. Deterministic models are built on a simplified scheme, ignoring various coincidences. The main thing is the principle of causality: one phenomenon (cause) and under certain conditions generates another phenomenon (consequence). This approach involves expert assessments. The expert evaluation procedure can be based both on the qualitative level and on obtaining some integrated criteria that reflect the state of the object as a whole.

The deterministic approach is implemented on the basis of fully defined initial data on the parameters of influence and properties of the object with the establishment of stock ratios of marginal (critical) states of controlled risk factors. The advantage of this method is clarity and simplicity, which requires a complex mathematical description of the system. The disadvantages of this method include the inability to obtain adequate estimates due to the neglect of random factors.

The procedure for obtaining integrated indicators is also problematic: a common method of "linear convolution":

$$L = \sum l_i \alpha_i \qquad (1)$$

where l_i is the expert assessment of the private indicator, α_i – the weight of the indicator.

This procedure is not legitimate enough, because components of the system are not the same. For these reasons, the procedure of «averaging» in determining the risk of agricultural enterprises loses all meaning.

The statistical method of risk analysis is based on the generalization of information about the frequency of occurrence of risk situations at objects of agro-industrial complex. The model is an analytical expression that takes into account the influence of random factors in the process of enterprise operation. It operates with quantitative criteria in assessing recurring phenomena and allows taking into account the dynamics of their change over time, as well as random perturbations of environmental factors.

The model is characterized by the level of uncertainty of knowledge about the object under study. This knowledge is replenished in the process of collecting and analyzing initial data as a result of a sample survey. Using further methods of mathematical statistics, it is possible to reveal certain patterns inherent in large samples of homogeneous events. In the case of heterogeneous events of different nature, statistical approaches can also be used by conducting a preliminary systematization of dangerous events, for example, by their types or scales. Then the probability of dangerous events for a time interval Δt can be estimated through their frequency when considering them as a stream of random events with the following properties: ordinary (for a sufficiently small Δt, no more than one event occurs); absence of consequences and stationarity (frequency of events – $\lambda(t)=const$).

Under these conditions, the flow of events is considered as the simplest Poisson, for which the number n of events occurring during the time Δt is distributed according to the Poisson law:

$$F(N) = P(n < N) = \sum_{k=0}^{N} P(k) \qquad (2)$$

where $P(k) = \alpha(\Delta t)_e^{k\ \alpha(\Delta t)}$ is a probability of an event over time Δt; $\alpha(\Delta t) = \lambda\,\Delta t$ – Poisson distribution parameter (average number of events $\alpha(\Delta t) = M[n]$ during the time Δt); λ – frequency (average number of events per single and rather small time interval (time unit)$^{-1}$).

Assuming that with an increase in the observation interval $T >> \Delta t$, the number of events will also increase. If we accept that $\alpha(\Delta t) = \lambda\, \Delta t \rightarrow \infty$, then the Poisson distribution approaches normal with the parameters $M[n]$ and $D[n]$. In this case, instead of (2) we can write:

$$F(N) = \Phi\left(\frac{N - M[n]}{\sqrt{D[n]}}\right) \qquad (3)$$

where Φ is the Laplace function.

In practice, the normal distribution is used provided that the number of events (homogeneous data) must be at least 100. Increasing the accuracy of estimates requires an increase in the volume of statistical data, which is associated with an increase in the observation interval. The latter leads to heterogeneity of statistical data, which causes statistical uncertainty, which increases the error in risk assessments and limits the scope of statistical method. To process the results of observations, methods of correlation, regression, factorial, cluster and other types of analysis are used, operating with statistical hypotheses.

The probabilistic-statistical method is based on a variation risk analysis of the system. This method involves calculating the probability of occurrence of events based on statistical data. A distinction is made between a posteriori and a priori risk assessment.

A posteriori estimation involves the use of the concept of «frequency» of the occurrence of an event. If a negative event is predicted, then a priori estimation involves the use of the term «probability». In this case, it should be taken into account that the frequency of occurrence of an event has a probabilistic nature, and the probability itself is interpreted as a possibility [8].

The probabilistic method is based on the stochastic nature of risk situations. In this case, the probability is estimated according to a well-known algorithm – from the identification of initiating events to the construction of graphic diagrams.

Mathematical models seem to be more simplified in comparison with deterministic calculation schemes. The main limitations of the use of variation risk analysis (VAR) are related to the lack of statistical information on risks, the methodological complexity of damage assessment, and the lack of distribution functions for diagnostic risk parameters. The logical-linguistic method of risk analysis is characterized by a high degree of formalization, using the symbolic language of logic and the formalism of the theory of graphs and algorithms.

