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THE MONITORING OF THE LIVESTOCK PRODUCT MARKET FOR THE FORMATION OF FOOD SECURITY

Introduction. The imbalance of the livestock product market due to significant challenges, such as large-scale military actions, reduced purchasing power, and changes in citizens' diets, presents other threats to food security. The influx of threats leads not only to a significant differentiation in the balance of demand and supply for meat and meat products by regions and strata of the population but also to a significant dynamism of the entire livestock market. This determines the need for changes in the methodology for monitoring and evaluating dynamic changes in the parameters affecting the production and consumption of livestock products.

Aim and tasks. This study aims to establish the peculiarities of monitoring the livestock market under significant dynamic changes in the main parameters affecting production and consumption volumes. The objectives of this study were to establish integral trends in the production of the main types of livestock products and to develop a mathematical model for evaluating the balance of production and consumption of livestock products.

Results. A break in the trend of stability of the pig and poultry population in 2021 and the continuation of the long-term trend of reduction in the cattle population was established, as evidenced by changes in the number of animals from 2023 to 2021: for cattle, by 20%; for pigs, by 16%; and for poultry, by 11%. This indicates that significant short-term fluctuations in influencing factors cause the production and consumption forecasts to be irrelevant. The influence of threats determines the deformation of markets for the production and consumption of livestock. This necessitates assessing dynamic changes in parameters affecting the volume of production and consumption of livestock products and the prompt formation of forecasts.

Conclusions. The developed mathematical model for assessing the balance of production and consumption of livestock products allows for considering dynamic changes in the main parameters of influence, which ensures the relevance of forecasts. This will enable prompt implementation of measures to regulate food security.

Keywords: monitoring, threats, food security, livestock production, mathematical model.

1. Introduction.

Due to the increase in threats due to large-scale military operations in Ukraine, various dangerous influences on all factors of food security formation have increased significantly.. This also applies to the market of livestock products as a significant component of ensuring the rational caloric content of the country's citizens' nutrition. Thus, owing to large-scale military operations in the first half of 2022, 43.2% of the country's cattle population was concentrated in the regions of Ukraine, in which there were active hostilities (Dolinskaya et al., 2023).

The imbalance in the livestock product market is due to a significant loss of the industry's potential due to the destruction of fixed assets and a large part of agricultural land that provided the fodder base of livestock production. The theft of the machinery of agricultural enterprises has also intensified due to the decrease in the income level of the majority of the population, which has the consequence of a decrease in purchasing power, a change in the diet of citizens, and other threats to food security. This leads not only to a significant differentiation of the balance of demand and supply for meat and meat products by regions and strata of the population but also to a significant dynamism of the livestock product market. This, in turn, results in a dynamic deformation of the process of forming food security, the formation of specific challenges to this process, and new requirements for the assessment and forecasting of the main influencing factors for the introduction of appropriate and timely institutional measures aimed at neutralizing threats (Andreichenko et al., 2021; Petrychenko et al., 2022).

The importance of the specified institutional measures is also strengthened by the need to ensure the export of food supplies in view of the urgent need to replenish the country's budget, provide jobs to workers in the agricultural sector, and provide producers with the necessary working capital for the formation of a sustainable process of agricultural production, which determines the survival of agricultural enterprises in conditions of significant threat.

It is also important that Ukraine maintain the status of one of the guarantors of global food security (Svyrydenko & Revin, 2022a), as this strengthens the authority of the country and, in turn, increases the possibility of forming national security.

2. Literature review.

A significant number of scientific works are devoted to regulating the problems of the livestock market for the formation of the country's food security and the tasks of monitoring this market. The impact of the war on the market for agricultural products and ensuring the food security of Ukraine and the world under extremely difficult circumstances was studied by Ben Hassen and El Bilali (2022), and Bioko and Bioko (2022). Hobela et al. (2022) indicated how the war changed the conditions for forecasting trends in the livestock market.

Lagodiienko et al. (2022) investigated possible changes in market trends in the post-war period. The peculiarities of food security monitoring during martial law are also indicated in an article by Kovalova et al. (2023). In particular, prompt decision-making on ensuring food security requires "improvement of monitoring indicators" (Kovalova et al., 2023). This was considered in this study.

