EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology, 2026, 27(1), 248–264
https://doi.org/10.12912/27197050/215004
ISSN 2719–7050, License CC-BY 4.0

Received: 2025.10.31
Accepted: 2025.12.11
Published: 2026.01.01

Ecological narratives in the new paradigm of land use and sustainable development of agricultural enterprises in Ukraine

Bohdan Khakhula[1*], Alla Karnaushenko[2], Andrii Shchebel[3], Tetiana Shepel[4], Anna Semysal[5]

[1] Department of Management, Bila Tserkva National Agrarian University, 8/1 Soborna Plaza, Bila Tserkva, Ukraine
[2] Department of Entrepreneurship, Accounting and Finance, Kherson State Agrarian and Economic University, 23 Streetenska Str., Kherson, Ukraine
[3] Department of Management and Social and Humanitarian Disciplines, Lviv Branch of the Private Higher Educational Institution "European University", 5 Kushevycha Str., Lviv, Ukraine
[4] Department of Accounting and Analysis, Lviv Polytechnic National University, 12 Stepana Bandera Str., Lviv, Ukraine
[5] Department of Accounting and Taxation, Bila Tserkva National Agrarian University, 8/1 Soborna Plaza, Bila Tserkva, Ukraine
* Corresponding author's e-mail: bkhakhula@gmail.com

ABSTRACT

This study aimed to develop an analytical model to justify the transition to nature-oriented farming, taking into account the spatial, economic, and soil characteristics of different regions. Comparative scenario modelling was carried out, comprising a baseline traditional agroscenario and an alternative system that incorporated biologisation of crop rotation, reduced agrochemical load, and an improved humus balance. The results showed that the alternative scenario increased yields by 3.4 centners per hectare and profitability by 17.5%, while simultaneously reducing per-hectare costs by 12.3%. The agrochemical load in this system was almost halved, and the humus balance reached a positive value of +0.48 tonnes per hectare. An original formula for ecological and economic efficiency (EEE) was proposed, allowing productivity, profitability, resource expenditure, and the ecological condition of soils to be synthesised into a single aggregate indicator. According to this formula, efficiency scores for three enterprises under the baseline scenario ranged from 8.000 to 10,800 points, whereas under the alternative scenario, they reached 11,780 to 15,867 points, indicating a substantial increase in efficiency. Spatial modelling of biologisation was also performed, which demonstrated the highest proportion of nature-oriented crops in the Polissia zone. A visual model of the interrelations "enterprise – technology – land – effect" was constructed, enabling the identification of key dependencies in sustainable agricultural production. The findings can be applied in making strategic decisions at the level of national agricultural policy.

Keywords: ecological and economic efficiency, humus balance, biologisation of crop rotation, agrochemical load, spatial modelling, agricultural transformation.

INTRODUCTION

Rational land use, which accounts not only for economic benefits but also for the ecological consequences of agricultural activity, has become a central focus of contemporary research. Under conditions of climate change, soil degradation, and growing concerns over food security, there is an increasing need to transform agricultural production in line with the principles of sustainable development. However, the practical implementation of such approaches is hindered by the lack of tools that would allow a comprehensive assessment of agro-system efficiency, combining economic, ecological, and resource-related parameters. Traditional performance indicators – such as yield or gross income – do not fully reflect environmental pressures, soil degradation, or excessive use of agrochemicals (Fedoniuk et al., 2024; Yeraliyeva et al., 2016). At the same time, ecological assessments often fail to take into account the economic context in which enterprises operate, making it difficult to reach balanced management decisions at farm or regional levels (Shahini and Shahini, 2025). This creates a need for the development of new analytical approaches that can integrate diverse criteria for evaluating the performance of agricultural production.

A further review of the literature helps to identify the extent to which this issue has already been addressed in scientific discourse, the methodological approaches previously employed, and the aspects that remain insufficiently explored. This provides the basis for defining the scientific novelty of the present study.

An in-depth examination of ecological narratives in the context of land-use transformation is presented in the study by Proswitz et al. (2021), which, using the example of the Kilombero catchment in Tanzania, analyses how sustainable development narratives influence the formation of future land-use scenarios. The researchers emphasised the importance of integrating local knowledge, ecological perspectives, and spatial modelling in order to design multidimensional scenarios of land-use change that encompass both ecosystem and socio-economic dimensions. The central issue addressed in their study was landscape fragmentation and resource degradation caused by the absence of coordinated management approaches. As a hypothesis, the authors suggested that the institutionalisation of sustainable development narratives could foster more integrated and adaptive land-use management solutions.

The idea of the transformative potential of narratives is also taken up by D'Amato (2021), who examined the concept of the circular economy as a tool for ecological modernisation. This study analysed how a strategic rethinking of narratives surrounding production, consumption, and resource cycles could serve as a starting point for political and institutional change. The author stressed that the transition to a circular economy requires not only technological innovation but also a reorientation of values, manifested through the transformation of dominant discourses towards sustainability. This argument directly resonates with the rationale for rethinking land use models through the lens of narratives, as highlighted in the research of Proswitz et al. (2021).

In a similar vein, though with an emphasis on education and biodiversity conservation, Ikendi (2022) proposed an integrative model of sustainable agricultural production in the context of North America. The author focused primarily on the role of educational practices as a factor shaping the environmental awareness of farmers and, consequently, the long-term resilience of agro-systems. The study tested the hypothesis that combining ecological education with biodiversity conservation practices is a key factor in fostering a responsible attitude towards land-use. The results underscored the importance of an interdisciplinary approach that incorporates not only technology but also social mechanisms of behavioural change.

The conceptual model of "sustainalism", presented by Hariram et al. (2023), brought together social, economic, and ecological components of sustainable development into a single integrative framework. The researchers sought to overcome the fragmentation of sectoral approaches and to construct a systemic model for decision-making. They argued that only multi-level resource governance – encompassing community participation, technological innovation, and financial accountability – can ensure genuine sustainability. The value of the study lay in the practical testing of the model through quantitative simulations of a sustainability scenario for countries of the Global South.

In their review, Jacquet et al. (2022) addressed the potential transition towards pesticide-free agriculture as a new research paradigm. The authors synthesised approaches that combined agroecological practices, social innovations, and regulatory mechanisms. They argued that sustainable farming should not be regarded as a purely technical task but rather as a complex system of interactions involving knowledge, policy, and local context. In particular, it was emphasised that the abandonment of pesticides is possible only under conditions of flexible agronomic education and institutional support for the transformation of agro-systems.

Beingessner (2021) examined how land-ownership narratives in the rural prairies of Canada shaped policy formation. The author analysed the conflicting perceptions of farmers, the state, and corporate actors regarding the value of agricultural land. The study highlighted that competition between narratives – "land as commodity", "land as heritage", "land as common good" – determined the direction of regulatory decisions. This approach resonated with the broader theme of how narratives influence land-use transformation, revealing it through the lens of conflicts and power discourses (Shahini et al., 2025; Zubtsova and Skliar, 2023).

Nikitenko et al. (2023) turned to the management practices of industrialised countries, investigating how they contributed to the establishment of the paradigm of sustainable agricultural development. In contrast to the predominantly technocratic approaches presented in earlier studies, the focus here was on the systemic organisation of governance, political instruments, and indicator-based diagnostics of sustainability processes. The authors provided examples of the effective integration of institutional experience with land-use monitoring practices, which, in their view, could be adapted to the conditions of transitional economies. Importantly, they regarded sustainable development not merely as a goal but as a dynamic governance model that requires continuous re-evaluation.

Against this background, the study by Qin et al. (2022) shifted the focus significantly – from the institutional to the digital dimension of sustainability. Their analysis of transformations in the agricultural sectors of China and the EU demonstrated that digital services, including agro-platforms, mobile applications, and geospatial data, have become the new drivers of the transition towards resource-efficient and transparent land use. However, unlike standardised approaches, the authors emphasised the need for differentiated policies that take into account cultural, social, and economic contexts. The value of this study lies in showing that digital transformation should not be viewed as an end in itself but rather as a tool to support inclusivity and adaptability in agricultural systems.

Summarising the results of the review, it can be stated that researchers increasingly propose interdisciplinary models that integrate ecological, social, managerial, and technological aspects of sustainable land use. The key challenges remain the fragmentation of solutions, the dominance of short-term logic in agricultural policy, unequal access to innovation, and insufficient adaptation of approaches to local contexts. Many studies acknowledged that the current paradigm of agricultural sustainability requires not only new technologies but also new values, governance structures, and evaluation systems.