The rigor of logical relationships can vary widely, from classical determinism to probabilistic logic. One of the types of logico-linguistic models is the scenario model, which is based on the functions of algebra of logic [8]. The basic position of this method is to study the truth of a risk event. For this, Boolean functions are introduced, denoted by numbers (*1 – true*, *0 – false*). Then the scenario of the occurrence of an event can be expressed in the form of sequentially interconnected states of the object deployed in time. In this case, the procedure for assessing risks is carried out using the appropriate semantic modeling.

The method of simulation modeling is based on the logical and mathematical representation of the object by the dynamic one. This class of models is used when a rigorous analytical solution of a problem or a full-scale experiment is impossible. With regard to the objects under consideration, which are characterized by a complex homogeneous structure, stochasticity, non-stationarity and uncertainty, simulation modeling is the only analysis tool. The simulation modeling method is widely used in the analysis of complex systems that describe risky production facilities. The method allows using any (qualitative-quantitative) information in combination with heuristic inaccurate estimates obtained intuitively.

The expert method is based on the use of knowledge and experience of experts – highly qualified specialists in the subject area under consideration. This method is used in the case when not only there are no statistical data on the object, but it is also quite difficult to choose an adequate mathematical model.

The essence of the expert method of risk assessment lies in the procedure of forming the rating scale. Statements (judgments) of experts are made in form of qualitative characteristics or quantitative values of the probabilities of events under consideration, related to a certain period of time. The algorithm of the expert method is quite widely used and consists in the fact that the results of expert assessments are considered in the form of random variables.

Let us assume that each expert sets the value of the possible damage, indicating the probability of its realization. Taking into account *N* experts, in the end, we can get the distribution of a discrete random variable. Thus, as a result of this procedure, a set of random variables is formed, the values of which reflect the point of view of a group of experts regarding the forecast of the considered value:

$$M_j(\tau) = \sum_{j=1}^{N} M_j \frac{\tau}{S_j} \qquad (4)$$

where *Sj* is the information received by the expert with the corresponding number *j*.

The method of expert assessments in the absence of reliable statistical data is conveniently combined with the use of the so-called basic linguistic assessments, which allow to obtain an integral risk assessment in a multidimensional vector space.

The disadvantages of the expert method include the doubtfulness of the reliability of estimates, as well as certain difficulties in conducting an expert survey and processing the data obtained. In this case, it is of interest to develop procedures and algorithms to reduce the proportion of subjectivity in the final risk assessment. To solve such problems in objects with the property of uncertainty, it seems promising to use combined techniques that combine the availability and breadth of qualitative methods of analysis and the effectiveness of quantitative estimates based on the construction of rigorous mathematical models.

Recently, fuzzy-logical modeling became one of the promising areas in the description of processes in which uncertainty is present, which makes it difficult to use traditional, accurate quantitative methods and approaches. This method belongs to the class of logical models, which are based on the concept of «statement» – a linguistic expression that makes sense, with the help of which it can be argued that it is true or false. In such models, for a semantic description of a human-machine system, it is advisable to use the formal means of set theory [9].

Often, to obtain an integral risk assessment in the agro-industrial complex, only the values of changes in quantitative variables, such as the use of agricultural technology, fertilization, irrigation, etc., are not enough. Many qualitative variables must also be taken into account, such as, for example, weather conditions. In natural processes, all meteorological parameters depend on each other. Due to the variability of values, they can be classified as a fuzzy set. The fuzzy logic method has certain advantages over other methods: ability to perform operations with values that constantly change over time; possibility of fuzzy formalization of evaluation criteria at three levels (*Low*, *Medium, High*) and their comparison; possibility of conducting qualitative assessments of both input data and output results; possibility of operational simulation of complex dynamic systems in various versions.

To compile an algorithm for solving a problem using the fuzzy logic method, it is necessary to introduce a certain set of statements consisting of sets of conditions and conclusions. The existing approaches to effective problem solving are as follows:

1. If the rules according to which the object of study operates are known, then they can be generalized and reduced to some system that operates and generates conclusions according to «if-then-other» scheme.

2. If the rules of the object's behavior are not known, but their presence is implied, then a system is created that first learns on a certain set of examples, and then adequately draws conclusions on new input data.

