



Fertilizer Application as a Factor of Economic Security in Achieving Effective Land Use in the Conditions of Environmental Development

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Abstract: The purpose of this study is to evaluate the process of agricultural development by determining the effectiveness of fertilizer application for various crops within the framework of fostering an ecological environment that underpins economic security. The following general scientific and special research methods were used in the research: monographic, logical-theoretical, statistical, economic-mathematical, system analysis, computational-analytical, abstract-logical, and generalization. The effectiveness of fertilization for sowing crops under conditions of restriction of agricultural land has been assessed. The essence of the concept of ecological environment, which is formed as a result of agricultural activity through the use of mineral and organic fertilizers to ensure effective land cultivation, has been proved. Correlation-regression analysis is used to identify the relationship between the volumes of application of mineral and organic fertilizers for crops of cereals and leguminous crops (without corn), corn, industrial crops, and fodder crops, which made it possible to identify a significant dependence in most cases. Still, a variety of types of regression equations are observed. Therefore, it is proposed to use a non-parametric method of estimation, which is the method of analysis of the operating environment. For the first time, the expediency of assessing the ecological environment by constructing a non-parametric boundary model based on two relative indicators, the share of the fertilized area and the volume of fertilizers per unit of sown area, has been substantiated. It has been determined that the first indicator – the share of the fertilized area – determines the degree of fertilizer use and its distribution in the agricultural landscape, taking into account the efficiency of their use; the second indicator – the volume of fertilizers per unit of sown area – is aimed at determination of the intensity of fertilization following the size of the land area, which affects the preservation of soil fertility and environmental sustainability. It has been determined that the most effective application of mineral fertilizers for crops of fodder crops, organic fertilizers for crops of cereals and leguminous crops (without corn), and organic fertilizers for crops of fodder crops turned out to be the most effective. This, firstly, indicates a significant impact of mineral nutrition on the yield and quality of fodder crops, contributing to high productivity indicators in conditions of providing the necessary nutrients; secondly, it points out the importance of ecologically balanced use of organic resources to maintain the productivity of grain crops; thirdly, it indicates the high efficiency of organic resources in providing the necessary components for the growth of fodder crops and improving their quality. Crucially, the study integrates the concept of economic security by demonstrating that efficient fertilizer application is not solely an agronomic need but also a critical factor for economic sustainability. The share of the fertilized area serves as an indicator for the degree of efficient resource distribution. In contrast, fertilization intensity (fertilizer volume per unit sown area) directly influences soil fertility preservation and long-term environmental stability. Thus, integrating these parameters provides a quantitative basis for aligning agricultural practices with economic security and sustainable development goals. The results obtained can be used in the formulation of recommendations for optimizing the dosage and distribution of mineral and organic fertilizers depending on the specifics of the crops grown, improving agro-landscape management systems to ensure high productivity and preserving soil fertility, planning measures aimed at maintaining the ecological balance, which includes the rational use of agrochemical resources; developing state policies and programs focused on ecological planning and sustainable agricultural production. Furthermore, by integrating both parametric and non-parametric analytical methods, the study provides a robust framework that links optimal fertilizer application to enhanced economic security—demonstrating that efficient resource management and ecological balance are crucial for sustaining the long-term economic stability of agricultural enterprises. The results reveal optimal fertilizer application practices and offer a basis for devising recommendations to optimize fertilizer dosage and distribution, enhance agro-landscape management, and formulate state policies and programs focused on ecological planning and sustainable agricultural production. Overall,



the findings underscore that improving the ecological environment is indispensable for achieving economic security in agriculture, thereby laying the groundwork for more effective and environmentally sustainable soil and fertilizer management strategies.

Keywords: ecological environment, land use, sown area, mineral fertilizers, organic fertilizers, economic security, fertilizer use efficiency, method of analysis of the operating environment

1. Introduction

Fertilizer application to crops can be viewed from two perspectives. On the one hand, it is a means to improve yield and ensure land productivity to ensure food security and obtain economic results (Kaletnik et al. 2020, Palamarchuk et al. 2021, Baik et al. 2021). On the other hand, fertilizer application is viewed from the perspective of intervention in the ecosystem, which requires compliance with certain environmental standards and measures to restore land resources (Mazur et al. 2020, Pansyryeva et al. 2020, Atamanyuk et al. 2023).

Currently, the issue of agricultural development is considered in the context of ecology, based on preventing harm to the environment and residents of nearby territories. In this situation, much depends on citizens' economic activity, needs, and ability to use natural resources (Kaletnik & Lutkovska 2021). In fact, human economic activity, transformed into a motivation to achieve efficiency, is aimed at using natural resources and forming its ecological environment.

The article does not consider aspects of environmental and environmental factors in the context of compliance with certain standards. Still, it analyzes the ecological environment as a result of agricultural activities, taking into account the sown and fertilized areas and the applied mineral and organic fertilizers.

The analysis carried out in this study will provide an opportunity to determine the optimal value contributions necessary to enhance economic security, which is the basis for rational land use in the system of ecological environment development (Denysiuk et al. 2022). Based on data on the use of mineral and organic fertilizers, in our opinion, it can be established that the interaction of these contributions creates special zones for sowing crops, which in turn contributes to the optimization of the agronomic process and the minimization of environmental risks. In this context, the mutual exchange of resources is a key evaluative factor of economic security, ensuring a balance between high productivity and maintaining environmental stability.

The issues of effective fertilizer application and the development of agricultural enterprises, in general, are in the field of view of many well-known scientists and specialists in the field of practical implementation of production projects. Thus, the study (Berezyuk et al. 2021, Halko et al. 2023) determines that research on applying mineral and organic fertilizers is urgent in the context of achieving a neutral level of land degradation and ensuring sustainable land use in general. Smart fertilizer applications can help reduce the impact of agricultural activities on water resources, particularly on aquatic and soil ecosystems (Honcharuk et al. 2023a, Nitsenko & Havrysh 2016). This may include the use of modern technologies that allow for precise control and optimization of fertilizer use, reducing soil oversaturation and the risk of chemical contamination of water sources. In some studies (Palamarenko et al. 2023, Honcharuk et al. 2024, Shovkun-Zablotska et al. 2024), we can see that organic agriculture, which directly depends on the technology of fertilizer application, is one of the main directions of the formation and development of the «green» economy. Thus, applying mineral and organic fertilizers is important in ensuring land use efficiency and increasing fertility (Didur et al. 2019, Didur et al. 2021, Mirzoieva et al. 2024). Research by Okhota et al. (2024) examines the issue of environmental development along with fertilizer use, which is vital for maintaining biodiversity and ecological balance. They also highlight the need for supportive policies and institutional frameworks to encourage responsible fertilizer use.

