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Semen Tanchyk

Doctor of Agricultural Sciences, Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
<https://orcid.org/0000-0002-4975-7720>

Oleksandr Pavlov

PhD in Agricultural Sciences, Associate Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
<https://orcid.org/0000-0002-7953-2696>

Antonina Babenko

PhD in Agricultural Sciences, Associate Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
<https://orcid.org/0000-0001-5102-3438>

Theoretical substantiation and development of ecologically friendly farming system in Ukraine

Abstract. Intensive farming has caused soil degradation, including the loss of humus, soil structure breakdown, compaction, and a decrease in both potential and effective fertility. Therefore, research into farming systems is highly relevant. In this regard, the purpose of this study is to scientifically substantiate, develop, and implement an ecologically friendly modern farming system under Ukrainian conditions. The primary methods used to determine the effectiveness of various farming systems and ensure the accuracy and reliability of experimental data were field, laboratory, and statistical methods. The study substantiated that an industrial farming system with the input of approximately 12.0 tonnes per hectare of crop rotation area of organic matter (8.0 tonnes per hectare of manure and 4.0 tonnes per hectare of plant residues) produces about 0.81 tonnes per hectare of humus, although 1.33 tonnes per hectare of it is mineralised, leading to a negative humus balance in the soil. The output of grain units in this system is 8.21 tonnes per hectare, feed units – 9.63, and digestible protein – 0.86 tonnes per hectare, with stability at 91.2% and profitability at 88.0%. The organic farming system, which includes the use of 24 tonnes per hectare of organic fertilisers and biological products to control weeds, diseases, and pests in agroecosystems, does not ensure a positive humus balance in the soil (-0.14 tonnes per hectare) and has significantly lower

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*Corresponding author



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productivity. The no-till system, which involves the application of 12 tonnes per hectare of organic fertilisers in the form of root and stubble residues, by-products of crop production, and mineral fertilisers during sowing and foliar feeding, ensures a positive humus balance (+0.12 tonnes per hectare) but has productivity levels comparable to the organic system. The ecological system provides stable, economically viable, and resource-adequate productivity of arable land, enhances the quality indicators of products, and preserves and restores soil fertility. It increased the output of grain units by 8.9%, feed units by 7.2%, and digestible protein by 8.1%, ensuring high stability at 94.1% and an increase in production profitability by 8.5% compared to the control. The materials in this study are of practical value for agricultural enterprises of various ownership forms and will serve as technological guidelines for the implementation of modern, ecologically safe, economically and energetically justified agricultural production.

Keywords: industrial farming; ecological farming; organic farming; no-till; productivity

INTRODUCTION

Objective and subjective factors, such as the growing global population, climate change, resource shortages, and agricultural land reduction and deterioration, significantly impact the production of high-quality and safe agricultural products. Conventional farming methods often lead to soil degradation, reduced fertility, and erosion. Developing ecologically preserving systems helps maintain and enhance soil fertility, ensuring the sustainable development of the agricultural sector. The further increase in the use of chemical industry products results in dangerous environmental consequences and significant economic losses. According to Y. Skliar *et al.* (2021), modern intensive farming is often accompanied by extensive use of chemical fertilisers and pesticides, contaminating water resources and soils. Ecologically preserving farming systems help reduce the chemical load on the environment, maintaining its ecological balance.

Research by J. Liebert *et al.* (2022) and J. Wright (2022) conducted in the USA and EU countries, indicates that the greening and biologisation of agriculture is the only way to improve the situation. However, there is a lack of comprehensive research on the greening of agriculture in Ukraine. Research and testing of the joint application of organic, mineral, and next-generation fertilisers under the conditions of the greening of agriculture are highly relevant. A. Rudinskienė *et al.* (2022) established that the basis of soil fertility is the formation, presence, and accumulation of organic matter. The content, quality composition, and nature

of the biochemical transformations of organic compounds in the soil determine its physical, physicochemical, and chemical characteristics, such as structure-forming capacity, water-air, thermal and technological properties, absorption capacity, composition and mobility of cations, buffering capacity, and reduction potential.