3. If the rules for the behavior of the object are not known, then you need to try to model the object using the known rules and dependencies «by analogy», and then draw conclusions about how the object corresponds to the model.

4. If there are a lot of rules, examples and models, then it is possible to evaluate and manage the object not only at the micro level (rules), but also at the macro level (principles). This «principles» approach is implemented using fuzzy mathematics in a variety of Matlab toolkits.

The solution of a specific problem involves a combination of the approaches above, which are implemented in fuzzy systems and allow, in comparison with others: the ability to operate with fuzzy input data; the possibility of fuzzy formalization of evaluation and comparison criteria – operating with the criteria «majority», «possibly», «preferably», etc.; the possibility of conducting qualitative assessments of both input data and output results; the ability to quickly simulate complex dynamic systems and their comparative analysis with a given degree of accuracy: using the principles of system behavior described by fuzzy methods.

The risk assessment procedure based on the fuzzy set method can be implemented, for example, as follows [10]. Based on the information obtained during the survey of experts, *p* matrices of dimension $m \times n$ are built, where *m* is the number of experts, *n* is the number of alternatives, showing the ratio of expert opinions for each criterion. To assess the consistency of experts, all alternatives are ranked in ascending order based on the number of points on a five-point system.

If there are equivalent alternatives, then in addition to the strict order relation between some alternatives, there will also be an equivalence relation. Equivalent alternatives are assigned associated ranks. In group peer review, each *i*-th expert assigns a rank to each *j*-th alternative. As a result of expert evaluation, a matrix of connected ranks is formed and an assessment of the consistency of experts is carried out.

Kendall's dispersion coefficient of concordance is chosen as a measure of the consensus of opinions of the expert group.

To determine the significance of the estimate of the concordance coefficient, the frequency distribution is specified for various values of the number of experts *m* and the number of alternatives *n*. In case of small values of *m* and *n*, the critical values of tabulated value of the concordance coefficient are used as critical statistics. For large values of *m* and *n*, the Pearson distribution is chosen as the critical statistic.

If the opinions of the experts are not agreed, their answers are summarized and, together with new additional information, are made available to the experts, after which they clarify their initial answers until an acceptable convergence of totality of expressed opinions is reached. Next, the coefficients of expert competence are determined. Various approaches can be used, for example. An expert survey is carried out by means of questioning and obtaining expert estimates of the matrix of pairwise comparisons of criteria. Pairwise comparisons are made in terms of the dominance of one element over another.

The resulting judgments are expressed in integers. In order to increase the degree of objectivity and quality of the decision-making procedure, it is necessary to take into account the opinions of several experts. To aggregate the opinions of experts, the geometric mean value of the estimates of the matrices of pairwise comparisons is used.

The cumulative risk calculation can be based on the following types of rollups: multicriteria choice of alternatives based on the intersection of fuzzy sets; fuzzy preference relation; additive convolution; standard five-level fuzzy classifier; a non-standard five-level fuzzy classifier, etc. It is necessary to take into account the difference in decision-making approaches when choosing each of the types of convolutions and choose a method that takes into account the specifics of decision-making in terms of innovative development.

Additive convolution assumes a realistic approach, when low criteria scores have the same status as high ones, this method is most suitable for calculating the risks of introducing innovations. For its implementation, linguistic variables are built according to the number of risk criteria, each of which has the following term-set of values: «*Very low risk*», «*Low risk*», «*Medium risk*», «*High risk*», «*Very high risk*».

The values of terms of the set are given by fuzzy numbers, which have a triangular form of membership functions (Fig. 1). The assessment of alternatives according to the criteria is carried out using linguistic variables of a five-point scales: 1 – *Very Low*, 2 – *Low*, 3 – *Medium*, 4 - *High*, 5 – *Very High* (Table 1).

The values of the terms of the set are given by fuzzy numbers *Yj*, for *j = 1, ..., 5*, the membership functions have the following form: *Very Low* {1,0/0,0; 0,0/0,1}; *Low* {0,0/0.0; 1,0/0.2; 0,0/0,4}; *Average* {0,0/0,3; 1,0/0,5; 0,0/0,7}; *High* {0,0/0,6; 1,0/0,8; 0,0/1.0}; *Very High* {0,0/0,9; 1,0/1.0}.