Kurman (2022) used the food security assessment method, which "is a dynamic quantitative and qualitative model of comparative analysis, built on the basis of 28 unique indicators". Unfortunately, the dynamism of this model in all parameters: "price and physical availability/availability of food products, quality and safety, resources, and sustainable development" is exaggerated due to the long time periods of providing statistical data for most indicators of the livestock market.

Shashkova et al. (2021) indicated that even before the start of large-scale hostilities, according to the Global Food Security Index, "the population of Ukraine had significant problems with economic access to a balanced diet with the necessary amount of high-quality caloric products, in particular meat, fish, and milk".

Tsikhanovskaya and Alekseenko (2018) pointed out the importance of the strategic planning tool for the development of the "meat product sub-complex" and therefore the need to diagnose changes, in particular, factors influencing the activities of enterprises. However, Tsikhanovskaya and Alekseenko did not develop this thesis (2018).

Seheda (2020) analysed the Ukrainian meat and meat product market from 1990 to 2018. In this period, there was a growing discrepancy between the levels of production and consumption of meat and meat products and the rational caloric content of human nutrition. The main factors affecting this process are "the decline of some branches of animal husbandry and the low-income level of the majority of the population".

Karpyak (2018) indicated that the formation of the country's food security requires "a change in the mechanism of state regulation of the livestock industry and raw meat processing," which requires a change in the institutional control of all related areas of agricultural production to ensure sustainability in the field of crop production. This was considered in the present study.

Vytvytska and Kovalova (2022) assessed the state of food security using the main indicators of the basis of this assessment, indicating that the established monitoring system needs to be changed; in particular, it is suggested to use indicators of the economic security component and the achievement of Sustainable Development Goals (SDG).

Zalizniuk (2019) pointed to a long-term trend of "an increase in the share of food expenditure in total final consumption expenditure". It is also noted that there is a trend toward a significant difference in the consumption of animal products for the "higher and lower quintiles of households".

Skydan and Hrynyshyn (2020) studied threats to the formation of a country's food security. To do this, an assessment of the sensitivity of agricultural production to certain types of food products "as determinants of food security" was conducted. In particular, it was established that "population has a significant influence on the production of meat in slaughter weight" which is not linear.

According to the results of the study, it was noted that "random fluctuations of these factors have a significant impact on the country's food security risks". This thesis was developed for the present study.

A mathematical model that "estimates income and price elasticity using quintile total expenditure per capita" (Dankevych et al., 2021) was also analyzed. Unfortunately, the feasibility of using such a model in Ukraine's modern conditions is questionable due to the dynamics of parameter changes.

The review of the literature indicated the need for research on factors affecting the market of meat and meat products, the determination of their nature (Nikmatul et al., 2020)., which conditions the peculiarities of monitoring the market of livestock products for the formation of food security, and development of a mathematical model for processing monitoring results.

3. Methodology.

Using the comparison method, it was established that indicative methods for monitoring food security require changes owing to the dynamic nature of external influences. The use of statistical methods made it possible to establish that the crisis in the field of animal husbandry has been ongoing for a considerable time; large-scale military actions only intensified it and determined the dynamics of changes in factors in the production and consumption of animal products. For an integral assessment of the consequences of threats, statistical analysis of trends in the number of farm animals by species and the formation of polynomial equations for these trends were used.

Using the method of analysis and synthesis, it was established that the uneven influx of threats and significant migration flows of the population cause both the differentiation of the levels of production and consumption of livestock products by region and the peculiarities of the dynamic deformation of specified markets. It was also established that the deformation of the consumption market would increase, particularly because the cost of the production of livestock products would increase.

Using the theoretical analysis method, the factors whose dynamic changes should be monitored are determined. The introduction of the mathematical analysis method made it possible to develop a mathematical model for evaluating the balance of production and consumption volumes of livestock products, which is based on the gradient method.

To monitor the livestock market and develop relevant forecasts, it is necessary to promptly assess changes in the level of feed base sufficiency in all its aspects: crop forecasts at the regional and global level, forecasts of feed prices, their cost, and the capacity of farms to provide them with logistics, and forecasts of export needs and domestic consumption. For this purpose, the FAO information system (GIEWS) can be used.