However, scientifically unsubstantiated farming has led to soil degradation and desertification, loss of fertility, natural biological properties, and buffer capacity. Over the last 100-120 years, the humus content in cultivated lands of Ukraine has decreased by twofold or more; in some fields, this decrease has been three to four times (Boyko *et al.*, 2019). A.M. Lishchuk *et al.* (2020) summarised that in the Odesa and Kherson regions, the areas of the organic agricultural land amount to 102.2 thousand hectares (3.93%) and 75.9 thousand hectares (2.95%), respectively, where grains, legumes, oilseeds, technical, vegetable, and melon crops are grown. Agroecological assessment of soils in the Kherson region revealed an imbalance of humus and nutrients, indicating a threat of fertility loss; therefore, measures are recommended to improve these indicators. According to O. Tarariko *et al.* (2021), 32% of arable land is affected by water erosion and 20% by wind erosion. In addition, acidic soils occupy 26%, saline soils 4.1%, and solonchaks 5.4% of arable land. This identifies Ukraine as one of the countries with the most intensive manifestation of the aforementioned degradation processes worldwide. R. Právělie (2021) found that aridity, wind and

water erosion, salinisation, loss of organic carbon, and vegetation degradation are among the top five global soil degradation processes and are critical for human well-being, sustaining life, and the stability of Earth's ecosystems.

V. Pinchuk & Yu. Podoba (2023) investigated that an untapped reserve for increasing agricultural crop yields in farming is the optimisation of plants' absorption of light energy, as the current utilisation coefficient of photosynthetically active radiation (PAR) under production conditions is only 1-2%, with theoretically possible values of 10-15%. Humus, as a global accumulator of assimilated solar energy, is the second most important indicator of energy use in agro-landscapes. During 2000-2021, the energy capacity of soils in Ukraine annually decreased by 11.0-39.9 GJ/ha. During this period, soils lost between 0.6 to 2.0 t/ha of humus annually. Therefore, 26.3 to 95.0 t/ha of manure must be applied annually to compensate for the organic matter lost from the soil.

Analysing the eco-economic aspects of soil fertility restoration, O.V. Khodakivska *et al.* (2017) indicate that with the prolonged use of agricultural lands under conditions of deteriorating ecological situation and intensifying soil degradation processes, the leading strategy of modern agriculture should be the preservation, restoration, and enhancement of soil fertility, prevention of degradation processes, which are important factors in ensuring high-yielding, competitive agricultural production and guaranteeing environmental and food security for the population.

In addressing these tasks, the greatest impact comes from farming systems. Therefore, the *purpose* of the study is to theoretically substantiate and develop a farming system that should include the efficient use of land and agro-climatic resources, the biological potential of plants, the enhancement of soil fertility, and the development and implementation of advanced technologies for growing all field crops.

MATERIALS AND METHODS

The study on farming systems was conducted during 2001-2020 on the experimental fields of the production unit of the National University of Life and Environmental Sciences (NULES) of Ukraine "Agronomic Research Station", located in the Right Bank Forest-Steppe of Ukraine and

part of the Bila Tserkva agro-soil region of Kyiv region. Geographic coordinates: latitude – 50° 06', longitude – 30° 11'. The groundwater level is at a depth of 5-6 metres. The soil of the experimental plots is represented by typical low-humus chernozem. The granulometric composition is coarse silty loam. In the 0-30 cm soil layer, the humus content at the beginning of these studies in 2001 was 4.00%. The mineral solid phase of the soil consists of 37% physical clay and 63% sand. The equilibrium bulk density of the soil is 1.16-1.30 g/cm³, and the wilting point moisture (WPM) is 10.8%.

A high content of total and available forms of nutrients characterised the soils. The content of available phosphorus by the Machigin method is 45-55 mg/kg of soil, available potassium by the Machigin method is 180-210 mg/kg of soil (DSTU 4114-2002, 2003), and available nitrogen forms are 31-40 mg/kg of soil. These described soils occupy about 55% of the soil cover of the Forest-Steppe zone of Ukraine. Thus, the soil conditions of the field research site were typical for the zone. The practical testing of the developed measures was conducted in farms in the Kyiv, Vinnytsia, and Cherkasy regions, where soil conditions are similar to those of the Agronomic Research Station of NUBiP Ukraine.

