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Monograph

NATURAL RESOURCE POTENTIAL
OF SUSTAINABLE DEVELOPMENT
OF AGRICULTURE OF UKRAINE



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The interdependence and interconnectedness of components that make up the natural resource potential of agriculture, which define the distinct characteristics of the industry, are examined. Current trends in the utilization of land and other elements of agricultural natural resource potential of Ukraine, along with their impacts, are analyzed. Challenges related to shaping a natural resource strategy of sustainable development of agriculture in the face of climate change, degradation processes and the effects of military conflict are being investigated. The need of a transition to agroecological farming practices is substantiated and their core principles are outlined. Proposals for transforming approaches and methods to shift from resource-intensive and environmentally harmful practices to agroecologically focused agriculture, as a key factor in achieving sustainable development, are presented.

This monograph is intended to scientists, educators, students of agricultural universities, professionals of ministries and agencies, as well as general readers who are committed to the protection and preservation of natural resource potential in agriculture.

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“...the reason of the emergence and disappearance of nations lies in the same thing. The depletion of soil fertility leads to their demise, while the preservation of this fertility ensures their life, wealth and power”.

Justus Liebig

INTRODUCTION

The current generation is facing an escalating array of threats to civilized development, largely due to the increasing intensity of natural resource utilization in the agrosphere. This overexploitation depletes agricultural land productivity, pollutes water resources, diminishes biodiversity and devastates local agricultural landscapes and systems. As a result of environmentally hazardous agricultural practices, the global area of degraded land expands by 10-15 million hectares each year, equating to approximately 19-29 hectares every minute.

The UN report “The State of the World's Soil Resources” (2015) notes that global degradation of agricultural land has covered 33% of the land, while in the early 2000s this figure was 20%.

The condition of soils is constantly deteriorating as a result of erosion, nutrient depletion, loss of organic carbon, flooding, salinity, acidification, chemical pollution, etc. Erosion annually causes the loss of 25 to 40 billion of topsoil, which takes hundreds of years to recover. Consequently, the global community loses up to 25% of its crops.

According to FAO experts, annual grain production losses due to erosion amount to 7.6 million tons. If measures are not implemented to mitigate erosion processes, grain losses could exceed 250 million tons by 2050. To compensate for this loss with average yields, more than 100 million hectares of agricultural land would be required.

Over the past 50 years, the area of cultivated land has expanded by 160 million hectares, primarily due to the reduction of forests, wetlands and meadows. Forested areas decreased by 135 million hectares between 1990 and 2000 alone. Simultaneously, a significant portion of cultivated land has been taken out of production due to Savanization, desertification and other factors stemming from both climatic conditions and human activities.

The intensification of agriculture, which continues to be the predominant method of increasing agricultural production, is accompanied by a rise in the consumption of agrochemicals, veterinary products and synthetic feed resources. This intensification ultimately results in soil, water and environmental pollution.

Industrialization has improved working conditions and increased productivity. However, the resulting anthropogenic pressure on soils has led to physical degradation, disruption and deterioration of their water and air regimes, adversely affecting land productivity.

Negative aspects of intensive industrial-chemical agriculture include the decline of wildlife, pesticide poisoning, loss of biodiversity and environmental pollution. These factors contribute to the deterioration of rural areas and the quality of life of rural population.

Given the increasing negative impact of human activity on natural resources, there is no alternative but to pursue a path of development that emphasizes the prudent use of natural resource potential, limits consumption and waste and improves the quality of living environments. This approach represents the only sustainable solution for ensuring the viability of the planet for future generations.

The transition to such a development model, which was declared "sustainable development" by the UN Conference on Environment and Development (Rio de Janeiro, 1992), has become an objective necessity whose importance is now widely acknowledged. The international community has defined sustainable development as a strategy for the twenty-first century. It is understood not only as a means to generate and promote economic growth but also as a framework for equitably distributing their benefits, restoring the environment to a greater extent than it is damaged and enhancing people's opportunities rather than impoverishing them. This human-centered development approach focuses on preserving soil and other components of the natural resource potential in agriculture, which are essential for livelihoods.

The concept of sustainable development emerged from a reevaluation of the technogenic and noospheric processes, along with associated social challenges, that began to intensify in the 1970s and threaten the livelihoods of people worldwide.

At the same time, what may seem obvious—the necessity for a balanced integration of economic efficiency, social justice and responsible environmental management—proves particularly complicated to implement in practice. This difficulty arises from the multitude of stakeholders involved in agricultural production, the divergence of their interests and the prevailing illusion of inexhaustible natural resources that exists in people's minds.

The complexity of sustainable development stems from the necessity for substantial advancements in human society, ethics and behavior. It also requires the recognition that economic growth cannot continue indefinitely on a planet with finite land, water and other natural resources that form the basis of agricultural production.

In light of the above, this study employs a retrospective analysis to identify the phased emergence of ecodestructive contradictions that developed into conflicts between nature and humanity during the twentieth and early twenty-first centuries.

From this perspective, the study assesses the state of the natural resource potential components in Ukrainian agriculture, investigating the reasons behind their significant degradation and its impact on industry development. It highlights the socio-ecological consequences of highly specialized farming practices that have shifted to monoculture crop rotations, focusing on the simplified cultivation of a few low-labor-intensive crops. This approach disregards natural laws related to the intended functions of natural resource potential components, ultimately leading to the degradation of agro-ecosystem in Ukrainian agriculture.

Systematized approaches for incorporating natural resources into the assessment of sustainable development in agricultural enterprises are examined in both foreign and national scientific literature.

On the basis of theoretical foundations and a synthesis of global scientific research and practices aimed at achieving a balance between short-term profitability—often attained at the expense of environmental and social well-being—and the long-term

productivity of land and other resources, the key components of a strategy for natural resource conservation and sustainable resource provision of food production for future Ukrainian society are formulated.

The strategy is based on the transition from crop rotation with elements of monoculture to agroecological farming, substantiates the essence of agroecology and its role in ensuring “beneficial” biological interaction and synergy between the components of the agroecosystem by combining scientifically based crop rotation systems, climate change-oriented farming systems, optimization of anthropogenic energy inputs, soil-saving anti-erosion tillage technologies, environmentally oriented ratio of arable land, pastures, hayfields and other eco-lands with the formation of forest-agrarian ecosystems and the creation of environmentally sustainable agricultural landscapes overall.

In agriculture, unlike in other industries, individuals interact directly with the land and other natural resources. Their activities can either support or hinder the vitality and productive capacity of these resources. An analysis of the historical development of destructive processes in natural resource management indicates that rural residents, who tend to live in harmony with nature, are less to cause harm to it. In this context, the monograph illustrates the concept of the socialization of land relations, emphasizing the creation of favorable institutional, legal and organizational conditions to enable peasants' rights to land, employment and fair wages. This socialization is a crucial factor for sustainable land use and serves as the foundation for the overall sustainable development of agriculture.

The monograph identifies the shortcomings in the institutional and legal frameworks supporting natural resource conservation in agriculture of Ukraine, as well as mechanisms for eliminating these shortcomings, gained by experiences from Western Europe and other countries. It analyzes the long-term objectives for preserving of natural resource potential of agriculture as outlined in the European Green Deal, examines the challenges associated with their implementation and explores strategies for overcoming these obstacles.

The author's team

Section I. THE CONFLICT BETWEEN HUMAN ACTIVITIES AND NATURE: IMPACTS ON AGRICULTURE.

1.1. THE EVOLUTION OF ECONOMIC-ENVIRONMENTAL RELATIONSHIP: RETROSPECTIVE AND NOWADAYS.

An economic system refers to the structure of production, distribution and consumption of goods and services. Within this framework, there exists a continuous interaction between society, its various groups, and the natural environment. Every production process involves the use of natural resources to varying degrees, which impacts the environment by changing its conditions.

Nature supplies essential resources for human being: land resources serve as the primary basis for food production, while natural resources provide the materials and energy required for human survival. Water resources are vital for daily living, irrigation of agricultural crops and various industrial processes. Furthermore, both humans and all living organisms are dependent on natural air for survival.

Nature significantly influences the distribution of society's productive forces and the specialization of economic activities. It can either accelerate or detain their development and has the potential to destroy the outcomes of human economic efforts. As the negative consequences of human activities accumulate, nature increasingly impacts people's awareness of the threats they pose to themselves.

In its pursuit to fulfill needs and establish comfortable living conditions, society utilizes natural resources without imposing limits on these needs, often leading to increased consumption and intensified extraction.

The scientific and technological revolution has significantly complicated the relationship between humans, their activities and nature. This complexity arises from the fact that, among the factors driving economic development – namely labor resources, means of production and natural resources – the latter are the most limited and the most adversely impacted by human activities.

The development of productive forces, driven by advancements in science and technology, has enabled humans to intensify the use of natural resources. However, food production has not been kept at pace with the increasing demand from consumers, despite these scientific and technological advancements. The availability of land is static and efforts to expand agricultural land through the development of virgin territories and deforestation have been exhausted. Additionally, the application of fertilizers and advancements in breeding have not resulted in sufficient yield increases. In the United States, there is a noticeable decline in yield growth and a decrease in the production of corn and other grains, while Japan and China are witnessing similar trends in rice production. Climate change, exacerbated by destructive human activities and population growth, adversely affects the utilization of water resources.

Simultaneously, the implementation of industrial technologies has resulted in soil degradation, reduced productivity and destruction of agricultural land. The “Green Revolution” of the 1960s and 1980s in Latin America enabled many countries to par-

ticipate in global markets for specific agricultural products in which they specialized. However, a significant opposite side of this process is the emergence of millions of hectares of degraded land, soil exhaustion due to monoculture practices, savannahization and desertification of substantial areas. Additionally, this has contributed to landlessness and the migration of peasant populations.

Every year, approximately 6 million hectares of land are lost globally due to soil erosion, a consequence of economically damaging activities that deplete natural resources, while the area of newly cultivated land increases by an average of only 3.9 million hectares.

The intensification of production is changing the structure of the natural environment, including the balance between arable land, natural pastures and forests, as well as the distribution of humid and arid regions, rainfed lands and areas flooded by artificial reservoirs.

The disruption of the balance between arable land, natural pastures and forests exacerbates soil degradation, leads to detrimental changes in biodiversity, reduces phytomass reserves and destroys the integrity of ecosystems. Consequently, 60% of the world's ecosystems have already experienced losses.

When individuals recognize environmental threats, they can modify their economic activities to foster the regeneration of natural resources. This can be achieved through the implementation of soil-restoring crop rotations, the conservation of degraded lands to restore fertility using specific technologies, changes in soil cultivation methods, the restoration of forest plantations and the adoption of technologies that reduce harmful emissions into the environment.

The algorithm of relations between human activity and nature is shown in Figure 1.

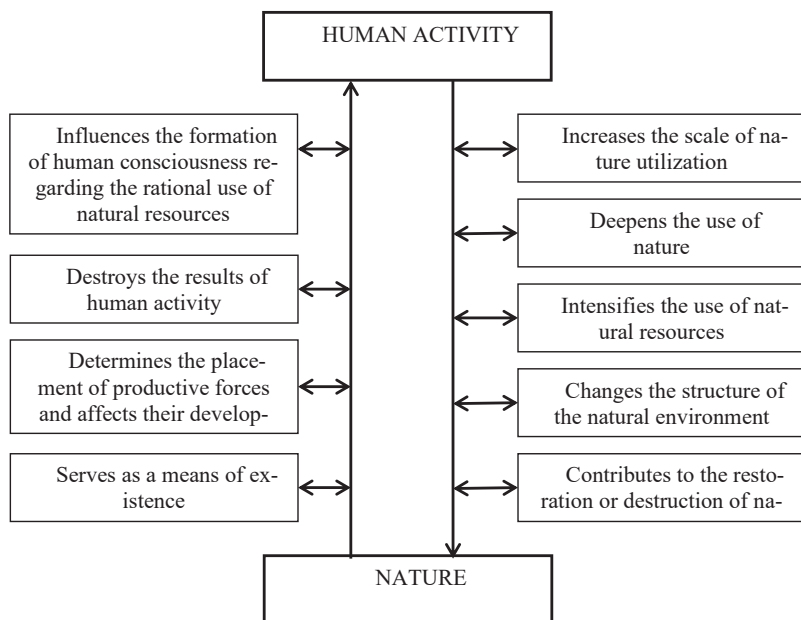


Figure 1. Algorithm of relations between human economic activity and nature. *Source:* compiled by the authors

Achieving a balance between human economic needs and the rational and sustainable use of natural resources, often referred to as ecological and economic balance, is increasingly recognized as a vital factor for the survival of humanity.

However, most of the world's economies, particularly those of developed countries, adhere to a model of continuous economic growth.

At the same time, in both economic theory and practice, the concept of "*development*" has been synonymous with "*economic growth*", which is often considered the primary indicator of economic activity. However, these concepts are fundamentally different. Economic growth is driven by an increase in the scale and intensity of consumption of the productive capacities of natural resources, aimed to increase gross output, trade turnover and other related metrics.

That is, growth is measured by quantitative parameters, while development refers to qualitative changes aimed at increasing gross production, trade turnover, etc. Conversely, development also encompasses qualitative changes in the state of natural resources and the environment, the quality of human life and collective well-being.

According to J. Schumpeter, economic development is characterized by innovation, representing the introduction of new elements that did not previously exist, whereas economic growth refers to the increase in the production and consumption of goods and services over a specific period (Schumpeter, J., 1992). The primary driver of eco-

conomic development is entrepreneurial innovation, which serves as a mechanism for overcoming stagnation and economic crises. Economic development is facilitated through the creation of new products, the introduction of novel production methods, the exploration of new markets, access to new sources of raw materials and the establishment of new organizational structures within companies, among other factors.

Economic growth represents merely one aspect of economic development, characterized by the intensified utilization of natural resources. Over the past fifty years, the relentless pursuit of economic growth has resulted in a scenario where, according to the United Nations, natural resources are being depleted at a rate significantly exceeding their renewal. Additionally, economic growth has outpaced the growth rate of the productivity of natural resources by a factor of three. In this century, environmental problems have been emerging as the foremost threat to humanity.

In the competition for resources, affluent, developed countries with significant capital tend to prevail, while developing nations continue to experience increased poverty. Economic stratification occurs not only between countries but also within each nation, creating disparities among social groups, as well as between large corporations and small to medium-sized enterprises. Consequently, economic growth engenders not only environmental challenges but also social issues.

The integration of economic, environmental and social aspects of human activity is essential for fostering economic development. This development can occur independently of economic growth and it can achieve profitability through innovations that do not produce unfavorable environmental or social consequences.

Contradictions between economic and environmental interests are inevitable in a highly competitive environment. Typically, economic interests prevail, as they yield the greatest immediate benefits, even though they may incur long-term losses. The consequences of these contradictions can take decades to materialize, particularly in agriculture. This dynamic fosters a culture of impunity regarding environmentally destructive practices while perpetuating the illusion of limitless resources. Such misconceptions continue to dominate economic activities aimed at maximizing profits “for the sake of prosperity.” The prevailing mindset is one of “mass consumption” and the belief that “humans are the rulers of nature”. Consequently, nature-destroying technologies become predominant, driven by the priority of economic gain without regard for the depletion of natural resource potential.

Continuing such practices may have detrimental consequences for future generations. The cycle of production, distribution and consumption cannot be sustained indefinitely. It is not independent of the physical substrate that supports it; rather, it extracts raw materials and energy from this substrate while throws out waste back into it. The law of entropy proves that economic processes are irreversible and that they dissipate raw materials and energy. Consequently, the concept of unlimited growth functions as an economic fallacy. Continuous economic growth is unsustainable in a finite world.

The antagonism between the two opposing forces – nature and human society – causes significant social and environmental consequences within the economic sphere. Tensions arising from the interactions between the environment and the economy in the human-society-economy-environment system turn into economic conflicts. Eco-

logical and economic conflicts are defined as a situational dynamic interplay of environmental, social and other conditions, along with the relationships between subjects and objects of economic activity. In this context, each party represents an opposing viewpoint regarding the relationship between the economy and the environment.

Conflicts can manifest in both active and latent forms, with the latter being the more prevalent and potentially dangerous type compared to visible conflicts. The negative aspect of this situation is that these hidden conflicts can delay the implementation of decisive measures needed to their neutralization. As a result, the social and environmental consequences over time, until conflicts become visible can increase significantly or become irreversible.

Since the 1970s, scientists across many countries and the progressive international community have increasingly recognized the irreversible consequences of environmental conflicts. The first significant document devoted to this issue was the World Conservation Strategy (WCS), which asserted that societal development must prioritize the preservation of wildlife. It emphasized the importance of protecting the structure, functions, and diversity of the Earth's natural systems, upon which depends the survival of all biological species, including humans. To achieve this, it is essential to safeguard life-support systems, maintain biodiversity and ensure the sustainable use of non-renewable resources.

