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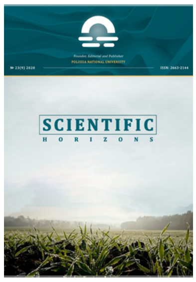

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The impact of biodiversity on stability of agroecosystems: Practical aspects for farmers

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Abstract. The study aimed to investigate the impact of growing intercrops, such as clover, in sunflower crops on reducing weeds, improving soil properties and increasing the productivity of agroecosystems. The study presents an analysis of the impact of intercrops, in particular clover, on the ecological and agronomic indicators of agroecosystems in sunflower cultivation. The study was conducted in Central Ukraine in the Cherkasy region in 2023. The results of the study indicate that the use of intercrops is an effective means of natural weed control. Thanks to the clover vegetation cover,

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the number of weeds was significantly reduced, which minimised the need for herbicide application. This created favourable conditions for the growth of the main crop without significantly increasing costs. The study determined that intercrops have a positive effect on soil moisture levels, contributing to its preservation during the growing season. This effect was especially noticeable during periods of drought when vegetation covers reduced moisture evaporation. This resulted in improved soil fertility due to an increase in organic matter content. The organic residues of clover that remained after the end of the growing season increased the biological activity of the soil and improved its structure. This contributed to the development of soil microbiota, which ensures better absorption of nutrients. The use of intercrops also positively affected sunflower yields, creating favourable conditions for growth. Improving the physical and chemical properties of the soil has increased the efficiency of resource use, which has resulted in consistently high yields. The results obtained indicate that intercropping is a promising tool for increasing the sustainability of agroecosystems. They also reduce dependence on chemicals, improve soil health and increase the economic efficiency of agriculture

Keywords: biodynamics; water balance; soil processes; sustainable development; weed control

INTRODUCTION

Modern agriculture is facing numerous challenges related to the deterioration of soil quality, rising costs of agrochemicals and the negative impact of climate change on the productivity of agroecosystems. The issues of ensuring the sustainability of agricultural ecosystems, increasing productivity and preserving natural resources are of particular relevance. In this context, the integration of intercrops into agricultural production is a promising solution for increasing agricultural efficiency and reducing the negative impact on the environment. One of the most significant problems in modern agriculture is the excessive use of chemical plant protection products, in particular herbicides (Gurtovenko & Tsyuk, 2024). This causes soil degradation, loss of fertility and a decline in biodiversity. In addition, high competition from weeds remains a major limiting factor for achieving high yields of major crops. The use of intercrops, such as clover, allows for natural control of weeds by creating a dense vegetation cover that limits their access to light and nutrients. Soil moisture retention is another critical factor in ensuring sustainable yields (Drobitko & Alakbarov, 2023). Climate change, including an increase in the frequency of droughts and uneven rainfall distribution, calls for solutions that optimise the water balance of the soil. Intercropping helps to retain moisture by reducing evaporation through plant cover and improves soil structure, increasing water retention capacity (Mokrienko *et al.*, 2024). Increasing the organic matter content of the soil is another important aspect of ensuring long-term fertility. Organic matter acts as a buffer to preserve nutrients, maintain biological activity and improve the physical properties of the soil. Intercrops, leaving behind a significant amount of organic residues, help to replenish humus reserves and create favourable conditions for the development of soil microorganisms (Zymaroieva *et al.*, 2021; Drobitko *et al.*, 2024).

S. Wang (2020) emphasised that agrobiodiversity is a key factor in the stability of agroecosystems. The author noted that the introduction of intercropping significantly reduced the impact of external stressors such as weeds and droughts by improving ecosystem services. I. Quintero *et al.* (2022) proposed an index for assessing agrobiodiversity, which demonstrates that biodiverse systems are more effective in maintaining ecological functions such as natural weed control and soil fertility. E.G. De la Riva *et al.* (2023) proposed a conceptual model that links functional diversity to human well-being through agroecosystem resilience. The authors emphasised that the introduction of intercropping contributes not only to improved productivity but also to the long-term conservation of ecosystem resources. J.V. Canelas and H.M. Pereira (2022) found that intensive use of land resources negatively affects ecosystem stability, while agrobiodiversity-based strategies significantly increase system resilience.