The climate of the location of the experimental sites is moderately continental. The calculated average long-term hydrothermal coefficient (HTC) for the agronomic research station of NUBiP Ukraine from 2001-2020 was 1.10, indicating that the area is classified as dry. Thus, during the period from 2001 to 2020, moisture was the limiting factor that restricted the productivity of field crops.

The study was conducted in a stationary experiment involving two short-rotation crop rotations typical for the Forest-Steppe zone under market conditions with the following crop sequences: (first crop rotation) peas-winter wheat-sugar beets-spring barley-corn for grain; (second crop rotation) soybeans-winter wheat-sunflowers-spring barley-corn for grain. The structure of sown areas and the set of crops in the rotations were developed according to the market demand for products, farm specialisation, and natural-economic conditions. The experiment included reviewing the

following farming systems: industrial (control), eco-friendly, organic, and no-till. Since 2000, the scientists of the Department of Agriculture and Herbiology of NULES of Ukraine have been developing and analysing these systems.

The content of the farming systems was composed according to resource provision with the goal of expanded reproduction of soil fertility. The control variant of the farming system was the model of industrial farming, where the resource provision of programmed arable land productivity involved applying 12 tons of organic fertilisers and 300 kg of active mineral ingredients ($N_{92}P_{100}K_{108}$) per hectare, along with intensive use of pesticides. The fertiliser rates (organic and mineral) were calculated to ensure a positive humus balance, considering the development of animal husbandry. The ecological index of this farming system was 25 (300/12), indicating its industrial chemical nature.

The ecologically friendly farming system was characterised by the prioritised use of organic fertilisers – 24 tonnes/ha (12 tonnes of manure, manure compost, poultry litter, etc., 6 tonnes of plant residues, 6 tonnes of post-harvest green manure). Mineral fertilisers were applied at a rate of 150 kg/ha of crop rotation area ($N_{45}P_{55}K_{50}$). Plant protection from harmful organisms (weeds, pests, disease pathogens) involved using chemical and biological preparations according to the ecologically economic damage threshold criterion. The ecological index of this farming system was 6.2 (150/24).

The organic farming system was based solely on the use of natural resources. Organic fertilisers were applied at a rate of 24 tonnes/ha of crop rotation area. Only mechanical and biological methods were used to control harmful organisms. The ecological index of this farming system was 0 (0/24), indicating complete biological farming. The no-till farming system involved applying 12 tonnes of organic fertilisers in the form of root and post-harvest residues, crop production by-products (straw, corn stalks, soybeans, and sunflowers), and post-harvest green manure crops. No organic fertilisers were applied. Mineral fertilisers were applied at a rate of 200 kg ($N_{90}P_{50}K_{60}$) for the planned yield of the cultivated crops. Intensive use of recommended pesticides was employed. The ecological index

for this farming system was 6.7 (200/14), indicating its chemical nature.

For all farming systems, organic fertilisers included manure, manure compost, poultry litter, non-commercial parts of the crop, and grown mass of post-harvest green manure. The rate of these fertilisers was calculated to ensure a positive balance of nutrients and humus, as well as the farm's ability to provide these types of organic fertilisers. Adherence to the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1973) was maintained during the study.

RESULTS AND DISCUSSION

The study results showed that at the beginning of the investigation of farming systems in 2001, the humus content in the 0-30 cm soil layer was 4.00%, while by 2020, it had decreased to 3.51%. Intensive farming over 20 years (intensive mechanical tillage; application of high rates of chemical substances – mineral fertilisers, pesticides, soil conditioners, growth stimulants, etc.) led to soil degradation – loss of humus, soil structure breakdown, compaction, and over time, reduced potential and effective fertility.