The strategy was further elaborated in the materials of the UN International Commission on Environment and Development (ICNED), led by Norwegian Prime Minister G. Brundtland. The main conclusions of the ICNED are as follows:

- Throughout the twentieth century, the relationship between humanity and nature, which sustains human life, underwent significant changes, giving rise to threats to the existence of human civilization and life on Earth.
- During this period, the rate of consumption increased dramatically, with the same amount of resources consumed in production during the twentieth century as in all previous centuries of human history combined. The international community and scientists across numerous countries have recognized that economic growth processes, which are unbalanced with the capacities of the natural environment, have resulted in trends that neither natural ecosystems nor society can endure for long.
- Economic growth is detrimental to the natural environment and leads to environmental degradation, which in turn undermines the very process of economic growth.
- All regions of the world currently face the risk of irreversible environmental destruction, threatening to undermine the foundations of civilization and the extinction of Earth's wildlife. This situation indicates that we are not dealing with separate global crises (environmental, economic, food) but rather a singular crisis of the global human-environment system.
- The pace at which humanity is destroying the environment surpasses the capacity of modern science to fully understand these changes, hindering timely assessments and the implementation of appropriate practical recommendations. If the current rates of economic growth, based on the exhaustive use of natural resources, persist, the inevitable global degradation of the environment will, within a few decades, undermine the entire economy and the life-support systems of the Earth (International Commission on Environment and Development, 1989).

The conclusions of the Brundtland Commission laid the foundation for the adoption of *Agenda 21* at the UN Conference on Environment and Development (Rio de Janeiro, 1992). It emphasized that if humanity does not establish appropriate mechanisms to optimize its relationship with nature, it will face inevitable degradation. Therefore, the priority is to shift the paradigm of economic development toward the principle of "sustainable development" is a model of development that aligns with the inherent evolution of natural ecosystems, ensuring that the needs of the present generation are met without compromising the ability of future generations to meet their own needs (Program of Action "Agenda 21", 2000). This concept has since gained the status of *an alternative to the traditional model of economic growth*, becoming the foundation of sustainable development thinking.

Sustainable development should be understood as a process of harmonizing productive forces to ensure that the essential needs of all members of society are met, while preserving and gradually restoring the integrity of the environment. It also entails creating opportunities for a balance between the potential of the environment and the needs of people across all generations. The foundation of sustainable development lies in achieving parity within the "human - economy - nature" triad, facilitating a shift towards an interaction between nature and society that is characterized as the era of the noosphere.

The transition to sustainable development is unavoidable, as the continued growth of the global economy driven by unrestrained growth of production, without consideration for the evolutionary laws governing Earth as part of the "field of living substance" within the universe, has already led to the depletion and destabilization of the biosphere's ecological systems. This trajectory poses a significant risk of catastrophe for humanity in the future.

A more comprehensive and relevant interpretation of sustainable development, suited to the current relationship between humans and nature, defines it as development that not only drives economic growth but also distributes its benefits equitably, restores the environment more than it depletes it and enhances opportunities for people rather than impoverishing them. This form of development prioritizes the needs of the poor, empowers them and ensures their participation in decisions that affect their lives. It is a people-centered development that focuses on environmental preservation while aiming to provide employment opportunities, including the realization of women's rights (United Nations, 2014). This approach integrates the social aspect alongside the environmental factor, giving the concept of sustainable development a distinctly humanistic orientation.

The transformations occurring in the modern world require a critical reevaluation of not only many established theories and historical perspectives, but also a search for innovative conceptual approaches of creating a new paradigm of social development. By generalizing the types of socio-economic development, three possible pathways are commonly distinguished: anthropocentrism, biocentrism and sustainable development.

Anthropocentrism represents the contemporary industrial path of development, driven by a "philosophy of consumption". At a certain stage of this development, it creates the illusion of prosperity and economic well-being. In the pursuit of satisfying ever-growing needs, humanity disregards both the environmental limits and the needs

of future generations. From a theoretical perspective, rooted in the natural sciences' understanding of laws, patterns and principles of development, it can be assumed that this trajectory ultimately leads to resource depletion and, consequently, the potential demise of humanity.

Biocentrism implies a return to to the evolutionarily established optimal structure of biogeochemical cycles. In its extreme forms, however, this developmental path can be considered utopian, as it may involve the rejection of many advancements brought by scientific and technological progress.

Sustainable development is a developmental approach focused on preserving the reproduction of production potential, human resources and the natural environment over time. This approach ensures a balance among three closely interrelated components of the system: the economic, social and environmental spheres.

The concept of sustainable development stems from a reevaluation of the technogenic and noospheric paradigms of human civilization. The term "sustainable" in "sustainable development" carries a dual significance. On one hand, it refers to maintaining the stability of the environment, while on the other, it ensures the sustainability of economic growth. As a result, the environment and the economy must be viewed as interconnected elements of the same system, requiring integrated and responsible management.

Sustainable development encompasses the integration of the goals related to a high quality of life, health and well-being with social justice, while ensuring that the planet remains capable of supporting life in all its diversity. These social, economic and environmental goals are interdependent and mutually reinforcing (Kovbasiuk, Y.V., Vashchenko, K.O., Surmin, Y.P. et al., 2013). See Figure 2.

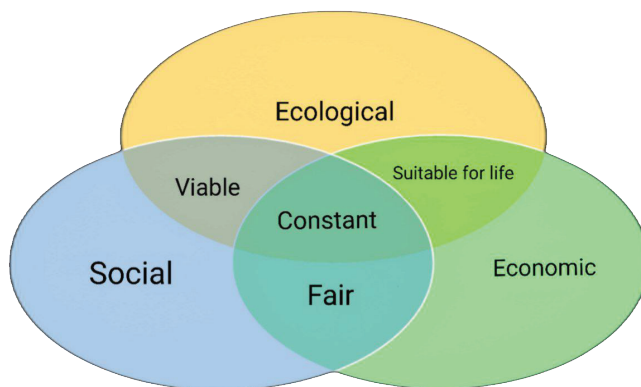


Figure 2. Conceptual scheme of sustainable development. *Source:* Compiled by the authors

The concept of sustainable development aims to ensure the stable functioning of economic processes at a qualitatively acceptable level. By identifying the necessary criteria, we can outline the core principles of sustainable development:

- maintaining a balance between the economic and environmental sectors – achieving a level of technological advancement where human economic activity no longer harms the environment;
- ensuring a balance between the economic and social spheres, which entails maximizing the use of resources generated by economic development for the benefit of the population;
- addressing development challenges not only for the benefit of the current generation but also for future generations, who have equal rights to access and utilize natural resources.

H. Daly outlined three key conditions for the sustainable consumption of raw materials and energy in a society:

- the rate of consumption of renewable resources must not exceed their natural rate of regeneration;
- the rate of consumption of non-renewable resources must not exceed the pace at which sustainable renewable alternatives are developed;
- the rate of pollutant emissions must not surpass the environment's capacity to absorb and neutralize them (Daly, H., 2002).

Among the challenges arising from the conflict between human activity and nature, those affecting agriculture are among the most concerning. Of the 17 Sustainable Development Goals (SDGs) set by the United Nations in 2015 for the period till 2030, nearly half are either directly or indirectly linked to the agriculture. These goals primarily focus on ensuring global food security, which is vital for the survival of humanity. Addressing hunger worldwide depends on the effectiveness of agricultural production. Furthermore, the agricultural sector plays a key role in addressing issues related to climate change, as well as in preserving non-renewable land and water resources and maintaining environmental integrity.

Agriculture is the primary industry that generates employment opportunities for the rural population, thereby ensuring their well-being and fostering a connection to their local workplaces. This sector plays a crucial role in promoting the settlement and development of rural areas, which is intrinsically linked to the overall development of the national identity and heritage of each country.

The foundation of agricultural production is land, which is a critical natural resource and a key factor in economic development, alongside labor, capital and technological advancement. Features of the land resources are characterized by their non-renewability and spatial limitations and they cannot be substituted with any other means of production.

Land can be utilized in both active and passive ways. In active use, it functions as a source of food and a means of production. According to the Food and Agriculture Organization (FAO), active land use constitutes 10% of arable land and 30% of pastures and hayfields. Conversely, passive land use pertains to its role as a spatial and operational foundation, serving as a carrier of social interests and environmental conditions for the population.

Land use in economic activities involves the spatial utilization of land within the cyclical process of land-user interactions. In this process, the user influences the land through its use, reproduction and protection, while the land, in turn, affects the user's

behavior through its returns, both in terms of food and other resources (Budziak, O.S., 2011).

The stages of the development of the eco-destructive impact of the economy on nature are closely linked to changes in land ownership structures, the advancement of productive forces, and the globalization of economies and markets.

From a historical perspective, agriculture has seen a gradual intensification of ecological contradictions, which escalated into significant conflicts during the 20th and early 21st centuries.

The first stage encompasses the pre-war period, marked by the initial spread of agricultural mechanization, the expansion of new lands and the rise of industrial irrigated agriculture. During this time, monoculture, particularly export-oriented wheat production, became prevalent in the western states of the United States. The environmental consequences of these developments began to emerge, including soil exhaustion, declining land productivity and degradation.

The second stage, spanning from the 1950s to the 1970s, was characterized by the first wave of the Green Revolution. This period saw large-scale projects such as the drainage of swamps and river lowlands, the construction of extensive irrigation systems and reservoirs and a significant increase in the use of synthetic mineral fertilizers. Additionally, large livestock complexes were built, concentrating poultry and livestock in confined areas. The environmental consequences were severe, including the contamination of food with chemicals, desertification, waterlogging, pollution of surface and groundwater and a reduction in species diversity. These issues were accompanied by health problems, such as diseases and genetic abnormalities, reduced life expectancy, acid rain, depletion of the ozone layer and global climate warming, among other environmental challenges. Furthermore, the widespread use of inefficient, resource-depleting technologies contributed to growing disparities in socio-economic development between developed and developing countries, exacerbating the global food crisis and the spread of hunger.

The third stage, from the 1980s to 2000, marked the peak of the Green Revolution. This period saw the widespread chemicalization of agriculture, the introduction of genetically modified organisms (GMOs) and a shift towards monoculture production in developing countries driven by the pressure of both international and national export-oriented capital. Additionally, there was significant deforestation to develop new lands for agricultural use. The consequences were severe, including increased chemical pollution of land and water resources, further contributions to climate change, the loss of over 40% of irrigated land due to technological failures and soil acidification, the transformation of land into savannah-like environments and the creation of new desert areas.

From 2000 to the present, has seen the spread of ecodestructive factors, previously characteristic of Latin America, Africa and other continents, into the agricultural sectors of post-Soviet countries, including Ukraine. This development has resulted in the expansion of degraded lands and the further intensification of the ecological contradictions mentioned earlier, both at the global and national levels within the agricultural sector.

Today, the environmental factor is increasingly becoming a constraint on the economic development of agricultural sector. There is a growing recognition that future development must take this factor into account. Ignoring the finite nature of land and other natural resources could result in significant long-term costs for humanity.

Therefore, the organization of sustainable land use entails the development of land ownership and land use models that promote economically efficient, environmentally safe and socially equitable utilization of natural resources. This approach aims to ensure the responsible use of these resources not only in the present but also for future generations.

The instruments for implementing the overarching framework in environmental and land policy, including methods of land use, are grounded in the fundamental principles of sustainable land use (Sirant, M.M., 2021). In both scientific discourse and practical applications, this overarching framework is defined by four primary principles.

The Principle of the Primacy of Nature. Land use, nature and society develop in accordance with the same objective laws governing the natural world. However, each of these domains exhibits distinct developmental characteristics, with one being guided by the laws of nature and the other by the laws of society. It is imperative for society to consider the foundational role of nature in its development, as human existence and labor are intrinsically linked to the natural environment. The core of this integral system is the interaction among its components. The existence and development of the system depend on the unity of three subsystems: society, land use and nature. The absence of this unity would render the system non-existent. This unity is dictated by natural laws and to maintain a sustainable relationship with land use and the natural environment, society must acknowledge and respect this interconnectedness, structuring its approach based on the objective laws of natural development (Sirant, M.M., 2021).

The Principle of Economic Feasibility. In a broad sense, the principle of economic feasibility underscores the normative approach to economic development as a whole. The fulfillment of this requirement is contingent upon the objectives of the farm's profitable activities, the demand in the agricultural market and the financial capabilities of the land user. However, the application of these factors must be guided by the agro-economic axiom that profit maximization cannot serve as the sole criterion for producers. This is because nature, an integral component of agricultural processes, operates according to its own laws, which may be misaligned with human economic interests. Where nature prevails, there is no inherent drive to achieve the greatest cost savings or the highest production outputs. Instead, agricultural activities must respect the natural processes that govern the environment.

Economic activity in agriculture refers to the utilization of land up to a threshold beyond which human actions conflict with the laws of nature. In other words, it concerns the maximum sustainable use of the productive capacity of agricultural land, which should serve as the primary economic benchmark for land users. Exceeding this limit risks disrupting the delicate balance between agricultural practices and the natural environment, leading to long-term ecological degradation.

A sense of responsibility and the establishment of appropriate behavioral norms are critical for the transition to environmentally sustainable development. In practical terms, a regulatory system for land use must be designed to ensure sustainability and should incorporate both natural and economic standards. An example of the former is the establishment of maximum permissible limits on land use and environmental impact, ensuring that they do not exceed the region's assimilative capacity while maintaining land use efficiency. However, the primary standard for land use is an environmentally conscious approach to human behavior, driven by awareness of the limitations of land, natural resources and living space. Human environmental ethics form the foundational norm for responsible land use.

The Principle of Greening Land Use. The greening of land use refers to the sustainable reproduction of land and other natural resources through the advancement of technology, improved land management and protection and enhanced efficiency in the environmental use of land. Key directions for greening land use include:

- preservation and restoration of ecological systems;
- adoption of advanced technologies for land use and natural resource management and protection;
- rational utilization of land and natural resources;
- development and implementation of low-waste and zero-waste production processes;
- expansion of nature reserves, sanctuaries and other protected natural areas;
- environmentally sustainable spatial organization and territorial planning of production;
- reduction and elimination of land and environmental pollution (Budziak, O.S. and Budziak, V.M., 2018).

The Principle of Socialization of Land Use emphasizes the transformation of land into a common good. In human terms, this principle calls for a broad and comprehensive harmonization of the relationship between society and land use. The system of land use itself determines the humanization of society's relations to its resources. The process of socializing land use implies that land and other natural resources should be utilized solely for the benefit of society and the nation as a whole, while strictly adhering to established rules and regulations.

Socialization, as a key condition for achieving sustainable land use, has a dual nature. On one hand, the benefits derived from land use are not solely the result of individual activity and, from the perspective of social justice, cannot be considered the object of absolute private ownership. On the other hand, the benefits of land use, particularly in relation to food production, are inherently social, as they meet the needs of many individuals simultaneously. This implies that land users should be compensated for the additional costs involved in the reproduction of land and other natural resources, with the support of the wider society.

The practical implementation of the principle of socialization requires the establishment of an appropriate economic and legal framework that balances individual land interests with collective (public) interests (Pronina, O.V., 2014).

Negative environmental changes that impact the productive capacity of natural resources are not yet adequately factored into economic analyses. This omission dis-

torts the true picture of the efficiency of human activity in agriculture. *In other words, environmental factors – which are as crucial, if not more so, than agricultural machinery or fertilizers – are often overlooked when assessing land use efficiency and agricultural productivity.*

The development and implementation of land ownership and land use systems in accordance with these principles is essential for the sustainable development of the agricultural sector. This sustainable approach aims to:

- preserve the environment and natural resources;
- maintain production potential for future generations;
- ensure long-term profitability for agricultural producers;
- guarantee the sufficiency and quality of food;
- enhance employment opportunities for the rural population and improve their quality of life.

The intensive technogenic model of development, which currently prevails in most countries, relies heavily on the utilization of production means and technologies without consideration for environmental constraints. This approach leads to the overexploitation of natural resources, particularly land, at a rate that surpasses its capacity for fertility regeneration.

The inconsistency of economic growth with the requirements of agricultural and environmental safety regulations significantly contributes to the anthropogenic pressure on natural agricultural resources. This pressure is nearing the threshold at which crisis changes in these resources occur, leading to consequences that adversely impact the final result of the agri-food sector.

There exists a discrepancy between the level of public danger posed by environmental offenses and the corresponding legal liability of business entities. The exploitation of natural resources is not accounted in the internal costs of enterprises, so the damage caused to the environment as a result of their economic activity is transferred to the whole society. Economic entities should be responsible for reimbursing the costs associated with natural resource utilization, without shifting this burden onto others. To achieve this, the state must implement appropriate regulatory and legislative measures to ensure a balance between the interests of food producers and the broader societal welfare.

Experts from the Organization of Economic Cooperation and Development (OECD) caution that "current economic models expose society to a significant risk of slowing growth. Limited measures aimed at preserving natural capital will inevitably lead to growth aimed at replacing it" (Bachinskiy, G.A., 1991).

State mechanisms of influence should serve a dual purpose. Firstly, they should establish conditions that incentivize producers to actively preserve the fertile potential of resources and enhance the environmental safety of their production practices. Secondly, these mechanisms should promote adherence to environmentally friendly technologies, emphasizing the social responsibility associated with the country's food security and the preservation of essential components of the natural environment vital for human life.

The future trajectory of the interaction between human economic activity and nature – now marked by contradictions and significant negative environmental phenomena – will largely depend on the pathways chosen by countries.

If the economy continues to take *precedence over environmental considerations*, the interests of the environment will inevitably be compromised. Consequently, humanity will face environmental degradation, which can adversely affect human health and potentially lead to the collapse of life on Earth.

If *the environmental factor takes precedence over economic interests*, it may jeopardize the material needs of humanity, thereby contradicting its natural instincts. Consequently, this scenario for future development is unlikely to be realized.