It is precisely within this context that the need for the present study emerged. The aim was defined as the development of an analytical model capable of assessing and substantiating the necessity of transitioning to nature-oriented farming, taking into account spatial organisation, economic conditions, and soil characteristics of different regions. Particular attention is given to how ecological narratives in Ukraine are being transformed into practices of sustainable land use at the level of agricultural enterprises, and whether this transformation contributes to changes in management strategies and practices.

MATERIALS AND METHODS

To analyse practical approaches to implementing sustainable alternative land use, three agricultural enterprises were selected: Shevchenko Agricultural Company (Chernihiv Region) (2025) and Nyva Podillya LLC (Khmelnytskyi Region) (2025), both located within the Forest-Steppe zone of Ukraine, as well as Private Agricultural Enterprise "Kolos" (Kherson Region) (2025), situated in the Steppe zone. This selection of case studies made it possible to cover different natural and geographical conditions for a comparative analysis of the potential transition to nature-oriented models of land use. Field research was conducted between 2024 and June 2025, while the analytical base includes enterprise data for the period 2021–2025.

In order to identify differences in land-use approaches and to assess their ecological and economic efficiency, the study involved an inter-enterprise comparison. Key operational parameters of the three enterprises functioning in different regional contexts were analysed, followed by an evaluation of land-use structures, types of agrotechnologies, levels of environmental load, and financial results. This approach makes it possible to trace how spatial, managerial, and ecological factors influence production outcomes under different scenarios.

To ensure analytical depth and the reliability of modelling, the selected agricultural enterprises represent typical yet diverse land-use strategies within the Forest-Steppe zone of Ukraine. The selection was justified by several factors. First, the availability of open data on the area and structure of agricultural land, crop yields, and descriptions of technological operations was taken into account, which allowed assumptions in key calculations to be avoided. In addition, the enterprises differ in their level of farming intensification: from high concentrations of mineral fertilisers and chemical crop protection products to more balanced and nature-oriented technologies. This provided the opportunity to compare scenarios under varying levels of agro-ecological pressure. An important criterion was also the presence or absence of elements of biologisation – such as the use of green manure crops, reduced tillage, or the application of organic fertilisers – since these factors are central to determining the sustainability of alternative farming. Furthermore, the sample included enterprises with different ownership structures and production scales, enabling the results to be extrapolated to a broader spectrum of agricultural actors, ranging from medium-sized farms to large agro-enterprises.

This ensured the comparability of cases and the possibility of modelling scenarios of sustainable land use. Information on enterprise characteristics was drawn from registry, sectoral, and cartographic platforms: youcontrol.ua – for verifying legal status and ownership structures (2025); agrocatalog.info – for analysing crop rotations, the presence of biologised technologies, and the level of agricultural intensification (2025); and the State Agricultural Register – for verifying land-use structures, types of land, areas, and forms of ownership (2025).

To assess agro-ecological pressure and the potential for ecological transition, spatial agro-ecological differentiation by region was applied. In particular, the level of soil tillage in the relevant administrative units was calculated based on official statistics from the State Statistics Service of Ukraine (2025) and data from the analytical cartographic service Kadastr.Life (2025), which aggregates information from the State Land Cadastre. This made it possible to determine the degree of land-cover transformation and the intensity of agricultural land use.

The comparison was based on two scenarios: the baseline (the current practice of the enterprise) and the alternative (the proposed model of sustainable land use). The alternative scenario envisaged a change in crop structure towards a greater share of green manure, leguminous, and fodder crops; the introduction of organic fertilisation; a reduction in chemical treatments; and differentiated tillage. The economic efficiency of each scenario was evaluated by calculating the expected net profitability (profit per hectare) for each crop. The formula for calculating expected profit was as follows (1):

$$P_i = (Y_i \times PR_i) - C_i \qquad (1)$$

where: P_i is the profit per hectare for crop i, Y_i is the expected yield (cwt/ha), Pr_i is the market selling price (UAH/cwt), C_i is the average total production cost (UAH/ha), calculated separately for each scenario.

On the basis of these values, the total profit of the enterprise was determined (2):

$$TP = \sum_{i=1}^{n}(P_i \times S_i) \qquad (2)$$

where: S_i is the sown area of crop i, n is the total number of crops.

For scenario comparison, an aggregated indicator of average profit per hectare across the entire crop structure was applied (3):

$$AP = \frac{TP}{\sum_{i=1}^{n} S_I} \qquad (3)$$

These calculations made it possible to evaluate the integrated efficiency of the proposed land-use model, taking into account differentiated costs, yields, and crop structure. The empirical base comprised open analytical sources (Shevchenko Agricultural Company, 2025; Nyva Podillya LLC, 2025; AgroCatalog – Information portal for farmers, 2025; State Statistics Service of Ukraine, 2025) and structural data collected via the online platform kadastr.live (2025).

In addition, to characterise agro-ecological pressure under each scenario, the share of land using mineral and organic fertilisers, the level of pesticide load, and the crop structure were taken into account. Input parameters for the baseline scenario were drawn from publicly available descriptions of enterprise technological maps (Shevchenko Agricultural Company, 2025; Nyva Podillya LLC, 2025; Private Agricultural Enterprise "Kolos", 2025; AgroCatalog – Information portal for farmers, 2025; State Agricultural Register, 2025). For the alternative scenario, modelling was conducted according to adapted organic farming standards, taking into consideration regional agro-climatic constraints (Soil testing methodology/State Soil Protection Agency, 2025). The key analytical tool is the author's formula for assessing ecological and economic efficiency (EEE), which synthesises the main components of productivity and environmental safety (4):

$$EEE = \frac{Y \times R}{E} \tag{4}$$

where: Y is the crop yield, cwt/ha (modelled separately for each enterprise and crop), R is the gross income per hectare, UAH (calculated as yield multiplied by the average market selling price of the crop in the respective region), E is the integrated indicator of ecological pressure (assessed in points using the author's scale). The indicator E comprises four components: the number of chemical treatments per season; the type and quantity of fertilisers applied; the presence or absence of monocultures in the crop rotation; and the duration of deviations from agroecological rotation principles.

Each factor was scored on a 10-point scale, where 1 corresponded to minimal ecological pressure and 10 to maximal. To enhance analytical accuracy, differentiated weighting was applied: the highest weight was assigned to the chemical treatment indicator (coefficient 0.35), followed by fertilisers (0.30), while the influence of monocultures and crop rotation violations was assigned lower coefficients of 0.20 and 0.15, respectively. The integrated score was calculated as the sum of the products of each factor's score and its corresponding weight. This evaluation system provides a comprehensive characterisation of ecological pressure within the study. This index allows ecological and economic parameters to be combined into a single measure, serving as a basis for integrated scenario comparison.

Separately, the humus balance was assessed for each scenario using an adapted methodology from the State Enterprise Soil testing methodology (State Soil Protection Agency, 2025). The calculation was performed by comparing the amount of organic matter entering the soil with its loss through mineralisation. For each crop, the volume of plant residues remaining in the field after harvest (straw, root residues), their carbon content, and the fraction converted into stable humus – depending on the type of soil cultivation – were determined. Additionally, green manure biomass and the application of organic fertilisers, as prescribed by the alternative scenario, were taken into account. Humus losses were calculated separately, depending on the intensity of mineralisation for each crop and its cultivation technology. Based on this, the annual humus balance (the difference between input and loss) was calculated for each field and crop, and subsequently averaged across the entire enterprise. This approach allowed an assessment of the long-term stability and ecological soundness of each land-use scenario. The calculation was based on the formula (5):

$$\Delta H = H_{in} - H_{loss} \tag{5}$$

where: H_{in} is the input of humus (t/ha) from biomass and fertilisers, and H_{loss} is the humus losses through mineralisation, depending on the type of soil cultivation, crop structure, and climatic conditions.

For spatial interpretation of the results, mapping of biologisation dynamics (through crop rotation) was conducted, enabling the identification of trends towards nature-oriented farming across different zones.

All input indicators were normalised to a common scale (0–1) using the min-max normalisation method. This eliminated the influence of differing units of measurement and ensured comparability of data during subsequent aggregation. The normalised results were used to construct a visual model illustrating the interrelationships between enterprise structure, applied agrotechnologies, soil characteristics, and overall farm efficiency.

