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Methodological foundations of applying three-axis graphs in the analysis of agricultural production efficiency

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The article considers the methodological principles of triaxial graphs using in the analysis of the agricultural production efficiency. It is substantiated that the methodology of triaxial graphs is based on the concept of barycentric coordinates, which are expedient to use for modeling systems with three components, where the sum of the particles is always equal to 100%, which limits the system to two degrees of freedom. It is emphasized that ternary diagrams are the world standard for soil texture classifying with the purpose of a well-founded cultivation strategy, make it possible to visualize the contribution of individual factors (number of spikelets, grain size) to the total grain yield and help to assess not the absolute content of N:P:K, but their mutual balance for precise adjustment of fertilization.

It is established that this methodological approach is expedient to use for assessing the balance between renewable (R), non-renewable (N) and purchased (F) resources, which allows to establish the dependence of modern systems on technological investments. It is argued that the use of graphs in the current environment is combined with machine learning (Random Forest) and satellite monitoring for real-time yield forecasting.

The necessity of applying three-axis graphs as a modern tool of statistical analysis in agricultural economics has been established. It has been clarified that tabular data provides the basis for production calculating and financial indicators, but their analytical value is limited by the difficulties of visual comparison between heterogeneous data series. Statistical data of SRL «AgroVerde» for the period 2020–2024, including gross yield, harvested area, cost of production, sales revenues, and profit, have been systematized. Calculations of return on sales, cost recovery, unit costs, and profit per hectare and per centner of wheat have been carried out.

The potential of three-axis graphical visualization, which enables the integrated representation of multi-level indicators (costs per hectare, unit production costs, profit per hectare, and profit per centner) in a single coordinate system, has been evaluated. It has been proven that the application of three-axis graphs allows to identify multidirectional trends — such as the growth of unit production costs accompanied by a simultaneous decline in profit per hectare. It has been substantiated that the use of trend equations in graphical interpretation increases the reliability of analysis and provides a quantitative confirmation of the dynamics of the studied indicators.

It has been emphasized that three-axis graphs should be considered not only as a means of statistical data visualization but also as a method of forecasting, contributing to the identification of development patterns in agricultural production and the formulation of scientifically grounded managerial decisions.

Keywords: three-axis graph, cost of production, profitability, profit, expenditures, agricultural economics, statistical analysis.

Problem statement and analysis of recent research. Modern trends in the development of the agro-industrial complex are characterized by a high degree of uncertainty caused by variable natural and climatic conditions, fluctuations in domestic and foreign market conjuncture, and instability of prices for agricultural products and resources. Under these circumstances, the search for analytical tools that ensure a comprehensive and visual assessment of production and economic processes in dynamics becomes increasingly important. One of the effective approaches in this context is the application of graphical visualization methods, which significantly expand the analytical capacity of traditional statistical data processing.

The analysis of agricultural enterprises requires consideration of a wide range of heterogeneous indicators — from sown area and gross harvest to production cost and profitability of sales. The interdependence among these indicators is often difficult to interpret based solely on tabular data, since the relationships are non-linear and multifactorial. Therefore, graphical modeling methods, particularly three-axis diagrams, gain growing relevance as they make it possible to simultaneously reflect the dynamics of several variables expressed in different units of measurement and to reveal key regularities that may remain hidden in conventional tabular analysis.

This study examines the potential of applying three-axis graphs to the analysis of production and economic indicators of enterprises in the agricultural sector. The proposed method not only provides a clear visualization of the relationships between yield, cultivated areas, cost of production, and profit level but also facilitates a deeper understanding of the structural changes that affect the efficiency of economic performance.

The relevance of the research lies in the need to improve tools for visual and analytical data interpretation, which is particularly important for agricultural enterprises operating under the conditions of increased natural and climatic risks. The use of graphical models based on three-axis representation principles ensures an integrated approach to assessing the sustainability of agricultural production and enables the development of more informed managerial decisions aimed at improving efficiency, stability, and overall performance in the agricultural sector.

The relevance of the methodology studying of triaxial graphs using, known as ternary diagrams or simplex plans in the scientific literature, offers a unique approach to the visualization and analysis of ternary mixtures, where the sum of the parts is always a constant [1]. It should be noted that in the analysis of the efficiency of agricultural production, this tool allows us to go beyond the traditional linear representation and explores the synergy between economic, technological and natural resources.

In scientific literature, methods of statistical analysis aimed at assessing the stability and efficiency of agricultural production are actively discussed. Researchers emphasize that the use of graphical methods makes it possible to comprehensively interpret the dynamics of heterogeneous indicators and to identify interrelations between them. Both domestic and foreign authors consider the application of multidimensional graphs as a tool for detecting hidden trends associated with changes in production and financial conditions. It is known that the methodological principles of three-axis graphs were laid at the beginning of the 19th century. In 1827, the German mathematician August Ferdinand Möbius proposed the concept of barycentric coordinates, which had become the foundation for constructing graphs in the form of an equilateral triangle. Initially, this method was used in geology, chemistry, but in the second half of the 20th century. began to be actively introduced into biological and economic sciences [2]. In agricultural research, this approach is critically important, since it allows modeling phenomena where resources are interchangeable or form a holistic structure, such as the composition of fertilizers, the structure of land, or the energy balance of an agroecosystem. The property of a ternary graph is that the system has only two degrees of freedom, since the third component is always rigidly defined through the other two.