The industrial farming system is the most intensive and energy-consuming, and it involves using all suitable land for agricultural production. Fertilising the soil with only mineral fertilisers, applying growth stimulants, and chemical plant protection products is the simplest and most effective way to achieve high crop yields. However, this is the most dangerous and harmful method for consumers. It was established that the optimal ratio between applied organic and mineral fertilisers is disrupted in Ukrainian farming. From the period of peak agricultural intensity (1960s-1990s) to the present, the ratio of mineral to organic fertilisers ranged between 1:20 and 1:29. However, the ideal proportion is 15 kg of mineral fertiliser resources (f.r.) for every tonne of organic fertilisers. The industrial farming system is aimed at depleting the soil's potential fertility rather than its expanded reproduction, which is the main condition for the sustainable development of the industry. For example, the industrial farming system (Fig. 1) provides the addition of about

12.0 tons/ha of organic matter (8.0 tonnes/ha of manure and 4.0 tonnes/ha of plant residues). From this organic matter, about 0.81 tonnes/ha

of humus were formed, but 1.33 tonnes/ha of humus were mineralised, resulting in a negative humus balance in the soil.

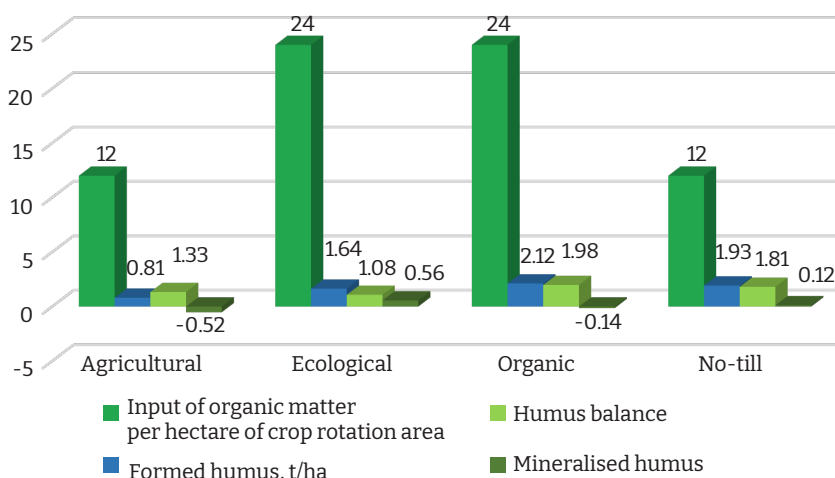


Figure 1. Influx of organic substances and humus balance in typical chernozem on 1 ha of crop rotation area, t (average for 2001-2020)

Source: developed by the authors

Such farming systems are feasible with high technical equipment of farms, sufficient quantities of organic and mineral fertilisers, means of protecting field crops from harmful organisms, high-quality seeds of high-yielding varieties and hybrids of agricultural crops, etc. Approximately 50% of all arable land in Ukraine should consist of such systems. Priority should be given to cereal, technical, and fodder crops within the structure of planting areas. Industrial farming systems should match the soil-climate potential of the specific zone and be soil-conserving and sustainable. However, the negative consequences of industrial farming may include increased energy and economic costs and the emergence of environmental problems (reduction of soil fertility, pollution of agricultural produce and the surrounding environment). Disruption of the NPK ratio in applied mineral fertilisers leads to agrophysical degradation of the soils, displacement of calcium ions and other divalent cations from the soil absorption complex, dispersion, and mineralisation of humus. The development of alternative farming systems, which are based on the ecological intensification of the industry, is one way to avoid these processes.

The proposed ecological farming system, which, along with the use of natural resources for soil fertility regeneration (organic fertilisers, green manures, by-products of plant production), does not exclude the normative application of mineral fertilisers and pesticides. It involves applying 24 tonnes/ha of organic fertilisers, which are 12 tonnes of manure, 6 tonnes of by-products, 6 tonnes of post-harvest green manure mass, and 150 kg of mineral fertilisers ($N_{45}P_{55}K_{50}$). Such a quantity of organic matter has enabled the formation of 1.64 tonnes/ha of humus. An organo-mineral fertilisation system promotes the least mineralisation of humus (at a level of 1.08 t/ha), leading to a positive balance of it in the soil (Fig. 1). To achieve bio-climatically justified yields (9.0-10.0 t/ha in feed units), the application of 150 kg/ha of active mineral fertiliser substances compensates for the deficiency of nutrients provided by organic fertilisers and from soil reserves. Hence, the ecological farming system ensures the enhanced reproduction of soil fertility.