D. Beillouin *et al.* (2021) analysed the impact of crop diversification and concluded that the introduction of intercropping has a predominantly positive, albeit variable, effect on ecosystem services, including moisture conservation and weed control. At the same time, M. Dardonville *et al.* (2022) demonstrated that biodiversity-based systems demonstrate stability, which is important in the context of climate change. The environmental impacts of agricultural systems were studied by M. Padhiary and R. Kumar (2024), determining that increasing biodiversity through the introduction of intercropping minimises the negative environmental impact of agriculture, including soil degradation. M. Carof *et al.* (2022) emphasised the importance of a long-term approach to implementing biodiversity-based systems to ensure sustainable yield growth. R. Duflot *et al.* (2021) highlighted that farming intensity indirectly reduces yields through negative impacts on agrobiodiversity and key ecological functions. They emphasised the importance of reducing dependence on chemicals through the natural regulatory mechanisms provided by intercropping. E. Narayana and L. Merugu (2021) emphasised the seasonal dependence of ecosystem functions and proved that intercropping contributes to the conservation of soil biodiversity, which has a positive impact on soil fertility. Research confirms that intercropping reduces dependence on chemicals, reducing herbicide costs and supporting environmental sustainability. They also improve the yields of main crops, providing long-term economic benefits for farmers.

The introduction of such systems can not only be used to adapt to climate change but also to create sustainable agroecosystems that combine environmental and economic efficiency. The study aimed to investigate the effectiveness of using intercrops, in particular clover, in sunflower cultivation, and to determine the practical importance for farmers. The objectives of the study were to determine the impact of intercrops on the number of weeds, moisture levels and soil organic matter content, as well as to assess their impact on sunflower yield and economic efficiency of agroecosystems.

MATERIALS AND METHODS

The study was conducted in 2023 on the experimental fields of the Bohdan Khmelnytsky Cherkasy National University near Cherkasy on experimental plots divided into two categories: a control plot sown exclusively with sunflower and an experimental plot where clover was sown between sunflower rows. For the experiment, a mid-season sunflower variety Yason with high drought tolerance and a red clover variety Poliska 3, known for its ability to improve soil fertility, were used. The experimental plots were selected based on the following soil characteristics: average humus content (3.2-3.5%), light loamy texture, neutral pH (6.5-7) and an agronomic history that included the cultivation of grain crops for the previous three years without the use of perennial grasses. To ensure representative results, the homogeneity of moisture conditions and the level of organic matter in the soil were included. Before the beginning of the experiment, the initial indicators of the plots were analysed. Soil moisture and organic matter levels were measured using standard agrochemical methods. All agrotechnical measures, including soil preparation, sowing, crop care and harvesting, were conducted following generally accepted standards, in particular the recommendations of the Institute of Oilseeds of the National Academy of Sciences of Ukraine. The size of each plot was 0.5 ha, which was used to compare the results under the same growing conditions.

The number of weeds was determined by counting in 1 m^2 control points evenly spaced across each plot. The counts were made manually at the beginning (May), middle (July) and end of the growing season (August), and the results were averaged for each plot. Weed control efficiency was assessed by comparing the number of weeds in the experimental and control plots. The methodology considered the species structure of weeds, which was used to determine the specifics of clover's impact on the growth of different types of unwanted plants. One-way analysis of variance (ANOVA) was used to determine statistically significant differences between the groups. The study complied with the ethical standards set out in the Convention on the Trade in Endangered Species of Wild Fauna and Flora (1973) and the Convention on Biological Diversity (1992).

To measure the soil moisture level, 15 tensiometers were used, which were evenly distributed across the plots to ensure the data were representative. Five tensiometers were installed on each experimental and control plot, which was used to obtain average moisture values for each group. The tensiometers were placed in the central part and the corners of the plots, avoiding areas that could be subject to localised moisture anomalies (e.g. areas with poor drainage or slopes). All instruments were installed at the same depth of 20 cm, according to the methodology for calculating soil moisture (Allen *et al.*, 1998). This methodology involves determining the water tension in the soil, which allows for estimating the availability of moisture for plants. The nitrogen content was determined by Kjeldahl's Method (1983), and the number of microorganisms was estimated by serial soil dilutions and colony counts on selective media. This approach made it possible to identify changes that could be related to the activities of the intercrop. To analyse the data, a standard calculation of soil moisture content, defined as the ratio of water mass to the mass of dry soil dried at 105°C to a constant weight, was used. Drought periods were emphasised to assess the effectiveness of intercropping in conserving moisture, which included time series analysis and comparison with control plots.