The purpose of the study is to evaluate the process of agricultural development by determining the effectiveness of fertilizer application for crops in the context of the formation of the ecological environment.

2. Methods

General scientific and special research methods were used when studying the issue of achieving effective land use in the context of environmental development by focusing on fertilizer application as a factor of economic security. Among them: 1) monographic – for a comprehensive analysis of individual problem aspects, the study of historical data and accumulated experience in the field of land use and agrarian economics; 2) logical-theoretical – for formulating conceptual provisions, building logical connections between concepts and substantiating hypotheses regarding the impact of fertilizer application on the economic security of the farm; 3) statistical – when processing and analyzing quantitative data, allowing to identify trends, correlations and patterns in the relationships between agricultural processes; 4) economic and mathematical – for building models, forecasting economic indicators and optimizing costs, which is necessary for calculating the efficiency of fertilizer use; 4) visualization – for visual demonstration of research results; 5) system analysis – when considering the problem as an integrated system, assessing the relationships between individual components of

the agroecological system and forming methodological principles for achieving effective land use in the context of environmental development; 6) computational and analytical – when constructing a non-parametric boundary model using the method of analyzing the operating environment in order to model development scenarios of the studied integrated system and analyze the dynamics of business processes; 7) abstract-logical method – for generalizing theoretical propositions, formulating generalized conclusions, and constructing new conceptual models based on the analysis of the obtained data; 8) generalizing method – when consolidating research results, synthesizing the data obtained and forming an overall picture of the problem in order to develop effective recommendations for practical application.

The information base of the study was made up of materials from the State Statistics Service of Ukraine scientific developments of foreign and domestic scientists on the specified topic.

3. Results

In the context of agricultural development, the efficiency of land use and the application of fertilizers is considered in two aspects – environmental and economic. The ecological approach involves soil conservation, using environmentally friendly methods, and maintaining biodiversity. From an economic point of view, it is important to strive to increase yields, optimize cultivation systems, ensure economic stability, and use innovative technologies (Chikov et al. 2023a, Balanovska et al. 2021). Combining these aspects contributes to ensuring the economy's productivity and preserving the environment (Farionik et al. 2023, Zakharchuk et al. 2023, Ostapchuk et al. 2021).

We propose to conduct a study based on the analysis of the needs of agriculture in mineral and organic fertilizers. On the one hand, this will allow the ecological component to be characterized in the context of the natural development of crop production due to the need to improve the ecological environment. On the other hand, it will provide opportunities to analyze the ecological environment and the state and level of development, allowing management to make decisions.

The ecological environment in the study is the environment, the main features of which are (Chikov & Titov 2023):

- availability of a resource that requires constant care and will ensure the effectiveness of agricultural activities. Such a resource is land as a factor in the environmental, economic, and social development of society;
- the presence of common and distinctive properties between crops in the context of fertilizer application;
- availability of sufficient mineral and organic fertilizers to improve the quality of the land and increase yields.

Organic fertilizers are a key component of sustainable agricultural production aimed at preserving and improving soil quality. This approach contributes to balanced and efficient plant nutrition, which is essential for achieving high yields and conserving natural resources. The use of organic fertilizers has a significant impact on soil fertility and plant growth. The main positive effects of this process include (Logosha & Harbar 2023): 1) an increase in the amount of humus substances in easily soluble form (substances that are quickly decomposed by microbes and become available to plants); 2) an increase in the amount of water-soluble organic substances; 3) impact on soil acidity (the use of organic fertilizers reduces soil acidity); 4) improving the structure and permeability of the soil, etc. Thus, judicious use of organic fertilizers is necessary for sustainable agriculture and food security (Kala et al. 2020, Tokarchuk et al. 2021). Taking into account these aspects of the development of agricultural enterprises and the efficient use of land resources, we propose to assess the impact of land resources on economic processes, focusing on the volume of agricultural land areas throughout the country, the amount of agricultural land in agricultural enterprises, as well as the area of crops that have been treated with mineral and organic fertilizers.

The development of agricultural enterprises is carried out in the context of the availability of land resources, which is the main factor in production relations. During the study period, the area of agricultural land in agricultural enterprises has constantly decreased from 34.1 million hectares in 2000 to 20.6 million hectares in 2022 (1.65 times) (State Statistics Service of Ukraine 2022). Table 1 shows the amount of agricultural land in the country, in agricultural enterprises, and the area of crops treated with mineral and organic fertilizers.

Table 1. The amount of agricultural land in the country, in agricultural enterprises, as well as the area of crops treated with mineral and organic fertilizers

Year	Area of agricultural land in the country, mln ha	Area of agricultural land in agricultural enterprises, mln ha	Area under cereals and legumes (excluding corn), mln ha	Corn sown area, mln ha	Sown area of industrial crops, mln ha	The area under fodder crops, mln ha
2000	41.8	34.1	10.6	0.9	3.6	6.3
2001	41.8	29.9	11.7	0.7	3.0	5.4
2002	41.8	28.4	10.3	0.6	2.9	4.7
2003	41.8	26.9	7.6	1.4	4.2	3.9
2004	41.8	24.8	9.5	1.6	3.7	3.0
2005	41.8	23.5	9.8	1.0	3.9	2.5
2006	41.7	22.1	9.4	1.1	4.7	2.1
2007	41.7	21.2	9.6	1.5	4.7	1.8
2008	41.7	21.0	9.7	1.8	5.4	1.5
2009	41.6	21.0	10.1	1.5	5.3	1.4
2010	41.6	20.9	8.7	2.0	6.0	1.3
2011	41.6	20.6	8.5	2.8	6.1	1.2
2012	41.6	20.5	7.5	3.5	6.4	1.2
2013	41.5	20.7	7.7	3.8	6.4	1.0
2014	41.5	20.4	6.6	3.6	6.9	0.9
2015	41.5	20.5	7.2	3.0	6.8	0.7
2016	41.5	20.7	6.9	3.1	7.2	0.7
2017	41.5	20.7	6.8	3.3	7.6	0.6
2018	41.5	20.7	6.6	3.3	7.3	0.5
2019	41.5	20.7	6.6	3.7	7.1	0.5
2020	41.5	20.6	6.2	3.9	7.1	0.5
2021	41.5	20.6	6.6	4.0	7.1	0.4
2022	41.5	20.6	4.7	3.0	6.4	0.3