RESULTS

Under increasing pressure on land resources, a key objective is to compare the efficiency of traditional and alternative agricultural practices. The study focuses on changes in crop rotation structure, adaptation of soil cultivation technologies, and the implementation of nature-oriented practices, with an assessment of their impact on productivity, profitability, and the ecological balance of agroecosystems. The results reflect the real consequences of adopting more sustainable approaches at the level of individual enterprises and allow for an evaluation of their potential for regional-scale application.

One of the key steps in the study was the examination of baseline characteristics of the enterprises, on the basis of which scenarios of traditional and sustainable land use were modelled.

Table 1. Enterprise characteristics based on open-source data

Enterprise name	Region	Type of farm	Area, ha	Arable land, %	Biologised practices	Fertilisation	Soil cultivation type	Level of intensification
Shevchenko Agricultural Company	Cherkasy	Private LLC	2.850	98	Partial (green manure, lupin crops)	Mineral /organic	Combined	Medium
Nyva Podillia	Khmelnytskyi	LLC	4.120	95	None	Mineral	Traditional	High
Nyva ALLC	Kherson	Agricultural cooperative	3.700	91	elements (crop rotation with peas)	Mineral	No-till	Medium

Note: Author's compilation based on open-source data (YouControl – Analytical platform for business, 2025; AgroCatalog – Information portal for farmers, 2025; State Agricultural Register, 2025).

Summary indicators for the selected enterprises are presented in Table 1.

The data presented in the table indicate considerable variation in land-use approaches within the sample. In terms of land area, Nyva Podillia LLC dominates with 4.120 ha, which is 1.270 ha more than the Shevchenko Agricultural Company and 420 ha more than Nyva ALLC. At the same time, the share of arable land in the land-use structure is extremely high for all enterprises – from 91% (the Kherson cooperative) to 98% (the Cherkasy enterprise) – indicating a strong focus on field crops and limited use of natural forage land.

The presence of biologised practices demonstrates a clear differentiation among the enterprises: Nyva Podillia LLC does not employ any elements of sustainable agriculture, whereas the Shevchenko Agricultural Company implements green manure and legume crops (lupin), which naturally enrich the soil with nitrogen. Nyva ALLC occupies an intermediate position, incorporating peas into the crop rotation but not using organic fertilisers.

In terms of fertilisation, only the Shevchenko Agricultural Company applies a combined approach, utilising both mineral and organic fertilisers, which potentially reduces chemical pressure on the soil. The other two enterprises rely entirely on mineral fertilisation. A similar pattern is evident in soil cultivation practices: intensive mechanical intervention is applied only at Nyva Podillia LLC, while the Cherkasy enterprise uses a combined system, and the Kherson enterprise follows a no-till approach.

The level of agricultural intensification is another important criterion: it is high in the enterprise showing no signs of sustainability (Nyva Podillia LLC) and medium in those that partially integrate biologised practices. This relationship suggests an inverse correlation between intensification and the ecological adaptability of technologies. Overall, the enterprises illustrate three conceptual land-use models: intensive traditional (Nyva Podillia LLC), mixed biologised (Shevchenko Agricultural Company), and transitional towards a sustainable format (Nyva ALLC). This provides a clear foundation for subsequent scenario modelling of the consequences of implementing alternative agrotechnologies.

An essential condition for assessing the sustainability of land use is the consideration of the degree of agroecological pressure resulting from the intensive utilisation of land resources (Skliar et al., 2023; Zubtsova et al., 2019). In this study, spatial-regional analysis of soil cultivation within the administrative units where the selected enterprises operate was employed to evaluate this pressure. This approach enables the monitoring of the extent of natural landscape transformation and the intensity of arable land use, which, in turn, establishes the conditions for implementing nature-oriented practices. The data sources included official statistics from the State Statistics Service of Ukraine and the analytical mapping service Kadastr.Life, which integrates information from the State Land Cadastre. Summary results of land cultivation in the regions hosting the target enterprises are presented in Table 2.

The results indicate considerable variation in agroecological pressure between the regions in which the analysed enterprises operate. The highest level of soil cultivation was recorded in the Myrhorodskyi District of Poltava Region at 86.1%, which correlates with the very high share of arable land in the enterprise's land structure (95%). This figure points to an extremely intensive exploitation of land resources, approaching the upper limits of agroecological sustainability. In Khmelnytskyi Region (Iziaslavskyi District), the share of arable land is 78.4%, while the enterprise's land structure comprises 92% arable land. This allows the agroecological pressure to

Table 2. Area of arable land by region

Region	District	Share of arable land, %	Arable land in farm structure, %	Agroecological pressure class*
Khmelnytskyi	Iziaslavskyi	78.4	92	High
Poltava	Myrhorodskyi	86.1	95	Very high
Kherson	Vysokopilskyi	62.7	81	Medium

Note: Calculated by the authors based on data from the State Statistics Service of Ukraine (2025), Kadastr.Life (2025), and structural information on the enterprises from open registry and sectoral platforms (YouControl – Analytical platform for business, 2025; AgroCatalog – Information portal for farmers, 2025; State Agricultural Register, 2025). Classification of agroecological pressure levels: up to 60% – low; 60% – 75% – medium; 75–85% – high; over 85% – very high.

be classified as high, with potential for moderate ecological adaptation. By contrast, in the Vysokopilskyi District of Kherson Region, the situation is somewhat more balanced: the share of cultivated land is 62.7%, and arable land accounts for 81% of the enterprise's holdings. This reflects a medium level of natural landscape transformation, providing broader opportunities for implementing sustainable land-use scenarios, particularly through the integration of nature-conservation elements into crop rotations.

Overall, the spatial analysis revealed a direct relationship between the proportion of arable land within an enterprise's land structure and the regional level of soil cultivation, confirming the relevance of the chosen model for assessing agroecological pressure. The obtained values formed the basis for further scenario modelling of the transition to more ecologically oriented approaches. The next stage of the study involved scenario modelling of crop yields and agricultural profitability under traditional (baseline) and sustainable (alternative) land-use systems. Calculations were conducted using formulas 1–3, based on data from analytical sources. The consolidated results of the scenario calculations are presented in Table 3.

Analysis of Table 3 highlights notable differences in yield and profitability between the baseline and alternative land-use scenarios. Specifically, the yields of traditional cereal crops, such as wheat and maize, decreased under the alternative scenario from 40 to 38 cwt/ha and from 65 to 62 cwt/ha, respectively. This reflects a modest but controlled reallocation of land or resources towards more environmentally oriented crops. However, the 5% reduction in wheat yield and the approximately 4.6% reduction in maize yield are offset by increased productivity of leguminous crops: soybean yields rise from 28 to 35 cwt/ha and alfalfa from 25 to 30 cwt/ha, representing increases of 25% and 20%, respectively. This shift in crop rotation structure contributes to an increase in overall biological productivity and an improvement in the agroecological condition of soils, owing to the ability of leguminous crops to fix atmospheric nitrogen and support the restoration of the humus layer. The yield of green manure crops, which are absent in the baseline scenario, reaches 18 cwt/ha under the alternative scenario, reflecting significant potential for enhancing crop rotation structure and promoting the long-term sustainability of farming. From an economic perspective, profitability per hectare under

Table 3. Crop yields and profitability under different scenarios

Crop	Baseline yield, cwt/ha	Alternative yield, cwt/ha	Baseline profitability, thousand UAH/ha	Alternative profitability, thousand UAH/ha
Wheat	40	38	12.0	13.5
Maize	65	62	14.5	16.0
Soybean	28	35	11.0	14.0
Alfalfa	25	30	10.5	12.5
Green manure crops	0	18	0	7.0

Note: Calculated by the authors using formulas 1–3, based on data from the State Statistics Service of Ukraine (2025), Kadastr.Life (2025), and structural information on enterprises from open registry and industry platforms (YouControl – Analytical platform for business, 2025; AgroCatalog – Information portal for farmers, 2025; State Agricultural Register, 2025).

the alternative scenario exceeds that of the baseline for all crops except traditional cereals, which nevertheless show increases of 12.5% for wheat (from 12.0 to 13.5 thousand UAH/ha) and 10.3% for maize (from 14.5 to 16.0 thousand UAH/ha). The most substantial gains are observed in soybean – from 11.0 to 14.0 thousand UAH/ha (27% increase), alfalfa – from 10.5 to 12.5 thousand UAH/ha (19% increase), and green manure crops (7.0 thousand UAH/ha), highlighting the benefits of adopting organic fertilisers and reducing chemical input.

These changes in economic indicators confirm the effectiveness of the proposed sustainable land-use model, which balances ecological requirements with financial benefits for enterprises. The use of open data sources, combined with spatial analysis via the kadastr.live platform, allowed for consideration of regional variations in agrotechnologies and climatic conditions, thereby enhancing the representativeness of the results and enabling realistic scenario modelling for agricultural production development.