The priority components of the system for protecting crops from harmful organisms in ecological farming are preventive, mechanical, and

biological control measures and, when necessary, the ecologically and economically justified use of chemical agents (pesticides). Technologies for the production and application of protective bio-preparations, which replace artificial pesticides that, along with harmful microflora and fauna, destroy up to 90% of beneficial ones, are becoming widely used. The regenerative resources of protective bio-preparations have high selectivity and are ecologically safe for growing cereals, technical, vegetable, and fruit crops; they are also used in greenhouses against weeds, pests, and diseases of agricultural crops, achieving technical efficiency of 60-80% and above.

These studies established the high effectiveness of differentiated variable-depth tillage by method and depth, which naturally increases soil fertility and exhibits high phytosanitary properties. This is achieved by ploughing once every 4-5 years for row crops and no-till practices in the periods between ploughings for other crops. Under such a system, the subsequent ploughing moves the more fertile, albeit less structured, top layer of soil, along with the beginnings of weeds, pests, and disease agents from the topsoil layer to the depth of its cultivation, where they remain for 4-5 years and primarily (90-95%) lose their viability. The next ploughing, prepared for 4-5 years, restores the structure of the soil layer, naturally clears it from weeds, pests, and disease agents, and moves it to the surface.

The ecological farming system in the country should occupy 25-30% of arable land with a priority on cultivating crops whose products undergo primary shallow processing and are used for human consumption (potatoes, cereal grains, peas, soybeans, lentils, chickpeas, buckwheat, millet, squash, medicinal, vegetable, and other crops). The application of industrial-origin substances (mineral fertilisers, chemical plant protection products (PPP), chemical growth stimulators, industrial ameliorants, etc.) is performed while adhering to the ecological-economic threshold criterion for the presence of harmful organisms. The ecological farming system should be environmentally safe, highly productive, soil-protective, conserving, and adaptive to the respective soil and climatic conditions of Ukraine.

However, the highest level of making agriculture eco-friendly is organic production

developed according to the laws of nature. Organic production models the natural process of soil formation. However, the removal of a significant portion of organic matter from the field through primary and secondary crop production necessitates increasing the rate of organic fertiliser application to maintain a positive humus balance and the possibility of developed livestock farming. The highest amount of organic matter added per hectare of arable land can reach up to 24 tonnes of organic fertilisers. This includes 12 tonnes of manure, 6 tonnes from non-commercial parts of cultivated crops, and 6 tonnes from the biomass of post-harvest cover crops, utilising various organic amendments such as manure composts and chicken manure. Furthermore, biological agents are applied to safeguard plants against harmful entities like weeds, pests, and pathogens. Under the influence of organic compounds released by the root system of plants, the intensified action of microorganisms and the absence of mineral fertilisers in the fertilisation system lead to enhanced mineralisation of humus, i.e., the conversion of the latter into minerals and mineral compounds. Mineralisation products are used by plants as nutrients, especially macronutrients – compounds of nitrogen, phosphorus, and potassium. According to the model of organic farming, the humus balance is negative and amounts to -0.14 t/ha per hectare of crop rotation area (Fig. 1).

In the no-till system, 12 tonnes of organic fertilisers come to 1 ha of crop rotation area in the form of root and post-harvest residues, secondary crop production (straw and stalks of cereal maize and sunflower) and post-harvest green manure crops. Organic fertilisers are not applied in the no-till technology. Such an amount of organic residues contributes to the formation of 1.93 t/ha of humus, while on average, about 1.81 t is mineralised per year, leading to a slightly positive balance of the latter (+0.12 t/ha).

The integral indicator of the effectiveness of farming systems is their productivity and, energy and economic efficiency. The productivity of individual crops and the crop rotation as a whole is an important indicator that enables a comparative assessment of crops from different biological groups and farming systems in general. Productivity is most often determined by the

output of fodder, grain, and fodder protein units and by the amount of energy that accumulates in a production unit.

According to the data in Table 1, the productivity of the ecological farming system in terms of grain and fodder units is not inferior to the

control variant – the industrial system. Moreover, it ensures a higher output of digestible protein by 10.4% in the first crop rotation and 8.1% in the second. The organic system and no-till have significantly lower productivity indicators compared to the control variant.