The scientific debate on the choice of the graph form is still ongoing. The most fundamental application of ternary diagrams in the agricultural sector is the classification of soil texture, which is determined by the relative content of sand, silt and clay, which directly affects fertility, drainage, aeration and the ability to retain nutrients [3]. It should be noted that the USDA texture triangle, which distinguishes 12 texture classes [4], dominates international practice. The use of ternary diagrams allows agronomists to visualize areas of optimal cultivation. For example, Mini-till and No-till technologies are most effective in specific segments of the texture triangle, where the soil structure allows the preservation of anaerobic microorganisms ecosystems and the prevention of erosion without mechanical turning of the plot. At the same time, three-axis diagrams are a powerful tool for yield decomposition.

The research of the Polish scientist Golba [5] demonstrated how ternary diagrams can be used to illustrate the relationships between the total grain yield, the number of spikelets per square meter and the grain size of each spike. This approach allows us to identify which component is the limiting factor for a particular variety under certain environmental conditions.

Another important direction is the analysis of macronutrients ratio in plant tissues. Thomas's work [6] on potato leaves showed that it is not the absolute content of nitrogen, phosphorus or potassium that is important, but their mutual balance. The methodological advantage is that each point on the ternary graph represents a unique combination of N:P:K. The shift of a point towards one of the vertices indicates a deficiency or excess of a particular element relative to the others, which allows for precise adjustment of feeding [7].

One of the most complex and profound methods of applying ternary diagrams is Emergy Accounting. It should be noted that emergy is the amount of energy of one form (usually solar) that was spent directly or indirectly to create a product or service [8]. In this methodology, all input resources of the agricultural system are divided into three categories that form the axes of the ternary graph: R (Renewable resources) - renewable natural resources (sun, rain, wind); N (Non-renewable resources) - non-renewable natural reserves (soil humus, groundwater); F (Purchased inputs) - purchased resources (machinery, fuel, mineral fertilizers, pesticides) [8].

Studies of agricultural systems in the provinces of Chaoyang and Fushun over a 25-year period (1980–2005) clearly demonstrated the process of intensification using ternary trajectories. The share of purchased inputs (F) has almost doubled, which has led to a shift in the system points from the peak of renewables (R) to the peak of technological dependence. This graphical analysis confirms that although modern investments in «high-quality» inputs (fertilizers, machinery) increase yields per hectare, the economic and energy efficiency of these investments often declines due to the depletion of natural capital [9].

The concept of eco-efficiency (Agricultural Ecological Efficiency, AEE) integrates economic output with ecological costs, which is defined as the ability to maximize output while minimizing resource consumption and environmental pollution. Modeling «unwanted outcomes» can be methodologically implemented through SBM-DEA (Slacks-Based Measure Data Envelopment Analysis) models, which take into account not only desired outputs (yields), but also unwanted ones (carbon emissions, nitrate leaching) [11]. In ternary diagrams, this allows us to distinguish specific zones: the zone of high efficiency and low emissions - includes areas in which agricultural enterprises operate, characterized by an optimal combination of technologies and natural conditions; in this case, high total factor productivity (TFP) is observed; the zone of «excess costs» - includes areas in which farms with a high level of chemicalization are located, where each additional unit of fertilizer gives a minimal increase in yield with a significant increase in the ecological footprint [11]; the zone of potential intensification - areas with low resource use, where the introduction of modern methods (for example, precision agriculture) can significantly increase yields without a critical impact on the environment [12].

Studies in the Yangtze River Basin (YEB) have shown that over the period 2008–2023, most regions have transformed from «low surplus and low efficiency» zones to «high efficiency» zones due to the introduction of green finance and technological innovation [9]. This is an important conclusion regarding the need for differentiated state support depending on the zone in which a particular farm is located on the ternary plan.

The methodological framework for sustainable development in agriculture requires the simultaneous analysis of five key domains: productivity, economy, environment, human factor and social aspect [13]. Ternary diagrams are used in this case to visualize trade-offs and synergies.

When evaluating new technologies such as intercropping (combined crops) or the use of legumes, researchers use ternary models to determine the optimal proportions. For example, a study of mountain meadows found that a certain degree of intensification (increased livestock and fertilizer application) is possible without a significant decrease in soil organic carbon (SOC) stocks, provided that the balance of cereals and legumes is maintained [14]. An interesting conclusion from the study on the effect of legumes on carbon accumulation is that the ternary plots clearly show that when a certain proportion of legumes in the grassland is exceeded (over 17%), their positive effect on SOC disappears. This demonstrates the nonlinear nature of agricultural systems, which cannot be adequately described by simple correlations, but can be easily identified visually on a three-axis plot.

The analysis of agricultural land use efficiency (CLUEE) is becoming critical in the context of global urbanization. Ternary modeling allows us to assess how urban expansion and changes in landscape structure affect the productivity of peripheral lands [15].

The modern methodology of triaxial graphs using is increasingly integrated with IT technologies. The use of Random Forest (RF) models and neural networks allows us to automate the process of classification and forecasting based on ternary outputs [16]. Thus, one of the breakthroughs is the use of satellite data for monitoring crop types in real time. Ternary diagrams display the accuracy of models (Overall Accuracy) depending on the share of different crops in the field [15]. To increase the reliability of the analysis, researchers propose replacing traditional calendar time with «thermal time» (Growing Degree Days, GDD). Such innovations are extremely relevant for agricultural producers who need accurate tools for predicting the yield of wheat, corn, and sunflower, taking into account the heterogeneity of soil cover and weather conditions variability.