To assess the ratio of production and consumption levels of livestock products, it is necessary to know the dynamics of prices of meat and meat products by types of livestock products, the dynamics of the purchasing power of the population, and the dynamics of changes in products in the diet due to changes in the ratio of their prices to real average daily income.

For this purpose, not the absolute values of these indicators should be used, but their changes over time depend on the individual impact parameters. Such changes mathematically show the gradients of the objective function over time:

$$grad\ \Psi_i = \frac{d\Psi_i}{dt} \qquad (1)$$

where Ψ_i is the objective function, i - is the index of the objective function in their set (in particular, for further analysis, let's denote the production volumes of livestock products as Ψ_1 and consumption volumes as Ψ_2), t is time.

The dynamics of changes in the objective function over time depending on individual parameters can be estimated by the formula:

$$grad\ \Psi_i = \frac{d}{dx}\frac{d}{dt}\Psi_i \qquad (2)$$

where x is one of a set of influencing factors $(x_1, x_2, x_3, ...)$.

The gradient method is important not only for forecasting, but also for management, as it can be used to detect bifurcation points, the non-smooth nature of dependence functions, which is a sign of a probable economic or social crisis:

$$\frac{d}{dx}\frac{d}{dt}\Psi_i \neq\ lim_{x_1 \to x_1^-}\frac{d}{dx}\frac{d}{dt}\Psi_i \qquad (3)$$

or to find the so-called "conditional extremum" of the objective function, that is, in order to find such a point in the parameter space under existing mathematical restrictions, for which the value of the objective function is greater or less than its segment on the response surface.

For this, it is necessary to use the Lagrange function with the connection equations, which are necessary but not sufficient for the formation of the solution:

$$\begin{cases}\varphi_{1i}(x_1, x_2, t) = 0 \\ \varphi_{2i}(x_1, x_2, t) = 0\end{cases} \qquad (4)$$

Sufficient conditions for the conditional extremum are determined by the sign $d^2\Psi_i$. Then, for the objective function $\Psi_i(x_1, x_2, t)$ the Lagrange function will have the form:

$$F_i(x_1, x_2, t, \lambda_{1i}, \lambda_{2i}) =\ \Psi_i(x_1, x_2, t) + \lambda_{1i}\varphi_{1i}(x_1, x_2, t) + \lambda_{2i}\varphi_{2i}(x_1, x_2, t) \qquad (5)$$

And to find the coordinates of the point of the conditional extremum in the state space, it is sufficient to use the system of equations added to the coupling equations:

$$\begin{cases}\frac{d\Psi_i}{dt} + \lambda_{1i}\frac{d\varphi_{1i}}{dt} + \lambda_{2i}\frac{d\varphi_{2i}}{dt} = 0 \\ \frac{d\Psi_i}{dx_1} + \lambda_{1i}\frac{d\varphi_{1i}}{dx_{1i}} + \lambda_{2i}\frac{d\varphi_{2i}}{dx_{1i}} = 0 \\ \frac{d\Psi_i}{dx_2} + \lambda_{1i}\frac{d\varphi_{1i}}{dx_2} + \lambda_{2i}\frac{d\varphi_{2i}}{dx_2} = 0\end{cases} \qquad (6)$$

To find the balance of production volumes of livestock products Ψ_1 and consumption volumes Ψ_2 it is necessary to solve their combined system of equations (2) for, respectively, two values of the objective function index i=1; i=2 and to find the point of intersection of their first derivatives. According to the well-known rule, such a point always exists for two non-parallel straight lines on the plane.

As the number of influencing parameters increases, the solution will belong to an isolated region of the multidimensional state space, where the points of conditional local extrema are concentrated. Operational relevant analysis and forecast of the state of production and consumption of livestock products will make it possible to promptly implement measures to neutralize negative impacts on food security.

4. Aim and tasks.

This study aims to establish the peculiarities of monitoring the livestock market under conditions of significant dynamic changes in the main parameters affecting production and consumption volumes.

This determines the formulation and solution of the following tasks: establishment of integral trends in the production of the main types of livestock products, and development of a mathematical model for evaluating the balance of production volumes and consumption volumes of livestock products based on the gradient method.

5. Results.

Several decisions on Ukrainian institutional structure indicated the need to monitor the state of food security. The monitoring tasks, measures, and indicators of their implementation were established in the Cabinet of Ministers of Ukraine (2022).