Table 1. Productivity of the studied agricultural systems and crop rotations (average for 2001-2020, yield from 1 hectare of crop rotation area, tonnes)

Agricultural systems	Performance indicators	Peas-winter wheat-sugar beet-spring barley-corn for grain	Soybean-winter wheat-sunflower-spring barley-corn for grain
Industrial (control)	Grain units	7.46	8.21
	Feed units	9.52	9.63
	Digestible protein	0.77	0.86
Ecological	Grain units	7.33	8.94
	Feed units	9.28	10.32
	Digestible protein	0.85	0.93
Organic	Grain units	4.98	5.37
	Feed units	5.46	7.05
	Digestible protein	0.53	0.59
No-till	Grain units	5.11	5.63
	Feed units	6.31	7.84
	Digestible protein	0.59	0.66

Source: developed by the authors

The results obtained convincingly demonstrate that ecological farming can achieve stable, bioclimatic, energetic, and economically justified productivity of arable land, improve the quality of crop production, and preserve and restore soil fertility (Table 2). On average, over two

crop rotations, the proposed ecological farming system provided an 8.9% higher yield of grain units, 7.2 feed units, and 8.1% digestible protein over twenty years of research, ensuring high stability at 94.1% and an 8.5% increase in production profitability compared to the control.

Table 2. Comparative assessment of the effectiveness of agricultural system models (average for 2001-2020)

Indicators	Industrial (control)	Ecological		Organic		No-till	
		Absolute values	± % to control	Absolute values	± % to control	Absolute values	± % to control
Grain units, t / ha	8.21	8.94	+8.9	5.37	-34,6	5.63	-31,5
Feed units, t / ha	9.63	10.32	+7.2	7.05	-26,8	7.84	-18,6
Digestible protein, t / ha	0.86	0.93	+8.1	0.59	-31,4	0.66	-23,3
Stability, %	91.2	94.1	+3.2	81.3	-10,9	85.2	-6,6
Adequacy of resource provision	0.90	0.92	+2.2	0.81	-10,0	0.83	-7,8
Profitability, %	88.0	95.5	+8.5	90.7	+3.1	92.3	+4.9
Protein content in wheat grains, %	14.3	14.1	-1,4	12.5	-12,6	12.7	-11,2
Gluten content in wheat grains, %	28.7	28.3	-1,4	24.7	-13,9	25.2	-12,2

Source: developed by the authors

The findings of the studies have been implemented in the crop rotations of the Agrofirma Kolos LLC in the Kyiv region during 2005-2020, which contributed to an increase in soil organic matter content by 0.44% (from 3.94% to 4.38%).

Similar studies have also been conducted by other foreign and Ukrainian scientists. V. Pichura *et al.* (2021) found that over the past 30 years, there has been a 62% decrease in the productivity of agricultural crops due to soil degradation, climate change, and inadequate use of modern agro-technologies. Measures are needed to improve the agroecological situation and implement innovative approaches in agriculture. T.O. Chaika *et al.* (2019) and N. Trusova *et al.* (2021) indicate that the implementation of intensive crop cultivation technologies, which included the use of industrial substances such as mineral fertilisers and pesticides, has negatively affected the ecological state of the environment, soil fertility, and the quality and safety of agricultural products. Overall, the potential of agro-landscapes in Ukraine is only utilised at 30-50% due to the violation of ecological compliance of modern technologies and disregard for the requirements of agricultural and natural laws. According to V.P. Dmytrenko *et al.* (2017), anthropogenic organisational and technological contributions dominate the level and variability of crop yields. This indicates that the application of modern technologies and effective management of agricultural processes can significantly influence yield. Therefore, investment in the development of agro-technologies and the improvement of farmers' qualifications are key to stable and high yields.

Analysing the current state of Ukraine's soils and their fertility, S.A. Baliuk *et al.* (2021) note a 6.5% decrease in humus content across Ukraine from 3.36% to 3.14% over a twenty-year period. The decrease in humus content demonstrated in this study even exceeded these figures, reaching 12.3% from 4.00% to 3.51% over 20 years.