In particular, the studies of Professor D. M. Parmakli and co-authors demonstrate the high effectiveness of using graphical models in assessing the sustainability of agricultural production, as well as in analyzing the yield and profitability of specific agricultural crops [17-20]. This approach confirms the relevance of integrating visualized data into a comprehensive system of economic and statistical research, which allows for the identification of structural changes and the evaluation of the dynamics of economic performance in agriculture. However, the problem of adapting three-axis visualization, especially when analyzing a set of four heterogeneous indicators (for example, yield, sown area, cost, and profit), remains insufficiently developed to date. This fact determines the relevance of the present study and highlights its specific feature, which lies in expanding the tools of comprehensive analysis of production and economic dynamics through three-axis visualization.

Purpose of the article. The purpose of the study is to substantiate and apply in practice three-axis graphs for analyzing the dynamics of statistical indicators of agricultural production, using the data of SRL «AgroVerde» for the period 2020–2024. The implementation of this objective involves demonstrating the potential of the graphical method in the comprehensive evaluation of production and economic results, as well as in identifying hidden trends in the enterprise's development.

The scientific significance of the research lies in the proposed methodological approach to the systematization and visualization of heterogeneous indicators (yield, sown area, production cost, and profit) within a unified coordinate system. The expediency of using a three-axis graphical model is substantiated as a tool for in-depth statistical analysis, which makes it possible not only to record current results but also to identify the regularities of their changes.

Special attention is given to the sectoral specificity of the agro-industrial complex, which is characterized by a high dependence on natural and climatic conditions and seasonal factors. These features make the results of economic activity less predictable and increase the importance of tools that allow for a clear comparison of multidirectional trends. The use of three-axis graphs in this field provides a deeper understanding of interrelations and contributes to well-founded planning and forecasting of production and economic dynamics.

Materials and research methods. The empirical basis of the study consisted of the financial and production reports of SRL «AgroVerde» for the period 2020–2024, which included data on gross harvest, harvested area, yield, production cost, and sales revenues. A unified methodological approach was applied as the calculation basis, ensuring the comparability of results across the years. Profit was defined as the difference between revenues and production costs; sales profitability was calculated as the ratio of profit to revenues; and cost recovery was determined as the ratio of revenues to production costs. In addition, specific indicators were calculated: costs per hectare, production cost, and profit per quintal of output and per hectare of cultivated area.

The application of a three-axis graphical model made it possible to present several heterogeneous indicators (yield, sown area, production cost, and profit) simultaneously within a unified coordinate system, thereby ensuring a more comprehensive perception of their dynamics. For the analysis, trend equations and determination coefficients were employed, which made it possible to quantitatively confirm the direction of changes.

Special attention was paid to the sectoral specificity of the agro-industrial complex. Agricultural production is highly dependent on natural and climatic conditions, seasonality, and biological cycles. These factors increase the volatility of indicators, making traditional tabular analysis less illustrative and limiting the possibilities of forecasting. Under such conditions, three-axis graphs serve as an effective tool, enabling the visualization of multidirectional trends, the identification of cause-and-effect relationships, and the provision of well-founded planning and strategic management of production and economic processes.

Summary of the main results of the study. The analysis of statistical data of SRL «AgroVerde» for 2020–2024 revealed a decline in yield and gross harvest while maintaining the sown areas, which resulted in a decrease in the enterprise's revenues and profits. A reduction in sales profitability and cost recovery was established, as well as an increase in the production cost per unit of output, accompanied by a decrease in profit per hectare and per quintal. The application of three-axis graphs made it possible to clearly record multidirectional trends and to confirm the negative dynamics of production efficiency.

Graphical methods play a particularly important role in studying the dynamics of statistical indicators in the agro-industrial complex. One of the most effective tools is the construction of three-axis graphs, which make it possible to analyze changes in three or more indicators expressed in different units of measurement. For agriculture, this is especially relevant, since it is necessary to simultaneously take into account the sown area, gross harvest, and yield level.

Table 1 presents the data on the dynamics of winter wheat production in SRL «AgroVerde» for 2020–2024. In 2020, the enterprise achieved comparatively high results: the gross harvest amounted to 3,625 tons with a harvested area of 1,140 hectares, and the yield was 31.8 quintals per hectare. In subsequent years, a steady downward trend was observed: in 2021–2022 the decline was moderate and was associated with unfavorable climatic conditions and rising costs; in 2023 the decline intensified, while the sharpest decrease was recorded in 2024 – with an increase in the harvested area, the yield fell almost threefold compared to 2020.

Analysis of the data presented in Table 1 makes it possible to identify a clearly pronounced downward trend in the production of winter wheat at SRL «AgroVerde» during the period 2020–2024. Thus, in 2020 the enterprise achieved relatively high indicators: the gross harvest amounted to 3,625 tons with a harvested area of 1,140 hectares, while the average yield reached 31.8 quintals per hectare. However, in the following years, a gradual reduction in production volumes was observed. In 2021–2022, the decline was moderate and was primarily associated with unfavorable climatic conditions, as well as rising costs for fuel, lubricants, and plant protection products.

In 2023, the situation deteriorated further: the gross harvest fell to 2,480 tons, while the yield decreased to 20.7 quintals per hectare. The sharpest decline was recorded in 2024, when the gross harvest dropped to 1,410 tons and the yield fell to only 10.9 quintals per hectare, despite an increase in the harvested area. Such dynamics indicate a decrease in the efficiency of land use, which is likely linked to insufficient renewal of the material and technical base and limited adoption of modern agrotechnologies.

This provides a rare case where indicators expressed in different units of measurement but comparable in scale can be represented on the same axis of a graph (Fig. 1).