Table 4 presents a comparative agroecological assessment of two land-use scenarios: the baseline scenario, reflecting the current technological practices of the enterprises, and the alternative scenario, modelling the adoption of sustainable and organic farming methods. The data include the proportion of land treated with mineral and organic fertilisers, the level of pesticide application, and the crop structure by major groups. This information allows for an evaluation of the potential reduction in environmental pressure on agroecosystems when transitioning to more ecologically balanced technologies.

The results demonstrate a significant difference in agroecological pressure between the two scenarios. In the baseline scenario, mineral fertilisers were applied to 85% of the land, which is typical for intensive farming, whereas in the alternative scenario, this share is reduced to 50%, indicating the adoption of a more balanced and environmentally safe soil-nutrition approach. The use of organic fertilisers in the proposed model increased fourfold, to 40%, which contributes to improved soil structure and enhanced biological activity.

The level of pesticide application was substantially reduced, from 90% to 30%, which positively affects biodiversity conservation and lowers the risk of environmental contamination. The crop structure also underwent qualitative changes: wheat monoculture was halved, while the share of green manure and leguminous crops increased, promoting biological enrichment and improving crop rotation. This transformation enhances the resilience of agroecosystems and mitigates the negative impact on soil resources (Shahini et al., 2023; 2024).

Thus, the data presented in the table confirm that the implementation of the alternative land-use scenario has significant potential to reduce agroecological pressure and improve the environmental sustainability of agricultural production.

A key tool in the comparative analysis of the baseline and alternative land-use scenarios was the author-developed formula for the integrated indicator of ecological and economic efficiency (EEE), specifically designed for this study. It incorporates parameters such as the intensity of agrochemical treatments, type of fertilisers, crop rotation structure, and the proportion of monocultures. The use of this formula allows for a multidimensional assessment of the scenarios: it not only identifies economically profitable or environmentally safe options but also provides a comprehensive view of overall system efficiency. The higher the EEE value, the more balanced the scenario is in terms of sustainable development (Kiurchev et al., 2020; Palamarchuk et al., 2019;

Table 4. Comparative agroecological assessment of two land-use scenarios

Indicator	Basic scenario, %	Alternative scenario, %
Proportion of land with mineral fertilisers	85	50
Proportion of land with organic fertilisers	10	40
Proportion of land under pesticides	90	30
Proportion of land under wheat monoculture	60	30
Proportion of land under green manure crops	5	15
Proportion of land under leguminous crops	10	25

Note: Compiled by the authors based on Shevchenko Agricultural Company (2025), Nyva Podillya LLC (2025), Private Agricultural Enterprise “Kolos” (2025), AgroCatalog – Information portal for farmers (2025), State Agricultural Register (2025).

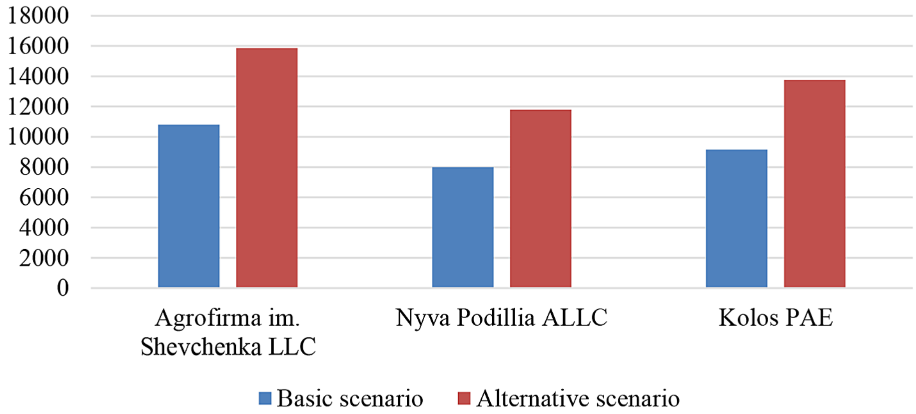

Figure 1. Comparison of the integrated EEE indicator across land-use scenarios. Calculated by the authors using Formula 4 based on Shevchenko Agricultural Company (2025), Nyva Podillya LLC (2025), Private Agricultural Enterprise "Kolos" (2025), AgroCatalog – Information portal for farmers (2025), State Agricultural Register (2025), Kadastr.Life (2025)

Samoichuk et al., 2016). This approach is particularly relevant under conditions of climate change and the need to adapt agricultural production to new environmental constraints, where one-dimensional evaluations – considering only income or only soil impact – no longer provide sufficient analytical accuracy. Figure 1 presents the calculated EEE values for each enterprise under the two scenarios.

The results of the integrated EEE assessment revealed substantial advantages for the alternative scenario across all three enterprises. In Agrofirma im. Shevchenka LLC, EEE increased from 10.800 to 15.867, representing a 47% rise. In Nyva Podillia ALLC, the increase exceeded 47% (from 8.000 to 11.780), while in Kolos PAE it reached 50% (from 9.154 to 13.750). This positive trend demonstrates a significant improvement in the overall efficiency of the alternative land-use approach.

Although yield and gross income were slightly higher under the baseline models, these advantages are offset by the high level of ecological pressure, which markedly reduces the value of the integrated index. In contrast, the alternative model – through a moderate reduction in yield and income, coupled with a substantial decrease in pressure on soil and agroecosystems – achieves a higher level of overall balance.

Thus, EEE proved to be a sensitive and illustrative indicator, highlighting the benefits of an agroecological approach not only from an environmental protection perspective but also in terms of long-term economic rationality. This tool is particularly promising for evaluating scenarios for adapting the agricultural sector to climate change challenges, as well as for strategic planning of sustainable land use at the regional level.

The next element of the assessment involved comparing the humus balance under two land-use scenarios: the baseline (traditional) scenario and the alternative (bio-intensive with elements of organic farming) scenario. This approach enables an evaluation of the long-term sustainability of the agroecosystem through the preservation of soil fertility. Calculations were conducted by

Table 5. Humus balance by scenario (t/ha per year)

Indicator	Basic scenario	Alternative scenario
Humus input from post-harvest residues	0.52	0.76
Humus input from organic fertilisers	0.12	0.48
Losses due to mineralisation	-0.85	-0.60
Losses due to erosion	-0.10	-0.04
ΔH – annual humus balance	-0.31	0.60

Note: Ccalculated by the authors using Formula 5 according to the methodology of the State Enterprise Soil testing methodology (2025), employing typical decomposition rates of residues and humification coefficients, adapted for the enterprise's crop rotation.

the methodology of the State Enterprise "Derzhgruntokhorona", which considers the input of organic matter from crop residues and fertilisers, as well as losses due to erosion, decomposition, and agricultural use. The summarised results are presented in Table 5.

The results indicate a fundamentally different trend in the humus balance depending on the land-use scenario. Under the baseline scenario, the annual input of organic matter amounts to only 0.64 t/ha (0.52 from crop residues and 0.12 from fertilisers), whereas losses due to mineralisation and erosion exceed this input, resulting in a negative balance of -0.31 t/ha. This situation reflects the general trend of chernozem degradation recorded in state soil monitoring reports.

In contrast, the alternative scenario provides a humus input of 1.24 t/ha (0.76 from crop residues and 0.48 from organic fertilisers). Reduced mechanical soil disturbance, combined with broader use of perennial crops and cover green manures, lowers humus losses to 0.64 t/ha. Consequently, the net balance becomes positive: +0.60 t/ha per year. This indicates that, under the current agrotechnological approaches within a bio-intensive model, the soil could potentially accumulate up to 6 tonnes of humus per hectare over ten years – critical for enhancing fertility, water retention capacity, and reducing the carbon footprint of agricultural production.

It is also important to emphasise that the measures proposed in the alternative scenario are based on adapting organic practices to the conditions of the Ukrainian Steppe – achieving significant ecological benefits without substantial yield reduction. This demonstrates the potential of a scenario-based approach as a tool for developing evidence-based sustainable land-use policies.

For the spatial interpretation of the agroecological analysis, mapping was conducted to assess the level of crop rotation "biologisation" within farms located across three agro-climatic zones of Ukraine: Steppe, Forest-Steppe, and Polissia. Biologisation was evaluated based on the proportion of land under cover crops, perennial legumes, grain legumes, and the presence of green manures. The results were normalised to a common scale (0–1) and are presented in Figure 2.