The obtained data on the possibility of reducing the amount of mineral fertilisers applied in ecological farming systems in the context of expanded use of organic fertilisers (manure, crop residues, and cover crops) are consistent with the studies by C. Li *et al.* (2022). Their research highlights the role of organic fertilisers in

carbon sequestration in soil. Specifically, the use of organic fertilisers such as animal manure and crop residues allows for a reduction in the use of mineral fertilisers by an average of 20-30%.

The data on the negative humus balance in organic farming systems align with the findings of C. Maucieri *et al.* (2022), who indicate that organic farming does not have an advantage over conventional farming in terms of organic matter accumulation in soil. According to their multi-year results, 14 years after the introduction of organic farming, the humus content decreased relative to the initial data. This trend in organic farming is explained by a higher frequency of soil tillage for crop care and, on average, 32% lower crop yields with corresponding fewer crop residues.

Similar results regarding the effectiveness of the no-till system were obtained by M.M. Al-Kaisi & R. Lal (2020), who point to carbon preservation in the soil. However, the data from Ya.P. Tsvei & M.S. Myroshnychenko (2020) indicate the absence of a significant increase in the amount of organic matter in the ploughed soil layer using no-till compared to conventional tillage. Moreover, the specifics of mineral fertiliser application in such farming systems (at sowing and foliar feeding) require additional inputs of nutrients for plants. Therefore, the no-till system requires both theoretical justification and practical research on increasing soil fertility through inputting organic matter into the soil, developing fertilisation systems, and plant protection systems against harmful organisms.

L. Tsentilo (2019) examined farming systems with different resource capacities over seven years. According to his results, the organo-mineral farming system with a balanced combination of organic and mineral fertilisers did not significantly differ in productivity from the mineral system. However, the organic system resulted in an average 36.5% decrease in crop productivity.

The results regarding lower productivity of organic farming compared to conventional farming align with the findings of D.J. Connor (2021). His analysis suggests that organic farming will require 2-3 times more land to achieve equivalent productivity than industrial farming. The efficiency of land use will decrease

in inverse proportion. This is the main drawback of the impact of organic production on food security and nature conservation.

Research and practical experience of Ukrainian scientists indicate that in existing crop rotations in different soil-climatic zones of Ukraine, the most effective method is combined tillage and differentiated by depth. In particular, V. Adamchuk *et al.* (2016) indicate that ploughing is one of the most important tillage measures. However, it should not be done annually but periodically based on the deterioration of the structure of the upper 0-10 cm soil layer (structural coefficient less than 0.76). A mandatory condition for ploughing is the use of subsoilers or two-layer ploughs. Only in this case does it serve as a means of restoring soil structure, one of the most important factors in preserving its fertility. Similar research results are proposed by I. Prymak *et al.* (2016), which indicate the high effectiveness of a differentiated approach in choosing the method and depth of soil cultivation.

Thus, the basis of a modern, environmentally safe and energy-efficient farming system is compatibility with natural processes and strict adherence to agricultural laws. In the conditions of a market economy, the priority area of the study is the stabilisation of cropping area structures based on market relations; adaptive application of new generation organic fertilisers, crop residues, and wide use of cover crops; conservation tillage; implementation of crop protection systems from harmful organisms following the ecological-economic threshold of their population; use of microbiological preparations based on new isolated strains-producers, etc. The theoretical and practical results of the study have stimulated the development of certain branches of science and production and significantly changed the measures for managing soil fertility and crop productivity.

CONCLUSIONS

The recommended ecological farming system is a comprehensive approach to cultivating agricultural crops to achieve high soil productivity and preserve ecosystems. This system is based on scientifically grounded methods and practical research that optimise resource

use, reduce negative environmental impact, and improve agricultural product quality and safety. The recommended system of ecological farming includes:

- n Introduction of an organic-mineral fertilisation system, which includes the application of organic fertilisers at a rate of 22-24 tonnes per hectare of crop rotation area (10-12 tonnes/ha of manure or compost, 6 tonnes/ha of crop residues, 6 tonnes/ha of cover crops) and 150 kg ($N_{45}P_{55}K_{50}$) of mineral fertilisers. This resource content provides an ecological index of this system at 6.2, indicating the state of ecological farming and crop productivity within the range of 9.0-10.0 tonnes/ha of feed units.