Finally, if humanity follows the path that ensures *a balance between economic and environmental interests*, it can achieve equilibrium between the conflicting processes, leading to the establishment of a high-quality environment. To accomplish this, it is essential for humanity to adhere to the standards of maximum permissible human impact on nature, as developed by progressive science and practice.

The concept of a unified mechanism for environmentally sustainable management, under the auspices of the United Nations, envisions the integration of all states in establishing international standards and norms for maximum permissible concentrations of various substances in air, water and soil. Additionally, it calls for the creation of coordinating international associations focused on the protection of the biosphere and the rational use of natural resources, as well as the preservation of the integrity and diversity of nature. This framework should serve as a guiding compass for the global community in ensuring the environmentally sustainable use of natural resources in general and specific resources in particular.

1.2. PRESERVATION OF NATURAL RESOURCE POTENTIAL IN AGRICULTURAL PRODUCTION AS A GLOBAL CHALLENGE.

Since the 1980s, the negative effects of the Green Revolution – characterized by a radical transformation of agriculture through intensified production, the development of high-yielding varieties, the implementation of irrigation and mechanization techniques and the use of high doses of fertilizers and phytosanitary products – have become increasingly apparent. Consequently, these issues have been at the forefront of discussions within the scientific community, the United Nations and international organizations focused on the condition of soil, water and forest resources, as well as the food supply that relies on these vital resources.

The "Green Revolution" in developing countries represented an extension of agricultural industrialization, characterized by chemicalization, land reclamation and selective breeding in both crop and livestock production. This movement began in the aftermath of the Great Depression of the 1930s in the United States, followed by Canada and the United Kingdom and expanded to Western Europe, Japan and New Zealand from the 1950s onward. Subsequently, the industrial-chemical approach to farming proliferated across all continents, facilitated by transnational corporations originating from Latin America and Southeast Asia.

Alain de Janvry, a professor of agricultural and resource economics at the University of California, examined the developments associated with the "Green Revolution" in his work "The Agrarian Question and Reformism in Latin America". He identifies several significant consequences of large-scale, export-oriented production driven by deep specialization, including the emergence of environmental disasters, the landlessness of peasants, rural-urban migration and the desolation of rural areas (Alain de Janvry, 1981).

American sociologist John Zerzan, in his work "Agriculture: The Demonic Engine of Civilization", asserts that the Green Revolution displaced millions of individuals from their arable lands across Asia, Latin America and Africa due to programs favoring large corporate farms. He describes this phenomenon as a horrific technological colonization that created a dependency on capital-intensive agricultural enterprises while dismantling traditional land-based communities. Zerzan emphasizes that this colonization necessitated substantial fossil fuel expenditures and ultimately resulted in unprecedented violence against nature (Zerzan, J., 2012).

This violence has manifested in the accelerated degradation of land, as well as the pollution of soil, water and the environment.

In 2011, the Food and Agriculture Organization of the United Nations (FAO) published the first consolidated report titled "The State of the World's Land and Water for Food and Agriculture: Managing Systems under Threat" (FAO, 2011). This report highlighted that a substantial portion of productive land and water ecosystems is at risk, necessitating urgent attention from both governments and the global community. In 2015, the United Nations adopted the 2030 Agenda for Sustainable Development, which emphasizes the importance of preserving the natural potential of agriculture (United Nations, 2015). Additionally, the Paris Agreement on Climate Change (2015)

(United Nations, 2015) and the Sendai Framework for Disaster Risk Reduction for 2015-2030 (United Nations, 2015) address specific aspects related to the threats facing land and other natural resources, as well as strategies to mitigate these threats.

In 2017, the United Nations Convention to Combat Desertification published the first edition of “Land Resources: A Global Overview” (UN, 2017). This report analyzes the overall condition of land resources subjected to significant anthropogenic pressure. Over the past two decades, many ecosystems have experienced degradation, with a consistent decline in the productivity of land and water resources observed on 20% of the land. This decline is attributed to the methods of land use and management practices employed.

According to the United Nations, drought has impacted 7.5% of the world's land resources and is responsible for 20% of the damage resulting from all natural disasters. Notably, over the past 30 years of the last century, the area affected by drought has tripled.

The decline in biodiversity and climate change are intensifying threats to the functionality and productivity of the land. These threats include rising temperatures, alterations in precipitation patterns, soil erosion, the extinction of numerous species and increasing water scarcity. Collectively, these factors can adversely impact the agricultural suitability of entire regions.

Land degradation diminishes the resilience of human communities to environmental stress, potentially exacerbating migration, instability and conflict. Currently, approximately 1.3 billion people are confined for degrading agricultural lands. As a result of declining land productivity and desertification, these individuals have lost their livelihoods.

Land use practices are inefficient, resulting in the degradation and pollution of natural resources and are primarily focused on short-term gains. The current agri-food business model disproportionately benefits a limited number of individuals at the expense of the majority. Large corporations with extensive, highly industrialized production systems reap the advantages, while small and medium-sized farms – historically the backbone of food production and community sustainability for thousands of years – struggle with significant challenges related to land protection, including insecurity of land tenure and the globalization of food markets.

Large-scale land acquisitions have surged dramatically over the past two decades. National elites, multinational corporations and developed countries that import food are acquiring extensive tracts of agricultural land along with associated water rights, seeking to conduct business today and capitalize on anticipated future price increases.

The preservation of natural resources, particularly land, relies on the strategies employed by governments and corporations, as well as the implementation of more effective planning and management practices that facilitate farmers' access to sufficient farmland for efficient management both now and in the future. Additionally, the adoption of technologies that prevent further land degradation is essential.

In 2021, the Food and Agriculture Organization (FAO) published the third Consolidated Report titled “The State of the World's Land and Water Resources for Food and Agriculture: “Systems on the Brink”, which was prepared by over thirty experts from

across all continents (FAO, 2021). The report indicates that the condition of the world's natural resources for agriculture has significantly deteriorated since 2011.

A global analysis reveals a convergence of factors that have exerted unprecedented pressure on land and water resources. The productivity of these resources is nearing a critical threshold, beyond which the negative impacts on human well-being, food security and access to clean drinking water are likely to escalate.

Agricultural Land Use and Climate. Currently, there are approximately 4,750 million hectares of land utilized for agricultural purposes, which includes 1,500 million hectares dedicated to crop production. The remaining 3,300 million hectares comprise meadows and pastures for livestock. Since the year 2000, the area of arable land has increased, whereas the extent of grassland has decreased. Additionally, there is a noticeable trend towards an expansion of irrigated land alongside an increase in unused land (see Table 1)

Table 1

Changes in land category, 2000-2019, million hectares

№	Land category	2000 year	2019 year	Change
1.	Land permanently used as grassland	3 387	3 196	−191
2.	Arable land (land under temporary crops)	1 359	1 383	+24
3.	Land under permanent crops	134	170	+36
4.	Land under agricultural crops (arable land and land under permanent crops)	1 493	1 556	+63
5.	Agricultural land (all land under crops and permanent grassland)	4 880	4 752	−128
6.	Land equipped for irrigation	289	342	+53
7.	Forest land (areas of more than 0.5 hectares with trees over 5 meters high and with a canopy closure of 10 percent)	4 158	4 064	−94
8.	Other lands	3 968	4 188	+220

Source: FAO. (2021). *The State of the World's Land and Water Resources for Food and Agriculture: Systems at the Limit. Synthesis Report 2021.*

The utilization of agricultural land is significantly influenced by climate change. Agricultural producers should adapt to alterations in temperature and precipitation patterns, which disrupt plant development stages and soil ecology, as well as impact the proliferation of diseases and pests affecting crops. Shifts in precipitation and the intensification of dry periods necessitate adjustments in the management of both irrigated and rainfed land.

Further climate change is expected to significantly impact the water cycle, which will, in turn, affect agricultural production as well as the environmental characteristics of productive land use and water management systems.

Climate models developed by specialized institutions and international organizations indicate that renewable water resources will decline across significant parts of the planet. Additionally, short-term water shortages may occur in regions with adequate soil moisture due to alterations in the frequency and volume of precipitation (Figure 3).

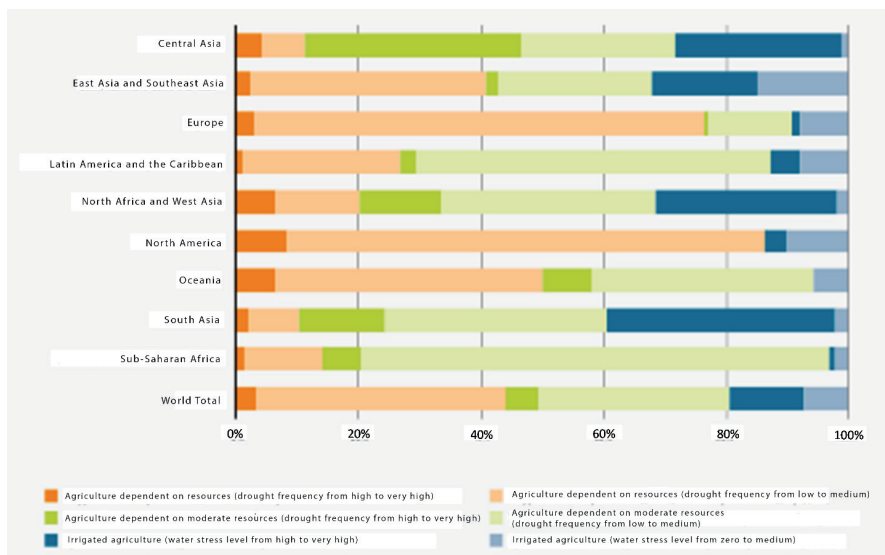


Figure 3. Share of arable land in different regions allocated to different production systems by water scarcity level. **NOTE:** The frequency of severe drought is classified as high or very high if the probability of such drought affecting more than 30% of arable land exceeds 20%. High or very high water stress is defined as occurring when total water withdrawals exceed 50% of renewable freshwater resources. The analysis includes only those areas of arable land for which data on drought frequency and water stress levels are available. The indicators for water stress levels pertain to the year 2015, while the historical frequency of drought is derived from all available time series data from 1984 to 2018. *Source:* FAO. (2021). *The State of the World's Land and Water Resources for Food and Agriculture: Systems at the Limit. Synthesis Report 2021.*

Forest Resources. Forests are a vital component of the water cycle and play a significant role in the sustainable management of water resources and associated ecosystems. They facilitate the return of precipitation to the atmosphere, which contributes to stabilizing and extending the growing season for crops. In regions where water is scarce and in areas impacted by drought, it is essential for forests to retain and release moisture, even during dry periods. In arid regions, reforestation can restore the productivity of degraded agricultural land and diversify food sources, thereby enhancing food security (Barbieri, P., Echarte, L., Della Maggiora, A., Sadras, V.O., Echeverría, H. & Andrade, F.H., 2012).

The water-related benefits of forests are most effectively realized through a holistic, comprehensive and integrated landscape approach. Forests and water resources are spatially interconnected and their distribution and location within the landscape can provide a range of environmental benefits related to water. Forests situated in the upper portions of a watershed contribute not only to local conditions but also to broader landscape health, as water flowing downstream typically exhibits higher quality. Extensive forest areas within river basins serve as significant sources of water vapor, which are essential for rainfed agriculture. The moisture that evaporates from the land can subse-

quently fall as precipitation, traveling up to 5,000 km in the direction of prevailing winds (International Fund for Agricultural Development, 2017).

Forests play a crucial role in the global carbon cycle and their condition is intricately connected to climate dynamics. From 2010 to 2020, the annual rate of deforestation was approximately 4.7 million hectares. In comparison, the first decade of the 21st century witnessed a higher deforestation rate of 5.2 million hectares per year, while the period from 1990 to 2000 experienced an even greater loss at 7.8 million hectares annually (Figure 4).

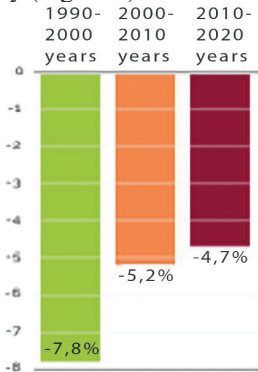


Figure 4. Net change in forest area in the world by decade, 1990-2020, %. Source: FAO. (2021). *The State of the World's Land and Water Resources for Food and Agriculture: Systems at the Limit. Synthesis Report 2021.*

The Role of Soils in Climate Change. Soils play a critical role in climate change as significant sources of carbon dioxide emissions. Notably, substantial emissions occur when peat soils are drained. From 1997 to 2016, approximately 4% of global carbon dioxide emissions were attributed to fires on peatlands. Furthermore, agriculture contributes to greenhouse gas emissions through methane released from flooded rice fields, nitrous oxide, and other gases.

In 2019, global anthropogenic emissions reached 54 billion tons of carbon dioxide equivalent (CO₂-e), with agri-food systems contributing 17 billion tons or 31% of the total. Specifically, agri-food systems were responsible for 21% of carbon dioxide emissions, 53% of methane emissions and 78% of nitrous oxide emissions. The per capita CO₂ emissions amounted to 2.1 tons, which is a decrease of 0.6 tons compared to 1990 (Figure 5).

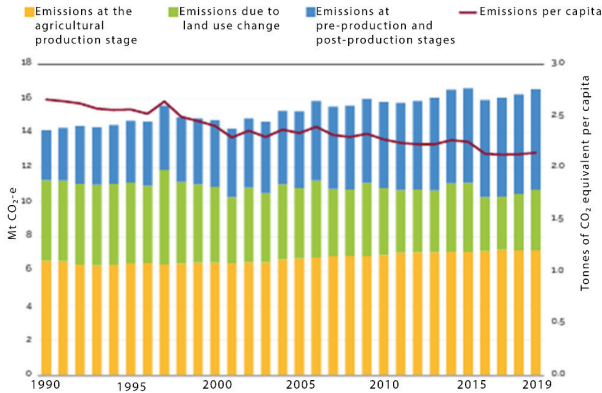


Figure 5. Global greenhouse gas emissions from agri-food systems by stage and per capita. *Source:* FAO. (2021). *The State of the World's Land and Water Resources for Food and Agriculture: Systems at the Limit. Synthesis Report 2021.*

Over the past decade, pressure on land and water resources has intensified. During this period, the area dedicated to agricultural crops has increased by 63 million hectares or 4%. This includes a doubling of irrigated arable land, while the area for rainfed crops has grown by 2.6%. Overall, the total area of agricultural land has decreased by 20% from 2000 to 2017. Currently, the availability of agricultural land stands at 0.19 hectares per capita, a decline from 0.41 hectares per capita half a century ago.

Increased fluctuations in precipitation will result in alterations to the suitability of land for cultivating specific crop types, leading to reduced yields. This reduction is particularly pronounced in areas where temperature stress negatively impacts the rate of carbon dioxide assimilation.

The impact of climate change on agricultural productivity necessitates a reevaluation of cropping patterns and farming practices to align with the adaptive traits of various crops. Different scenarios for future climate change indicate that adjustments in the structure of sown areas and farming methods are essential. This shift requires modifications to the traditional metrics used to assess land and water productivity, as an increasing number of production factors must now be considered in these evaluations (Figure 6).

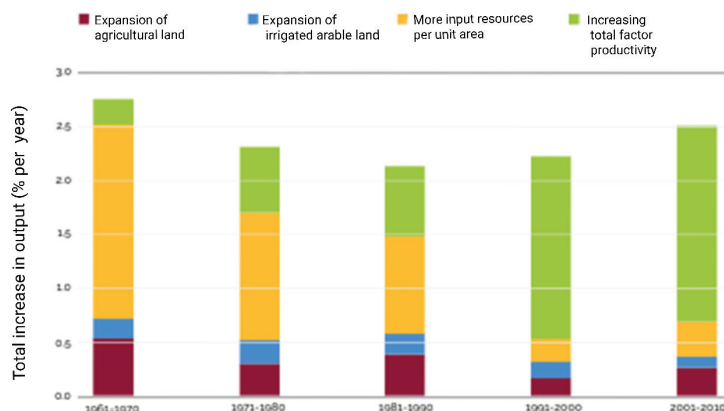


Figure 6. Growth of agricultural factor productivity, 1961-2010. Source: FAO. (2021). *The State of the World's Land and Water Resources for Food and Agriculture: Systems at the Limit. Synthesis Report 2021*.

The significance of intensification indicators is diminishing, while the importance of metrics related to the efficiency of natural resource utilization in agriculture is on the rise. Opportunities to enhance agricultural productivity through the expansion of irrigated land and the conversion of new land into agricultural use are virtually nonexistent.

Anthropogenic Land Degradation. As agricultural intensification increases, land degradation has also become more pronounced, characterized by the following key features:

- expansion of erosion processes;
- depletion of soil nutrient reserves;
- increased acidification and salinization of soils;
- decrease in soil biodiversity.

The application of mineral fertilizers now exceeds the balance with organic matter, adversely impacting soil conditions and resulting in water pollution due to drainage.

Anthropogenic degradation currently affects 1660 million hectares or 34% of agricultural land (Table 2)

Table 2

Scale of anthropogenic land degradation, 2015, million hectares

Degradation	The whole world	Arid lands	Areas with a humid climate
Total	1 660	733	927
Strong	850	418	432
Insignificant	810	315	495

Notes. Antarctica, Greenland and areas with more than 90 percent of their surface area devoid of vegetation (Great Deserts) are excluded from consideration. The cold zone, where the potential evapotranspiration is more than 400. Source: FAO. (2021). *The State of the World's Land and Water Resources for Food and Agriculture: Systems at the Limit. Synthesis Report 2021*.