Source: completed with using (State Statistics Service of Ukraine 2022)

Economic security in research is the achievement of economic efficiency through the optimization of fertilizer costs and an increase in the volume of sown areas, which allows for ensuring the development of the ecological environment (Perevozova et al. 2021, Honcharuk et al. 2023b, Koliadenko 2023). This involves the rational use of resources, the introduction of innovative agricultural technologies, and a reduction in the cost of production, which contributes to increasing competitiveness in the market (Chikov et al. 2022, Chikov et al. 2023b).

As the above data show, analyzing the use of mineral fertilizers for corn crops, in three cases the presence of a linear equation with a high binding density is observed. This means that the volume of application of mineral fertilizers for corn crops directly affects the application of mineral fertilizers for crops of technical, organic fertilizers for corn crops, and mineral fertilizers for crops of cereals and legumes (without corn). Thus, we can talk about the level of sufficiency (insufficiency) of fertilizers following the trend for 2000-2022, which allows us to make effective decisions on planning economic and environmental measures, considering the existing conditions of agriculture.

We will use correlation regression analysis, which will allow us to assess the use of mineral fertilizers for corn crops in the context of the need to apply mineral and organic fertilizers for crops of other crops by determining the regression equation and the density of ovaries (Table 2). It is worth noting that although correlation-regression analysis allows us to draw indirect conclusions about economic security, it allows us to identify fundamental patterns in using agrochemicals, which reflect the rationality of resource allocation and the organization of production processes. These patterns serve as guidelines for further optimization of technological measures and creating a basis for forming sustainable production systems, which, in turn, contribute to the preservation of the resource base and ensure the overall stability of management.

Table 2. Evaluation of the use of mineral fertilizers for corn crops in the context of the need for the application of mineral and organic fertilizers for crops of other crops

Fertilization	Regression equation. Connection density	Characteristic
Dependence of the volume of application of mineral fertilizers for corn crops on the volume of		
application of mineral fertilizers for crops of cereals and legumes (without corn)	$y = 0.8578x - 171.27$ $R^2 = 0.8997$	The connection density is high. If there is no application of mineral fertilizers for grain and leguminous crops (without corn), 171.27 thousand tons of mineral fertilizers will be lost for corn crops
Influence of the volume of application of mineral fertilizers for corn crops on the volume of		
application of mineral fertilizers for industrial crops	$y = 1.1987x + 78.156$ $R^2 = 0.9451$	The connection density is high. In the case of no application of mineral fertilizers for corn crops, the volume of application of mineral fertilizers for technical crops will be 78.156 thousand tons
application of mineral fertilizers for crops of fodder crops	$y = -0.0028x + 30.305$ $R^2 = 0.0155$	The connection density is low. Application of mineral fertilizers under corn crops does not affect application of mineral fertilizers under crops of fodder crops
application of organic fertilizers for crops of cereals and legumes (without corn)	$y = 25340x^{-0.392}$ $R^2 = 0.9586$	The connection density is high. The increase in the number of mineral fertilizers applied to corn crops significantly reduces the need to apply organic fertilizers to cereal and leguminous crops (without corn)
application of organic fertilizers for corn crops	$y = 3.9935x + 737.46$ $R^2 = 0.9214$	The connection density is high. In case of no application of mineral fertilizers for corn crops, the volume of organic fertilizers for corn crops will be 737.46 thousand tons
application of organic fertilizers for industrial crops	$y = -1818\ln(x) + 13599$ $R^2 = 0.7223$	The connection density is high. In the case of application of 1 thousand tons of mineral fertilizers for corn crops, the required number of organic fertilizers for crops of industrial crops will be 13,599 thousand tons
application of organic fertilizers for crops of fodder crops	$y = 14487x^{-0.335}$ $R^2 = 0.9138$	The connection density is high. An increase in the number of mineral fertilizers applied to corn crops significantly reduces the need to apply organic fertilizers to fodder crops

Source: developed by the authors

As the above data show, analyzing the use of mineral fertilizers for corn crops, in three cases the presence of a linear equation with a high binding density is observed. This means that the volume of application of mineral fertilizers for corn crops directly affects the application of mineral fertilizers for crops of technical, organic fertilizers for corn crops, and mineral fertilizers for crops of cereals and legumes (without corn). Thus, we can talk about the level of sufficiency (insufficiency) of fertilizers following the trend for 2000-2022, which allows us to make effective decisions on planning economic and environmental measures, considering the existing conditions of agriculture.

In one of the cases, there is a low level of bond density, which indicates no relationship between the volume of mineral fertilizers applied for corn crops and the volume of mineral fertilizers applied for fodder crops. Thus, using fertilizers should be planned based on the characteristics of fodder crops as a separate component in the ecological environment.

Two power functions indicate that in case of an increase in the volume of mineral fertilizers applied to corn crops, the volume of organic fertilizer application for crops of cereals and legumes (excluding corn) and the application of organic fertilizers for crops of fodder crops will decrease, respectively. Thus, the dependence is

inverse, and therefore, the magnitude of the power plays a decisive role – it determines the rate of increase or decrease in indicators. In our case, the exponent is less than one.

One function is logarithmic – a negative value indicates the need to apply more than 1,775 thousand tons of mineral fertilizers for corn crops to achieve zero demand for organic fertilizers for fodder crops.

Estimation of the use of mineral fertilizers for industrial crops in the context of the need to apply mineral and organic fertilizers for crops of other crops is carried out based on two linear equations at high bond density, one linear equation at low bond density, two power equations and one polynomial equation (Table 3).