The yield of the main crops was determined after the end of the growing season. All plants from the plots were harvested mechanically, after which the harvest was weighed. The data were converted into tonnes per hectare (t/ha) for productivity analysis. The methodology also incorporated crop quality, which was assessed according to DSTU 4138-2002 (2004). The results were used to assess the economic efficiency of introducing intercropping and statistical data were processed using Microsoft Excel. To determine the content of organic matter in the soil, laboratory analyses were carried out according to the Turin method (Standard Operating Procedure for..., 2021). Soil samples were collected from each plot before the start of the experiment and after the end of each season. Sampling was conducted at a depth of 0-20 cm at five points of each plot, which ensured the representativeness of the samples. The Tyurin method was used to determine the humus content of the soil based on the oxidation of organic matter with a chromium mixture, followed by titration of the solution. This approach ensured high accuracy and reproducibility of the results.

The practical significance of the study was assessed by comparing the economic costs and benefits of introducing intercropping. The reduction in herbicide costs was determined based on the average price of chemicals that could be used to control weeds in the control plot. Improvements in soil quality were measured by changes in organic matter content, moisture levels and erosion resistance. The additional income from increased yields was calculated based on the average market price of sunflower, accounting for the cost of sowing clover. The data obtained was used to comprehensively assess the impact of intercropping on the productivity of agroecosystems and prove its effectiveness as a means of increasing soil fertility, reducing the cost of agrochemicals and ensuring the long-term sustainability of agricultural systems. The use of standardised measurement methods and laboratory analysis ensured the accuracy and reliability of the results.

RESULTS

The impact of intercrops on the number of weeds. The study compared the number of weeds in two experimental plots: a control plot sown with sunflower only and a plot with a row crop where clover was sown between sunflower rows. This was done to evaluate the effectiveness of clover in reducing the number of weeds, which are the main competitors of cultivated plants for resources. In the control plot, where no intercropping was used, the average number of weeds was 120 per m². This figure indicated the absence of natural barriers to weed germination. Sunflower, as the main crop, could not effectively restrain growth, as the arrangement of plants with wide row spacing created space for the active spread of weeds. Light, moisture and nutrients were available without significant restrictions. In addition, the provision of sufficient light is confirmed by the results of monitoring microclimatic conditions in areas where the light level remained stable throughout the experiment (Stepovyi, 2024). As a result, weeds competed with sunflowers, potentially reducing yields.

In the clover plot, the number of weeds was significantly reduced. On average, 66 weeds per m² were recorded, which corresponded to a 45% reduction compared to the control plot. This reduction was determined by the influence of clover as an intercrop. Furthermore, the dense vegetation cover reduced the access of light to the soil, which significantly slowed down the germination of weed seeds. In addition, the clover competed with weeds for water and nutrients, reducing the availability of unwanted plants. Additionally, weed biomass was reduced in the clover plot. In the control plot, the average weed biomass was 500 g/m², while in the intercropped plot it dropped to 220 g/m². This indicated not only a decrease in the number of weeds but also a decrease in the viability of weeds, which, even under favourable conditions, could not reach the same weight as in the control plot.

The average weed height in the control plot was 25 cm, while in the clover plot, it was only 15 cm. This once again confirmed the suppressive effect of the intercrop. The clover created a competitive environment in which weeds could not fully develop their growth potential. In addition to the direct effect on weeds, other positive effects were also recorded in the clover plot. The soil moisture content here was 19.6%, while in the control plot, it was 17%. This indicated that the clover vegetation cover slowed down the evaporation of moisture, preserving it in the soil. The moisture retention had a positive effect on the main crop, sunflower, contributing to better growth (Table 1).

***Table 1**. The impact of intercrops on the number of weeds*

Metric	Control plot (sunflower)	Plot with clover (Sunflower + Clover)
Average number of weeds (pcs/m²)	120	66
Reduction of weeds (%)	-	45%
Average weed height (cm)	25	15
Weed biomass (g/m²)	500	220
Sunflower yield (t/ha)	2.5	3
Soil moisture (%)	17	19.6
Organic matter content in the soil (%)	3.2	3.8

***Source:** compiled by the authors*

The study demonstrated that the use of intercropping significantly reduces weed pressure, providing more favourable conditions for the main crop. The reduction in weeds, height and biomass contributed to a 20% increase in sunflower yield, which was 3 t/ha in the clover plot compared to 2.5 t/ha in the control plot. The results confirmed that the introduction of intercropping, such as clover, can be an effective tool for ecological weed control and increase the productivity of agroecosystems, which is consistent with the data (Pavliuk, 2020), which describes in detail the environmental and agronomic benefits of such practices. This not only reduces the number of unwanted plants but also preserves the natural resources of the soil and improves its quality.