Thus, the trend of recent years demonstrates growing problems in the enterprise's production process. The use of graphical methods of analysis, in particular three-axis line graphs, makes it possible not only to capture the overall decline but also to clearly show the interrelation between the reduction of gross harvest, the change in sown areas, and the decrease in yield. This represents a rare case in which indicators expressed in different units of measurement but comparable in magnitude can be presented on the same axis of a graph, making the analysis more compact and illustrative (Fig. 1). On the left vertical axis, it is advisable to display the cultivated area in hectares and the gross harvest in tons, since their absolute values fall within comparable ranges. This avoids excessive overloading of the chart while simultaneously demonstrating the relationship between sown areas and production volumes. Yield, expressed in quintals per hectare, is placed on the right vertical axis, which ensures correct perception and maintains analytical accuracy.

Table 1 – **Indicators of winter wheat production in SRL «AgroVerde» for 2020–2024**

Year	Gross harvest, t	Harvested area, ha	Yield, q/ha
2020	3625	1140	31,8
2021	3360	1150	29,2
2022	3015	1185	25,5
2023	2480	1200	20,7
2024	1410	1290	10,9

Source: compiled on the basis of the financial reports of SRL «AgroVerde».

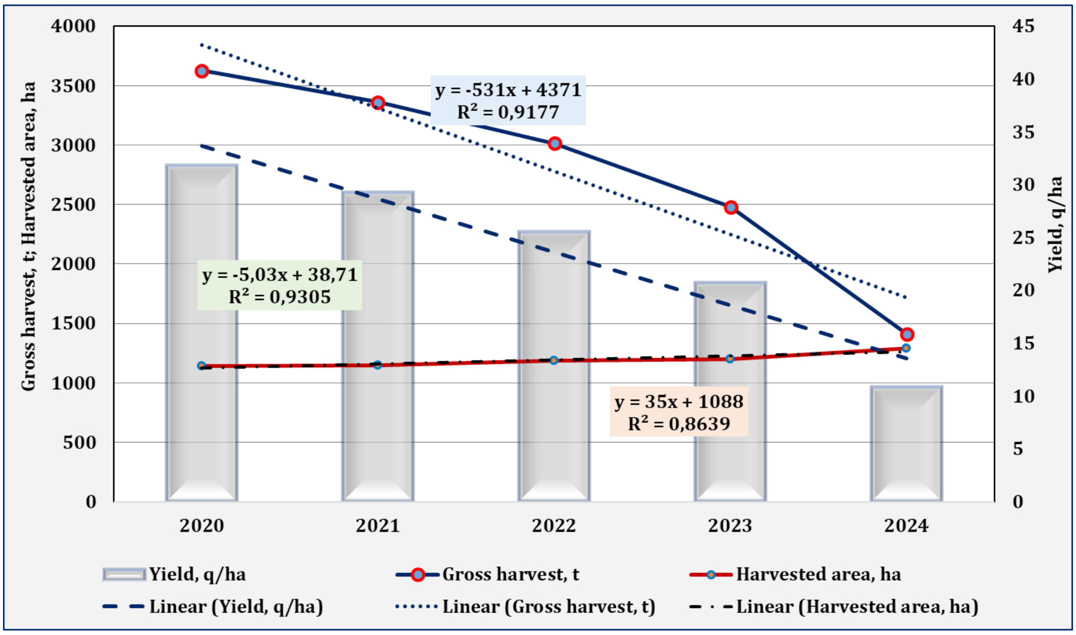

Fig. 1. **Dynamics of cultivated area, gross harvest, and yield of wheat in SRL «AgroVerde» for 2020–2024**

Source: compiled on the basis of Table 1.

Analysis of the three-axis graph (Fig. 1) makes it possible to clearly trace the dynamics of the key indicators of winter wheat production in SRL "AgroVerde" for 2020–2024. The use of a three-axis scheme allows for the simultaneous observation of the interrelation between cultivated area, gross harvest, and yield—something that cannot be demonstrated as clearly in tabular form. The constructed trend lines and corresponding equations make it possible not only to capture general tendencies but also to quantitatively assess the rate of change of the indicators.

Thus, the trend equation for the gross harvest is: $y = –531x + 4371$ ($R^2 = 0.9177$), which indicates an annual decrease in gross harvest of approximately 530 tons. This is confirmed by the high degree of reliability of the model ($R^2 = 0.9177$).

For the cultivated area, the trend equation is: $y = 35x + 1088$, $R^2 = 0.8639$, which shows a slight upward tendency of expansion—about 35 hectares per year. However, this increase does not compensate for the decline in yield. The determination coefficient $R^2 = 0.8639$ confirms the presence of a stable but moderate relationship.

The most significant is the yield trend: $y = –5.03x + 38.71$, $R^2 = 0.9305$, which indicates an annual decrease in yield of about 5 quintals per hectare. The high R^2 value (0.9305) confirms the reliability of the model and demonstrates that yield is the factor determining the decline in gross harvest, despite the relative stability or even slight increase in sown areas.

The three-axis graph confirmed that the decisive factor in the production dynamics is yield, whose decline determines the overall downward trend of gross harvest. Even with an expansion of cultivated area, the enterprise cannot increase production volumes without stabilizing and improving the efficiency of land use. This result emphasizes the analytical value of the graphical method, which performs not only an illustrative but also a generalizing function, and can serve as a tool for forecasting and managerial decision-making in the agro-industrial complex.

Let us now consider the specifics of using three-axis graphs in the analysis of sales efficiency indicators. As an example, we take the wheat sales data presented in Table 2. The information provided makes it possible to evaluate the dynamics of the enterprise's sales over the past five years, to identify trends in changes in sales volumes and average price levels, as well as to establish the interrelation between sales revenues and the physical volume of products sold.