An additional 656 million hectares (12%) of land are experiencing a decline in biophysical condition without clearly defined degradation processes. Overall, the deterioration of biophysical land conditions worldwide encompasses an area of 5,670 million hectares. Alongside human activity, land degradation is driven by both natural and anthropogenic processes. Degraded areas are significantly more vulnerable to climate change compared to ecologically sustainable lands, which may further compromise their productivity in the future. Table 3 presents a global assessment of anthropogenic land degradation, broken down by region.

Table 3

Scale of anthropogenic degradation of the world's land by region, 2015

Continent/ region	Area of land degraded by human activ- ity (mln ha)	Total area of the re- gion (mln ha)	Share of of degraded land in the to- tal area of the region %	Severely de- graded (mln ha)	Moderately degraded (mln ha)
Sub-Saharan Africa	(mln ha)	Moderately degraded	14	149	181
South Amer- ica	(mln ha)	1 778	16	153	128
South Asia	180	439	41	126	54
North Amer- ica	177	2083	8	82	95
East Asia	156	1 185	13	84	72
Western Asia	123	615	20	92	31
South-East Asia	122	501	24	74	48
Australia and New Zealand	94	796	12	34	59
Eastern Eu- rope and the Russian Fed- eration	83	1 763	5	21	62
Western and Central Eu- rope	56	489	11	12	44
Central Asia	31	456	7	12	19
North Africa	22	579	4	9	13
Central America Caribbean	11	76	14	5	5
Pacific Is- lands	0.14	7	2	0.11	0.03
All the world	1 660	13 178	13	850	810

Notes. The share of degraded land in the total area of the region is the part of the region where the land is degraded. Antarctica, Greenland, and areas with more than 90 percent of their area devoid of vegetation (great deserts) are excluded from consideration. *Source: FAO. (2021). The State of the World's Land and Water Resources for Food and Agriculture: Systems at the Limit. Synthesis Report 2021.*

Soils in South Asia are the most affected by anthropogenic degradation, with 41% of the region's soils being degraded. In Southeast Asia, 24% of the land is affected, while in West Asia the figure stands at 20%. Similarly, 20% of land in North Africa is degraded, 17% in South America, and 11% in North America.

Overall, one-third of rainfed lands and more than half of irrigated lands are degraded, with only 38% of the total global area remaining in a stable condition.

Over the past twenty years, grasslands used for grazing have decreased by 191 million hectares, as many have been plowed and converted to arable land. The remaining pastures have suffered degradation due to high anthropogenic pressure (Table 4)

Table 4

Categories of land degradation with different soil and vegetation cover, 2015

Soil and vegetation cover	Total area (mln ha)	Degradation (mln ha)	The deterioration condition (mln ha)	Stable condition (mln ha)	Degraded (%)	The deterioration condition (%)	Stable (%)
Land under agricultural crops	1 527	479	268	780	31	18	51
Rainfed lands	1 212	340	212	660	28	17	54
Irrigated land	315	139	57	120	44	18	38
Meadow and grassland lands	1 910	246	642	1 022	13	34	54
Trees	4 335	485	1 462	2 388	11	34	55
Shrubs	1 438	218	584	636	15	41	44
Grasses	203	16	51	136	8	25	67
Scanty vegetation	1034	85	499	450	8	48	44
Protected land areas	880	76	361	443	9	41	50

Notes. The term “degradation” means a high load of anthropogenic factors. All other types of decline in biophysical status are defined as deterioration. *Source: FAO. (2021). The State of the World's Land and Water Resources for Food and Agriculture: Systems at the Limit. Synthesis Report 2021.*

Overgrazing and inadequate livestock mobility contribute to soil compaction and erosion, which negatively impact both the physical and biological condition of soils, hinder grass growth and impair the land's ability to provide hydrological services. The concentration of livestock on grazing lands has exacerbated water pollution and increased methane emissions. In East Asia and the Middle East, the decline in land's biophysical condition is primarily attributed to reduced access to fresh water, heightened water stress, diminished soil protection and population growth. In Southeast Asia, additional drivers of land degradation include the rapid decline in forest biomass alongside the aforementioned factors.

Water resources are essential for sustaining the life of all living organisms. However, the global water balance is currently under threat. Increasing water shortages and the pollution of freshwater sources are becoming widespread across the planet. Addition-

ally, both surface water flow and groundwater levels are declining. The adoption of non-traditional water sources for agricultural purposes, such as desalination and water reuse, is progressing very slowly, primarily due to the high costs associated with the required technology.

The total average annual volume of water withdrawal per capita is shown in Figure 7.

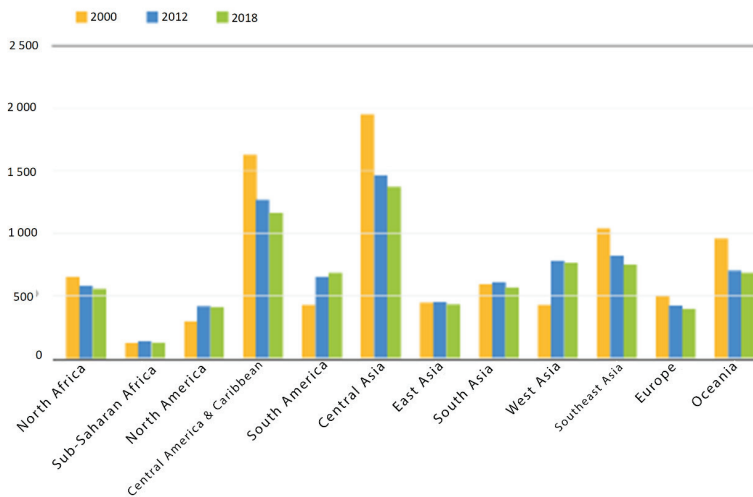


Figure 7. Total average annual water withdrawals per capita by geographic region, 2000, 2012 and 2018 (in m³ per capita). *Source:* FAO. (2021). *The State of the World's Land and Water Resources for Food and Agriculture: Systems at the Limit. Synthesis Report 2021.*

Total water withdrawals have decreased since 2000 in all regions except Central and South America and Southeast Asia. Water abstraction from underground sources for irrigation is significant in many regions. The total volume of this withdrawal reaches 820 km³ per year, reflecting an increase of 19% compared to 2010. Within the context of irrigated agriculture, this accounts for 30% of all freshwater withdrawals used in agriculture. Various estimates suggest that this figure could potentially rise to 43%.

Simultaneously, the pollution of freshwater sources is a significant cause for concern. The primary pollutants include industrial and municipal wastewater; however, agriculture contributes to 10% of the total volume of these pollutants. Water sources are primarily contaminated due to a substantial increase in the use of nitrogen fertilizers. In 2000, 81 million tons of nitrogen fertilizers were applied, whereas by 2017, this figure had risen to 110 million tons. A similar trend is observed with phosphate fertilizers, although at a slower rate.

The anthropogenic impact on the soil cover of arable land and pastures has reached a level where these soils can no longer effectively retain and decompose waterborne pollutants. As a result, there has been a significant increase in the concentration of nitrogen and phosphorus compounds in freshwater systems. This issue extends to the presence of pesticides and pharmaceuticals used in livestock production as well.

Climate Change. Various scenarios predict that one of the defining features of climate change will be an increase in both the frequency and intensity of precipitation, a trend that is already being observed. The Intergovernmental Panel on Climate Change (IPCC) special report titled "Climate Change and Land Resources (IPCC (2013) notes that tropical cyclones are currently shifting toward the poles, thereby altering their forward velocity.

The increase in the frequency and duration of intense storms in coastal regions is contributing to land degradation and adversely impacting the composition and structure of coastal forests. Additionally, these areas are threatened by rising sea levels, which are exacerbating erosion and increasing the salinity of coastal lands.

In regions distant from coastal zones, these climate changes are manifested as severe flooding, which adversely affects land restoration efforts and disrupts planned agricultural activities.

The 2022 report on the Sustainable Development Goals indicates that the world is on the verge of a climate catastrophe (United Nations, 2022), with the window of opportunity to avert it rapidly closing. The increasing frequency of climate change-induced extreme heat events, droughts and floods is already adversely affecting billions of people globally and causing potentially irreversible alterations to the planet's ecosystems. To limit the global temperature rise to 1.5°C above pre-industrial levels, the Paris Agreement stipulates that global greenhouse gas emissions must peak by 2025. Subsequently, the Intergovernmental Panel on Climate Change (IPCC), the United Nations body tasked with assessing climate change science, projects that emissions should be reduced by 43 percent by 2030, ultimately achieving net zero emissions by 2050.

Countries are actively developing climate change action plans aimed at adapting to its impacts and reducing emissions, which are included in their nationally determined contributions. However, the current national commitments fall short of what is necessary to limit the global temperature rise to within 1.5°C. Projections indicate that greenhouse gas emissions may rise by nearly 14 percent over the next decade under these commitments. To avert the imminent threat of climate catastrophe and progress towards a sustainable future, it is essential to implement immediate and substantial reductions in emissions across all sectors of the economy.

Developed countries have collectively committed to mobilizing USD 100 billion annually by 2020 to address climate change in developing nations, a deadline that was later extended to 2025. However, the Organization for Economic Cooperation and Development (OECD) indicates that these nations have failed to meet this commitment. In 2019, the total funds provided and mobilized by developed countries for climate change initiatives amounted to USD 79.6 billion, up from USD 78.3 billion in 2018. Alternative forecasts from the OECD suggest that achieving the USD 100 billion target is likely to be postponed further.

While the commitment to mobilize USD 100 billion annually is regarded as the primary international source of financing for climate change, this figure is significantly lower than the Intergovernmental Panel on Climate Change (IPCC) estimates. According to the IPCC, achieving a transition toward a low-carbon future and limiting the global temperature rise to 1.5°C necessitates an annual allocation of between USD 1.6 trillion and USD 3.8 trillion by 2050.

In its sixth assessment report, the Intergovernmental Panel on Climate Change (IPCC) underscores a grave threat to humanity and outlines the potential consequences of a global temperature increase of 1.5°C or more. Extreme weather events and climate-related phenomena are already being observed across all regions of the world. Scientists anticipate that as global temperatures continue to rise, there will be an increase in the frequency and intensity of heatwaves, floods, heavy precipitation, droughts and cyclones.

According to the United Nations Office for Disaster Risk Reduction, if current trends persist, the number of medium- and large-scale disasters is projected to reach 560 annually by 2030, averaging 1.5 incidents per day, which represents a 40 percent increase compared to 2015. The Intergovernmental Panel on Climate Change (IPCC) forecasts that by 2100, at least one-third of the land area will experience moderate drought conditions. Furthermore, any additional increase in global warming is expected to exacerbate the frequency and intensity of extreme weather events.

Sea levels are rising at a rate unprecedented in previous centuries. Even with significant reductions in greenhouse gas emissions and efforts to maintain temperature increases well below 2°C, projections indicate that sea levels could rise by 30 to 60 centimeters by 2100. This rise in sea levels is likely to result in more frequent and severe flooding, as well as increased erosion in coastal regions.

Ocean temperatures are projected to rise further, leading to more frequent and intense episodes of extreme heat, as well as increased acidification and reduced oxygen levels in the ocean. Once the global temperature reaches 1.5°C, it is estimated that approximately 70-90% of warm-water coral reefs will be lost and at 2°C, these reefs are expected to become extinct. These changes are predicted to persist at least until the end of the century, posing significant threats to marine ecosystems and the livelihoods of over 3 billion people who rely on the ocean for their sustenance.

In many regions of the world, climate change-induced droughts, floods and extreme heat are placing additional strain on food production. Areas in Africa, along with parts of Central and South America, are already experiencing heightened food insecurity and malnutrition as a result of these climate events. Projected impacts further include soil degradation, increased infestations of pests and diseases and diminished quality of ecosystem services, such as pollination.

Climate change affects all populations, but its impact is most pronounced on the most vulnerable groups. According to the IPCC report, the number of individuals living in conditions highly susceptible to climate change is estimated to be between 3.3 and 3.6 billion. Furthermore, projections indicate that by 2030, approximately 700 million people may be at risk of displacement due to drought alone.

According to the latest IPCC report, "the scientific evidence is unequivocal that climate change poses a significant threat to human well-being and the health of the planet. Any further delay in taking coordinated global action will lead to the loss of the limited time remaining to secure a livable future". The report emphasizes the urgent need for immediate action in the fight against climate change.

Protecting Biodiversity. The ecological health of ecosystems and the biodiversity they support is crucial for providing food, water, medicine, shelter and other essential resources. Furthermore, these ecosystems offer vital services, such as water and air

purification, which sustain life and enhance resilience against increasing environmental pressures. However, human activities are causing significant alterations in most terrestrial ecosystems. It is documented that approximately 40,000 species are at risk of extinction in the coming decades, while an estimated 10 million hectares of forest are destroyed annually—an area comparable to the size of Iceland. Additionally, more than half of key biodiversity areas remain unprotected.

In an effort to prevent and halt the degradation of ecosystems, many countries are implementing the principles of sustainable forest management, protecting areas critical for biodiversity and enacting environmental legislation and measures. However, significant opportunities are being overlooked. In the allocation of funds for economic development, biodiversity concerns are often neglected. As a result, the risk of species extinction is increasing at an unprecedented rate in human history. According to the Red List Index, which assesses the overall risk of extinction for specific taxonomic groups, the situation deteriorated by 9.2 percent from 2000 to 2022. The extent of extinction risk and the rate of decline vary significantly by region.

In Central and South Asia, East and Southeast Asia, as well as small island developing states, the risk of species extinction and the rate of ecological deterioration are notably higher than the global average. The primary factors contributing to this situation are unsustainable agricultural practices and the overharvesting of wild species. Human activities, including logging and farming, encroach upon natural ecosystems, placing approximately 20 percent of reptile species at risk, for instance. To conserve biodiversity and sustainably utilize its benefits, significant efforts are required, including the cessation of environmental degradation, a reassessment of land use practices, and a transition to sustainable agricultural methods.

Biodiversity plays a critical role in the direct and indirect achievement of most Sustainable Development Goals (SDGs). There is a steady increase in the number of countries that incorporate the value of ecosystems and biodiversity into their national accounting systems. According to Aichi Biodiversity Target 2 (Secretariat of the Convention on Biological Diversity, 2010), effective from 2020, the value of biodiversity should be integrated into national and local development strategies, poverty reduction programs and planning processes, as well as into accounting and bookkeeping systems where appropriate.

The majority of countries, guided by this framework, have established national targets as part of their Strategic Plan for Biodiversity 2011-2020. As of January 2022, 37 percent of the assessed countries are on track or ahead of schedule to meet their targets, while 58 percent are making progress but not at a sufficient pace to achieve their objectives. Additionally, 5 percent of countries reported no progress or a worsening situation. Despite significant achievements, Aichi Biodiversity Target 2 was not met by 2020. To date, biodiversity concerns are largely overlooked in the allocation of funds for economic development.

The above-mentioned documents introduce goals and mechanisms for achieving them in the field of sustainable development, define national contributions to achieving goals for water protection, land protection and soil health. Within the framework of a set of mechanisms, the concept of a neutral balance of land degradation is being formed.

To monitor the implementation of the mechanisms outlined in the documents of international organizations, periodic global assessments of the state of natural resources (including soils, forests, biodiversity and climate change) are conducted, along with their impacts on the exacerbation of land desertification.

Summary and Conclusions:

1. The interconnected systems of land, soil and water resources are nearing their breaking point. Evidence indicates that agricultural systems are deteriorating, with repercussions felt throughout the global food system.

2. Current models of agricultural intensification have proven unsustainable. The pressure on land and water resources has intensified to the extent that the productivity of major agricultural systems is declining, jeopardizing livelihoods.

3. A polarization process within agricultural systems is underway, characterized by the dominance of large commercial holdings in land use, while small farmers are relegated to subsistence farming on land vulnerable to degradation and water scarcity.

4. Future agricultural production will depend on managing the risks of land and water degradation. To sustain the functionality of land, soil and water resource systems, achieving a more significant synergistic effect is essential. This is crucial to maintain necessary growth rates in agriculture while preventing further deterioration of environmental services.

5. Protection of land and water resources is imperative. The potential for reversing the degradation and depletion of these resources has diminished significantly and the complexity and magnitude of the challenge should not be underestimated.

6. Land and water management should become more inclusive and adaptive. Inclusive governance is vital for the equitable distribution and rational use of natural resources. In its absence, technical solutions aimed at mitigating land degradation and water scarcity are unlikely to succeed.

7. Scaling up comprehensive solutions necessitates planning at all levels. Effective planning aids in identifying critical thresholds within natural resource systems and implementing measures to combat land degradation. When formalized as complexes or programs encompassing technical, institutional, managerial and financial support, such measures can help reverse the degradation process.

8. Technical and managerial innovations can be harnessed to tackle priority issues and expedite transformative changes. The challenges of restoring abandoned lands, combating drought and addressing water shortages can be addressed through the introduction of new technologies and management strategies.