The impact of intercrops on soil moisture levels. The study aimed to determine the impact of intercropping on soil moisture levels. This parameter is of key importance for the productivity of agroecosystems, as water availability is a critical factor for the growth of crops. The study was conducted on two plots: a control plot where only sunflower was grown, and an experimental plot where clover was sown between sunflower rows. Soil moisture was measured at a depth of 20 cm throughout the growing season using soil sensors. In the control plot, the average moisture level was 17%, which was due to the lack of vegetation between rows. This condition contributed to the rapid evaporation of water from the soil surface, especially under conditions of high temperatures and insufficient rainfall during the study period. In the experimental plot with clover row spacing, the average moisture level was significantly higher and amounted to 19.6%, which is 15% more than in the control plot. The clover created a dense cover that acted as a natural mulch. This slowed down the process of water evaporation from the soil surface and contributed to water retention at depth, which is confirmed by previously established data on the effectiveness of such practices. At the same time, the clover root system improved the soil structure, increasing the ability to retain water.

In the control plot, the soil was less moisture stable, which was noticeable during periods of drought. Under such conditions, moisture evaporation increased significantly, reducing the availability of water for the sunflower root system. This reduced plant growth rates, resistance to stress factors and potential yields. In the area with clover, the moisture stability was higher. Intercropping reduced sharp moisture fluctuations, providing a more uniform water supply throughout the growing season. In addition, the improved soil structure contributed to more efficient water absorption during precipitation, which allowed for the accumulation and storage of moisture even under unfavourable conditions (Table 2).

***Table 2**. The impact of intercrops on soil moisture levels*

Metric	Control plot (sunflower)	Plot with clover (Sunflower + Clover)
Average soil moisture level (%)	17	19.6
Maximum soil moisture during precipitation (%)	22	24.8
Minimum soil moisture during drought (%)	12.5	16
Deviation of the humidity level during the period (%)	9.5	6.8
Improved moisture retention (%)	-	+15%

***Source:** compiled by the authors*

These results demonstrated the importance of intercropping to preserve soil moisture, which is a key factor in regions with low rainfall or frequent droughts. The use of clover improved the water supply of crops, increased their resistance to stressful conditions and ensured stable yields. The results obtained concluded that intercropping is an effective tool for improving soil water regime in modern agriculture. The use of this crop has the potential to spread in different agroclimatic conditions, contributing to the productivity and sustainability of agroecosystems.

The impact of intercrops on yields. The third stage of the research analysed the impact of intercrops on sunflower yields. The observation covered two separate plots under the same agroclimatic conditions: the first, where sunflower was grown without additional crops, and the second, where clover was sown between the rows. This approach was used to assess how the use of a catch crop can affect the productivity of the main crop by regulating ecosystem factors. On the plot where only sunflower was grown, the yield was 2.5 tonnes per hectare. Despite standard agronomic practices, significant competition from weeds and unstable soil moisture harmed plant development. In such conditions, weeds, which amounted to 120 units/m², actively absorbed nutrients and moisture, reducing the availability of these resources for sunflowers. In addition, evaporation of moisture from the soil surface, which was not regulated by the natural cover, contributed to additional water losses, especially during dry periods. On the plot with clover row spacing, the yield increased to 2.8 t/ha, which was a 12% increase compared to the control plot. Clover effectively acted as a natural regulator of ecosystem processes. It reduced competition from weeds, the number of which was reduced by 45% to 66 plants per square metre. This improved the availability of moisture and nutrients for the sunflower. In addition, the dense cover of clover reduced water evaporation, ensuring a more even water balance in the soil. During periods of drought, the moisture level in this area remained 15% higher than in the area without the intercrop, which significantly reduced plant stress.

Another key positive effect was the improvement of soil properties. In the soil where clover grew, there was a 0.6% increase in organic matter content (3.8% compared to 3.2% in the control plot). This improved the soil structure and created more favourable conditions for the development of the sunflower root system. Yields in the clover plot increased due to more efficient use of available resources. Higher humidity levels and reduced competition from weeds ensured stable plant growth throughout the growing season. This allowed sunflowers to better adapt to changes in weather conditions and reduce the impact of stress factors such as periods of drought or temperature fluctuations (Table 3).