Table 2 – **Summary indicators of wheat sales in SRL «AgroVerde» for 2020–2024**

Year	Quantity sold, t	Production cost, thousand MDL	Sales revenue, thousand MDL	Harvested area, ha
2020	3625	6 200	9 800	1140
2021	3360	6 400	9 740	1150
2022	3015	6 300	9 000	1185
2023	2480	5 900	8 400	1200
2024	1410	5 100	6 200	1290

Source: compiled on the basis of the financial reports of SRL «AgroVerde».

Based on the data presented in Table 2, it is advisable to carry out sequential calculations of the key indicators characterizing the efficiency of wheat sales in the studied enterprise. The application of these calculations makes it possible to determine the production cost and selling price per unit of output, to establish the profitability of sales, and to calculate the cost recovery ratio. The obtained results are summarized and systematized in Table 3, which provides a more illustrative representation of the dynamics of indicators over the analyzed period.

For greater clarity, the results of the performed calculations will be presented in graphical form, which will make it possible to more clearly trace their dynamics and to identify the main trends of change during the analyzed period (Fig. 2).

Analysis of wheat sales efficiency indicators in SRL «AgroVerde» demonstrates a steady tendency toward declining profitability of production, expressed in the gradual narrowing of the profit margin. In the dynamics of recent years, an increase in the selling price is recorded, averaging 27.8 MDL/q per year ($y = 27.8x + 238.8$; $R^2 = 0.9938$), while production cost has grown even faster—by approximately 42.9 MDL/q per year ($y = 42.88x + 115.68$; $R^2 = 0.8226$). The mismatch in growth rates leads to a systematic decline in cost recovery, which is quantitatively confirmed by the equation $y = –0.082x + 1.68$, with a high level of approximation ($R^2 = 0.8999$), reflecting an annual decrease in the cost recovery ratio by about 0.08 MDL/MDL.

The specific feature of three-axis graphical visualization lies in its ability to present heterogeneous series jointly, thereby revealing the divergence in the rates of change of price and production cost, as well as their impact on the decline of cost recovery and the narrowing of the margin per unit of output. Unlike the tabular form, the graph makes interrelations and patterns visible, while trend equations make it possible to quantitatively assess the intensity of processes and to use the obtained relationships for analytical forecasting.

The identified negative dynamics correspond to the specific risks of the agro-industrial complex: the high dependence on natural and climatic conditions increases yield volatility and, through the mechanism of allocating fixed costs over a smaller volume, drives the growth of unit production cost. This was manifested most clearly in 2024, when the combination of unfavorable natural and climatic factors amplified the decline in yield and reinforced the trend of weakening profitability.

Table 3 – **Efficiency indicators of wheat sales in SRL «AgroVerde» for 2020–2024**

Year	Selling price, MDL/q	Production cost, MDL/q	Sales profitability, %	Cost recovery ratio, MDL/MDL
2020	271,0	171,0	36,7	1,58
2021	290,0	190,5	34,3	1,52
2022	320,0	260,5	30,0	1,43
2023	350,0	237,9	29,8	1,42
2024	380,0	361,7	17,7	1,22

Source: compiled on the basis of Table 2.

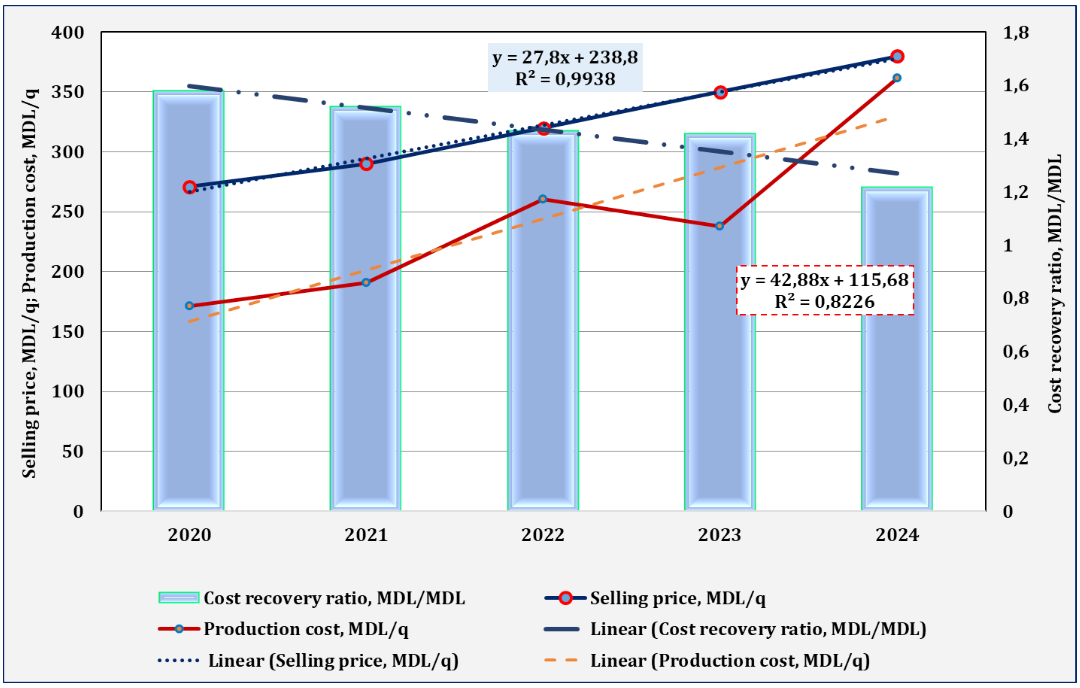

Fig. 2. **Dynamics of wheat sales efficiency indicators in SRL «AgroVerde» for 2020–2024**

Source: compiled on the basis of Table 3.