This determined the following methods: assessment of the balance of demand and supply of livestock products, and monitoring the prices of basic food products by the State Statistics Service. Thus, according to the methods for determining the leading indicators of food security (Cabinet of Ministers of Ukraine, 2007) and methodological recommendations (Ministry of Economic Development and Trade of Ukraine, 2013), the indicators with which assessments and forecasts of the state of food security should be made include: average daily caloric content of human nutrition; the ratio of volumes of production and consumption of agricultural products by their types (in particular, meat and meat products, milk and dairy products); the level of grain stocks at the end of the period; the share of sales of imported food products in the retail network.

However, the specified number of indicators at significant time intervals of their assessment by the State Statistics Service of Ukraine does not make it possible to consider the dynamic effects of threats. Averaging the values of indicators leads to errors in estimating the main trends. For example, the FAO (2020) considers it for operational assessment and forecasting in the field of crop production.

Thus, the Global Information and Early Warning System (GIEWS) (FAO, 2023) allows data to be obtained in the field of crop production in all regions of the world using satellite systems.

With the help of GIEWS, changes in the main factors affecting future harvests are monitored; the amount of cultivated area, weather conditions, droughts, and forecasts of changes in the yield of individual crops are formed almost in real time. Since 1988, data has been accumulated in the environmental monitoring information system ARTEMIS, which allows analysts to build relevant scenarios for the development of events. This makes it possible to assess the dynamics of the animal feed base in individual regions, including Ukraine.

Unfortunately, there are no similar systems for operational digital monitoring in the livestock industry. The above set of indicators is insufficient for a relevant taxonomic assessment of the country's food security level (Strashynska & Mykhailyk, 2023), nor for the appropriate level of relevance for the assessments of "forecast supply and demand balances" specified in government documents. There is no specification of indicators in other governmental (Cabinet of Ministers of Ukraine, 2022) or international documents (FAO, 2020; Svyrydenko & Revin, 2022b).

Uncertainty in the effects of threats and their dynamic nature leads to uncertainty in forecasts based on the available statistical data. This is confirmed by the differences in the conclusions of experts, particularly regarding the forecasts of the milk market for 2023 (Fig. 1), given the rapid reduction in milk production noted by the State Statistics Service from 2013 to 2021 (State Statistics Service of Ukraine, 2023).

Significant fluctuations of the main factors of influence in short periods of time: the adequacy of the fodder base, the availability of workers under the conditions of mobilization, the dynamics of livestock losses due to missile and bomb strikes, affect, for example, the relevance of the assessment of the volume of production of milk and dairy products (Fig. 1).
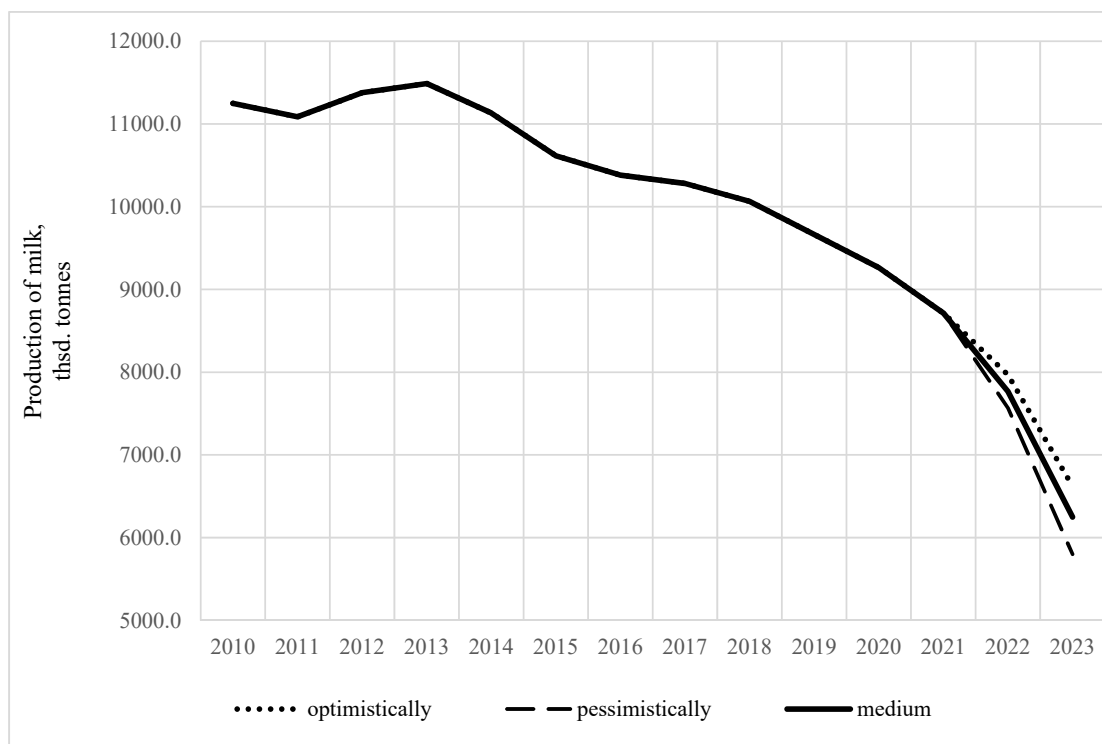
Fig. 1. Prediction of milk production, thousand tons.
Source: based on data by the State Statistics Service of Ukraine (2023); Infagro (2023).