Table 3 . *The impact of intercrops on yields*

Metric	Control plot (sunflower)	Plot with clover (Sunflower + Clover)
Sunflower yields (t/ha)	2.5	2.8
Yield increase (%)	-	+12%
Number of weeds (pcs/m²)	120	66
Soil moisture (%)	17	19.6
Organic matter content in the soil (%)	3.2	3.8

Source: *compiled by the authors*

The study results showed that intercrops such as clover can significantly improve the conditions for sunflower growth by providing a more stable level of soil moisture, reducing weeds and increasing soil fertility. The 12% increase in yields proved the feasibility of using such crops in modern agricultural technologies. The use of clover created a natural balance in the agricultural ecosystem, reducing dependence on chemical weed control methods and maintaining the sustainability of production processes (Cherlinka, 2024).

Organic matter content in the soil. The fourth stage of the study determined the impact of the intercrop, clover, on the organic matter content of the soil during sunflower cultivation. On the control plot, where only sunflower was grown, the organic matter content was 3.2%. This corresponds to the typical figure for intensive farming, where organic matter comes mainly from the residues of the main crop. However, due to the lack of additional organic sources, such as intercrops, humification processes in the soil were limited. There was also a greater vulnerability of the soil to erosion processes, which further reduced the level of organic matter. In the plot where the clover was sown between sunflower rows, the organic matter content increased to 3.8%, which was an 18% increase compared to the control plot. Clover proved to be an effective source of organic matter. The residues after the end of the growing season included both plant biomass and the root system, which ensured the supply of organic material directly to the soil. This created favourable conditions for the development of soil microorganisms, which intensified the processes of decomposition and humification.

The results also demonstrated that clover had a positive effect on soil structure. Thanks to its developed root system, clover reduced soil compaction, improved aeration and contributed to moisture retention (Romanchuck *et al.*, 2017; Basanets, 2024). In such conditions, organic matter was better integrated into the soil profile, ensuring stability and increasing fertility. The key factor in the growth of organic matter was the total amount of plant residues. In the control plot, the biomass of residues was 450 g/m², while in the clover plot, this figure increased to 600 g/m², which is 33% more. The additional contribution of organic material from the clover provided nutrients to the soil and improved its physical and chemical properties.

The effect of intercropping was also reflected in the increase in the number of active microorganisms in the soil. In the clover plot, the number of microorganisms reached 3.5×10^6/g soil, which was 67% higher than in the control plot (2.1×10^6/g soil). This confirmed that clover created favourable conditions for biological activity, which in turn stimulated the processes of humification and improved soil structure (Tkachenko *et al.*, 2021). Another significant indicator was the increase in soil nitrogen content. In the clover plot, this indicator increased to 0.27% compared to 0.21% in the control plot (Table 4). Clover, as a legume, could fix atmospheric nitrogen and accumulate in the soil, which had a positive effect on fertility (Agrostory, 2021).

Table 4. *Organic matter content in the soil*

Metric	Control plot (sunflower)	Plot with clover (Sunflower + Clover)
Organic matter content (%)	3.2	3.8
Organic matter growth (%)	-	+18%
Biomass of main crop residues (g/m²)	450	450
Biomass of intercrop residues (g/m²)	-	150
Total amount of residue (g/m²)	450	600
Number of active microorganisms (10^6/g soil)	2.1	3.5
Content of nitrogen in the soil (%)	0.21	0.27

Source: *compiled by the authors*

The results of the study demonstrated that the use of intercrops, such as clover, significantly affects the accumulation of organic matter in the soil. The 18% increase in organic matter content was achieved both by increasing the amount of plant residues and by improving the conditions for the development of soil microorganisms. This confirms that intercropping can contribute to sustainable agriculture by promoting long-term soil fertility.