Table 3. Evaluation of the use of mineral fertilizers for sowing technical crops in the context of the need to apply mineral and organic fertilizers for sowing other agricultural crops

Fertilization	Regression equation. Connection density	Characteristic
Dependence of the volume of application of mineral fertilizers for crops of technical crops on the volume of		
application of mineral fertilizers for crops of cereals and legumes (without corn)	$y = 1.0812x - 155.01$ $R^2 = 0.9401$	The connection density is high. To ensure the expediency of applying mineral fertilizers to crops of technical crops, it is necessary to apply more than 143.37 thousand tons of mineral fertilizers to crops of grain and leguminous crops (without corn)
The influence of the volume of application of mineral fertilizers under sowing of technical crops on the volume of		
application of mineral fertilizers for crops of fodder crops	$y = -0.0038x + 31.102$ $R^2 = 0.044$	The connection density is low. The introduction of mineral fertilizers under the crops of technical crops does not affect the introduction of mineral fertilizers under the crops of fodder crops
application of organic fertilizers for crops of cereals and legumes (without corn)	$y = 87376x^{-0.566}$ $R^2 = 0.9389$	The connection density is high. The increase in the number of mineral fertilizers applied to crops of industrial crops significantly reduces the need for organic fertilizers to be applied to crops of grain and leguminous crops (without corn)
application of organic fertilizers for corn crops	$y = 3.1803x + 539.77$ $R^2 = 0.8884$	The connection density is high. Even if there is no application of mineral fertilizers for crops of technical crops, the volume of application of organic fertilizers for crops of corn will amount to 539.77 thousand tons
application of organic fertilizers for industrial crops	$y = 0.0289x^2 - 31.817x + 10527$ $R^2 = 0.7841$	The connection density is high. In case of no application of mineral fertilizers for crops of technical crops, the volume of application of organic fertilizers for crops of technical crops will be 10,527 thousand tons
application of organic fertilizers for crops of fodder crops	$y = 41808x^{-0.483}$ $R^2 = 0.8977$	The connection density is high. The increase in the number of mineral fertilizers applied to crops of technical crops significantly reduces the need for organic fertilizers to be applied to crops of fodder crops

Source: Developed by the authors

If mineral fertilizers are not applied for crops of cereals and legumes (without corn), then the lack of mineral fertilizers for crops of technical crops will be 155.01 thousand tons. Applying each additional ton of mineral fertilizers for industrial crops will additionally increase the volume of organic fertilizers for industrial crops by 3.1803 times.

The volume of application of mineral fertilizers for industrial crops does not affect the volume of applied mineral fertilizers for crops of fodder crops, since the bond density is weak. Therefore, the value of mineral fertilizers for crops of fodder crops is proposed to be considered in this case from the point of view of exclusively the needs of the ecological environment.

Power equations show the influence of the volume of application of mineral fertilizers for crops of industrial crops on the volume of application of organic fertilizers for crops of cereals and legumes (without corn) and the volume of application of organic fertilizers for crops of fodder crops in the form of an inverse dependence. This indicates an indirect link between the fertilization processes for different plants.

The application of mineral fertilizers for industrial crops affects the application of organic fertilizers for industrial crops based on two aspects: firstly, as mentioned above, the absence of mineral fertilizers for industrial crops ensures the application of organic fertilizers for industrial crops in 10,527 thousand tons; Secondly, to ensure the application of more organic fertilizers for industrial crops than 10,527 thousand tons, it is necessary to apply more than 1,100.93 thousand tons of mineral fertilizers for industrial crops.

The peculiarities of assessing the use of mineral fertilizers for fodder crops in the context of the need for applying mineral and organic fertilizers for crops of other crops are given in Table 4.

Table 4. Assessment of the use of mineral fertilizers for crops of forage crops in the context of the need to apply mineral and organic fertilizers for crops of other agricultural crops

Fertilization	Regression equation. Connection density	Characteristic
Dependence of the volume of application of mineral fertilizers for crops of fodder crops on the volume of		
application of mineral fertilizers for crops of cereals and legumes (without corn)	$y = -0.0033x + 31.241$ $R^2 = 0.0259$	The connection density is low. The introduction of mineral fertilizers under crops of grain crops and legumes (without corn) does not affect the introduction of mineral fertilizers under crops of fodder crops
The influence of the volume of application of mineral fertilizers under crops of fodder crops on the volume of		
application of organic fertilizers for crops of cereals and legumes (without corn)	$y = 179.2x - 1537.1$ $R^2 = 0.181$	The connection density is low. The introduction of mineral fertilizers under crops of fodder crops does not affect the introduction of organic fertilizers under crops of grain and leguminous crops (without corn)
application of organic fertilizers for corn crops	$y = -51.044x + 3364.4$ $R^2 = 0.0757$	The connection density is low. The introduction of mineral fertilizers under crops of forage crops does not affect the introduction of organic fertilizers under crops of corn
application of organic fertilizers for industrial crops	$y = 268.35x - 3709$ $R^2 = 0.2575$	The connection density is low. The introduction of mineral fertilizers under crops of fodder crops does not affect the introduction of organic fertilizers under crops of technical crops
application of organic fertilizers for crops of fodder crops	$y = 144.54x - 1444.9$ $R^2 = 0.2374$	The connection density is low. Applying mineral fertilizers to forage crops does not affect the application of organic fertilizers to forage crops

Source: developed by the authors

Analyzing the regression equations and the density of the relationship between the application of mineral fertilizers under the crops of fodder crops, which we have given above (Table 2 and Table 3), it is possible to assert their special role in developing the ecological environment. Since we are talking about the absence of a tight connection, there is no need to study possible impacts in the context of fertilizing crops of other crops. Table 3 confirmed these conclusions: the binding density ranges from 0.0259 to 0.2575.

Assessment of the use of organic fertilizers for crops of cereals and legumes (without corn) in the context of the needs for the application of mineral and organic fertilizers for crops of other crops shows that only in one case there is a linear relationship between the volume of organic fertilizers for crops of cereals and legumes (without corn) and the volume of application of organic fertilizers for crops of fodder crops (Table 5). In case of an increase in the volume of organic fertilizer application for grain and leguminous crops (excluding corn),

the volume of organic fertilizer application for fodder crops will increase by an additional 0.666 times from the volume of application.