This reduces the relevance of the assessment of measures to ensure the rational nutrition of the population.

This was confirmed by data from the State Statistics Service of Ukraine (2023) for the latest period, in particular, regarding the number of animals by species (Fig. 2).

Combat operations in some regions of Ukraine have reduced the ability to provide animals with fodder. Some of the farms, with significant differentiation by region, were unable to pay for fodder due to a lack of working capital, which resulted in a change in animal rations. This led to a change in the priorities of agrarians from preserving the productivity of animals, in particular cows, to preserving livestock. That is why, for example, dairy farms have even switched from three to two milkings per day.

Unfortunately, this approach turned out to be insufficient to preserve livestock. According to the assessment of the change in the number of farm animals (see Fig. 2), there is a long-term trend towards a significant reduction in the livestock of all their species. This, in particular, is indicated by the ratio of indicators of the number of animals in 2023 to 2021: for cattle, by 20%, for pigs, by 16%, and for poultry, by 11% (State Statistics Service of Ukraine, 2023).

A significant reduction in the number of pigs starting in 2022 after a relatively stable period of 2018–2021 is also evidence of the crisis in the livestock industry, as pork makes up a significant part of the structure of meat and meat products production (State Statistics Service of Ukraine, 2023).
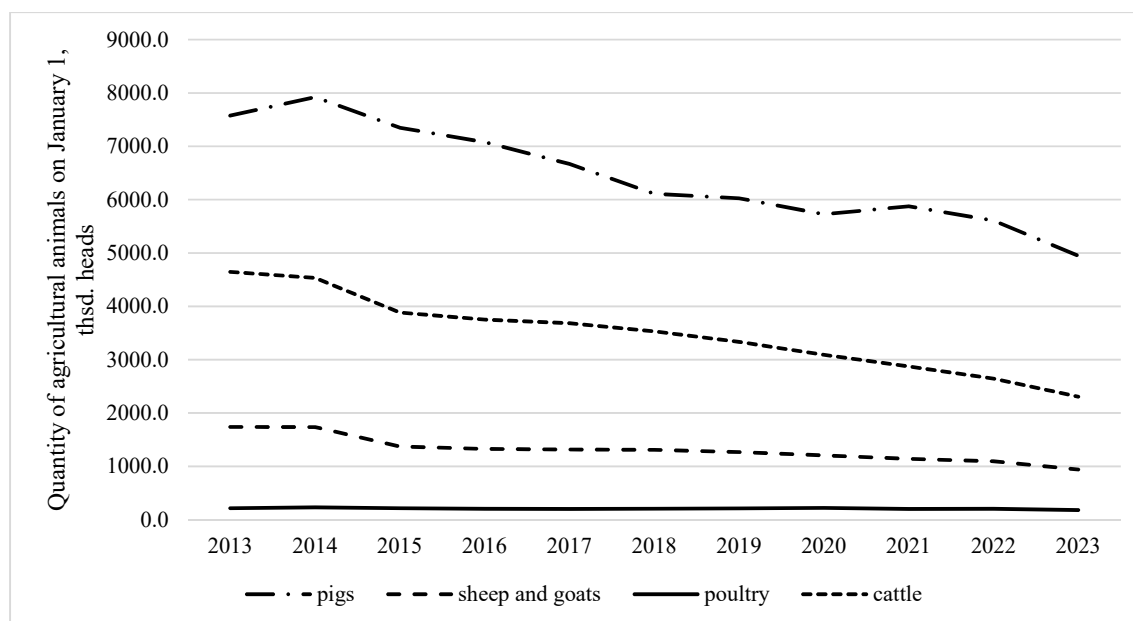
Fig. 2. Trends in changes in the number of farm animals by species.
Source: based on data by The State Statistics Service of Ukraine (2023).