The calculation of profit indicators, both for the enterprise as a whole and recalculated per unit of output and per unit of area, is presented in Table 4 and visualized in Figure 3. Such an approach makes it possible to compare the overall results of economic activity with the specific efficiency of land resource use and production, thereby providing a more comprehensive understanding of the enterprise's economic dynamics.

Considering the data from Table 4 and Figure 3, it can be noted that it is precisely the graphical representation that makes it possible to identify the most significant patterns in the dynamics of profit in SRL «AgroVerde» for 2020–2024. While the table records absolute values and their annual distribution, the three-axis graph and trend lines make it possible to determine the average rates of change and to assess the stability of these tendencies.

Thus, the trend equation of total profit y = –543.1x + 3884.5, with a high coefficient of determination ($R^2 = 0.91$), shows that during the analyzed period the annual decrease averaged 543 thousand MDL. The graph demonstrates not only the fact of reduction but also the nature of the process—stable and consistent decline.

Table 4 – **Profit indicators from wheat sales in SRL «AgroVerde» for 2020–2024**

Year	Total profit received, thousand MDL	Including per unit, MDL	
		1 quintal	1 ha
2020	3600	99,3	3158
2021	3340	99,4	2904
2022	2700	89,6	2278
2023	2500	100,8	2083
2024	1100	78,0	853

Source: compiled on the basis of Table 2.

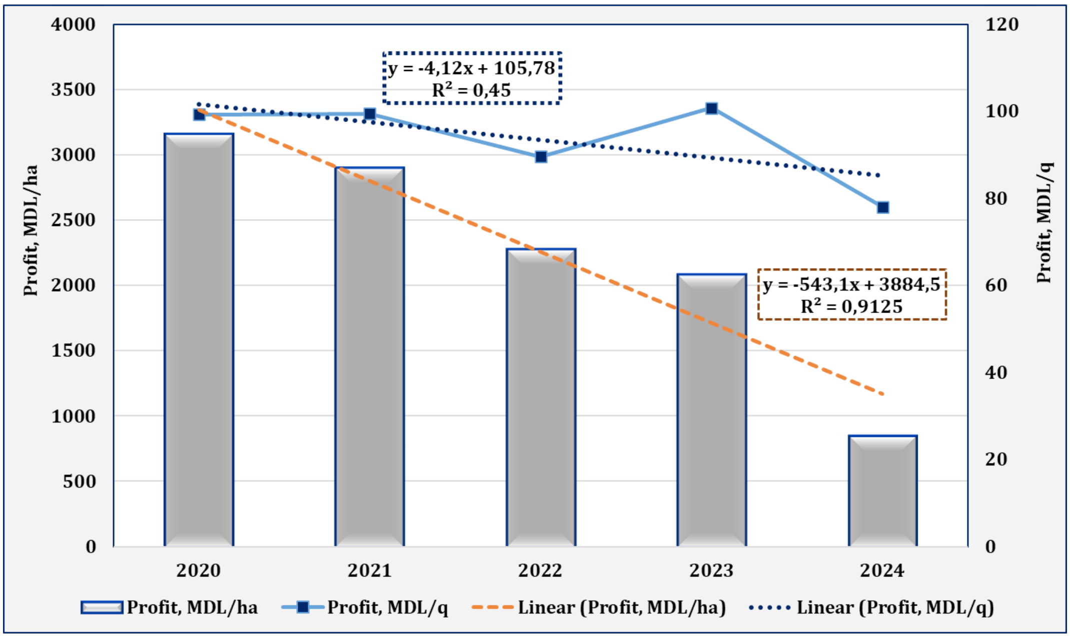

Fig. 3. **Profit indicators per unit of output and per hectare of sown area in SRL «AgroVerde» for 2020–2024**

Source: compiled on the basis of Table 4.

As for the specific indicators, the situation has its own particularities. Profit per hectare decreased especially sharply: from 3,158 MDL in 2020 to 853 MDL in 2024. This dynamic reflects the decline in the economic return of land resources, that is, the reduction in their productive efficiency. At the same time, profit per unit of output is characterized by a less stable trend ($y = -4.12x + 105.78$, $R^2 = 0.45$), which indicates a stronger dependence on natural and climatic conditions and the variability of yields. It is precisely the graphical display of the two curves within a single coordinate system that makes it possible to clearly compare their divergence and to show that the key factor in the reduction of efficiency is the decline in land return as the main factor of production, rather than the productivity of each individual unit of output.

Thus, the graph, unlike the table, makes it possible to see not only the final values but also to identify a hidden pattern: the structural reduction of the enterprise's profitability, manifested in the progressive decrease of profit per hectare, while profit per unit of output decreases less linearly and reflects to a greater extent climatic variability. For SRL «AgroVerde» this is a signal of the need to adjust its production strategy: without renewing technologies and improving the efficiency of land use, the enterprise will face further declines in total profit.

A comprehensive assessment of the enterprise's efficiency requires taking into account several interrelated indicators at once. Table 5 presents data on the dynamics of costs per hectare, production cost per unit of output, as well as profit calculated both per hectare of land and per unit of output. Such a comparison makes it possible not only to identify the level of economic performance but also to determine the factors that exert the greatest influence on the formation of the final financial result.

It should be emphasized that even with the high informativeness of tabular data, its graphical representation provides significantly greater analytical opportunities. The construction of three-axis graphs ensures a holistic perception of trends, making it possible to reflect the interrelation of four indicators simultaneously within a single coordinate system. This enables a clear tracing of how the growth or decline of costs and production cost is associated with the dynamics of profit per hectare and per unit of output.