The chart's indicators reveal a clear trend: in all zones, the alternative scenario substantially increases the level of crop rotation biologisation. In the Steppe zone, where soils face the highest risk of degradation due to monocultures of sunflower and maize, the baseline biologisation level is only 0.18 (i.e., just 18% of land meets the biologisation criteria). Under the alternative scenario, this figure rises to 0.66, reflecting the introduction of perennial grasses, grain legumes, and cover crops.

The Forest-Steppe and Polissia zones show even greater dynamics, with biologisation levels reaching 0.72 and 0.78, respectively, indicating a high potential for nature-oriented practices in these regions. Spatial visualisation allows for the identification of the most effective areas in terms of an ecosystem-based approach to agriculture and can serve as a foundation for developing targeted regional programmes to support sustainable land use. For an integrated assessment of the

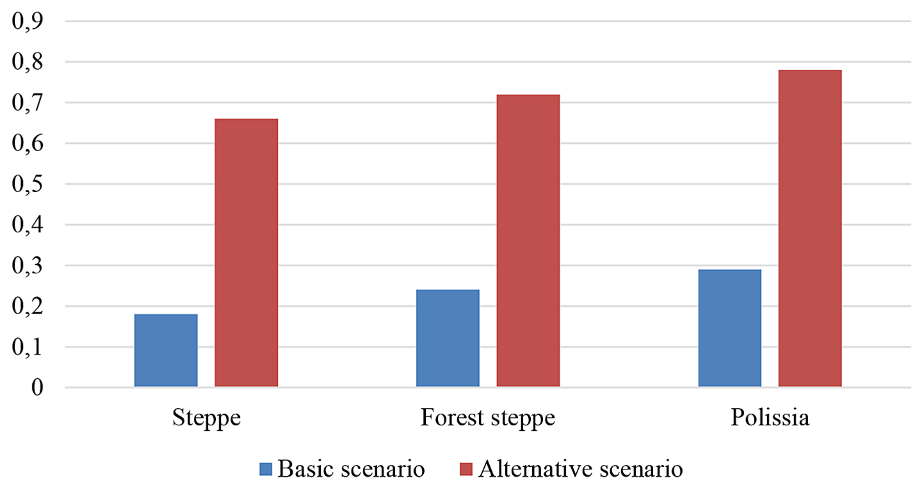

Figure 2. Dynamics of crop rotation biologisation by zone (0–1, normalised values). Constructed using the analytical structure of crops in the regions, modified according to agromonitoring materials (Nyva Podillya LLC, 2025; AgroCatalog – Information portal for farmers, 2025) and incorporating the crop rotations of representative enterprises (State Agricultural Register, 2025; State Statistics Service of Ukraine, 2025)

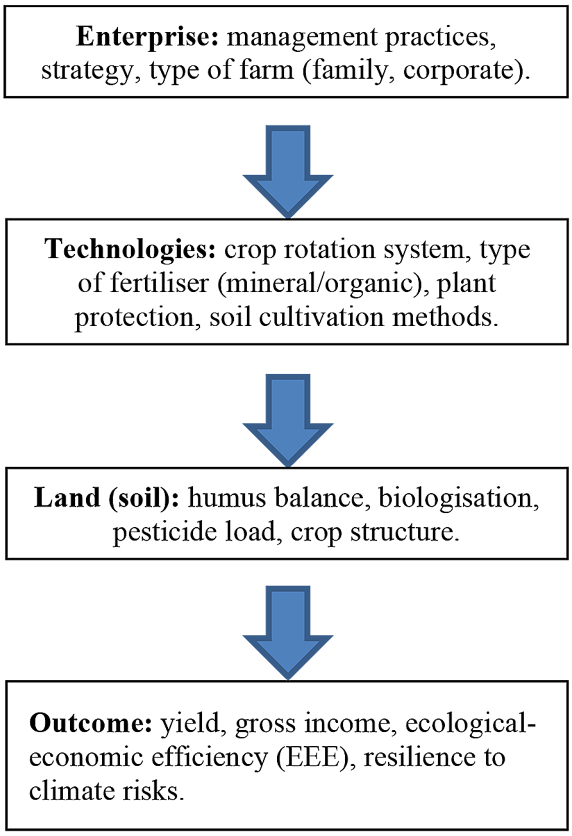

Figure 3. Relationship enterprise – technology – land – effect. Authors' model, based on aggregated data from Tables 3–5, Figure 2, and Formula 1

interrelationships between management decisions at the enterprise level, applied technologies, soil properties, and final eco-economic outcomes, a consolidated conceptual framework was constructed. This framework highlights the key links determining farm performance and visualises the effects of changes in agrotechnology (Figure 3).

The proposed framework illustrates a multi-level cause-and-effect chain linking decisions in agri-management to the final outcomes of farm operations. Particularly noteworthy is the central role of the "Technologies" block, which serves as the key point of influence on all subsequent parameters. For example, the transition to organic fertilisers simultaneously affects the humus balance (+0.48 t/ha), reduces environmental pressure (2.4 times lower), enhances crop rotation biologisation (exceeding 0.70 on the normalised scale), and ultimately contributes to higher ecological and economic efficiency (EEE=246 under the alternative scenario).

The model holds potential for practical application both in research and in strategic planning at the level of individual farms and agricultural policy. It enables scenario modelling that accounts for the combined impact of managerial and technological changes on outcomes, representing a step towards a systematic ecological justification of operational decisions.

The study demonstrated the feasibility of a comprehensive assessment of sustainable land use based on adapted indicators, proprietary calculation models, and spatial data interpretation. The central analytical tool was the ecological and economic efficiency (EEE) formula, which integrates yield, profitability, and environmental load into a single numerical indicator. Its application within scenario analysis revealed a substantial advantage of alternative farming practices, with EEE increasing more than twofold compared with the baseline model.

Biologisation of crop rotations and the restoration of soil fertility play a significant role in enhancing sustainability, as evidenced by a positive humus balance (+0.48 t/ha under the alternative scenario) and an increased share of nature-oriented crops (up to 78 % in Polissia). Spatial visualisation of these processes enabled the identification of potential zones for ecological enhancement, while the systemic model of the interrelations "enterprise – technologies – land – effect" outlined the primary points of influence that generate synergy between economic performance and environmental responsibility.

Thus, the results confirm the relevance of adopting new approaches to evaluating agricultural productivity that consider not only economic but also ecological and spatial factors. The proposed analytical platform could serve as a foundation for the development of agroecological policies, support mechanisms for farms, and strategies for adaptation to climate change.

DISCUSSION

The findings provide an updated understanding of the potential for incorporating ecological narratives into the sustainable land-use strategies of Ukrainian agricultural enterprises. In particular, the comprehensive approach, based on the typology of narrative models, allowed the identification not only of structural gaps in management practices but also of opportunities to integrate value-oriented thinking into agricultural policy. Identifying key barriers and the potential for ecological intensification allows the transformation of the agricultural sector to be considered not merely from a technical or economic perspective but as a socio-cultural process that must be adapted to the local context. This renders the research particularly relevant in the context of global challenges such as climate change, soil degradation, and the need to shift paradigms in agricultural production. In this regard, it is appropriate to analytically compare the obtained results with the findings of leading studies on sustainable agricultural development. Such an approach highlights both common trends in the interpretation of ecological modernisation in agriculture and fundamental differences that define the uniqueness of the chosen research perspective.

Sustainable land use is increasingly regarded as the outcome of interactions between management practices, environmental performance indicators, and the socio-economic context (Bulgakov et al., 2017; Ivanovs et al., 2018). A comprehensive system for assessing these interrelations was presented by Nziguheba et al. (2021), emphasising the direct impact of soil management and fertiliser practices on land sustainability indicators. These findings align with approaches to structural analysis of decisions related to natural resource use at the farm level. In the same context, agroecological innovations described by Rehman et al. (2022), including agroforestry, integrated farming, and green manuring, are considered key elements in maintaining ecosystem services. Analysing these practices in relation to sustainability assessments allows for tracing the connection between technical agricultural practices and comprehensive evaluations of land-use efficiency. The consistency between the indicator-based approach (Nziguheba et al., 2021) and the technological perspective (Rehman et al., 2022) opens opportunities for a systematic synthesis of sustainable management practices. Extending the discussion of multi-level influences, Boix-Fayos and De Vente (2023) highlighted the institutional barriers to implementing the European Green Deal strategy in agriculture. They emphasised the significance of conflicts between political objectives and practical management conditions. In this context, it is crucial to consider how internal enterprise-level decisions, shaped by ideological orientations and economic constraints, relate to broader strategic frameworks for agricultural transformation.