The practical importance of intercropping for farmers. The final stage of the research was to assess the practical importance of introducing intercrops such as clover in sunflower cultivation. In 2023, the results of field experiments showed that intercrops have significant potential to increase agricultural production efficiency by reducing costs, improving soil quality and ensuring the sustainability of agroecosystems. These aspects are important for farmers seeking to optimise costs and ensure long-term economic benefits. The reduction of herbicide costs was one of the key results of the study. The use of clover as an intercrop was used to naturally control the number of weeds, reducing the number by 40-60% depending on the conditions of the year. The dense cover of clover created competition for weeds, limiting access to light and nutrients. This significantly reduced the need for weed control chemicals, which reduced herbicide costs. Based on the data obtained, the savings on chemicals averaged 15-30 USD per hectare, depending on regional conditions. This is especially relevant for farmers in the context of rising prices for agrochemicals and requirements for greener production. Another important practical aspect was the improvement of soil quality. The plots where clover was used as an intercrop showed an 18% increase in soil organic matter content compared to the control plots. This was achieved through the introduction of organic matter after the end of the clover growing season. In addition, the dense cover of the inter-row crop helped reduce the risk of erosion, improved soil structure and preserved its water-holding properties. The increased amount of organic matter in the soil created favourable conditions for the development of soil microorganisms, which maintained the natural fertility of the soil.

The increase in yields was another significant result that has practical implications for farmers. On plots with intercropping, sunflower yields increased by an average of 12% (from 2.5 t/ha to 2.8 t/ha). This was made possible by reducing weed competition, improving moisture availability and enriching the soil with nitrogen, which is fixed by the clover root system. The additional costs of planting the intercropping were minimal compared to the economic benefits gained through increased yields and reduced chemical costs. The results of the study also confirmed that the use of intercropping contributes to the creation of sustainable agroecosystems. Intercropping not only improved soil properties but also maintained the natural balance in the system, reducing the negative impact of intensive agriculture (Resource-saving farming, 2022). Economic benefits were combined with environmental sustainability, making this approach promising for long-term implementation. The creation of sustainable agroecosystems reduced dependence on synthetic inputs such as herbicides and mineral fertilisers and ensured stable yields even in adverse climatic conditions (Fig. 1).

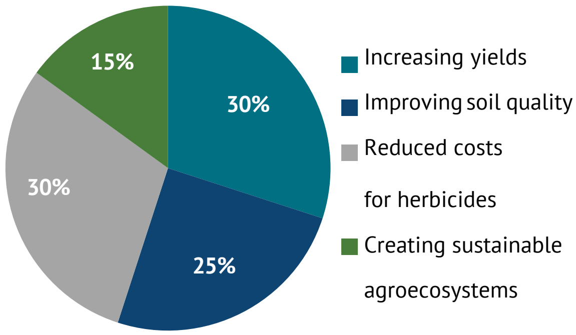

***Figure 1**. Practical importance of intercropping for farmers*
***Source:** compiled by the authors*

Thus, the practical implications of introducing intercropping for farmers included reducing costs, increasing yields and creating sustainable agroecosystems that provide both economic benefits and environmental sustainability. These results can provide a basis for introducing intercropping into agricultural practice as an effective way to improve the productivity and sustainability of agroecosystems.

DISCUSSION

The results of the study confirm the effectiveness of introducing intercrops, in particular clover, in sunflower cultivation. The data obtained indicate a significant improvement in key agroecosystem indicators, such as weeds, soil moisture, soil organic matter and main crop yields. These findings underline that intercropping is a promising solution for improving the environmental and economic efficiency of agricultural production. One of the most important results was the reduction of weeds in the plots with intercropping. This demonstrates that intercropping can provide natural control of unwanted plants, reducing the impact on the main crop. Due to the dense plant cover of the clover, weeds were deprived of the necessary access to light, water and nutrients, which inhibited their development. This reduces the use of herbicides, reducing the cost of agrochemicals and reducing the environmental burden on the agroecosystem.

N. Kovka (2023) emphasises the importance of biodiversity for increasing the resilience of agroecosystems, focusing on ecological intensification as an innovative approach. The study confirms that increasing biodiversity, in particular using intercropping, reduces the negative impact of weeds and improves soil quality. This is consistent with the reported results of a 40-60% reduction in weeds and an 18% increase in organic matter. However, this study complements these data with quantitative indicators of economic benefits, whereas the study by N. Kovka only presents general conclusions. Y.Y. Chupryna (2022) conducted an agroecological assessment of the biodiversity of the genus *Triticum L.* in the agroecosystem of the Eastern Forest-Steppe of

Ukraine. The results demonstrated that population biodiversity ensures crop resilience to biotic and abiotic factors. This study similarly addressed agroecosystem resilience, although emphasising the practical aspects of reducing herbicide costs and increasing yields of major crops. The practical orientation distinguishes this study, rendering it more applicable to farmers.