9. Aid measures and investments in agriculture can be redirected to facilitate the social and environmental benefits associated with the prudent use of land and water resources. There is potential for phased, gradual financing of agricultural projects that could be linked to a reallocation of subsidies to support the effective functioning of land and water systems.

1.3. COMPLIANCE TO REGULARITY OF INTERCONNECTION AND INTERDEPENDENCE OF NATURAL RESOURCE COMPONENTS AS THE BASIS FOR RESOLVING CONFLICTS IN THE "NATURE-HUMAN" SYSTEM.

The stability and reliability of the functioning of natural resource potential of agriculture within the reproductive process depend on optimizing the interactions between natural resource components and elements of natural and climatic conditions. Without such optimization, both individual components and overall natural resource potential experience degradation, which in turn negatively impacts agricultural productivity.

A comparative analysis of the characteristics of all components and the nature of their interconnections allows for two key objectives: first, to identify and manage inter-component interactions in accordance with natural laws; and second, to optimize the functioning of any natural and economic system. Achieving this optimization requires a comprehensive and conceptually consistent understanding of how natural (biological) laws interact with technical, economic, social and environmental laws. This integrated knowledge forms the foundation for the sustainable development of the system.

The coordinated and integrated actions of these components are what ensure the overall functioning of the natural resource system and the sustainability of its resource potential.

The concept of "natural resource potential" emerged in the 1970s. As the conditions for natural resource use evolved, scientists ascribed different meanings to this term, defined its boundaries and components in various ways and often equated it with terms such as "resource potential", "natural potential" and "ecological potential" among others.

Researchers from the Institute of Environmental Economics and Sustainable Development of the National Academy of Sciences of Ukraine define natural resource potential as a collection of natural resources and environmental conditions within specific geographical boundaries, which facilitates the fulfillment of economic, environmental, social, cultural, recreational and aesthetic needs (Dorohuntsov, S.I., Khvesyk, M.A., Horbach, L.M. and Pastushenko, P.P., 2006). Reimers (Reimers, N.F., 1990) characterizes a natural resource complex as comprising natural objects and phenomena utilized for both direct and indirect consumption, which contribute to the generation of material wealth, the sustenance of human living conditions and the enhancement of life quality.

The interpretation of the term "natural resource potential" presented above illustrates that, while the concept was originally understood in a more limited production-oriented context, it has evolved to encompass a broader perspective in contemporary conditions. Today, it emphasizes the balanced use of natural resources, accounting for the needs of present generations while ensuring that future generations have the same opportunities. This understanding aligns with the principles of sustainable development.

Agricultural development, more than any other economic sector, is highly dependent on the availability of natural resources utilized in the production process, as well as on natural and climatic conditions that either facilitate or hinder production. Together,

these factors constitute the natural resource potential of agricultural industry (Figure 8).

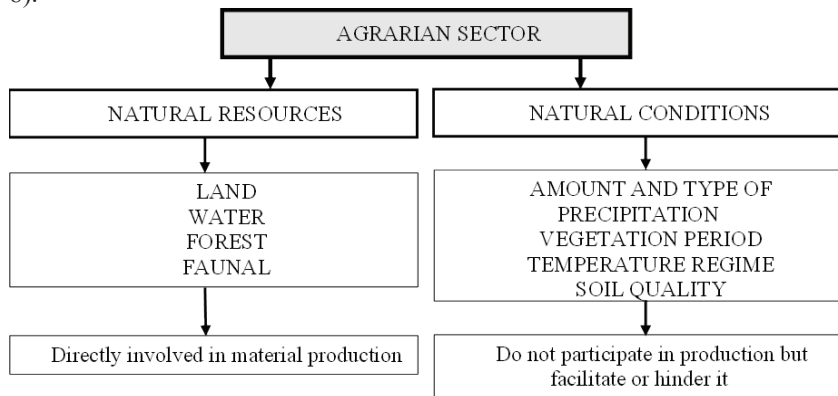


Figure 8. Components of natural resource potential. Source: Compiled by the authors

The specificity of agricultural production lies in the fact that natural and climatic conditions simultaneously perform a certain set of functions of natural resources.

The natural resource potential of agriculture, as a complex system of resources and production conditions that are interconnected and interdependent, possesses characteristics typical of any system. Primarily, it exhibits integrity, which indicates that all elements of this potential are aligned with the overarching objective of the system's functionality.

The complexity of natural resource potential is evident in the presence of constituent elements, each comprising a collection of distinct components that encompass smaller parts of the overall potential. This arrangement creates a multi-level structure characterized by a diverse array of resources available for utilization. Each element within this aggregate function as a system of interdependent and interacting parts, exhibiting relative autonomy and multifunctionality.

An optimally balanced relationship among these components, coupled with the implementation of lean technologies and effective management practices, creates opportunities for the operation of an economic system characterized by high productivity and resource efficiency (Vishnevskaya, O.M., 2007).

Natural resources including land (comprising arable land, hayfields, pastures, and fallow land), water (including surface runoff and groundwater) and forest resources (both woody and non-woody) along with natural conditions such as climate, topography and geographical location, play a crucial role in determining the specifics of agricultural development. These factors influence the specialization and nature of territorial division of labor, affect the condition of agricultural landscapes and shape the living standards and overall well-being of populations.

Agricultural production involves the development of living organisms within specific natural and climatic conditions. Consequently, the essence of agricultural activity lies in the integration of various methods and techniques aimed at optimizing the utili-

zation of natural factors to enhance the growth of living organisms while preserving their capacity for reproduction.

If humans disregard the laws of the nature and act against them, attempting to transform and dominate the nature for their own purposes, the resulting altered environment poses a significant threat not only to humanity but to all life on the planet.

In the component structure of the natural resource potential of agriculture, *Land Resources* play a primary role, while water and forest resources hold significant structural and supportive importance.

Soil cover is a crucial self-regenerating component of the biosphere. The primary biosphere functions of soils include:

- supporting life on the Earth by concentrating biophilic elements essential for organisms;
- facilitating the interaction between large geological and smaller biological cycles of matter and contributing to the creation of primary organic material;
- regulating the composition of the atmosphere and hydrosphere;
- controlling the density and productivity of organisms, as well as the intensity of biosphere processes;
- accumulating biochemical energy in humus.

Soil forms a biogeochemical layer on the Earth's surface, playing a critical role in addressing key challenges such as maintaining the normal functioning of the biosphere, preventing environmental pollution and enhancing the biological productivity of terrestrial ecosystems. These functions are closely tied to the rational use of land resources and the improvement of soil fertility.

Soil harbors a vast array of living organisms, along with the products of their metabolism and decomposition. It is within the soil that human waste undergoes decomposition, serving as a source of carbon and other essential elements required for the survival of these organisms.

The biochemical processes occurring in soil are directly linked to its sanitary condition. Soil serves as a natural purifier and sanitizer for plants, water and air. Maintaining healthy soil is crucial for ensuring a clean environment and safe, nutritious food for human populations.

The accumulation of harmful microbes, nitrates, chemical elements and heavy metals in soil beyond its capacity for self-purification has a significant impact on plant growth and development, which in turn affects human health and bodily functions. For example, nitrates can accumulate in plant products and enter the bodies of humans and animals upon consumption, leading to poisoning and serious illnesses. Similarly, radioactive substances that enter the soil through radioactive waste, atmospheric fallout from nuclear tests and research involving radioisotopes can have detrimental effects on both plant and human health.

Biochemical processes in the soil and the formation and metabolism of chemical elements in living organisms are interconnected as distinct stages in the natural cycle of substances, functioning as mutually exchanged processes that underpin life. Among the 106 elements identified by D.I. Mendeleev, 86 are consistently found in living organisms, playing crucial roles in essential physiological functions even at low concen-

trations. However, an excessive presence of these elements can lead to significant alterations in the organisms themselves.

Soil impacts from economic activities can significantly contribute to climate change. The application of synthetic and organic fertilizers, the proliferation of nitrogen-fixing crops, the drainage of organic soils and the practice of irrigation all enhance the availability of nitrogen in the soil, resulting in increased emissions of nitrogen oxide (N₂O) (Khitakhunov, A., 2020). Additionally, deep plowing with shelf-type tillage implements releases considerable amounts of carbon dioxide (CO₂) into the atmosphere, which is typically stored in the topsoil that supports the development of plant root systems.

Soils and *atmospheric composition* are intricately interconnected. The continuous activity of soil microorganisms enables soil to serve as a significant regulator of atmospheric gas composition. Soil porosity can exceed 60%, facilitating the penetration of gaseous substances from the atmosphere and enhancing biochemical processes involved in the exchange between soil and atmospheric air. This phenomenon, known as soil respiration, is essential for the healthy functioning of most soils. Respiration rates can reach between 1,000 and 4,000 liters per hectare per hour, allowing for the complete renewal of air in the upper soil layer within just one hour.

Soil air has significantly lower levels of oxygen and approximately ten times more carbon dioxide than atmospheric air. Reducing excess carbon in the atmosphere is crucial for enhancing its composition. As Vernadsky noted, this process primarily contributes to the production of free oxygen masses within the biosphere.

Soils exhibit varying capacities to reflect solar radiation. For instance, chernozems reflect approximately 5-7% of solar radiation, while brown loams reflect 18-19%. In contrast, arable podzols and salt marshes reflect 30% and 35%, respectively. Intensive plowing of different soil types results in an increasingly heterogeneous surface cover, which enhances the variability of heat supply in the upper layers of the atmospheric envelope.

Soils play a crucial role in the formation and regulation of moisture circulation within the atmosphere. Human economic activities significantly influence this process; practices such as intensive plowing, reduced forest cover and excessive deforestation enhance surface runoff, thereby diminishing the water-regulating capacity of soils. Collectively, these factors contribute to a decline in overall humidity and an increase in the aridity of climatic conditions.

Soil is also interconnected with the atmosphere as it serves as a source of airborne solids and microorganisms. The primary mechanism for the introduction of dust into the air is deflation, which occurs when soil is blown away by winds during dust storms from surfaces that lack continuous vegetation cover. Alongside soil dust, microscopic life forms such as fungal spores, pollen and protozoa are released into the air, dispersing across the planet through air currents. An excessive accumulation of solid particles and living organisms in the atmosphere can have significant negative consequences for human health and wellbeing.

Soil plays a crucial role in the functioning of the Earth's hydrosphere. Vernadsky highlighted the hydrological significance of soil by emphasizing the importance of soil solutions, which serve as the primary substrate for life. When precipitation infiltrates

the soil, it significantly influences the chemical properties of groundwater, as atmospheric moisture interacts with the soil and alters its initial state. Additionally, as precipitation moves through the soil, its gas composition changes, leading to a reduction in oxygen levels and an increase in carbon dioxide concentrations.

An essential hydrological function of soil is its involvement in the formation of annual runoff and the maintenance of the water balance. A notable characteristic of soil is its ability to quickly renew and restore water reserves throughout much of the year. Due to its active surface, soil can intercept a substantial portion of harmful compounds and elements before they reach water bodies, thereby serving as a protective geochemical barrier. However, in environments with excessive anthropogenic pollutants, soils can become inhospitable to beneficial microflora and unsuitable for agricultural use.

It is impossible to realize the natural fertility of the soil for growing crops without its moisture supply.

Water is a crucial component of plant cells. Cell hydration is essential for the physiological processes that occur within plants, including photosynthesis, respiration and all metabolic exchanges. Within the plant, water serves as the primary solvent and medium for the continuous transport of metabolic products between different organs. It helps stabilize the plant's temperature, as its evaporation (transpiration) prevents overheating of leaves and other plant organs, which is critically important for photosynthesis and the normal functioning of aerial nutrition. Furthermore, transpiration acts as a driving force for the movement of water and dissolved mineral substances within the plant.

Vernalization processes occur in the presence of water. Insufficient water levels lead to cell dehydration, a decrease in turgor pressure, and the disruption of various physiological processes. Conversely, excessive moisture negatively affects plant growth and development by creating oxygen deficiency for the root system and resulting in water-logging of crops.

The primary source of water influx into the soil is *precipitation*, which is a critical factor influencing the condition of land and other natural resources.

For most crops, the availability of moisture during the growing season, which is defined as the period when temperatures reach 10°C and above is crucial. Of the total volume of water that enters the plant, only 0.2% is utilized in the formation of chemical compounds, while the remaining 99.8% is expended through evaporation. For instance, a single corn plant can evaporate approximately 200 kg of water during its growing season.

Water reserves in the soil also depend on its water properties like water permeability and moisture capacity, which are determined by the mechanical composition of the soil, the amount of clay particles, porosity etc. (Table 5)

Table 5

Water reserves in the soil depending on its composition and moisture capacity

SOILS BY MECHANICAL COMPOSITION	MOISTURE CONTENT (in % of soil volume)	WATER STOCK IN THE METER LAYER (m³/ha)
Sandy	15 – 18	1500 – 1800
Sandy loam	22 – 24	2200 – 2400
Loamy	26 – 28	2600 – 2800
Clay	34 – 38	3400 – 3800

Source: Compiled by the author based on scientific literature.

The hydrological function of wetlands, natural unique ecosystems that play a significant role in the biosphere, is related to the water balance. They perform such important functions as accumulative, biological, landscape, hydrological and climatic.

The primary aspects of wetland soils' impact on other natural resource components encompass biodiversity conservation, flood mitigation, regulation of river flow, protection of coastal areas from storms, enhancement of water quality, recharge of underground aquifers and regulation of the local climate through cooling effects associated with water evaporation, among others.

The key aspects of the impact of wetland soils on other natural resource components include biodiversity conservation, flood mitigation, regulation of river flow, protection of coastal areas from storms, improvement of water quality, recharge of underground aquifers and the regulation of local climate through cooling effects resulting from water evaporation.

Wetlands constitute a critical component of the hydrological network and serve as the largest reservoir of freshwater. Although they cover only 6% of the Earth's surface, wetlands account for 11% of the global freshwater reserves (Oki, T. & Kanae, S., 2006). Furthermore, wetlands function as natural filters; depending on the type and depth of the peat deposit, one hectare of wetland can process between 100 and 685 m³ of water per day. These ecosystems effectively filter out numerous hazardous pollutants that enter surface waters through contaminated precipitation, soil runoff and watershed drainage.

The ratio of components within the water balance of a bog undergoes temporal changes. According to the water balance equation, variations in nutrient conditions and moisture consumption within a wetland result in fluctuations in the water table, which typically resides near the marsh surface. This water table responds rapidly to alterations in the components of the water balance.

Floodplain wetlands consistently mitigate the frequency and intensity of floods, often delaying their occurrence. This influence significantly affects changes in river flow and the hydrological regime of rivers, depending on the types of wetlands and their geographical location.

Czech researchers (Pokorný, J., Vymazal, J., 2016) investigated the impact of wetlands on climate using thermal imaging and found that the temperature difference between wetlands and drained areas in a modern cultural landscape on a clear, sunny day can reach up to 20°C. This significant finding underscores the role of wetlands in regulating air temperature through the process of evaporation. The direct influence of wet-

lands on regional climate, specifically through the reduction of temperature gradients and the role of water vapor and clouds in diminishing solar radiation transmission, has been clearly established.

Researchers have established that the drainage of wetlands in the Northern Hemisphere over the past 260 years has resulted in a greater radiative forcing of the atmosphere's surface layer than that caused by the increase in greenhouse gases during the same timeframe.

This further underscores that climate change is not solely a consequence of the greenhouse effect resulting from greenhouse gas emissions; it is also significantly driven by the destruction of natural ecosystems that directly influence climate and the water cycle. Consequently, it is crucial to preserve and restore natural vegetation structures, such as wetlands and forests, to effectively mitigate climate warming.

The condition of soils, the realization of their natural potential, as well as precipitation, thermal conditions and other climatic factors, are significantly influenced by *forest resources*, which play crucial roles in soil protection, water protection and water regulation. From an economic perspective, these functions serve as vital tools for labor and resource management.

The primary effect of the soil protection function of forest resources is the prevention of losses resulting from soil erosion. Each hectare of field plantations safeguards approximately 25 to 30 hectares of arable land. In fields shielded by scientifically designed forest belts, the value of additional crop yields is 2 to 2.5 times greater than the losses incurred from the land required for the establishment of these protective forest belts.

The functioning of forest plantations leads to significant changes in the natural environment. Under the forest canopy, soil permeability is four times greater than in open areas. Surface water runoff in these plantations is nearly eliminated, which enhances groundwater recharge. This process intensifies soil formation, metabolic activities and energy exchange. During years of extreme weather conditions, afforestation serves as a protective measure for land and crops, mitigating the impacts of wind erosion, windstorms and droughts.

The water protection and regulation functions of forests are critical for reducing surface runoff in agricultural fields, maintaining water levels in rivers, improving water quality and safeguarding water sources from depletion and pollution. These functions play a vital role in sustaining the water balance and hydrological regime of the region.

Field protective forest belts ensure a more even distribution of snow and regulate moisture consumption during the growing season.

The soil beneath forest plantations remains undisturbed by machinery and recreational activities, thereby preserving its high filtration capacity. The intensive evaporation from various types of forest plantations positively influences the moisture content of adjacent agricultural lands. As a result of these plantations, the accumulation of moisture and the transition of surface runoff to subsurface runoff exceed the total moisture evaporation rates observed in open areas.