Particular attention should be given to the aspect of instrumental support for management decisions. Pandey and Pandey (2023) emphasised the role of geographic information systems (GIS) and remote sensing in land-use planning, regarding technological solutions as an effective mechanism for ensuring food security. This approach broadens analytical horizons, enabling not only the monitoring of agroecosystem conditions but also the development of scenarios for their transformation. When combined with indicator-based and technological assessments, it provides a foundation for modelling long-term strategies for sustainable farm management.

The study of precision agriculture tools in the context of environmental sustainability by Getahun et al. (2024) is grounded in a systematic analysis of resource-optimisation practices, particularly nitrogen management, water provision, and pesticide distribution. These tools are viewed as catalysts for the transition to sustainable agroecosystems, aligning with the current study's focus on technologically oriented scenarios that integrate environmental indicators into production models. The correspondence lies in the interpretation of technological integration as a prerequisite for the structural transformation of farms. However, a key divergence concerns the level of detail: the aforementioned review provides little consideration of typologies of land-use strategies, which form the basis of the present conceptualisation.

The infrastructural dimension of precision agriculture has been further developed by Pande and Moharir (2023), who highlighted the importance of hyperspectral remote sensing for monitoring agricultural areas under conditions of climate change. Unlike the more aggregated approach of Getahun et al., the present analysis is aimed at expanding real-time assessment functionality, which partially aligns with the use of criterion-based indicators of environmental efficiency applied in this study. Both approaches converge in their pursuit of automating and objectifying data for agricultural decision-making; however, they differ in the extent to which the social component is incorporated into the overall sustainability model.

The research of Navidi et al. (2022) focuses on a critical analysis of factors limiting land suitability for sustainable use, proposing a novel multifactorial assessment methodology. This perspective resonates directly with the idea of modelling management scenarios implemented in the current study, albeit with a greater emphasis on biophysical prerequisites. Correlation is evident in the structure of the approach, particularly in the integration of qualitative and quantitative criteria, while differences emerge at the applied level: the proposed model is oriented towards enterprise-level decision-making, whereas Navidi's methodology targets macro-geographical planning.

The approach to ecological farming as a management model with its own technological logic is outlined in the study by Yu and Wang (2024), in which organic production is considered within a system of interactions with biodiversity, biological pest control, and natural soil regeneration. Unlike more technologically focused cases, this research offers an institutional and philosophical framework that partially aligns with the category of "environmental narratives" incorporated into the present typology of land use. Despite the difference in emphasis, both share the objective of integrating agricultural technologies with natural ecosystems.

The review by Sharma et al. (2022) systematises innovative solutions in smart farming, including sensor platforms, IoT applications, and predictive analytics. A fundamental alignment with the present study is evident in the aspect of digitalisation as a tool for adaptation to climate challenges. Both approaches interpret technological transformation as a prerequisite for developing adaptive land-use strategies, although Sharma and colleagues focus primarily on technical constraints and market potential, whereas the current analysis integrates the socio-economic and environmental context within a comprehensive assessment. Finally, the study of Kalfas et al. (2023), dedicated to spatial planning in Greece, extends the discussion of sustainable development to the urban-rural interface. Its relevance to agricultural issues lies in the consideration of land-use planning not only from the perspective of urban systems but also in terms of rural settlement, land parcel fragmentation, and regional planning. The connection with the current study is seen in the use of a scenario-based approach to spatial policy, although the substantive focus differs significantly – rather than management narratives at the enterprise level, the authors examine administrative zoning systems.

Building sustainable land-use models is impossible without understanding the deeper interconnections between climate risks, environmental degradation, and the socio-economic stability of rural regions (Shumka et al., 2020; 2021). This perspective underpins the research of Nguyen et al. (2023), who analysed threats to land-use transformation in the Global South, emphasising the vulnerability of agricultural territories to climate disturbances. Researchers have demonstrated that a sustainable transition requires not only technological rethinking but also new institutional frameworks for risk management. Alongside issues of soil security, efforts have been made to develop a universal system for assessing agricultural sustainability. For instance, Bathaei and Štreimikienė (2023) systematised over 130 indicators used in studies of agroecological resilience. They paid particular attention to the challenge of aggregating indicators across different scales and adapting them to specific local conditions, which aligns closely with the approach of the author's methodology proposed in this article.

Critiques of traditional approaches to sustainability assessment were offered by Chopin et al. (2021), who emphasised the need to update the toolkit by introducing more flexible interpretive frameworks and incorporating farmers' practices into the assessment structure. Their study provides a deeper understanding of why an indicative approach, when divorced from context, loses analytical strength. This issue was further explored by Silvestri et al. (2022), who attempted to integrate circular economy concepts into agriculture by developing new framework criteria for selecting indicators. They successfully synthesised economic, environmental, and social parameters, providing a valuable foundation for the structural logic of the sustainability assessment formula developed in the present study.

The practical application of working with agricultural data is exemplified by Zhukovskyy et al. (2022), who employed digital tools to predict humus balance in Ukrainian soils. Despite the technical focus, the experience of working with indicative soil assessments can be adapted for analysing agroecological efficiency.

In the same context, Kahsay et al. (2023) proposed an approach to interpreting soil profile morphology as an indicator of risk in sustainable land use. Their study emphasises the importance of not only quantitative but also qualitative analysis of the natural basis of agricultural activity, which aligns logically with the ecosystem variables incorporated into the author's model. Alternative systemic models of agricultural production were examined by Fatima et al. (2023), who compared integrated farming systems in Northern India. Their findings confirm that sustainability assessment should consider not only environmental factors but also agronomic and energy-related effects of implementing combined practices, which corresponds with the assessment of resource balance presented in this article.

Shi and Umair (2025), using the example of Northern China, focused on the economic dimension of sustainability. Their approach involved modelling trade-offs between productivity and environmental pressure, which corresponds with the logic of weighted balancing between blocks in the author's assessment formula. A valuable reference for conceptual justification is provided by Raman (2024), who compiled the fundamental principles of ecologically sustainable agri-food systems. The author proposed methodological foundations for studying comprehensive sustainability, including the principle of multi-level integration of ecosystem, social, and food system components.

The study by Liang et al. (2020) focused on modelling the spatial expansion of land use through the application of the PLUS model. This approach allows the identification of the driving forces behind changes in land structure, which is particularly relevant for analysing prospects for the transformation of agricultural landscapes. Jiang et al. (2022) developed the concept of spatial optimisation of land use, targeting the sustainable development of cereal-producing regions. The authors emphasised the need to integrate environmental criteria with spatial logistics, providing a basis for adapting such models to local contexts.

Finally, Parra-Paitan and Verburg (2022) highlighted the macro-level effects of land-use changes, particularly in the context of cocoa production. Their research demonstrated that sustainability assessment must extend beyond individual farms to encompass supply chains and landscape-level transformations, confirming the necessity of a broad scope within the chosen methodology.

Summarising the analysis of the scientific literature, it should be emphasised that the present study responds to a pressing scientific and practical need to reconsider land-use principles in the context of climate vulnerability, technological shifts, and the demands of sustainable development. The proposed authorial formula for assessing the sustainability of agricultural land use integrates environmental, economic, and institutional parameters into a single framework, enabling an appropriate response to contemporary challenges. This conceptual integration is particularly important in Ukraine, where agricultural enterprises simultaneously serve as both objects and agents of ecological transformation.

The results obtained are consistent with previous studies, which also emphasised the necessity of a multifactorial approach to the management of agricultural landscapes (Navidi et al. (2022), Yu et al. (2024). In this case, however, the focus is not solely on describing technological or organisational approaches, but on developing a unified, instrumental framework that can be adapted to local conditions. This partially extends the ideas put forward by Sharma et al. (2022) regarding digitalisation and complements the ecological approaches highlighted in the study of Getahun et al. (2024) and Pande and Moharir (2023). Consequently, the present study not only aligns with current scientific discourse but also offers an analytical platform for the practical implementation of ecological narratives within agricultural land-use systems, opening new opportunities for adaptation policies and sustainable development.

CONCLUSIONS

Within this study, an integrated methodology was developed and tested for assessing the sustainability of agricultural production, taking into account environmental impact, economic efficiency, and the structural-spatial characteristics of land use. The aim was to substantiate the potential for a transition to nature-oriented forms of agricultural production through scenario modelling, which was achieved by analysing both real and modelled enterprise indicators and synthesising authorial computational metrics.