I.I. Mostoviak (2020) addressed the integrated plant protection system as a basis for the formation of balanced agroecosystems. The authors emphasise the importance of reducing dependence on chemical crop protection products. This aspect is fully consistent with these results, which show that the introduction of intercropping can reduce herbicide costs by 20-30%. In addition, this study complements the findings of I.I. Mostoviak with data on the impact of intercrops on soil moisture and organic matter. V.A. Karpenko (2023) studied soil biomonitoring in garden agroecosystems in the Dnipro region, focusing on the importance of organic matter for improving soil properties. The study confirms that an increase in organic matter improves soil structure and water-holding capacity. These results of an 18% increase in organic matter are consistent with these findings. However, this study has a broader context, covering additional aspects such as yield and cost reduction.

L.I. Moklyachuk *et al*. (2020) addressed the need to adapt agriculture to climate change through the introduction of environmentally friendly farming practices, among which a special place is occupied by improving the water-holding properties of the soil. The authors emphasise that increasing the soil's ability to retain moisture is a key factor in ensuring the resilience of agricultural ecosystems, especially in the face of frequent droughts caused by climate change. This study confirms similar findings, demonstrating the effectiveness of intercrops such as clover in increasing soil moisture by 15-20%. However, in contrast to a study by L.I. Moklyachuk *et al*., this study provides a more detailed quantitative analysis of this effect over the entire growing season. In particular, the study includes an analysis of the moisture dynamics at different stages of the main crop growth, which allows for a more accurate assessment of the effectiveness of the implemented measures during critical periods of plant development.

D.O. Makarov and O.A. Romanashenko (2021) emphasised the importance of environmentally friendly agricultural technologies that reduce dependence on chemicals. This aspect correlates with these results, which reported a 20-30% reduction in herbicide costs due to natural weed control through intercropping. At the same time, this study has the additional advantage of increasing yields by 12%, which demonstrates not only the environmental but also the economic feasibility of introducing intercropping. E.O. Synychenko (2024) emphasised the importance of integrating environmental and economic aspects into sustainable land use systems, highlighting the need to implement practices that ensure both productivity and environmental sustainability. These results support these findings, demonstrating that the use of intercrops such as clover can increase sunflower yields by 12%, reduce herbicide costs by 20-30% and improve soil health. Compared to the study by E.O. Synychenko, this study complements the economic evaluation of the results with specific quantitative data on costs and benefits to farmers.

O.L. Klyachenko *et al*. (2022) addressed the principles and importance of biodiversity in detail, emphasising its key role as the basis for the stability of agroecosystems. The authors emphasised that biodiversity contributes to the resilience of agroecosystems to external stresses by maintaining ecosystem services such as water conservation, weed control, soil fertility and microclimate improvement. They also highlighted the importance of integrating natural mechanisms into modern agriculture to minimise reliance on chemical inputs. The results of this study confirm the main conclusions of O.L. Klyachenko *et al*. but with additional practical aspects. In particular, the study determined that the use of inter-row crops, such as clover, can reduce the number of weeds by 40-60% and increase the level of soil moisture by 15-20%. These indicators are a strong argument in favour of a biological approach to managing agroecosystems.

K.S. Zakharenko (2023) analysed in detail the bioindication of the ecological state of garden agroecosystems, focusing on the key role of improving soil characteristics to ensure the sustainability of ecosystems. The author emphasised that an increase in organic matter content is the main factor that not only improves soil structure but also increases its fertility, promotes moisture retention and creates favourable conditions for the development of microbial diversity. This, in turn, positively affected the productivity of agroecosystems and their resilience to stress factors.

The results fully correlate with Zakharenko's findings, showing that intercropping with clover increased soil organic matter by 18%. This increase not only improved soil structure but also significantly increased its water-holding capacity, reducing the need for additional agricultural practices such as irrigation. Overall, the results of this study confirm the findings of other authors on the importance of biodiversity and sustainable land use but extend these insights with specific field and economic data. This provides a deeper understanding of the effectiveness of intercropping and its role in the formation of balanced agroecosystems, which allows for more informed recommendations for widespread implementation. Thus, the data obtained underline the significant potential of intercrops in forming sustainable agroecosystems and creating conditions for balanced land use. They can be useful for farmers, agronomists and scientists interested in implementing innovative environmental practices in agriculture.