Forest plantations contribute to the accumulation of additional precipitation. This phenomenon occurs as a result of increased surface roughness in forested areas, which slows air movement, cools the atmosphere and promotes cloud formation. Forests are

capable of accumulating 9-14% of the annual precipitation. Overall, atmospheric precipitation can increase by 5 to 25% annually due to the presence of forest plantations.

Global experience demonstrates that regions with extensive forest cover experience less degradation of natural resources, establish more reliable systems for conserving agricultural land and water resources and more effectively maintain their productive capacity.

Shelterbelt forests serve to protect agroecosystems from detrimental dry winds, deflation, blizzards and other wind currents. These plantations function as a spatial lattice, effectively reducing wind speed and altering the turbulence of airflow.

In areas with optimized forest belts, wind speeds decrease by 30–50%, while the temperature of the surface air layer increases by 1–3°C and relative humidity rises by 3–5%. Concurrently, evaporation rates decline by 12–35% and the transpiration coefficient of crops decreases by 10%.

Research institutions have demonstrated that optimally designed field forest plantation systems can result in an average annual increase in precipitation of 40–80 mm, a reduction in surface runoff by 1.9% and a decrease in the average annual temperature amplitude by 2–3°C, along with a reduction of 7–15 days in the duration of dry winds (Gladun, H.B., 2005). In this context, field forest belts can be classified as biogeocoenotic geochemical barriers, serving not only to enhance the buffering capacity of the environment but also to facilitate the bioconversion of agricultural lands that have already reached the limits of agrochemical and agrophysical degradation (Loghinov, V.B., 2009).

On sloping lands, the complex influence of runoff-regulating forest belts leads to an increase in the thickness of the humus horizon by 9-13 cm, enhancing both the productivity and erosion resistance of agrocenoses in the affected zone (Lukisha, V.V., 1978). Additionally, integrated assessments indicate that field protective forest plantations contribute to a 20-80% increase in the species diversity of flora within agrosystems, a 25-60% increase in entomofauna and a 1.5 to 3-fold rise in zoofauna diversity (Soloviy, I.P., Ivanyshyn, O.T., Lavnyy, V.V. et al., 2004).

The key role of forests in climate change is manifested in the fact that in the process of photosynthesis, they absorb carbon in the air with their biomass, which makes up about 65% of the planet's plant biomass (Soloviy, I.P., Ivanyshyn, O.T., Lavnyy, V.V. et al., 2004) and also accumulate other gases that cause an increase in average temperature. Forests contain about 75% of the planet's carbon through their vegetation (Information on CRISTAL, 2023).

In turn, climate change is affecting forests, putting pressure on their ability to maintain an appropriate level of diversity and productivity. As temperatures rise, water regimes change and carbon dioxide emissions increase, resulting in changes in both physiology and metabolism and in ecosystem functioning.

Global warming significantly reduces the resilience of forests through both abiotic and biotic factors. The growing consumption of forest products, large-scale forest fires, which are becoming more frequent and covering more and more areas due to rising temperatures, are exacerbating climate change.

Forests clean the air and water. Air is cleaned because forests adsorb a number of harmful substances from the air, including sulfur dioxide, nitrogen dioxide and other

pollutants. Forest trees and plants remove them from the air through the process of photosynthesis.

Water conservation and water purification are carried out by the roots of trees, which, by holding the soil, prevent it from being carried away into rivers and lakes and polluting the water.

All components of the natural resource potential are equally important for agricultural production. The knowledge of the laws of their interaction and interconnection has been transformed into the laws of agriculture, compliance with which is the basis for eliminating conflict in the nature-human system on the path to sustainable development.

According to the law of equivalence and indispensability of plant life factors, formulated by W.R. Williams, “none of the factors of plant life can be replaced by any other”. The normal functioning of the plant organism requires the presence of all terrestrial (water, air, macro and micro nutrients) and cosmic (light and heat) factors (Figure 9).

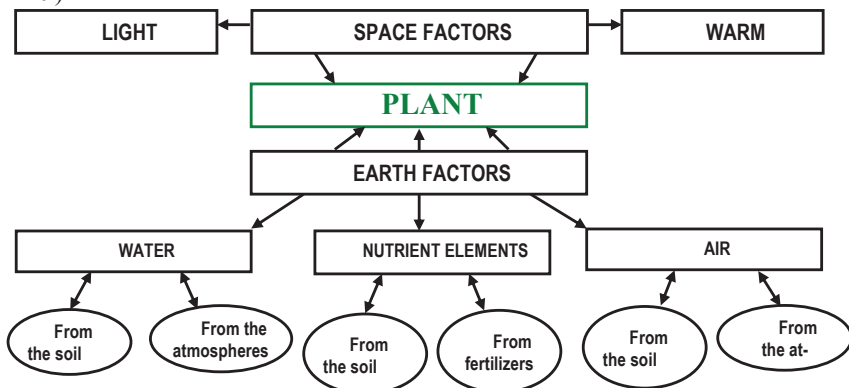


Figure 9. Equivalence of plant life factors. *Source:* created by the authors.

Water is the medium in which substances move and metabolize. In the presence of water, photosynthesis is carried out and organic matter is synthesized. Water is an indispensable thermoregulator for plants: it regulates the temperature of the plant organism, thereby increasing its resistance to high and low temperatures, maintains cell turgor and distributes assimilation products to individual organs. Interacting with the soil, water becomes one of the main factors in the soil formation process, determining the level of effective and potential fertility.

Air is necessary for plants as a source of oxygen for respiration of plants and soil microorganisms, as well as a source of carbon dioxide, which is absorbed by plants in the process of photosynthesis. Air is necessary for microbiological processes, as a result of which soil organic matter is decomposed by microorganisms to form water-soluble mineral compounds of nitrogen, phosphorus, potassium and other nutrients necessary for plants.

Light provides plants with the necessary energy, which they use in the process of photosynthesis to create organic matter. The productivity of plants is determined by

the inflow of PAR (photosynthetically active radiation) and the coefficient of its use for photosynthesis. Cultivated plants use 0.5-2% of the PAR. The higher the PAR utilization rate, the higher the biomass yield.

Heat is an important condition for plant life. Its main source is solar radiation. Each period of life of different groups of plants is characterized by its own interval of optimal temperatures at which biochemical processes are most intense.

The *law of plant autotrophy* combines the theory of photosynthesis and plant mineral nutrition. Green plants, using the energy of sunlight, carbon dioxide from the air, water and minerals from the soil, synthesize all the necessary organic compounds in an amount sufficient for their new full development. Accordingly, a person should implement a set of agrotechnical measures that would create conditions for maximum compliance with the law. For the intensive development of plants, it is important to increase the optimal assimilative surface of the leaves, which can effectively absorb solar energy for the synthesis of protoplasmic cells, tissues and organs of the plant organism, as well as the constant presence in the soil of sufficient water and all the necessary mineral nutrients in available forms and favorable conditions for their entry into the root system.

The *law of the combined action of plant life factors* states that "the yield increase depends on each growth factor and its intensity and is proportional to the difference between the possible maximum and the actual yield". That is, all plant life factors do not act in isolation, but in close interaction.

E. Mincherlich derived the coefficients of utilization of individual factors: N - 0.2, P₂O₅ - 0.6, K₂O - 0.4, MgO - 2.0 per 1 mm of precipitation. In production conditions, when influencing any factor, it should be borne in mind that it is interconnected with all other factors that will be affected by this influence.

J. Liebig formulated the *law of the minimum* as follows: "The productivity of a field is directly dependent on the essential nutrient that is available in the soil in the least amount." Applying this law requires that, during the cultivation of crops, agrotechnical measures focus on addressing the factor currently at a relative minimum.

Later, based on research by A. Mayer and E. Volney, which demonstrated that the law of the minimum should be considered in conjunction with the entire set of influencing factors, J. Liebig established the diminishing returns of increasing a single factor. Variations in yield related to soil moisture illustrate the diminishing effectiveness of a consistent amount of any growth factor. Whether moisture is insufficient or excessive, crop yields can approach zero, even if other factors are optimal.

Based on numerous experiments that confirmed this principle, R. Sachs formulated the law of minimum, optimum and maximum: "The yield is determined by the factor that is at its minimum. The highest yield is achieved when the factor is present in optimal amounts. At both the minimum and maximum levels of availability of a factor, no yield is possible".

In other words, according to the law, the greatest yield can be obtained with the optimal amount of a factor; a decrease or increase in this amount leads to a decrease in yield.

Any biological process in plants initiates at a specific minimum temperature, operates most effectively at an optimal temperature and subsequently slows down before

eventually ceasing as the temperature continues to rise. Consequently, when cultivating crops, it is essential to consider the factors that are at their minimum levels and to implement agronomic practices that ensure these factors remain consistently available in optimal quantities for the plants.

The essence of the law of nutrient return, formulated by the scientist Justus Liebig, is as follows: the basis of agriculture is that the soil must receive “back what has been taken from it. This is an unchanging law of nature”. K.A. Timiryazev called this law one of the greatest achievements of the science.

The law of return serves as the foundation for the reproduction of soil fertility. Crop yield, as a tangible substance, is produced from material components influenced by various factors essential for plant growth. The majority of these yields are derived from the substances and energy that plants obtain from the soil, which acts as both a medium for plant development and an intermediary in supplying necessary life factors. Consequently, a significant portion of nutrients is extracted from the soil each year through harvesting. Without their replenishment, soil degradation occurs, resulting in diminished fertility. Conversely, when these removed nutrients are returned to the soil, fertility is maintained; if the return exceeds the amount of nutrients extracted, it leads to an enhancement of soil fertility.

The law of crop rotation is founded on the biological interactions between cultivated plants and the soil. Implementing crop rotation is essential because different plants utilize soil nutrients unevenly; some species absorb more nitrogen, while others preferentially take up phosphorus or potassium. Recognizing this variability allows for the maintenance of effective soil fertility within crop rotation systems. The annual alteration of crops not only hinders the proliferation of pests and diseases that have adapted to specific plants but also influences the activity of soil microorganisms, the distribution of nutrients and moisture across various soil layers, and the accumulation of root residues and other nutrients.

Different stages of crop growth exert varying impacts on the soil and the surrounding environment. Factors such as soil density, compaction, particle size distribution and moisture content, as well as the quantitative composition of the soil microflora, undergo distinct changes depending on the growth period of the crops.

Crop rotation has a significant impact on the balance of nutrients in the soil, while monoculture causes soil depletion of certain elements.

In addition to light and heat, the differentiation of agricultural practices within each zone is influenced by factors such as the amount and seasonal distribution of precipitation, groundwater depth, soil fertility and the length of the frost-free and growing seasons. In practice, the law of zoning is applied to determine regional specializations in crop production and related livestock activities. Adhering to this law enables the regulation of production processes according to the specific soil and climatic conditions unique to each zone.

The systematization of agricultural laws based on their relationship to specific elements allows for their more rational and efficient use, enhancing their positive effects on plants, soil and the environment. This, in turn, supports increased crop production while preserving and improving soil fertility. These laws can be categorized into three groups:

1) laws related to soil characteristics: including crop rotation, the return of nutrients to the soil, the synthesis and decomposition of organic matter and the reduction of soil fertility;

2) laws related to plant life: such as the equivalence and indispensability of plant life factors, the principles of minimum, optimum and maximum, the combination of plant life factors and the autotrophy of green plants;

3) laws determined by atmospheric (climatic) conditions: encompassing the law of agricultural zoning and the differentiation of crop-specific agrotechnical practices.

Failure to comply with the requirements of the first group of laws results in soil degradation, dehumidification and a decline in fertility. Non-compliance with the second group negatively affects plant growth and crop development. Ignoring the third group leads to the inefficient use of the bioclimatic potential of agricultural land, particularly in regions with varying levels of natural resource availability.

The laws of agriculture illustrate the interdependence and interconnection of the components within the natural resource potential of the agricultural sector and their collective influence on agricultural outcomes. The ideal point in the development of any system is its equilibrium state. A key criterion for identifying such a state is the extent to which the system fulfills its target functions. When one component of the natural resource potential system loses its functionality, it inevitably disrupts all other interconnected components, leading to functional changes across the entire system.

Thus, preserving the optimally functioning of natural resource potential of the agricultural sector as a system involves identifying a model that achieves its equilibrium state. This equilibrium is characterized by a set of indicators that reflect the extent to which the system fulfills its target functions, specifically in providing food for humanity and maintaining a favorable environment.

1.4. THE PEASANTRY WITHIN THE "NATURE-HUMAN" SYSTEM.

"He who tills the land... is the lifeblood of the entire nation; it is he, and no one else, who creates, in the most literal sense, the conditions without which neither its hands nor its thoughts would function", – this is how the renowned early 20th-century plant physiologist, member of the Royal Society of London and honorary doctor of the universities of Cambridge, Glasgow and Geneva K.A. Timiryazev, described the place and role of the peasantry in human society.

According to the United Nations Declaration on the Rights of Peasants and Other People Working in Rural Areas, peasants are individuals who are engaged or intend to engage, either individually, collectively, or as part of a community, in agricultural production for their own subsistence and/or for market purposes. They primarily rely on the labor contributions of family members and other forms of non-monetary (non-profit) work organization and they are especially dependent on the land, maintaining a personal and direct connection with it.

This definition of the peasantry captures the objectively determined characteristics of the interrelationship and interdependence between natural resources, particularly land and the individuals who use them for agricultural production. The forms and methods by which these relationships are integrated within the "nature-human" system are shaped by the biological laws governing the development of living organisms, which drive the synthesis of organic matter – the core process of agricultural production.

If industrial production is a "mechanism of dead adaptations", in which the human functions merely as a mental and "muscular subject", then "agricultural production is a cosmos of living beings, where the substantial life of humans resides".

In industrial production, which is organized based on the division of labor, the work of one participant directly influences and controls the work of others. However, in agriculture, this form of internal control is largely absent. Consequently, there arises a need for the worker to have a personal stake in the production outcomes (David, E., 1906).

At the beginning of the twentieth century, N.P. Makarov observed that "in peasant farming, executive activity is not clearly distinguished from organizational activity... This is largely due to the nature of agricultural production process, where overseeing and monitoring work is... difficult to separate from the actual labor, particularly during the most intensive phases of agricultural production" (Makarov, N.P., 1920).

Therefore, rural people, peasants, who are "inclined to live in harmony with nature" (A. Thayer), are generally the ones capable of successfully managing a farm.

The patterns established by the founders of Western European agro-economics and their successors demonstrate that the *close interconnection between economic and natural reproduction processes in agriculture objectively necessitates the integration of production and management functions. This integration is essential for ensuring the sustainable use of land and other natural resources, entrusted to the direct producers of agricultural goods.*

The concept of organizationally rational farming has been a subject of discussion since ancient times. Notably, Xenophon, in his treatise "Oeconomicus", defined the economy as a holistic entity, with the key role played by the *owner* in organizing and

managing of agricultural activities (Xenophon, 1935). Marcus Cato, in turn, emphasized subsistence farming and regarded the owner as both a proprietor and organizer who effectively manages the processes of production and marketing of goods while exercising control over the labor of slaves (Cato, M.P., 1950). M.T. Varro and Columella emphasized the efficiency of small farms, criticizing large latifundia for their lack of profitability stemming from the absence of direct management by the owners, who delegated these responsibilities to others (Varro, 1963). All these thinkers believed that the personal involvement of the owner in managing the agricultural enterprise is crucial for the success and rationality of the farm.

Thus, even in ancient times, M.T. Varron and Columella highlighted that *latifundia* were not only inefficient but also unprofitable. They assumed that this inefficiency stemmed from landowners' lack of direct involvement in agricultural activities, as they often resided in cities and delegated all management responsibilities to others. This detachment resulted in a loss of control over the farming operations and diminished efficiency, ultimately questioning the viability of large landholdings within the framework of rational agriculture.

Thus, the thinkers of Ancient Greece and Rome were united in their emphasis on the *necessity of having a master* who serves as the owner, organizer and manager of agricultural activities. They contended that the highest efficiency and rationality in land use could be attained through the direct labor participation of the owner. Even then, these thinkers recognized that large latifundia were inefficient for agricultural production, attributing this inefficiency to the lack of personal involvement from the owners, which adversely affected productivity.

The recognition of specific aspects of agricultural practices can be traced back to the physiocrats. They were the first to highlight the unique nature of production relations within the agricultural sector and placed exceptional emphasis on its reproductive functions. This focus stems from the fundamental nature of food, which is essential for human sustenance throughout life and cannot be substituted.

The physiocrats also emphasized that agriculture is a self-sufficient industry. They argued that the contributions of natural elements such as sunlight, air, precipitation and the intrinsic resources of the land as well as the roles of productive plants, animals and farmers themselves, far exceed the importance of mineral fertilizers and other external inputs. In light of the scientific and technological advancements, this perspective necessitates a relatively greater degree of autonomy of agricultural enterprises compared to other sectors.

Classical economists like D. Ricardo and A. Smith did not focus extensively on peasant farming, while K. Marx and his followers viewed it as a temporary phenomenon (Bulgakov, S., 2006). However, they did acknowledge the distinctive features of peasant farming. K. Marx recognized peasants as commodity producers, noting that "their production is not governed by the capitalist mode of production" (Marx, K. & Engels, F., 1961).