It is in this regard that Figure 4 has been constructed, where the development of these indicators for 2020–2024 is presented. The graphical expression makes visible the patterns that remain less evident in tabular form, which is especially important for analyzing the sustainability of agricultural production and for developing managerial decisions.

Table 5 – **Dynamics of costs, production cost, and profit per unit of output and per hectare of sown area in SRL «AgroVerde» for 2020–2024**

Year	Costs per 1 ha, MDL	Production cost, MDL/q	Profit per 1 ha, MDL	Profit per 1 q, MDL
2020	5 439	171,0	3 158	99,3
2021	5 565	190,5	2 904	99,4
2022	5 317	260,5	2 278	89,6
2023	4 917	237,9	2 083	100,8
2024	3 954	361,7	853	78,0

Source: compiled on the basis of Tables 3 and 4.

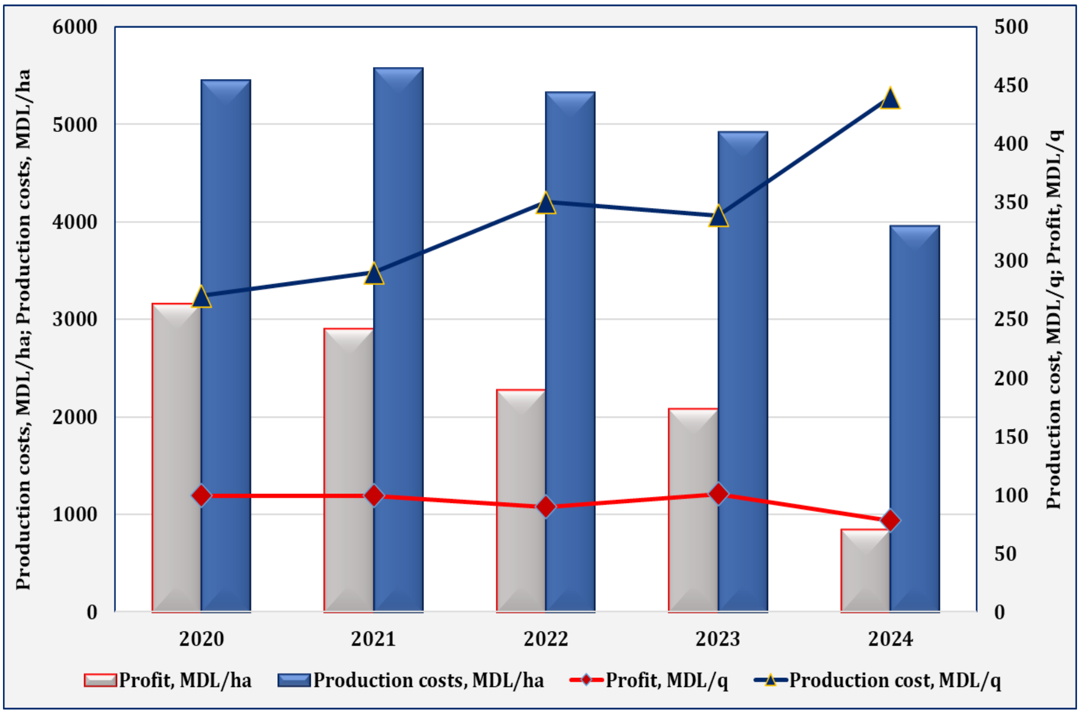

Fig. 4. **Dynamics of costs, production cost, and profit per unit of output and per hectare of sown area in SRL «AgroVerde» for 2020–2024**

Source: compiled on the basis of Table 5.

The consideration of data in graphical form makes it possible to go beyond the simple recording of absolute values and to reflect the internal interrelations between costs, production cost, and production performance. Unlike tabular presentation, the graph simultaneously combines four indicators that determine the economic sustainability of the enterprise: costs per hectare, production cost per unit of output, profit per hectare, and profit per quintal of wheat.

It is precisely their joint comparison within one graph that makes it possible to identify hidden disproportions. Thus, the high cost burden combined with the simultaneous growth of production cost clearly demonstrates the decline in efficiency, even despite the fact that in certain years it was possible to maintain profit per unit of output. The situation worsened in 2024, when, against the background of relatively lower costs, there was a sharp decline in profit, which indicates the instability of the production process and the enterprise's high dependence on natural and climatic conditions.

The significance of this graph lies in the fact that it allows for the evaluation of not just one aspect of efficiency but a comprehensive picture: how well costs and production cost correspond to the obtained profit, how results change per hectare and per unit of output, and which trends emerge when they are combined. Thus, the visualization of four key indicators provides the basis for a more precise analysis of economic activity and forms the foundation for managerial decisions aimed at reducing production cost and stabilizing enterprise revenues.

Discussion. It is substantiated that the use of three-axis graphs in the analysis of the efficiency of agricultural production turns dry statistics into a dynamic model of system interaction. The main value of the method is the ability to simultaneously observe three critical parameters without losing the context of their interdependence. It is summarized that the development of this methodology in scientific research and practical activities involves: the introduction of compositional analysis - when processing data on the structure of costs, soil composition or animal rations, CoDA methods (logarithmic transformations) should be used to avoid statistical evidence; the use of rectangular three-axis graphs - in economic reports, rectangular shapes should be preferred due to their higher accuracy of data reading; the integration of energy indicators - to assess the real sustainability of farms, it is necessary to analyze the balance between natural and purchased resources, using ternary development trajectories; the allocation of efficiency zones - use ternary plans for zoning territories by the level of eco-efficiency, which will allow developing point measures of state agricultural policy. It is emphasized that the risov graphs are the very tool that helps to find this balance in the complex multidimensional world of agricultural science.