Table 5. Evaluation of the use of organic fertilizers for crops of grain and leguminous crops (without corn) in the context of the need to apply mineral and organic fertilizers for crops of other agricultural crops

Fertilization	Regression equation. Connection density	Characteristic
Dependence of the volume of organic fertilizers applied to grain and leguminous crops (without corn) on the volume of		
application of mineral fertilizers for crops of cereals and legumes (without corn)	$y = 0.0147x^2 - 23.526x + 11269$ $R^2 = 0.8566$	The connection density is high. If there is no application of mineral fertilizers for grain and leguminous crops (without corn), the volume of organic fertilizers for grain and leguminous crops (without corn) will amount to 11,269 thousand tons
The influence of the volume of organic fertilizers applied to crops of grain and leguminous crops (without corn) on the volume of		
application of organic fertilizers for corn crops	$y = 20000000x^{-1.128}$ $R^2 = 0.8738$	The connection density is high. The increase in the number of organic fertilizers applied to grain and leguminous crops (without corn) significantly reduces the need to apply organic fertilizers to corn crops
application of organic fertilizers for industrial crops	$y = 0.0002x^2 - 0.8289x + 3727.4$ $R^2 = 0.915$	The connection density is high. If there is no application of organic fertilizers for crops of grain and leguminous crops (without corn), then the volume of application of organic fertilizers for crops of technical crops will be 3,727.4 thousand tons
application of organic fertilizers for crops of fodder crops	$y = 0.666x + 322.74$ $R^2 = 0.8941$	The connection density is high. If there is no application of organic fertilizers for crops of grain and leguminous crops (without corn), then the volume of application of organic fertilizers for crops of fodder crops will be 322.74 thousand tons

Source: developed by the authors

The power function indicates the possibility of reducing the volume of organic fertilizer application for corn crops due to an increase in the volume of organic fertilizers for grain and leguminous crops (excluding corn). In the case of application of organic fertilizers for crops of cereals and legumes (without corn) in the amount of 1,000 tons, the need for application of organic fertilizers for corn crops will be 20 billion tons.

Suppose there is no application of mineral fertilizers for cereals and legumes crops (without corn). In that case, the volume of application of organic fertilizers for crops of cereals and legumes (without corn) will be 11,269 thousand tons. Thus, based on the above equation, the application of mineral fertilizers for crops of cereals and legumes (excluding corn) should be carried out in the amount of more than 1,600 thousand tons.

The influence of the volume of application of organic fertilizers for crops of cereals and legumes (excluding corn) on the volume of application of organic fertilizers for crops of industrial crops is characterized by two limits: firstly, the application of organic fertilizers for crops of industrial crops in the amount of 3,727.4 thousand tons in the absence of application of organic fertilizers for crops of cereals and legumes (without corn); secondly, the application of organic fertilizers for crops of cereals and legumes (excluding corn) in the amount of more than 4,144.5 thousand tons to maximize the volume of application of organic fertilizers for crops of industrial crops.

Estimation of the use of organic fertilizers for corn crops in the context of the need to apply mineral and organic fertilizers for crops of other crops is given in Table 6.

Table 6. Assessment of the use of organic fertilizers for corn crops in the context of the need to apply mineral and organic fertilizers for other crops

Fertilization	Regression equation. Connection density	Characteristic
Dependence of the volume of application of organic fertilizers under corn crops on the volume of		
application of mineral fertilizers for crops of cereals and legumes (without corn)	$y = -0.0018x^2 + 5.4032x - 389.82$ $R^2 = 0.8203$	The connection density is high. If there is no application of mineral fertilizers for grain and leguminous crops (without corn), the lack of fertilizers for corn crops will amount to 389.82 thousand tons
The influence of the volume of application of organic fertilizers under corn crops on the volume of		
application of organic fertilizers for industrial crops	$y = 7E - 13x^5 - 7E - 09x^4 + 3E - 05x^3 - 0.0489x^2 + 29.455x + 2801$ $R^2 = 0.7022$	The connection density is high. If there is no application of organic fertilizers for corn crops, the number of organic fertilizers applied for technical crops will be 2,801 thousand tons
application of organic fertilizers for crops of fodder crops	$y = 268107x^{-0.629}$ $R^2 = 0.7543$	The connection density is high. The increase in the number of organic fertilizers applied to corn crops significantly reduces the need to apply organic fertilizers to fodder crops

Source: developed by the authors

As the data of the table show, there is not a single variant of the formation of a linear function, and the last two cases are characterized by coefficients of determination, which are achieved through the search for sufficiently complex variants of substantiation of the given equations. Thus, it can be concluded that the application of organic fertilizers for corn crops affects the ecological environment in the context of certain conditions for the compatibility of fertilizer use with respect to other crops.

Estimating the use of organic fertilizers for industrial crops in the context of the need to apply mineral and organic fertilizers for crops of other crops is based on the properties of two equations (Table 7). The dependence of the volume of application of organic fertilizers for industrial crops on the volume of mineral fertilizers for crops of cereals and legumes (excluding corn) is characterized by the limits of application of mineral fertilizers for crops of cereals and legumes (excluding corn): more than 1,359 thousand tons to maximize the volume of application of organic fertilizers for crops of industrial crops and 14,943 thousand tons as the optimal value of the volume of application of organic fertilizers for crops of industrial crops for the existing environment.

Table 7. Evaluation of the use of organic fertilizers for crops of technical crops in the context of the need to apply mineral and organic fertilizers for crops of other agricultural crops

Fertilization	Regression equation. Connection density	Characteristic
Dependence of the volume of application of organic fertilizers under crops of industrial crops on the volume of		
application of mineral fertilizers for crops of cereals and legumes (without corn)	$y = 0.0279x^2 - 37.917x + 14943$ $R^2 = 0.7935$	The connection density is high. The lack of application of mineral fertilizers for crops of grain and leguminous crops (without corn) ensures the amount of application of organic fertilizers for crops of industrial crops by 14,943 thousand tons
The influence of the volume of application of organic fertilizers under crops of industrial crops on the volume of		
application of organic fertilizers for crops of fodder crops	$y = 0.5145x + 654.53$ $R^2 = 0.8412$	The connection density is high. The lack of application of organic fertilizers for crops of technical crops ensures the amount of application of organic fertilizers for crops of fodder crops by 654.53 thousand tons

Source: developed by the authors

Thus, in the first case, the linear equation shows a tendency to increase the volume of organic fertilizers application for industrial crops with an increase in the volume of mineral fertilizers for grain and leguminous crops (excluding corn), and in the second – a tendency to increase the volume of organic fertilizers application for industrial crops with an increase in the volume of organic fertilizers for fodder crops.