According to Marx, the independent peasant holds a unique position: as the owner of the means of production, he functions as a capitalist, while also acting as his own laborer. This dual role provides the peasant with a competitive advantage over large, capitalistically organized agricultural enterprises. In the case of the latter, the market price of

products should account for the capitalist's profit margin, the landowner's rent and the wages of hired workers. In contrast, the peasant farmer can sell his goods at a lower price by forgoing part of the profit and rent and reducing his own consumption.

"The absolute limit for him as a small capitalist is only the wages he pays himself, minus expenses. As long as the price of the product covers his wages, he will cultivate his land" (Marx, K. and Engels, F., 1961). Therefore, the inherent characteristics of peasant farms offer them greater flexibility in adapting to market challenges compared to large capitalist enterprises.

The recognition of agriculture's unique characteristics as an indispensable food-producing sector, one that is heavily dependent on natural and climatic conditions, marked by seasonal production, heightened risks and tied to specific local conditions with spatial dispersion and delayed outcomes, has led to the acknowledgement that the forms and organization of agricultural production should differ from those in industry and other sectors.

In Ukraine, the theory of peasant economy began to develop at the turn of the nineteenth and twentieth centuries, in parallel with the emergence of capitalist market relations in agriculture.

The theory of the peasant economy emerged from the need to objectively assess and justify the existence of the peasantry as a social group, as well as the viability of peasant farming as an economic entity. In addressing this issue, national agricultural economists aimed to demonstrate that the theory of peasant farming represented a new and significant area of economic science at the time.

The fundamentals of peasant economy and the forms of its organization are widely covered in the works of national classical scholars, such as: S.M. Bulgakov, M.I. Tugan-Baranovsky, A.V. Chayanov, V. Vernadsky, M.H. Bunge, E.E. Slutsky, M.I. Ziber, A.Y. Antonovich and others.

S. M. Bulgakov was one of the first scholars to study peasant economies as agricultural producers involved in market relations, given that they sell surplus products on the market (Bulgakov, S., 2006), thereby demonstrating the effectiveness of their operations. He examined the economic nature of peasant income, which includes both income from the sale of agricultural products and wages. Bulgakov also identified the key factors influencing the formation of prices for peasant products (Bulgakov, S., 2006).

The researcher identified the primary factors contributing to the lower production costs of peasant economies in comparison to agricultural enterprises. A significant reason is the absence of land rent, which is not factored into the price of the products. Unlike in a capitalist economy, where landowners typically receive a return on their investment through capitalized rent, peasant economies do not recoup costs associated with land purchase in the form of rent. Furthermore, the pricing of their products does not incorporate the value of their own labor.

According to S. Bulgakov, the products produced by peasant farms are of higher quality than those offered by agricultural enterprises. Consequently, prices for products are frequently lower at peasant economies compared to agricultural enterprises, which primarily aim to maximize the percentage of profit on the capital invested in their operations (Bulgakov, 2006).

According to S. Bulgakov, the peasant economy is fundamentally rooted in the peasant family, which relies exclusively on the labor of family members rather than employing hired labor for management activities.

A significant milestone in the development of the theory of peasant economy was S. Bulgakov's identification of the role of peasant economy within the broader agricultural production system. He argues that the peasantry produces agricultural products under more favorable conditions than agricultural enterprises. As a result, peasant farming is considered the most advantageous form of agricultural organization for society (Bulgakov, 2006).

Fundamentally new approaches to the study of subject-object relations in the economic process are presented in S. M. Bulgakov's work "Philosophy of Economy". In this work, the author undertakes a re-examination of the essence of human economic activity by integrating economic and philosophical perspectives (Bulgakov, 1990). Bulgakov posits that human life is "first of all an economic process" (Bulgakov, 1990), leading him to conceptualize the object of "economy" as encompassing the following dimensions:

- human labor activity;
- the art and creative endeavors of individuals;
- spiritual phenomena and human existence;
- the creative relationship between humans and nature.

According to the scientist, "labor is the highest beginning of economic life" (Bulgakov, 1990). Labor is regarded not only as a factor of production but also as a creative activity undertaken by individuals. However, in the economic context, creative labor is a function uniquely associated with the human owner. The business entity—referred to as the owner – is not merely the possessor and user of the means of production; rather, this individual is also accountable for their activities and strives for their development. S. Bulgakov conceptualizes both economy and labor as phenomena of human spiritual life. In exploring the philosophical essence of the economy, Bulgakov emphasizes the inner world of the individual, asserting that the owner is a person who engages in creative work within their economic sphere (Bulgakov, 1993).

Bulgakov viewed the economy as "constant modeling and designing of reality" (Bulgakov, 1990). He posited that a business entity engages with nature, interacts with it and ultimately subdues it. He stated, "The economy is a creative interaction of man with nature" (Bulgakov, 1990).

Economic activity is regarded as a form of culture, a way of life and a means of self-realization for those engaged in it. The human personality is considered an independent "factor" within the economy. Bulgakov asserts that "the economy is the interconnection of freedom, the creative initiative of the individual and the mechanisms of necessity; it is the struggle of the individual against the mechanisms of nature and social forms to adapt them to the needs of the human spirit. Consequently, the economy is driven by the owner" (Bulgakov, 1993).

Thus, in contrast to the founders of classical political economy, Bulgakov centers his research not on the economic man, but on a free and creative individual. While humans conquer nature through economic activity, they also become increasingly dependent on the economy. He asserts that "the economy is the creative activity of man over nature;

by harnessing the forces of nature, he creates from them what he desires. Man constructs his new world, new goods, new knowledge, new feelings and new beauty – he creates culture” (Bulgakov, 1990). Bulgakov views the economy primarily as a creative process, with individuals acting as artists who shape history and engage creatively within the economic sphere. For him, the economy should be regarded as a phenomenon of spiritual life (Bulgakov, 1990).

A comprehensive theory of the organization of peasant economy was proposed by A. V. Chayanov in his works “The Doctrine of Peasant Economy” and “Organization of Peasant Economy”. He contended that the foundation of the peasant economy lies in the labor of the owner and their family members. In this context, the peasant, as the head of the family, assumes the role of the owner. Consequently, the peasant’s family generates labor income rather than capital gains from their activities. The primary objective of a peasant household is to secure its livelihood by making the fullest possible use of its own means of production and the labor of its family members.

A significant advancement in the development of the theory of peasant economy was the classification of types of peasant farms. In his work “Main Ideas and Forms of Organization of Agricultural Cooperation”, O. V. Chayanov identified six types of peasant farms (Table 6). Among these, only the first two operate on an entrepreneurial basis, employing hired labor with the objective of generating entrepreneurial income (Chayanov, A.V., 1991).

Table 6

Social types of peasant farms according to the classification of A. V. Chayanov

Types	Characteristics
First	are households that do not employ hired labor. They receive income not only from the sale of produced goods but also from providing loans and renting out agricultural equipment to other peasants;
Second	are households that, in addition to personal labor, also utilize a significant amount of hired labor. They generate income from the sale of produced goods;
Third	are households that have large families and use only the labor of their own family. They are characterized by possessing all necessary means of production, including the modern agricultural equipment. They generate income from the sale of produced goods;
Fourth	are households that have small families and use only the labor of their own family. Due to the limited number of workers in the family, the capacity of the household is not developed. They generate income from the sale of produced goods;
Fifth	are households with a small number of workers in the family, who fully or partially sell their own labor to other types of peasant farms. They have small land plots and limited agricultural equipment. They generate income from the sale of produced goods and external earnings;
Sixth	are households whose primary income is wages from the sale of their own labor. The products grown in these households are used only for personal consumption.

Source: Compiled by the authors based on data from: Chayanov, A.V. (1991). “Main Ideas and Forms of Organization of Agricultural Cooperation”. Edited by A.A. Nikonov. Moscow: Nauka. 456 p.

The remaining four types of peasant households make up the vast majority of peasants, with the primary objective of their labor activity being the generation of labor income, which refers to products whose value serves as a substitute for wages. The

amount of labor income is primarily influenced by the size and composition of the household, specifically the number of able-bodied members, the productivity of the working day and the degree of labor intensity, which determines the total number of working days available (Chayanov, A.V., 1989).

Chayanov's most important achievement was the development of methods of natural development of the peasant economy. He insisted that a peasant family produces as much food as is necessary to meet the needs of the household (the need for food, clothing, maintenance and development of their own farm). Further development of peasant farming requires significant expenditures for the purchase of agricultural machinery and the construction of special warehouses for storing agricultural products, which peasants usually lack the financial resources to do. That is why a system of agricultural cooperation is needed.

According to M. Tugan-Baranovsky, a prominent scholar in cooperative studies: "A cooperative is an economic enterprise formed by several individuals who join together in good faith, not with the aim of maximizing profit from the capital invested, but rather to enhance, through joint management, the labor income of its members or to reduce their expenses". A sugar factory organized on a cooperative basis and owned by its member peasants seeks to "retain in the hands of the peasants the largest possible share of their labor income, which could otherwise be significantly appropriated by trade capital if the product of their farm (beet) were sold without being processed into sugar" (L.P. Horkina, 2010).

By forming cooperatives for the joint marketing of products, their processing, the collective purchase of inputs and other activities that are impractical or economically unfeasible to achieve individually, a peasant family can maintain its economic independence. This means that the peasant remains the private owner of the land plot, as well as the owner of the products produced and the income generated from their sale. Agricultural cooperatives provide small farms (its members) with the advantages typically associated with larger farms. An analysis of the historical experience of the cooperative movement demonstrates that the collective efforts of peasant farms operating on a cooperative basis have been crucial for their preservation and successful operation amidst the pressures exerted by globalized capitalist forms of management.

Scholarly economists in agriculture have demonstrated that peasant economy (farming) is a stable and independent commodity-economic form capable of developing freely in a market environment. One of the main issues that scholars faced was identifying the social aspect of the development of small peasant farms.

Peasantry serves a vital social function by producing essential crop and livestock products to meet both the family's needs and for sale. Consequently, the products generated by peasants constitute the material basis of life. As the owner of a farm, which serves as both the residence and workplace for the peasant and their family, the peasant is committed to preserving and maintaining the quality of the soil on their land. Moreover, they are motivated to produce environmentally friendly products.

Peasant economy represents not only a form of economic activity but also an organizational structure for peasant life. The production activities of peasant farming are inextricably linked to its social and demographic functions, as well as to the broader life of rural society. Through production, peasant farming is interconnected with hu-

man reproduction, whereby economic and demographic processes converge within the farm. This integration promotes respect for agricultural labor and ensures the continuity of farming generations. The symbiosis of economics, demography and agricultural culture is a defining characteristic of peasant farming.

The works of economists who examined agricultural issues at the turn of the 19th and 20th centuries provide a generalized framework of theoretical principles regarding peasant farming, which can be summarized as follows:

- the peasant family serves as the foundation of the peasant economy;
- the peasant economy is a significant and independent commodity-economic form;
- the peasant economy is capable of functioning and developing freely within market conditions;
- the peasant economy represents a distinct form that, during the management process, does not align with either entrepreneurs, capital owners and employers, or with employees;
- peasant farms consist of small and medium-sized owners who manage and work on their own behalf;
- peasant farms can operate and develop effectively when organized into agricultural cooperatives.

In the current context of agricultural development, the most prevalent form of farming for peasant families in the EU, North America, Asia and Oceania is the farm. In EU countries, a farm is classified as such if it utilizes at least 1 hectare of agricultural land, while in the United States, a farm is identified based on generating an income of more than \$1,000 from agricultural products.

According to the Ukrainian Wikipedia, a farmer is a category of entrepreneur in agriculture, while a peasant is described as a tiller, plowman and harvester.

Farmers are landowners or lessees who manage their farms as family operations and/or with the use of hired labor. They produce, process and sell agricultural products using land and property that they lease, inherit or own for life.

In the world practice, a farm (also referred to as a peasant economy or peasant farm) is a production, social and biological unit. Its functioning not only involves the production of food and raw materials for industry but also ensures the socio-demographic reproduction of its workforce and the preservation of the ecological balance within the agrobiocenosis. Within a farm, there are both direct and reciprocal interactions between the factors of economic activity, which include labor, production and technical assets, energy, agricultural land and other natural resources, as well as the outcomes in the form of agricultural products, labor resource regeneration and the enhancement of the productive properties of the agrobiocenosis. This implies that the factors of agricultural production are partly outcomes, and conversely, the results themselves can also serve as production factors.

The intricate interconnection and organic fusion of production, economic, social and biological processes within a farm define the fundamental essence of this organizational and legal form of management.

The advantages of peasant farming include the production of environmentally friendly and organic products, the opportunity to apply creative skills in working the

land and a strong sense of ownership and stewardship over the natural landscape. The peasant is directly responsible for the quality of his work, the land and the farm, as production is primarily for personal use, with only the surplus sold. The profitability of small-scale market production is enhanced through the formation of agricultural co-operatives, which boost the income of small farmers by facilitating more efficient economic activities on limited land areas.

In modern conditions, a farmer acts not only as the owner of his land, but also as an entrepreneur who should ensure the profitability of his farm. In this context, the farmer faces the challenge of performing not only traditional agricultural work, but also key management functions such as planning, organization, control and analysis. The ability to effectively perform these functions determines his success as an entrepreneur, ensuring the sustainable development of the farm and the achievement of economic, social and environmental balance.

The family farming system preserves a person's direct interest in the subject matter of their work and thus the need of professional knowledge of this subject.

In countries with developed agricultural sectors, the organizational structure is predominantly composed of individual and corporate family farms. For example, in the United States, the average farm size is 147 hectares of cultivated land, while in the Czech Republic it is 89 hectares, in France 52 hectares, in Italy 8 hectares and in Romania 3 hectares. These farms typically employ a relatively low level of hired labor. In the European Union, there is an average of up to 10 hired workers per 100 family farm workers, ranging from 2 in Greece and Italy, where landholdings are smaller, to 17-18 in France and Denmark.

The integration of the roles of land and property owner, production manager and employee within a family farm enhances labor productivity and overall production efficiency. This arrangement also allows family farms to reduce institutional costs associated with the organization and management of production processes. Additionally, since farmers' income is not segmented into profits and wages, they possess greater flexibility in balancing investment and consumption, a flexibility that commercial corporate enterprises typically lack.

The advantages of a farm are that disabled members, pensioners and teenagers can participate in family production, if necessary, which makes it possible to maneuver the workforce during seasonal work and adverse weather conditions.

An important social aspect of a family farm is that it guarantees employment for young heirs and contributes to their development. Inheriting a farm solves the problem of the initial capital needed to start an agricultural business.

Farms are naturally inherent in environmental functions, as the farm is both a place of work and a place of residence for its owner. Here, the greening of production is a factor in the self-preservation of the farm family.

Due to these and other characteristics, the family farming model of management is recognized as the most effective in fulfilling the economic, social, and environmental functions of agriculture and has not only persisted despite predictions from proponents of classical capitalist schools that it would disappear from the historical landscape, but it continues to dominate in many countries around the world.

The farmer type of business is acknowledged as the most effective organizational and legal form that promotes the sustainable development functions of the agricultural sector.

The economic function of a business is to generate profit through its economic activities. The growth of small businesses enhances the financial capacity of both farmers and local government budgets, enabling greater investment in the economic development of agriculture and rural areas.

The social function of the economy is aimed at ensuring:

- production of quality agricultural products that meet the needs of society;
- food security and food independence of the country;
- jobs for the rural population;
- preservation of settlement in rural areas;
- preservation of the gene pool, national agricultural and rural traditions.

The ecological function of the farm is to:

- preservation of nation soils;
- ensuring environmental safety and maintaining the ecological balance of the country;
- protecting water sources from pollution and ensuring their rational use;
- maintaining agro-pasture and forest landscapes;
- preservation of flora and fauna and their biodiversity.

This ultimately supports the economic, social and environmental advancement of the agricultural sector. The economic function ensures the profitability of agricultural activities, which is crucial for the sector's expanded reproduction. The social function contributes to meeting social needs for high-quality agricultural products, enhances food security, generates employment for rural populations and helps to preserve rural communities and their cultural and genetic heritage. The environmental function aims to preserve the country's natural resource potential, ensure environmental safety and maintain ecological balance.

The foundation of the peasant-farmer management model is a responsible owner capable of fulfilling these three core functions. Such a farmer plays a central role in achieving a balance between economic profitability, social stability and environmental sustainability, which are essential elements for the long-term sustainable development of both the agricultural sector and the national economy.

In Ukraine, the formation of the farm type of economy is still in its infancy. In the process of reforming the agricultural sector, in the absence of clear legislation on the agricultural system, various forms of management have emerged: individual peasant economies (households), farms, corporate private agricultural enterprises and large agro-trade and industrial capitalist companies in the form of agroholdings or latifundia.

A farm is a legal entity that carries out agricultural activities for profit using its own labor, the labor of its family as well as hired labor and manages its own farm. It is classified by law as an enterprise.

Farms cultivate 7% of agricultural land.

A private peasant economy is an unincorporated organizational and legal form that has been and remains a peasant family's economy, which carries out economic activi-

ties mainly with the help of the peasant and his family's own labor and whose purpose is to meet their own needs for food and sell the surplus to generate income.

They cultivate 1/3 of agricultural land. According to the law, private peasant economy is not considered a business entity.

Thus, both farms and peasant economies are producers of agricultural products and participants of market relations, since the products they produce are sold in full or in part on the market: for farmers, in accordance with their business plan and for peasants, in the form of surplus. Both the farmer and the peasant are directly involved in the production of agricultural products and are responsible for the results of their business (quality of products, economic attitude to the land, compliance with crop rotations, etc.) Therefore, both the farmer and the head of a private peasant economy are owners.