As a result of large-scale hostilities, there is a significant decrease in the production potential of the livestock industry, which has had a catastrophic effect on the volume of production of meat and dairy products. This is indicated by the growth of imports of some types of products (State Statistics Service of Ukraine, 2023). This indicates an increase in the rate of risks to food security in this direction. An approximate integral assessment of the effects of threats can be carried out by statistical analysis of trends in the number of agricultural animals by species and the formation of polynomial equations of these trends (Table 1).

Table 1. Degrees of trend parameters (polynomial equations).

Kind of agricultural animals	Degrees of trend parameters		
	2	**1**	**0**
Cattle	3.66	112.31	1818.7
Pigs	4.25	- 325.25	8200.8
Sheep and goats	1.29	- 233.2	4819.6
Poultry	-0.25	0.51	216.1

Source: based on data by State Statistics Service of Ukraine (2023).

The structure of meat and meat product production in Ukraine is very different from that of European countries and global trends. The types of meat and meat products for Ukraine are cattle (16%), pigs (31.8%), poultry (50.8%), and lamb and goat meat (0.6%). In EU countries, the structures of meat and meat products are cattle (16%), pigs (49.7%), poultry (30.5%), and lambs (1.8%). The average global indicators of meat and meat production are cattle (19.9%), pigs (35.8%), poultry (36.4%), and lamb and goat meat (4.5%) (Pchelianska, 2018). At the same time, as evidenced by the data in Table 2, poultry meat had an insignificant weight in the amount of meat product processed by domestic enterprises. That is, poultry meat is consumed mainly in unprocessed form. This can be explained by the relatively low price of chicken, which focuses its consumption on a low-income population. Thus, the significant difference in the preference for chicken meat and meat products in Ukraine is not related to the traditions of agricultural production, but, first, to the differentiation of prices for the specified products according to their types and the income level of the majority of the population.

Nowadays, this factor undergoes significant changes in separate regions, particularly as a result of significant population migration due to hostilities, relocation of enterprises. Deformation of the consumption market will increase, in particular due to the fact that the cost of production of livestock products will increase due to a number of negative factors (Hadzalo & Luzan, 2021).

This is evidenced by the data presented in Table 2 regarding the significant increase in purchase prices for the relatively short period of 2020–2021, even before the start of large-scale military operations.

The peculiarity of this process was also its dynamism, which, in particular, is evidenced by the data shown in Table 2.

Table 2. The weight and price of agricultural animals (in live weight) purchased by processing enterprises in IY quarter of 2020-2021 years.

By types of animals	By purchased weight, kg		By cost purchased weight, hryvnias		Share in the total volume of processing	
	2021	2020	2021	2020	2021	2020
Cattle	20296538	20633410	995250425.9	666513884.7	0.28	0.31
Pigs	46133634	46538315	1736850384	1625198896	0.63	0.69
Sheep, Goats	20748	16380	817762.4	497770	0.0003	0.0003
Poultry	6409183.2	6409183.2	155956791.2	145007769.9	0.09	0.09
In total	72860103.2	67188105	2888875363	2437218321	-	-

Source: based on The State Statistics Service of Ukraine (2023).

The purchase price increase, as shown in Table 2, did not occur uniformly by product type. From 2020–2021, the increase in purchase prices for poultry products was 7.6%, 6.9% for pig products, and 49.3% for cattle meat. This has led to increased retail prices and disproportionate consumption of meat products by type. All these factors affect the state of food security in the country.