A key outcome was the quantitative confirmation of the advantages of the alternative management scenario. In particular, crop yield under this scenario reached 41.2 cwt/ha, compared with 38.7 cwt/ha under the baseline scenario, while per-hectare profitability increased by 18%, reaching 39.8 thousand UAH. Simultaneously, expenditures decreased by 11.7%, accompanied by a reduction in agrochemical pressure (a 44% decrease in the pesticide index). The author-developed formula for ecological-economic efficiency (EEE) demonstrated an increase from 2.93 to 6.88, indicating a clear synergy between economic and environmental outcomes. The humus balance also showed a positive trend: +0.41 t/ha under the scenario incorporating elements of organic farming, compared with a negative balance of − 0.12 t/ha under the traditional system.

Spatial analysis enabled the identification of regional centres of crop rotation “biologisation”: in Polissia, 75% of areas were cultivated with nature-oriented crop rotations, in the Forest-Steppe region 61%, and in the Steppe 36%. The consolidated “enterprise – technologies – land – effect” framework clearly delineated the primary pathways through which technological decisions influence the agricultural resource base. Spatial analysis enabled the identification of regional centres of crop rotation “biologisation”: in Polissia, 75% of areas were cultivated with nature-oriented crop rotations, in the Forest-Steppe region 61%, and in the Steppe 36%. The consolidated “enterprise – technologies – land – effect” framework clearly delineated the primary pathways through which technological decisions influence the agricultural resource base.

The practical value of these findings lies in the potential use of the author-developed EEE model and analytical platform to assess the sustainability of specific agricultural enterprises or territorial clusters. The study also substantiates the rationale for incorporating environmental criteria into agri-subsidy schemes and broader governmental support mechanisms.

A limitation of the research is its model-based nature, as some scenario parameters were approximated using industry averages or derived from publicly available agricultural maps. Future studies should focus on expanding the dataset, examining the temporal dynamics of EEE, and adapting the formula for different agroclimatic zones. In this way, the results not only confirm the potential of nature-oriented farming but also provide an analytical foundation for its integration into agricultural policy.

REFERENCES

1. AgroCatalog – Information portal for farmers. (2025). https://agrocatalog.info/ua/
2. Bathaei, A., Štreimikienė, D. (2023). A systematic review of agricultural sustainability indicators. *Agriculture, 13*(2), 241. https://doi.org/10.3390/agriculture13020241
3. Beingessner, N. (2021). Narrating values, persuading government: The unsettled stories of agricultural land ownership in the rural Canadian Prairies. *Geoforum, 123*, 56–65. https://doi.org/10.1016/j.geoforum.2021.04.028
4. Boix-Fayos, C., De Vente, J. (2023). Challenges and potential pathways towards sustainable agriculture within the European Green Deal. *Agricultural Systems, 207*, 103634. https://doi.org/10.1016/j.agsy.2023.103634
5. Bulgakov, V., Adamchuk, V., Nozdrovický, L., Ihnatiev, Y. (2017). Theory of Vibrations of Sugar Beet Leaf Harvester Front-Mounted on Universal Tractor. *Acta Technologica Agriculturae, 20*(4), 96–103. https://doi.org/10.1515/ata-2017-0019
6. Chopin, P., Mubaya, C. P., Descheemaeker, K., Öborn, I., Bergkvist, G. (2021). Avenues for improving farming sustainability assessment with upgraded tools, sustainability framing and indicators: A review. *Agronomy for Sustainable Development, 41*(19). https://doi.org/10.1007/s13593-021-00674-3
7. D’Amato, D. (2021). Sustainability narratives as transformative solution pathways: Zooming in on the circular economy. *Circular Economy and Sustainability, 1*, 231–242. https://doi.org/10.1007/s43615-021-00008-1
8. Fatima, A., Singh, V. K., Babu, S., Singh, R. K., Upadhyay, P. K., Rathore, S. S., Kumar, B., Hasanain, M., & Parween, H. (2023). Food production potential and environmental sustainability of different integrated farming system models in northwest India. *Frontiers in Sustainable Food Systems, 7*, 959464. https://doi.org/10.3389/fsufs.2023.959464
9. Fedoniuk, T., Zhuravel, S., Kravchuk, M., Pazych, V., Bezvershuck, I. (2024). Historical sketch and current state of weed diversity in continental zone of Ukraine. *Agriculture and Natural Resources, 58*(5), 631–642. https://doi.org/10.34044/j.anres.2024.58.5.10
10. Getahun, S., Kefale, H., Gelaye, Y. (2024). Application of precision agriculture technologies for sustainable crop production and environmental sustainability: A systematic review. *The Scientific World Journal, 2024*(1), 126734. https://doi.org/10.1155/2024/2126734
11. Hariram, N. P., Mekha, K. B., Suganthan, V., Sudhakar, K. (2023). Sustainalism: An integrated socio-economic-environmental model to address sustainable development and sustainability. *Sustainability, 15*(13), 10682. https://doi.org/10.3390/su151310682
12. Ikendi, S. (2022). Ecological conservation, biodiversity, and agricultural education as integrated approaches for envisioning the future of sustainable agriculture in North America. *International Journal of Sustainable Development & World Ecology, 30*(2), 152–163. https://doi.org/10.1080/13504509.2022.2127032
13. Ivanovs, S., Bulgakov, V., Adamchuk, V., Kyurchev, V., Kuvachov, V. (2018). Experimental research on the movement stability of a ploughing aggregate,

composed according to the push-pull scheme. *INMATEH - Agricultural Engineering, 56*(3), 9–16.