The results of the study confirm that the use of three-axis charts in the analysis of wheat production and sales indicators provides a more comprehensive and visually clear representation of the interrelations between costs, yields, and the enterprise's final performance outcomes. Graphical visualization made it possible to identify hidden trends that are difficult to trace through tabular analysis alone: the decline in yield and the increase in production costs proved to be the determining factors behind the decrease in profit, despite the gradual rise in selling prices. This combination of analytical and graphical methods enables not only the recording of facts but also the interpretation of the causes of changes, thus contributing to more informed managerial decision-making. This represents the main value of the three-axis approach as a tool of modern statistical analysis.

Conclusions. It is substantiated that the methodology of three-axis graphs is based on the concept of barycentric coordinates, which are expedient to use for modeling systems with three components, where the sum of the particles is always equal to 100%, which limits the system to two degrees of freedom. It is emphasized that ternary diagrams are a world standard for classifying soil texture for the purpose of a well-founded cultivation strategy, make it possible to visualize the contribution of individual factors (number of spikelets, grain size) to the total grain yield and help to assess not the absolute content of N:P:K, but their mutual balance in tissues for precise adjustment of feeding.

It is established that this methodological approach is expedient to use for assessing the balance between renewable (R), non-renewable (N) and purchased (F) resources, which allows to establish the dependence of modern systems on technological investments. It is argued that the use of graphs in the current environment is combined with machine learning (Random Forest) and satellite monitoring for real-time yield forecasting.

The analysis conducted has shown that the use of three-axis graphs made it possible not only to identify the general tendencies of declining yield, gross harvest, and production profitability, but also to establish hidden interrelations between the dynamics of costs, production cost, and enterprise profit. The graphs demonstrated that the reduction of efficiency has a complex nature and is determined by a combination of factors – from natural and climatic conditions to the cost structure and the level of technological renewal.

Graphical methods acquire particular significance when compared with tabular data. While tables record absolute values, graphs make it possible to visually capture the entirety of indicators, trace their interrelations and dynamics, identify the degree of fulfillment of planned parameters, and evaluate the structure of changes. In this way, graphs become not only a visual form of data presentation but also an effective analytical tool.

The method of three-axis graphs is especially valuable for agro-industrial production, where key indicators are often expressed in different units of measurement. The possibility of combining them in a single coordinate system facilitates information perception, allows for a systemic evaluation of development trends, and enables a more accurate identification of cause-and-effect relationships. The simplicity of construction and interpretation makes this method accessible both to students mastering statistical analysis and to practicing specialists making managerial decisions.

Thus, it has been substantiated that graphical methods, and particularly three-axis graphs, are an essential complement to statistical tables, enhancing the analytical depth of research and increasing the reliability of conclusions.

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Методологічні основи застосування триосьових графіків в аналізі ефективності сільськогосподарського виробництва

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У статті розглянуто методологічні засади застосування триосьових графіків в аналізі ефективності сільськогосподарського виробництва. Обгрунтовано, що методологія триосьових графіків базується на концепції барицентричних координат, які доцільно використовувати для моделювання систем із трьома компонентами, де сума часток завжди дорівнює 100 %, що обмежує систему двома ступенями свободи. Наголошено, тернарні діаграми є світовим стандартом для класифікації текстури ґрунту з метою обґрунтованої стратегії обробітку, дають можливість візуалізувати внесок окремих факторів (кількість колосків, озерненість) у загальний збір зерна та допомагають оцінювати не абсолютний вміст N:P:K, а їхній взаємний баланс для прецизійного корегування підживлення.

Доведено, що цей методологічний підхід доцільно використовувати для оцінювання балансу між відновлюваними (R), невідновлюваними (N) та купленими (F) ресурсами, що дозволяє встановити залежність сучасних систем від технологічних інвестицій. Аргументовано, що використання графіків у нинішніх умовах поєднується з машинним навчанням (Random Forest) та супутниковим моніторингом для прогнозування врожайності в реальному часі.

Встановлено необхідність застосування триосьових графіків як сучасного інструменту статистичного аналізу в аграрній економіці. З'ясовано, що табличні дані є основою для розрахунку виробничих та фінансових показників, але їх аналітична цінність обмежена труднощами візуального порівняння між різнорідними рядами даних. Систематизовано статистичні дані НДЛ «Агро-Верде» за період 2020–2024 років, включно з валовим збором, зібраною площею, собівартістю продукції, виручкою від реалізації та прибутком. Проведено розрахунки рентабельності реалізованої продукції, окупності витрат, собівартості продукції на один гектар та центнер пшениці.

Оцінено потенціал триосьової графічної візуалізації, яка дозволяє інтегровано представляти багаторівневі показники (витрати на гектар, собівартість продукції на одиницю продукції, прибуток на гектар та прибуток на центнер) в єдиній системі координат. Доведено, що застосування триосьових графіків дозволяє виявити різноспрямовані тенденції — такі як зростання собівартості продукції на одиницю продукції, що супроводжується одночасним зниженням прибутку на гектар. Обґрунтовано, що використання рівнянь тренду в графічній інтерпретації підвищує достовірність аналізу та забезпечує кількісне підтвердження динаміки досліджуваних показників.

Наголошено, що триосьові графіки слід розглядати не лише як засіб статистичної візуалізації даних, а й як метод прогнозування, що сприяє виявленню закономірностей розвитку сільськогосподарського виробництва та формулюванню науково обґрунтованих управлінських рішень.

Ключові слова: триосьовий графік, собівартість продукції, рентабельність, прибуток, витрати, аграрна економіка, статистичний аналіз.

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