Assessment of the use of organic fertilizers for fodder crops in the context of the need for applying mineral and organic fertilizers for crops of other crops allows us to assess the dependence of the volume of organic fertilizers applied for crops of fodder crops on the volume of application of mineral fertilizers for crops of cereals and legumes (without corn) (Table 8).

Table 8. Assessment of the use of organic fertilizers for forage crops in the context of the need to apply mineral and organic fertilizers for other crops

Fertilization	Regression equation. Connection density	Characteristic
Dependence of the volume of application of organic fertilizers under the crops of forage crops on the volume of		
application of mineral fertilizers for crops of cereals and legumes (without corn)	$y = 235843x^{-0.734}$ $R^2 = 0.8051$	The connection density is high. The increase in the number of mineral fertilizers applied to grain and leguminous crops (without corn) significantly reduces the need to apply organic fertilizers to fodder crops

Source: developed by the authors

The power function allows us to conclude that when applying mineral fertilizers for crops of cereals and legumes (excluding corn) in the amount of 1,000 thousand tons, the need for applying organic fertilizers for crops of fodder crops will be 235,843 thousand tons.

The carried-out study allows us to conclude that different variations of the dependence of the volume of application of mineral and organic fertilizers for the given crops are characterized by different types of regression equations. In addition to linear dependence, there are many cases of power functions, polynomial functions, and even a logarithmic function. There are cases of lack of correlation.

As a result, the above dependencies testify to the possibilities of the existence of the ecological environment within the limits characterized, on the one hand, by the possibilities to improve land resources and, on the other hand, by the need for agricultural crops. We believe it is expedient to carry out an analysis from the point of view of the entire environment by using a non-parametric relationship in all cases justified by correlation equations.

To do this, we will use the method of analysis of the operating environment (Farrell's method) (Sakhno et al. 2019, Sakhno et al. 2023), the essence of which is to build a limit for assessing the level of inefficiency of relatively effective economic entities. This method was initially used to analyze the activities of natural monopolies, which made it possible to calculate a fair tariff for consumers. Still, later, it began to be used in many spheres of economic relations, ranging from the activities of enterprises, institutions, banks, and corporations to the economics of industries and the national economy. An example of the use of the method of analysis of the operating environment is the works (Pryshliak et al. 2022, Sakhno et al. 2023), in which all aspects of its application are considered from the point of view of building strategic decisions in the system of management of production, investment, and financial processes.

The proposed methodology allows us to construct an "efficiency line" that reflects the variability of fertilizer application along two coordinates: the share of the area treated with fertilizers and the amount of fertilizer application per unit of sown area. The key element of our methodology is the integration of parametric approaches (based on correlation-regression analysis) with non-parametric methods of average functionality analysis. Parametric analysis allows us to assess economic security as the ability of the system to generate a stable parametric flow of resources. In contrast, non-parametric analysis helps to identify structural features of the functioning of the agricultural system without any pre-determined assumptions. Combining these approaches allows us to obtain a more comprehensive model that demonstrates how the consistency of the main indicators directly reflects the level of economic efficiency of agricultural production.

Thus, the proposed method allows to form a reliable model, which is the basis for assessing economic security by determining the efficiency line. It is worth noting that the preliminary results of applying this approach indicate a satisfactory stability of the model, which provides justification for further research to improve this approach.

In our case, we consider three factors – one effective, as the volume of sown area, two resource, as the fertilized area and the volume of fertilizers applied (Table 9).

Table 9. Provision of mineral and organic fertilizers for the sown area of agricultural land for 2022

№	Fertilization	Part of the fertilized area, %	Fertilizers applied per unit of sown area
1	Application of mineral fertilizers for crops of cereals and legumes (without corn)	89.7	128
2	Mineral fertilizers were applied for corn crops	91.7	157
3	Mineral fertilizers have been applied for industrial crops	86.0	114
4	Mineral fertilizers have been applied for fodder crops	59.7	55
5	Application of organic fertilizers for crops of cereals and legumes (without corn)	3.7	448
6	Organic fertilizers have been applied for corn crops	6.9	1067
7	Organic fertilizers have been applied for industrial crops	4.8	465
8	Organic fertilizers have been applied for crops of fodder crops	11.8	4250

Source: developed by the authors

Share of fertilized area = fertilized area (X1) / area of crops (Y). Fertilizers applied per unit of sown area = fertilizers applied (X2) / crop area (Y) (Fig. 1).

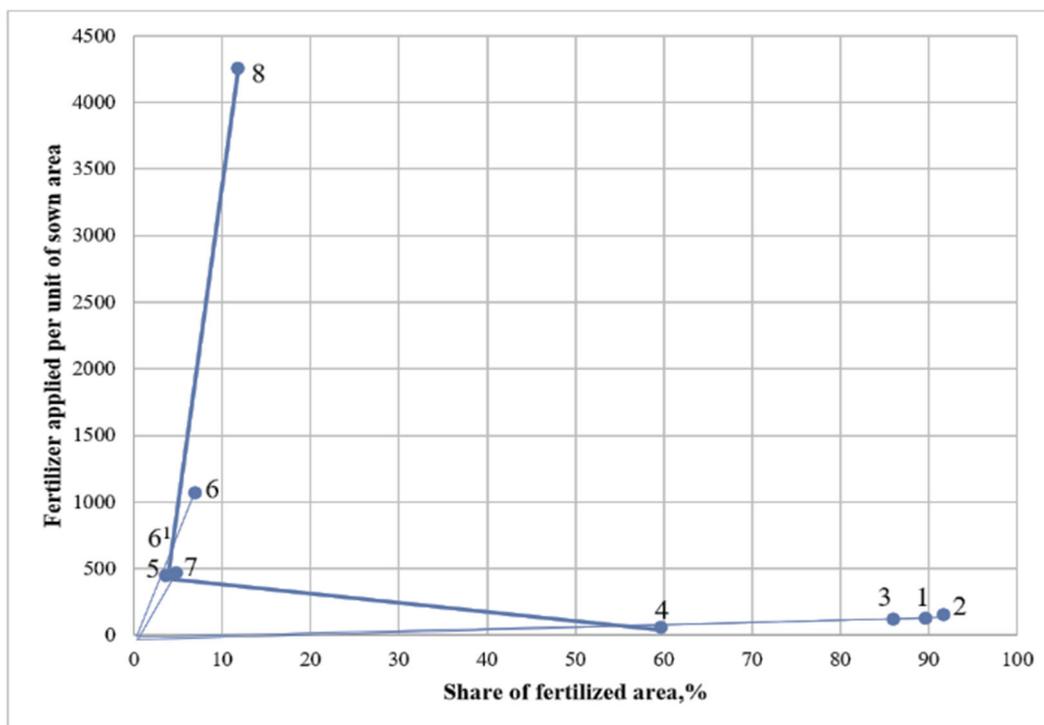


Fig. 1. Analysis of the operating environment by the level of fertilization of sown areas