- n Implementation of a combined method involving varied-depth primary tillage in crop rotations is recommended. This method includes ploughing for row crops such as sugar beets, sunflowers, or maize for grain once every 4-5 years and non-ploughing techniques like different-depth chiselling and disking for other crops in the rotation.

- n Combined crop protection system from weeds, pests, and diseases based on ecological-economic levels of harmful organism populations and the index of optimal selection of these measures.

- n Use of biological preparations that improve nitrogen nutrition of crops, mobilise phosphorus and potassium in the soil, and enhance its biological activity.

Further research should focus on the theoretical justification and development of an environmentally conserving farming system in Ukraine, considering modern challenges and the needs of the agricultural sector. Research activity may include a deeper analysis of the relationships between agro-industrial production, ecological processes, and soil conditions, the development of new methods and technologies to preserve and restore soil fertility, reduce environmental impact, and increase the resilience of agricultural ecosystems to external factors.

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CONFLICT OF INTEREST

None.

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Семен Танчик

Доктор сільськогосподарських наук, професор
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
<https://orcid.org/0000-0002-4975-7720>

Олександр Павлов

Кандидат сільськогосподарських наук, доцент кафедри землеробства та гербології
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
<https://orcid.org/0000-0002-7953-2696>

Антоніна Бабенко

Кандидат сільськогосподарських наук, доцент кафедри землеробства та гербології
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
<https://orcid.org/0000-0001-5102-3438>

Теоретичне обґрунтування та розроблення еколого-зберігаючої системи землеробства в Україні

Анотація. Інтенсивне землеробство стало причиною деградації ґрунтів – втрати гумусу, знеструктурення, переущільнення, зниження потенційної та ефективної родючості. Тому, актуальними є дослідження систем землеробства. У зв'язку з цим, метою досліджень стало наукове обґрунтування, розроблення та впровадження еколого-зберігаючої сучасної системи землеробства в умовах України. Для визначення ефективності варіантів систем землеробства, точності та достовірності експериментальної інформації провідними методами цього дослідження стали: польовий, лабораторний та статистичний. Дослідженням обґрунтовано, що промислова система землеробства з надходженням близько 12,0 т/га сівозмінної площі органічних речовин (8,0 т/га гною та 4,0 т/га рослинні рештки) забезпечує утворення близько 0,81 т/га гумусу, проте мінералізувалося його 1,33 т/га, що приводить до від'ємного балансу гумусу в ґрунті. Вихід зернових одиниць за цієї системи становить 8,21 т/га, кормових одиниць – 9,63, перетравного протеїну – 0,86 т/га за стабільності 91,2 % та рентабельності 88,0 %. Органічна система землеробства, що передбачає використання 24 т/га органічних добрив, застосування біологічних препаратів для контролювання бур'янів, хвороб та шкідників у агроценозах не забезпечує позитивного балансу гумусу в ґрунті (-0,14 т/га) та має суттєво нижчу продуктивність. Система No-till, що передбачає внесення 12 т/га органічних добрив у вигляді коренових та пожнивних решток, побічної продукції рослинництва та мінеральних добрив при сівбі та позакореновому підживленні, забезпечує позитивний баланс гумусу (+0,12 т/га), проте має продуктивність на рівні органічної системи. Екологічна система забезпечує одержання стабільної, економічно вигідної та адекватної ресурсному наповненню ґрунтово-кліматичної зони продуктивність ріллі, підвищує якісні показники продукції, зберігає й відтворює ґрунтову родючість. Вона підвищила на 8,9 % вихід зернових одиниць, 7,2 кормових одиниць та 8,1 % перетравного протеїну, забезпечуючи при цьому високу стабільність на рівні 94,1 % та підвищення рентабельності виробництва на 8,5 % порівняно з контролем. Матеріали статті мають практичну цінність для сільськогосподарських підприємств різних форм власності та слугуватимуть технологічними регламентами впровадження сучасного екологічно безпечного, економічно і енергетично обґрунтованого виробництва сільськогосподарської продукції

Ключові слова: промислове землеробство; екологічне землеробство; органічне землеробство; No-till; продуктивність