The study of changing trends in the number of agricultural animals indicates a break in the trend of stability of the pig population, the number of poultry heads in 2021, and the continuation of the long-term trend of reduction in the number of cattle, sheep, and goats.

The dynamics of changes in the production of livestock products negatively affect all related industries. For example, a significant decrease in the sheep population led to a decrease in wool production for the period 2015–2022 by more than 52%, which undermined the production of fabrics and other woolen products and led to a significant increase in imports of these goods.

The indicated significant level of dynamism of changes in factors affecting the livestock market creates peculiarities of

monitoring, such as the need to obtain information about changes in factors at shorter time intervals to assess not only the values of these factors.

However, the dynamics of changes in their trends also necessitate changing the monitoring methodology and mathematical processing of information. Accordingly, this will increase the efficiency of forecasting and its relevance.

This also strengthens the requirements for shortening the periods for obtaining statistical data on the purchasing power of the population, particularly in the regional dimension (Turpurova & Vorona, 2022). This will provide an opportunity to assess dynamic changes in the level of regional disproportion in the market for the consumption of livestock products.

Increasing military operations and requirements for market conditions to provide the population with livestock products, considering food security problems. There is a need for comprehensive development of regional food production, particularly livestock products, to reduce costs, primarily logistics (Nikmatul et al., 2020).

This requires certain institutional steps since, in previous times, trends were formed for the specialization of regions by types of agricultural products (Bondarchuk, 2020). The transition from a mono-product structure of production, avoiding approaches aimed at increasing the productivity of agricultural production through intensification, and encouraging large-scale agricultural projects. This will require the selection of the main objective function of planning agricultural activities at the country level, the formation of an appropriate level of food security, and changes in economic and non-economic institutional incentives for agricultural production.

6. Conclusions.

The methods of monitoring food security, implemented in the past and even agreed upon by international organizations, particularly the FAO, require changes due to the dynamic nature of external influences. It is noted that international organizations are introducing information technologies for the operational assessment of the main impact parameters, an example of which is the Global Information and Early Warning System.

A study of statistical data from past periods indicated that the crisis in the field of animal husbandry has been ongoing for a considerable period; large-scale military actions only significantly intensified it and caused dynamic changes in both the production and consumption of animal products. Statistical analysis of trends in changes in the number of farm animals by species and the formation of polynomial equations for these trends have been introduced for an approximate integral assessment of the effects of threats.

This indicates that in short periods, significant fluctuations in the main influencing factors, such as the sufficiency of the fodder base, the availability of labor resources under the conditions of mobilization, significant migration flows, and the dynamics of livestock losses due to missile and bomb attacks affect the relevance of the assessment of livestock production volumes.

The inaccuracy of the statistical data of the State Statistics Service at significant time intervals was confirmed by itself regarding the data of the last period, particularly regarding information on the number of animals by their species. Note that this information is essential for forecasting production and consumption volumes. The uneven influx of threats and significant migration flows of the population are determined by the differentiation of the levels of production and consumption of livestock products by region, and by the peculiarities of the dynamic deformation of the production and consumption markets. The deformation of the consumer market will increase because the cost of production of livestock products will increase due to several negative factors.

To monitor the market for livestock products and develop relevant forecasts, it is necessary to evaluate, in an operational manner, changes in the level of sufficiency of the fodder base in terms of crop forecasts, forecasts of animal feed prices, cost and capacity of farms in their logistical support, and forecasts of export needs and domestic consumption. To assess the ratio of the production and consumption levels of livestock products, it is also necessary to know the dynamics of prices of meat and meat products by type of livestock product, the dynamics of the purchasing power of the population, and the dynamics of changes in products in the diet due to the change in the ratio of their prices to the real average daily income. This does not require the absolute values of these indicators, but their changes over time depend on individual impact parameters. Therefore, a mathematical model for assessing the balance of production and consumption volumes of livestock products based on the gradient method of mathematical analysis was developed.

The specified mathematical model allows the consideration of dynamic changes in the main parameters of influence, which ensures the relevance of the monitoring results.

The specified approaches and mathematical tools will enable prompt implementation of measures to neutralize the negative effects on the state of food security.

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