To assess the relative importance of the criteria, the linguistic variable *W* {*Practically Unimportant; Not Very Important; Medium Importance; Important; Very Important*} is used. The values of the terms of the set are given by fuzzy numbers X_i (*i = 1, ..., 5*), which have a triangular form of functions accessories (Fig. 2):

Practically Unimportant {1,0/0,0; 0,0/0,2}; *Not Very Important* {0,0/0,0; 1,0/0,2; 0,0/0,4}; *Medium Importance* {0,0/0,3; 1,0/0,5; 0,0/0,7}; *Important* {0,0/0,5; 1,0/0,7; 0,0/0,9}; *Very Important* {0,0/0,8; 1,0/1,0}.

Translation of criterion weights into values of a linguistic variable: *Very Low* – up to 0,01*; Low* – 0,01-0,02*; Average* – 0,02-0,03; *High* – 0,03-0,04*; Very High* – more than 0.04.

The weighted estimate of the *k*-th alternative Z_k $(k = 1, ..., n)$ is the result of a linear combination of fuzzy numbers (Fig. 1, Fig. 2) and will also have the function of belonging to the triangular form.

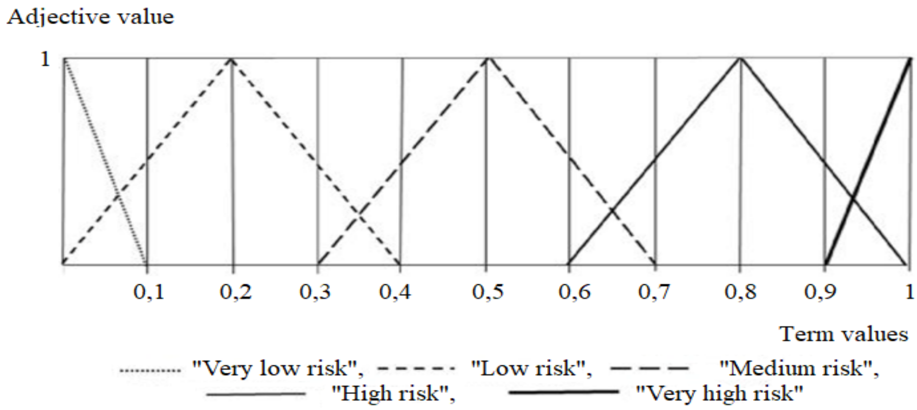

Fig. 1. Membership function of the term value of the linguistic variable set for the level of risk

Table 1

Linguistic variables of risk level

Linguistic risk variable	Points	Weighted score
Very low	1	1,00 – 1,91
Low	2	1,91 – 2,61
Medium	3	2,61 – 3,21
High	4	3,21 – 3,91
Very high	5	3,91 – 5,00

Source: according [10]

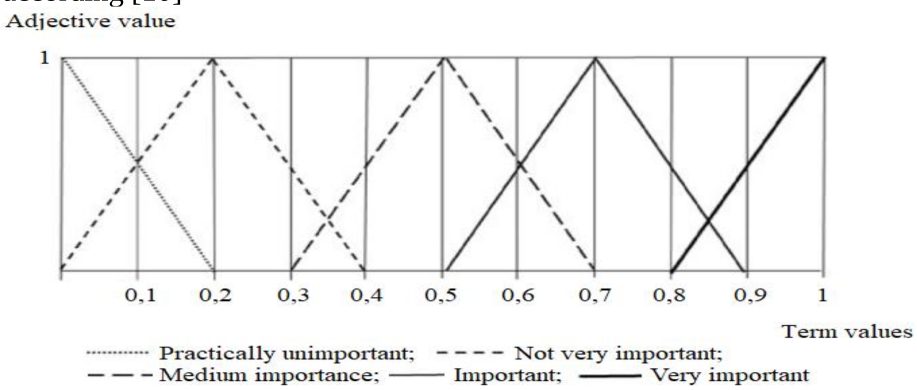

Fig. 2. Functions of membership of terms of terms of a set of linguistic variable for definition of weights of risk

Ranking of alternatives using the obtained weighted estimates is based on their fuzzy composition:

$$\mu_J(j) = \sup_{MIN} \mu_J(Z_j)$$
$$Z_1 ... Z_n; Z_k \geq Z_j; j = 1, ..., n \qquad (5)$$

where $\mu_J(Z_j)$ is fuzzy set of alternatives corresponding to the concept of «best alternative»; the alternative with the highest value (*j*) is considered the best.

Then, based on the aggregate risk indicator, a decision is made to implement an innovation. The conclusion on expediency of such a solution is based on the forecast of effectiveness of innovation project, including the basis of priority and level of risk.