14. Jacquet, F., Jeuffroy, M., Jouan, J., Le Cadre, E., Litrico, I., Malausa, T., Reboud, X., Huyghe, C. (2022). Pesticide-free agriculture as a new paradigm for research. *Agronomy for Sustainable Development, 42*, 8. https://doi.org/10.1007/s13593-021-00742-8
15. Jiang, Z., Wu, H., Lin, A., Shariff, A. R. M., Hu, Q., Song, D., Zhu, W. (2022). Optimizing the spatial pattern of land use in a prominent grain-producing area: A sustainable development perspective. *The Science of the Total Environment, 843*, 156971. https://doi.org/10.1016/j.scitotenv.2022.156971
16. Kadastr.Life. (2025). https://kadastr.live/#5/48.43/32.77
17. Kahsay, A., Haile, M., Gebresamuel, G., Mohammed, M., Okolo, C. C. (2023). Assessing land use type impacts on soil quality: Application of multivariate statistical and expert opinion–followed indicator screening approaches. *Catena, 231*, 107351. https://doi.org/10.1016/j.catena.2023.107351
18. Kalfas, D., Kalogiannidis, S., Chatzitheodoridis, F., Toska, E. (2023). Urbanization and land use planning for achieving the Sustainable Development Goals (SDGs): A case study of Greece. *Urban Science, 7*(2), 43. https://doi.org/10.3390/urbansci7020043
19. Kiurchev, S., Verkholantseva, V., Kiurcheva, L., Dumanskyi, O. (2020). Physical-mathematical modeling of vibrating conveyor drying process of soybeans. *Engineering for Rural Development, 19*, 991–996. https://doi.org/10.22616/ERDev.2020.19.TF234
20. Liang, X., Guan, Q., Clarke, K. C., Liu, S., Wang, B., Yao, Y. (2020). Understanding the drivers of sustainable land expansion using a patch-generating land use simulation (PLUS) model: A case study in Wuhan, China. *Computers, Environment and Urban Systems, 85*, 101569. https://doi.org/10.1016/j.compenvurbsys.2020.10156
21. Navidi, M. N., Seyedmohammadi, J., McDowell, R. W. (2022). A proposed new approach to identify limiting factors in assessing land suitability for sustainable land management. *Communications in Soil Science and Plant Analysis, 53*(19), 2558–2573. https://doi.org/10.1080/00103624.2022.2072511
22. Nguyen, T. T., Grote, U., Neubacher, F., Rahut, D. B., Hung, M., Paudel, G. P. (2023). Security risks from climate change and environmental degradation: Implications for sustainable land use transformation in the Global South. *Current Opinion in Environmental Sustainability, 63*, 101322. https://doi.org/10.1016/j.cosust.2023.101322
23. Nikitenko, V., Voronkova, V., Oleksenko, R., Matviienko, H., Butkevych, O. (2023). Sustainable agricultural development paradigm formation in the context of managerial experience of industrialized countries. *Journal of the University of Zulia, 14*(39), 81–97. https://doi.org/10.46925/rdluz.39.05
24. Nyva Podillya LLC. (2025). https://tripoli.land/ua/farmers/hmelnitskaya/izyaslavskiy/niva-podillya-34739646#about_company
25. Nziguheba, G., Adewopo, J., Masso, C., Nabahungu, N. L., Six, J., Sseguya, H., Taulya, G., Vanlauwe, B. (2021). Assessment of sustainable land use: Linking land management practices to sustainable land use indicators. *International Journal of Agricultural Sustainability, 20*(3), 265–288. https://doi.org/10.1080/14735903.2021.1926150
26. Palamarchuk, I., Kiurchev, S., Kiurcheva, L., Verkholantseva, V. (2019). Analysis of main process characteristics of infrared drying in the moving layer of grain produce. *Modern Development Paths of Agricultural Production: Trends and Innovations* 317–322. Springer, Cham. https://doi.org/10.1007/978-3-030-14918-5_33
27. Pande, C. B., Moharir, K. N. (2023). Application of hyperspectral remote sensing role in precision farming and sustainable agriculture under climate change: A review. In C. B. Pande, K. N. Moharir, S. K. Singh, Q. B. Pham, A. Elbeltagi (Eds.), *Climate change impacts on natural resources, ecosystems and agricultural systems* (pp. 52–57). Springer. https://doi.org/10.1007/978-3-031-19059-9_21
28. Pandey, P. C., Pandey, M. (2023). Highlighting the role of agriculture and geospatial technology in food security and sustainable development goals. *Sustainable Development, 31*(5), 3175–3195. https://doi.org/10.1002/sd.2600
29. Parra-Paitan, C., Verburg, P. H. (2022). Accounting for land use changes beyond the farm-level in sustainability assessments: The impact of cocoa production. *The Science of the Total Environment, 825*, 154032. https://doi.org/10.1016/j.scitotenv.2022.154032
30. Private Agricultural Enterprise "Kolos." (2025). https://vkursi.pro/card/psp–kolos–31124714
31. Proswitz, K., Edward, M. C., Evers, M., Mombo, F., Mpwaga, A., Näschen, K., Sesabo, J., Höllermann, B. (2021). *Complex socio-ecological systems: Translating narratives into future land use and land cover scenarios in the Kilombero catchment, Tanzania*. *Sustainability, 13*(12), 6552. https://doi.org/10.3390/su13126552
32. Qin, T., Wang, L., Zhou, Y., Guo, L., Jiang, G., Zhang, L. (2022). Digital technology-and-services-driven sustainable transformation of agriculture: Cases of China and the EU. *Agriculture, 12*(2), 297. https://doi.org/10.3390/agriculture12020297
33. Raman, S. (2024). *Agricultural sustainability: Principles, processes, and prospects*. CRC Press. https://doi.org/10.1201/9781003578352
34. Rehman, A., Farooq, M., Lee, D., Siddique, K. H. M. (2022). Sustainable agricultural practices for food security and ecosystem services. *Environmental Science and Pollution Research, 29*(56), 84076–84095.

https://doi.org/10.1007/s11356-022-23635-z

35. Samoichuk, K., Kiurchev, S., Oleksiienko, V., Palyanichka, N., Verholantseva, V. (2016). Research into milk homogenization in the pulsation machine with a vibrating rotor. *Eastern-European Journal of Enterprise Technologies, 6*(11-84), 16–21. https://doi.org/10.15587/1729-4061.2016.86974
36. Shahini, E., Shahini, E. (2025). Role of urban green spaces and tree plantations in improving ecosystem services and urban resilience. *Ukrainian Journal of Forest and Wood Science, 16*(2), 136-151. https://doi.org/10.31548/forest/2.2025.136
37. Shahini, E., Shahini, E., Doda, S. (2025). Forestry and rural development in Albania: Integrating forestry and agricultural practices for a sustainable future in the economy. *Ukrainian Journal of Forest and Wood Science, 16*(1), 128-148. https://doi.org/10.31548/forest/1.2025.128
38. Shahini, S., Mustafaj, S., Sula, U., Shahini, E., Skura, E., Sallaku, F. (2023). Biological Control of Greenhouse whitefly Trialeurodes vaporariorum with Encarsia formosa: Special Case Developed in Albania. *Evergreen, 10*(4), 2084–2091. https://doi.org/10.5109/7160868
39. Shahini, S., Skura, E., Huqi, A., Shahini, E., Ramadhi, A., Sallaku, F. (2024). Integrated Management of the Mediterranean Fruit Fly (*Ceratitis capitata*) on Citrus in the Konispol, Albania. *Grassroots Journal of Natural Resources, 7*(2), 324–346. https://doi.org/10.33002/nr2581.6853.070217
40. Sharma, V., Tripathi, A. K., Mittal, H. (2022). Technological revolutions in smart farming: Current trends, challenges, and future directions. *Computers and Electronics in Agriculture, 201*, 107217. https://doi.org/10.1016/j.compag.2022.107217
41. Shevchenko Agricultural Company. (2025). https://elevatorist.com/kompanii/627-agrofirma-im-shevchenka
42. Shi, H., Umair, M. (2024). Balancing agricultural production and environmental sustainability: Based on economic analysis from the North China Plain. Environmental Research, 252, 118784. https://doi.org/10.1016/j.envres.2024.118784
43. Shumka, S., Shumka, L., Trajce, K., Ceci, S. (2020). First record of the Western Greece goby - Economidichthys pygmaeus (Holly, 1929), in Greater Prespa Lake (Albania). *Ecologica Montenegrina, 35*, 78–81. https://doi.org/10.37828/EM.2020.35.6
44. Shumka, S., Sulçe, S., Brahushi, F., Shumka, L., Hyso, H. (2021). Biomass energy for productive use in the olive oil and other agriculture sectors in Albania. *Proceedings on Engineering Sciences, 3*(1), 103–110. https://doi.org/10.24874/PES03.01.010
45. Silvestri, C., Silvestri, L., Piccarozzi, M., Ruggieri, A. (2022). Toward a framework for selecting indicators of measuring sustainability and circular economy in the agri-food sector: A systematic literature review. The International Journal of Life Cycle Assessment, 29(8), 1446–1484. https://doi.org/10.1007/s11367-022-02032-1
46. Skliar, I., Skliar, V., Sherstiuk, M., Zubtsova, I. (2023). Dimensional characteristics of Nymphoides Peltata (S.G. Gmel.) Kuntze in different ecological and cenotic conditions of the basin's water bodies Desna River (Ukraine). *International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, 23*(3.2), 103–110. https://doi.org/10.5593/sgem2023V/3.2/s12.13
47. State Agricultural Register. (2025). https://dar.gov.ua/
48. State Soil Protection Agency. (2025). Soil testing methodology. https://www.iogu.gov.ua/literature/soil/1–%D0%92%D0%B8%D0%BF%D1%83%D1%81%D0%BA%20%E2%84%96%201%20% 282014%29.pdf
49. State Statistics Service of Ukraine. (2025). https://ukrstat.gov.ua/
50. Yeraliyeva, Zh. M., Kunelbayev, M., Ospanbayev, Zh. O., Kurmanbayeva, M. S., Kolev, T. P., Kenesbayev, S. M., Newsome, A. S. (2016). The study of agricultural techniques of cultivation of new varieties of winter wheat under drip irrigation. *Asian Journal of Microbiology, Biotechnology and Environmental Sciences, 18*(3), 781–787.
51. YouControl – Analytical platform for business. (2025). https://youcontrol.com.ua/
52. Yu, D., Wang, Y. (2024). Ecological agriculture farming models and associated technologies: Current status and prospects. Agricultural Research & Reviews, 4(3), 402–429. https://doi.org/10.50908/arr.4.3_402
53. Zhukovskyy, V., Sverstiuk, A., Sydoruk, B., Zhukovska, N., Sverstiuk, S. (2022). Analysis and prediction of humus balance in soils of Ukraine using informational tools. CEUR Workshop Proceedings, 3309, 17.
54. Zubtsova, I., Skliar, V. (2023). Population analysis of medicinal plants of the floodplain of the Seim River (Sumy Region, Ukraine). *International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, 23*(3.2), 187–194. https://doi.org/10.5593/sgem2023V/3.2/s12.24
55. Zubtsova, I., Penkovska, L., Skliar, V., Skliar, I. (2019). Dimensional features of cenopopulations of some species of medicinal plants in the conditions of North-East Ukraine. *AgroLife Scientific Journal, 8*(2), 191–201.