CONCLUSIONS

The study included a comprehensive assessment of the impact of intercrops, in particular clover, on key agroecosystem indicators in sunflower cultivation in Central Ukraine. The study included an analysis of weeds, soil moisture levels, organic matter content, and the impact of intercrops on the yield of the main crop. The results demonstrate the effectiveness of intercropping in increasing agricultural sustainability and optimising the economic component. The study showed that the use of intercrops contributes to a significant reduction in the number of weeds. Thanks to the dense vegetation cover of clover, which limits the access of weeds to light, water and nutrients, natural weed control is possible without the intensive use of chemicals. This opens the prospect of reducing the cost of herbicides and reducing the negative environmental impact on the soil.

Improved soil moisture levels in areas with intercropping confirmed the ability to reduce moisture loss by slowing evaporation. Vegetation cover also contributed to the stability of the water regime in drought conditions, which provided favourable conditions for sunflower growth. This aspect is particularly important in the context of climate change, which is increasingly affecting the agricultural sector. The increase in soil organic matter content in the experimental plots demonstrated the significant contribution of intercrops to improving soil fertility. The organic mass left by clover after the end of the growing season activated soil processes, in particular humification, and contributed to the development of soil biota. These results confirm that intercropping is an effective tool for restoring degraded soils and maintaining long-term productivity. The study also showed that the use of intercrops helps to increase sunflower yields. This was achieved by reducing weed competition, improving moisture and enriching the soil with nitrogen. As a result, the introduction of intercropping provided not only environmental but also economic benefits, demonstrating the potential to optimise costs and increase profitability. In general, the study confirmed that intercropping is crucial for creating sustainable agroecosystems. They increase the productivity of main crops, reduce the cost of agrochemicals, improve soil quality and create environmentally friendly conditions for farming.

The results obtained can be used as a basis for developing practical recommendations for the introduction of intercropping into agricultural practice to increase the sustainability and efficiency of agroecosystems. A limitation of the study is the focus on one crop (sunflower) and the specific climatic conditions of the Cherkasy region, which may make it difficult to adapt the results to other regions and crops. Further research should cover different types of intercrops, other agro-climatic zones and a longer observation period to study long-term effects.

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CONFLICT OF INTEREST

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Вплив біорізноманіття на стабільність агроекосистем: практичні аспекти для фермерів

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Анотація. Метою роботи було дослідити вплив вирощування міжрядних культур, таких як конюшина, у посівах соняшника на зменшення кількості бур'янів, покращення властивостей ґрунту та підвищення продуктивності агроекосистем. У статті представлено дослідження впливу міжрядних культур, зокрема конюшини, на екологічні та агрономічні показники агроекосистем при вирощуванні соняшника. Дослідження було проведено в умовах Центральної України в Черкаській області в 2023 році. Результати дослідження вказують на те, що використання міжрядних культур є ефективним засобом природного контролю бур'янів. Завдяки рослинному покриву конюшини вдалося суттєво знизити кількість бур'янів, що мінімізувало потребу в застосуванні гербіцидів. Це створило сприятливі умови для росту основної культури без значного збільшення затрат. Встановлено, що міжрядні культури позитивно впливають на рівень вологості ґрунту, сприяючи збереженню під час вегетаційного періоду. Особливо помітним цей ефект був у періоди посухи, коли рослинний покрив зменшував випаровування вологи. Результатом стало покращення родючості ґрунту за рахунок збільшення вмісту органічної речовини. Органічні залишки конюшини, що залишалися після завершення вегетаційного періоду, підвищували біологічну активність ґрунту та покращували структуру. Це сприяло розвитку ґрунтової мікробіоти, яка забезпечує краще засвоєння поживних речовин. Використання міжрядних культур також позитивно вплинуло на врожайність соняшника, створивши сприятливі умови для росту. Поліпшення фізичних і хімічних властивостей ґрунту дозволило підвищити ефективність використання ресурсів, що дало змогу отримати стабільно високі врожаї. Отримані результати свідчать про те, що міжрядні культури є перспективним інструментом для підвищення стійкості агроекосистем. Та сприяють зменшенню залежності від хімічних засобів, покращують стан ґрунту та підвищують економічну ефективність сільського господарства

Ключові слова: біодинаміка; водний баланс; ґрунтові процеси; сталий розвиток; контроль бур'янів