At the last stage, based on the aggregate risk indicator, a decision is made on the appropriateness of management decisions based on the priority and level of risk (Table 2).

Conclusions. The growth of risks in the activities of agricultural enterprises is due to many reasons, including the imperfection of scientific and methodological support in the field of safety of their activities.

Table 2

Decision-making based on the risk-priority indicator

Risk-priority indicator	Very low risk	Low risk	Medium risk	High risk	Very high risk
1	Positive	Positive	Positive	Positive	Negative
2	Positive	Positive	Positive	Negative	Negative
3	Positive	Positive	Negative	Negative	Negative
4	Positive	Negative	Negative	Negative	Negative

Source : [10]

There is no unified methodology based on a unified interpretation of agricultural risks, which allows for a comprehensive accounting of the factors of occurrence and development of hazards of different nature. There are also objective difficulties in making risk management decisions. These difficulties are caused by the following reasons: low structure, uncertainty, physical heterogeneity of components of activity; the presence of numerous restrictions of natural, technological, environmental, regulatory and economic nature; initiating preconditions leading to dangerous situations; Insufficient initial data and lack of accurate (satisfactory) description of the occurrence and development of hazardous processes, which makes it impossible to make adequate estimates.

Crucial to the development and implementation of measures to prevent risks at agricultural sites is the development of a methodology for identifying and describing sources of danger, as well as the conditions of their manifestation during the operation of these facilities. the limited and quality of available scientific and methodological materials does not meet practical needs. In this regard, it seems promising to evaluate the source information, which has a vague, uncertain and probabilistic nature, based on the use of logical-linguistic modeling. Such an assessment of the presentation of fuzzy information is the most acceptable, as it makes it possible to formalize the knowledge of experts in a convenient semantic form.

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МАТЕМАТИЧНІ МЕТОДИ ОЦІНКИ РИЗИКІВ АГРАРНИХ ПІДПРИЄМСТВ

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Методологія дослідження. Результати отримані за рахунок застосування методів: абстракції – при визначенні сутності категорії «ризик»; аналізу й синтезу – при висвітленні сутності ризиків аграрних підприємств; логічного й історичного – при дослідженні процесу еволюції підходів до визначення ризиків аграрних підприємств; метод класифікацій – при зведенні наявних підходів до математичних методів оцінювання ризиків в групи; загального й особливого – при встановленні єдності існуючих методів оцінки ризиків; порівняння – для визначення переваг та недоліків видів математичної оцінки величини ризиків; абстрактно-логічного аналізу – для узагальнення та формулювання висновків.

Результати. Встановлено, що на тлі великої кількості визначень ризику у науковій літературі відсутнє його усталене розуміння. Проаналізовано суттєві особливості аграрного виробництва та визначено їх вплив на формування ризиків аграрних підприємств. Виявлено сутнісні ознаки ризиків аграрних підприємств та їх особливостей. Проаналізовано зміст основних сучасних методів оцінки та моделювання ризиків стосовно підприємств агропромислового комплексу (детерміністичного методу, статистичного методу, ймовірнісно-статистичного методу, теоретико-імовірнісного методу, логіко-лінгвістичного методу, методу імітаційного моделювання, експертного методу, методу нечітких множин) та виділені їх особливості. Показано переваги використання для оцінки ризиків аграрних підприємств методів нечіткої логіки. Наведено алгоритм оцінки ризику на основі методу нечіткої логіки.

Новизна. На основі теоретичних та аналітичних узагальнень щодо математичних методів оцінки ризиків аграрних підприємств обґрунтовано можливість використання математичного апарату нечіткої логіки та логіко-лінгвістичного моделювання для оцінки вихідної інформації, яка має нечіткий, невизначений та ймовірнісний характер

Практична значущість. Вирішальним для розробки та впровадження заходів щодо запобігання ризикам на сільськогосподарських об'єктах є розробка методики виявлення та опису джерел небезпеки, а також умов їх прояву під час експлуатації цих об'єктів. Обмеженість і якість наявних науково-методичних матеріалів не відповідає практичним потребам. У зв'язку з цим перспективним видається використання логіко-лінгвістичного моделювання для оцінки ризиків. Така оцінка подання нечіткої інформації є найбільш прийнятною, оскільки дає можливість формалізувати знання експертів у зручній семантичній формі.

***Ключові слова*:** аграрне підприємство, ризик, оцінка, ідентифікація, математичні методи оцінки ризиків, нечіткі множини.

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