Source: developed by the authors

Thus, the line of efficiency consists of three positions for the application of fertilizers: 8 (Applied organic fertilizers for crops of fodder crops) – 5 (Application of organic fertilizers for crops of cereals and legumes (without corn)) – 4 (Applied mineral fertilizers for crops of fodder crops). The efficiency coefficient for all cases of application of mineral and organic fertilizers is equal to one.

Ineffective are: 6 (Organic fertilizers applied for corn crops), 7 (Organic fertilizers applied for industrial crops), 3 (Mineral fertilizers applied for industrial crops), 1 (Mineral fertilizers applied for grain and leguminous crops (without corn)), 2 (Mineral fertilizers applied for corn crops).

Let's determine the level of efficiency of these crops based on the calculation of the efficiency factor using the example of position 6 (Organic fertilizers applied for corn crops): $E_f = \frac{0-6^1}{0-6}$, where 6^1 – the point of intersection between segments 5-8 and 0-6. Respectively, $0 - 6^1$ and $0 - 6$ are the length of the segments. The results of the calculations are shown in Table 10.

Table 10. Assessment of the level of effectiveness of mineral and organic fertilizers applied to crops

No	Fertilization	Efficiency Factor
1	Application of mineral fertilizers for crops of cereals and legumes (without corn)	0.60
2	Mineral fertilizers were applied for corn crops	0.58
3	Mineral fertilizers have been applied for industrial crops	0.62
6	Organic fertilizers have been applied for corn crops	0.60
7	Organic fertilizers have been applied for industrial crops	0.99

Source: Developed by the authors

Thus, a slight inefficiency is observed in applying organic fertilizers for industrial crops – 0.99 (1-0.99). In other cases, from 0.38 to 0.42.

Using the approaches of marginal efficiency assessment, it is possible to present the entire structure of the ecological environment to ensure the relationship between the volume of fertilizers and the sown area of agricultural crops (Fig. 2).

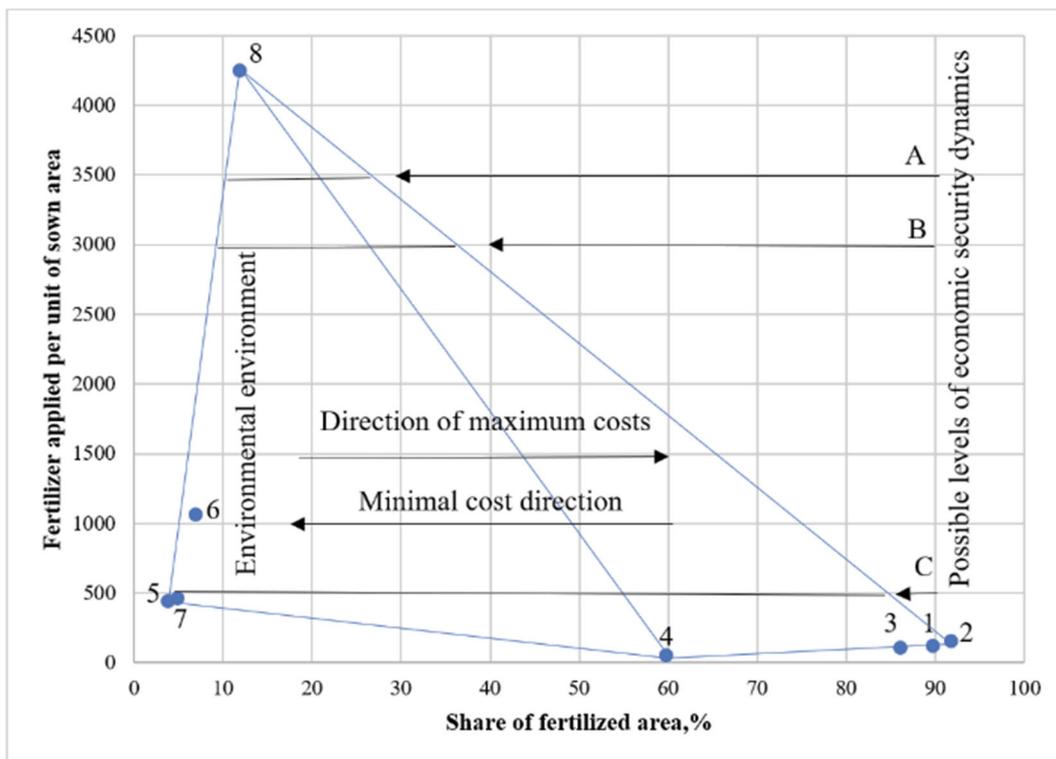


Fig. 2. Structure of the ecological environment in the context of ensuring economic security based on the relationship between the volume of fertilizers and the sown area of agricultural crops

Source: developed by the authors

Possible levels of economic security dynamics are the ability to manage fertilizer costs to increase the share of sown areas. Depending on the volume of fertilizers applied per unit of sown area, the ability to achieve the required proportion of the fertilized area is different (for example, A, B, C).

To clarify this relationship, we introduced an additional efficiency level, allowing us to separate the zones of optimal and ineffective use of fertilizers. In particular, the analysis allowed us to distinguish three variations of the system conditionally:

- Option A characterizes the situation of the most effective use of fertilizers when the ratio between the amount of fertilizer application and the sown area ensures minimal costs and optimal productivity;
- Option B reflects balanced dynamics, where costs are within acceptable indicators, which ensures the stability of economic security;
- Option C demonstrates the inefficient use of fertilizers when unjustified costs negatively affect the overall efficiency of the agricultural process.

Based on Fig. 2, the ecological environment is characterized by an area of 5-8-2-4. This environment was formed due to the cultivation of agricultural land and the application of the entire planned volume of mineral and organic fertilizers. With the help of the constructed efficiency line by the method of analysis of the operating environment, the ecological environment can be assessed based on features such as the efficiency of fertilizer application, questionable feasibility of fertilizer application, and losses and costs from fertilizer application.

The following can be distinguished evaluating the given structure:

I. Area of triangles:

1) triangle 4-5-8, characterized as the area of efficient use of mineral and organic fertilizers for the existing ecological environment by application (efficient environment):

- mineral fertilizers for fodder crops,
- organic fertilizers for crops of cereals and legumes (without corn),
- organic fertilizers for fodder crops.

2) triangle 8-4-2, characterized as the area of inefficient use of mineral and organic fertilizers for the existing ecological environment, and the feasibility of application is questionable (inefficient environment):

- mineral fertilizers for corn crops.

II. Boundary Lines:

3) line 8-4 is the boundary of the area of the effective medium, which is an inverse reflection of the efficiency line, which shows the ability to minimize losses from the application:

- organic fertilizers for corn crops,
- organic fertilizers for industrial crops.

4) line 8-2 is the boundary of the area of the inefficient environment, which is built by finding the position of the most questionable activity for the application of fertilizers for crops (mineral fertilizers for corn crops), which is characterized by maximum costs and rejection of the ecological environment, and also allows you to measure the doubtfulness of application:

- mineral fertilizers for crops of cereals and legumes (without corn),
- mineral fertilizers for industrial crops.

Thus, the structure analysis allows us to clearly identify optimal fertilizer application zones and areas where their use is questionable. Implementing the obtained results will contribute to the improvement of agrotechnical measures and ensure more effective resource management considering environmental requirements.

4. Discussion

The article raises the controversial issue of whether intensive application of mineral fertilizers allows for high yields, which positively impacts economic efficiency. In this context, the intensive use of mineral fertilizers has a dual impact, manifested in the economic efficiency of production and potential environmental risks (Kovalchuk et al. 2019, Guo et al. 2021, Petrychenko et al. 2022). On the one hand, mineral fertilizers contribute to the maximum saturation of soils with nutrients, which allows for high yields. Thanks to stable and high yields, farmers can compete more effectively in the market, which in turn has a positive impact on the overall economic efficiency of the agricultural sector. This is an important factor for ensuring food security and increasing farmers' incomes. On the other hand, excessive use of mineral fertilizers can lead to systemic soil degradation, decreased biological activity, pollution of water resources, and even impacts on human health (Bazaluk et al. 2022). In addition, intensive chemical treatment can affect microorganisms living in the soil, disrupting the ecosystem's natural balance and reducing its ability to self-renew. Thus, increasing productivity often hides long-term environmental and economic costs that can transform the agricultural sector from a source of profit into a heavy obligation to restore soil resources (Sirant et al. 2022, Fatkhutdinov et al. 2021). In this

context, it is worth noting the authors' research (Honcharuk & Tokarchuk 2023) that reducing the intensity of chemical fertilizer use and switching to more sustainable farming methods can ensure the preservation of soil cover and biodiversity. Although such methods may not provide an instant jump in productivity, they allow preserving the potential of soil fertility in the long term. Based on this, there is a need for additional research on the economic feasibility of implementing sustainable agricultural technologies, as well as assessing their impact on ecosystem services (Dankevych et al. 2021). Special attention should be paid to adapting modern agricultural practices to regional conditions, which will allow for achieving a balance between productivity and environmental stability (Honcharuk et al. 2024).

In addition to the above issues, it is worth paying attention to the prospects for using the Farel method to study problems that are not typical for this approach. Despite the success of testing the described methodology in practice, we are convinced that using alternative variations in the selection of factor (resulting) indicators and the potential expansion of the mathematical tools can improve the accuracy and flexibility of assessing such models. For example, conducting a sensitivity analysis of the obtained coefficients and scenario analysis taking into account variations in the sown area can help determine how much a decrease in the base volume of the sown area affects the final efficiency indicator. To eliminate the uncertainty that arises due to the possibility of artificially reducing the efficiency coefficient by reducing the sown area (and, accordingly, creating the illusion of achieving high efficiency), it is advisable to use adjustment coefficients or normalized indicators that take into account changes in the sown area, which will allow objectively reflecting the real impact of technological measures on the efficiency of fertilizer use.

Anyway, as we can see, the results are obtained based on the methodology based on Farrell's approaches, which allows to obtain a consistent assessment of the economic security of agricultural activity. The integration of additional options and expansion of the functional capabilities of the method will be considered in further studies, with the aim of a more comprehensive analysis of agricultural systems in dynamic environmental conditions.

5. Conclusions

In the process of writing the article, the main attention was paid to environmental issues not from the point of view of assessing the damage caused to the environment due to the use of natural resources, but the efficiency of the use of agricultural land in the context of applying mineral and organic fertilizers for crops. Therefore, correlation and regression analysis were initially used to assess the relationship between the volumes of mineral and organic fertilizers applied to crops of cereals and legumes (excluding corn), corn, industrial crops, and fodder crops.

It was found that for most cases, there is a tight connection in different models of equations – starting from linear (for most cases), including power, polynomial equations, and ending with logarithmic equations. At the same time, although the presence of an exclusively parametric factor allows us to assert the systematic nature of fertilizer application and the validity of the cultivation process in relation to each individual crop, this is not enough to assess the ecological environment.

Therefore, the method of analysis of the operating environment was used as a non-parametric method, which allows the use of marginal efficiency to identify the degree of sufficiency and/or doubtfulness of fertilizers on the area of agricultural land. When implementing the method of analysis of the operating environment, the structure of the ecological environment in the context of ensuring the relationship between the volume of fertilizers and the sown area of agricultural crops is proposed. It was found that for the available sown areas in the current situation, it is advisable to apply mineral fertilizers for crops of fodder crops, organic fertilizers for crops of cereals and legumes (without corn), and organic fertilizers for fodder crops.

Further studies should be concerned with optimizing the main factor based on which the calculations were made – the efficiency line. In particular, in the future, the main attention should be paid to the objectivity of the criteria for evaluating efficiency in terms of environmental friendliness in the context of standards and measures for environmental protection.

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