Private peasant economies were formed on the basis of peasants' subsidiary households as a result of the right granted to them in the course of land reform to expand up to 2 hectares at the expense of state or communal land, as well as by joining land shares received in reorganized collective farms without registering a legal entity.

The existing small farms are adequate to farms in Poland, Romania, Italy and other countries. However, they are not institutionalized as such in the legal field. At the same time, having taken over the production of all labor-intensive products, private peasant farms provide 2/3 of the assortment of the food basket, contribute to the employment of 2 million people displaced from production by highly specialized large enterprises, are the main contributors to local budgets and preserve rural settlements and rural areas.

Private peasant economies, which are not legally recognized as farms, are excluded from full access to state support for agricultural production. As a result, they fall outside the scope of social protection and guaranteed pension benefits, which creates a discriminatory situation for this category of food producers.

The unresolved nature of this problem, as one of the significant components in the formation of the farming economy, has led to the spread of "holdingization" in Ukraine. Large capitalist agro-industrial and trade enterprises have seized hundreds of thousands of hectares of agricultural land for the cultivation of 2 to 3 of the most profitable, mechanized, export-oriented crops. These crops are grown using heavy machinery, mineral fertilizers, pesticides and other plant protection products to maximize yields, resulting in corresponding negative ecological and social consequences. These effects are similar to those known from the history of the western United States in the first half of the 20th century, as well as from several Latin American and East Asian countries during the Green Revolution period and are currently evident in some African countries and other regions.

The suspension of these processes is the responsibility of the Ukrainian legislature and government. Failure to address them could result in significant negative consequences, including threats to food security, the destruction of soil cover, the degradation of rural areas and mass urbanization of rural population. These developments could also present obstacles to the country's progress toward European integration.

Section II: AGRO-ENVIRONMENT IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT STRATEGY.

2.1. ASSESSMENT OF THE COMPONENTS OF THE NATURAL RESOURCE POTENTIAL OF UKRAINIAN AGRICULTURE AND THEIR IMPACT ON INDUSTRY DEVELOPMENT.

The natural resource potential is assessed using the resource, target and system approaches. The resource approach is determined by quantitative parameters that characterize the amount of resources, their structure, dynamics and the level of satisfaction of the population's needs. According to the target approach, the potential is assessed in terms of the possibilities of its most efficient use to solve the problems of economic, social and environmental development of the territory, improve the living standards of the region's population and ensure the appropriate development of the country's economy.

The systemic approach makes it possible to identify the key factors influencing the functioning and development of the natural resource system and to establish a hierarchy of these factors based on the strength of their impact on the system in relation to both external and internal environments. This approach combines the principles of integrity, the systematic interconnection of components and their structured organization (Riday, N.M., Horbatenko, A.A. & Kucherenko, Y.A., 2013).

The application of these approaches enables a comprehensive assessment of the state of natural resource potential as a whole, as well as an evaluation of each of its individual components. It also allows for the identification of zonal characteristics and their influence on agricultural production.

The share of land resources in the productive forces of the country exceeds 44%. In the Polissya zone, this indicator varies within the natural resource potential of the region, ranging from 19.4% in Zakarpattia to more than 59.0% in Zhytomyr and Chernihiv regions. In the Forest-Steppe zone, the share of land resource potential is higher, ranging from 50% in Chernihiv to 79% in Vinnytsia. In the Steppe zone, this indicator falls in the intermediate range.

The potential of water and forest resources is greater in the Polissya zone and progressively decreases from north to south.

The potential of water and forest resources is higher in the Polissia zone and gradually decreases as one moves from north to south.

One of the most critical components of the natural resource potential in agriculture is land, particularly its soil cover, which is represented by agricultural land. This land serves as the foundation that integrates all other components of natural resource potential. As a natural resource, farmland becomes both a means of production and an object of labor during the production process. The size, structure and fertility of this land primarily determine the level of natural resource potential in the agricultural sector.

Land productivity is primarily determined by the natural fertility of the soil, which in turn depends on the chemical composition and physical properties of the surface

layer. This layer is shaped by various factors, including climatic conditions, topography, air moisture, heat, vegetation and the activity of living organisms. Ukraine's land is distinguished by its high bioproductive potential, with fertile soils forming a significant part of its overall structure. In Ukraine, there are about 40 types and 800 varieties of soils.

The grouping of soils by types shows that the structure of the soil cover is dominated by chernozem varieties (almost 60%), chestnut soils occupy 9%, sod-podzolic - 7%, gray forest - 6.7%, saline - 2.5%, alkaline - within 2%, meadow and swamp - 2%.

Ukrainian black soil constitutes over 8% of the world's total black soil and approximately 30% of that in Europe. These soils cover a significant portion of the Forest-Steppe region. Typical chernozems in the Forest-Steppe are characterized by a deep, well-humified profile, ranging from 120 to 130 cm in depth. The humus content in the topsoil (0-30 cm) is influenced by the humusometric composition and the hydrothermal conditions during the warm period. In areas with light loams, which account for 25% of the total area, the humus content ranges from 2.5% to 3.5%, while in regions dominated by heavy loams (40% of the area), it ranges from 5.5% to 6.0%. Medium loamy chernozems occupy an intermediate position in terms of humus content. The pH of the soil solution is neutral, measuring between 6.7 and 7.3.

A smaller area in the Forest-Steppe is occupied by podzolized black soils. Their humus profile is 70-115 cm and the humus accumulation is 15-30% in the arable layer.

In the Steppe zone, chernozems constitute the primary foundation of the soil cover. The northern, relatively dry Steppe sub-zone is characterized by ordinary deep black soils, which possess a humified profile ranging from 100 to 130 cm. These soils are predominantly heavy loamy and light loamy chernozems, with humus content in the topsoil varying between 4.5% and 5.5%. The total reserves of soil organic matter in the profile are estimated at 400 to 550 t/ha. As one transitions into the north-central sub-zone, there is a notable decrease in the humus profile by approximately 30%, accompanied by a reduction in humus content in the arable layer to between 4.0% and 4.8%.

Further south, the humus horizon exhibits a decrease, with humus content varying; in some areas, it increases to between 5.3% and 5.7%, while in others, it declines to between 3.0% and 3.5%.

In the Forest-Steppe and Steppe regions, meadow-chernozems and meadow soils are found in areas of low relief. These soils are distinguished by their enhanced moisture availability and greater humus accumulation. Notably, saline and saline-alkaline soils also occupy significant areas within this landscape.

In the dry Steppe region, dark chestnut and chestnut saline soils, primarily consisting of heavy loam and light loam granulometric compositions, are predominant. The humus reserves in these soils decline, with the topsoil of dark chestnut soils exhibiting humus content ranging from 2.3% to 2.8%, while chestnut soils show a lower humus content of 1.8% to 2.2%.

Clear gray, gray forest and dark gray soils are predominantly found in the Forest-Steppe zone. Clear gray soils are characterized by a humus profile ranging from 45 to 55 cm, with humus content in the topsoil varying between 1.3% and 2.9%. The soil solution in these soils is predominantly acidic, with a pH ranging from 4.8 to 6.1. In contrast, dark gray soils exhibit a deeper humus profile and higher humus content, with

light loam varieties containing 2.0% to 2.5% humus and heavy loam varieties containing 3.0% to 3.5%. These soils also display a slightly acidic reaction in the soil solution.

Sod-podzolic, sod-ashy and sod-carbonate soils are characteristic of the Polissya zone. Sod-podzolic soils serve as the baseline soils for this region, exhibiting low humus content and an acidic reaction in the soil solution.

Regarding the ecological and agrochemical assessment of soil cover, the results from the XI round of agrochemical certification of agricultural land [hereinafter referred to as 2] indicate a score of 50 points, corresponding to average quality (satisfactory soils of class VI). In the Forest-Steppe and Steppe zones, the ecological and agrochemical scores for soils are higher than those in the Polissya zone, with weighted averages of 50 and 55 points, respectively. In contrast, the Polissya zone records an indicator below the national average for Ukraine, with a score of 42 points.

Soils are categorized based on quality assessment as follows:

- very high quality (I—II class): 1.5%, found only in the Forest-Steppe zone (2.14%) and the Steppe zone (1.8%);
- high quality (III—IV class): 18.9%, the vast majority of which are located in the Steppe zone (35.3%);
- medium quality (V—VI class): 55.9%, which make up the majority and are distributed as follows: 46.1% in the Polissya zone, 63.8% in the Forest-Steppe zone, and 51.6% in the Steppe zone;
- low quality (VII—VIII class): 23%, with the majority found in the Polissya zone (44.6%);
- very low quality (IX class): 0.5%, with the majority also located in the Polissya zone (1.7%);
- inconvenient soils (X class): only 0.1%, with the majority found in the Steppe zone (0.2%).

The average scores by region range from 38 in Sumsky region to 69 in Kirovohrad region. The highest-quality soils, as indicated by their qualitative assessment, are found in Dnipropetrovsky (57 points), Kirovohradsky (69 points), Mykolaivsky (55 points), Ternopilsky (57 points), Kharkivsky (63 points), Cherkasky (56 points) and Chernivetsky (51 points) regions.

Based on the scores, soil fertility increases from the north, reaches a high level in the central part of the country and declines in the extreme southern regions. The highest natural fertility of arable land is observed in Kirovohrad, Mykolaiv, Dnipro and Kherson regions, with scores ranging from 57 to 69 points, while other regions in the Steppe zone also exhibit relatively high fertility levels.

In the Forest-Steppe zone, the Kharkiv, Cherkasy, Poltava, Vinnytsia and Chernihiv regions exhibit natural fertility levels that are comparable to those of the Steppe region, with scores ranging from 45 to 63 points. In the Polissya zone, the natural fertility of arable land varies between 39 and 45 points.

An analysis of scientific literature and the results of agrochemical certification tours shows that the limiting factors for realizing the natural fertility of soils include, first of all, the level of soil degradation.

Degradation is a natural and anthropogenic process of deterioration of natural properties and regimes of soils that negatively affect their functions, reduce their stability and decrease their fertility (State Enterprise "Dergruntohora", 2023).

According to various specialized institutions, the area of degraded land in Ukraine ranges from 6 to 8 million hectares to 10 to 15 million hectares (State Enterprise "UkrNDNC", 2016). Degradation occurs when the degree of impact on soils exceeds their capacity for self-regulation. Among the various degradation processes, the most prevalent include erosion, dehumidification, nutrient depletion, physical degradation, as well as salinization, waterlogging and flooding on reclaimed lands.

According to the Sokolovsky Institute of Soil Science and Agrochemistry, water and wind erosion affects 31% of arable land, while humus loss is widespread across 43%, and nutrient depletion occurs on 49%. Over-compaction is recorded on 39% of arable land, with siltation and crusting affecting 38%. Various types of pollution are present on 29% of arable land, while acidification and waterlogging each affect 14% (see Table 7)

Table 7

Degradation of soil cover in agricultural lands of Ukraine

TYPE OF DEGRADATION	KIND OF DEGRADATION	% of arable land
Mechanical	Water erosion	20
	Deflation	11
	Mechanical breach	38
	Other types of erosion and breach	4
Physical	Deterioration of physical properties of soils, over-compaction, persistent changes in particle size distribution and aggregate composition	39
Chemical	Deterioration of the humus condition of soils	43
	Nutrient depletion of the soil	49
	Salinity	4,1
	Pollution	9,3
Physical and chemical	Acidification, alkalization	14
	Secondary salinization	
	Decalcification	
Biological	Decrease in biodiversity	80
Radiological	Radioactive pollution	19

Source: Balyuk, S.A., Medvedev, V.V., Tarariko, O.G., et al. (2010). *On the state of soil fertility in Ukraine*: National report. Kyiv.

More than 6 million hectares are under the influence of *wind erosion* and in years with dust storms, erosion processes cover up to 20 million hectares of agricultural land. Dust storms are not unusual in Ukraine, especially in the southern and eastern regions. The largest dust storm in the last 30 years occurred in 2007. It affected a total land area of 125 thousand km². This is 20% of the territory of Ukraine, or 50% of the Steppe zone (Balyuk, S.A., Medvedev, V.V., Vorotyntseva, L.I., and Shymel, V.V., 2017). As a result of the dust storm, an amount of soil was blown from the surface of various agricultural landscapes that exceeded the rate of soil formation by 10-

4000 times. It is classified by experts as a national-level environmental disaster that led to a significant decrease in soil fertility in various regions of Ukraine.

The area of agricultural land affected by water erosion is 13.3 million hectares, or 32% of the total area. Of these, arable land accounts for 10.6 million hectares (Figure 10).

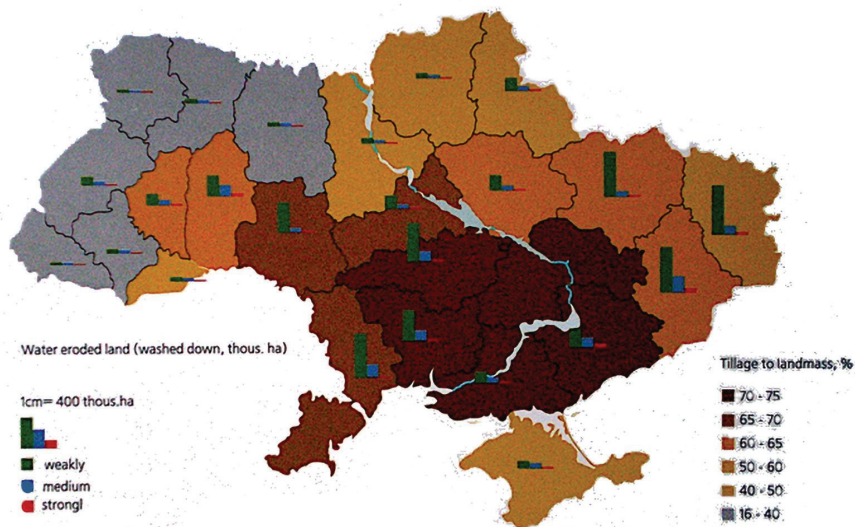


Figure 10. Lands affected by water erosion (washed away, thousand hectares). *Source:* Compiled by the authors based on data from (State Enterprise "Dergruntohorona, 2023).

The eroded soils include 4.5 million hectares of highly and moderately washed soils and about 70 thousand hectares have completely lost their humus horizon. The processes of linear erosion and gully formation are developing intensively. The area of ravines exceeds 140 thousand hectares and their number is over 500 thousand hectares. The intensity of erosion of ravine and gully systems exceeds the average by 10-20 times.

Each year, the area of eroded land increases by 90 thousand hectares or more. As a result of water and wind erosion, about 500 million tons of top productive fertile soil are washed away and blown away annually, which is equivalent to the loss of 8-9 million tons of grain or 0,4-0,5 Mt/ha (Chornyi, S.G., Pysmennyi, O.M., Khotynenko, O.M. and Chorna, T.M., 2008).

Erosion processes are intensified by soil *dehumidification*. Humus is involved in all properties of the soil cover. Its quantitative composition and physical and chemical properties determine the structure of the soil, the associated water-air and oxidation-reduction regimes, erosion resistance, agrotechnical and other soil indicators.

The results of agrochemical certification tours conducted every 5 years by the State Soil Protection Service show a catastrophic decrease in the humus content of Ukrainian soils. While in 1991-1995, this figure for the country was 3.3%, in 2016-2020 it was 3.07 (Figure 11).

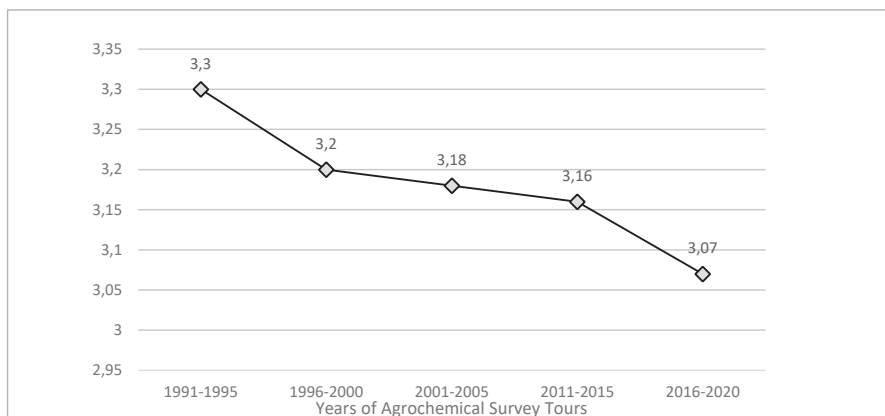


Figure 11. Dynamics of humus content in Ukrainian soils by rounds of agrochemical certification
Source: Compiled by the authors according to (State Enterprise "Dergruntohorona", 2023; Furdychko, O.I., 2009).

The lowest weighted average humus content is recorded in Polissia, Forest-Steppe regions of Chernivtsi, Khmelnytskyi, Vinnytsia and Cherkasy as well as Steppe Kher-son, while the highest is recorded in the remaining Steppe regions and Kharkiv as well as Sumy Forest-Steppe regions (Table 8, Figure 12)

Table 8

Soil characteristics by humus content

REGIONS AND ZONES	Very low <1.1		Low 1.1-2.0		Medium 2.1-3.0		Elevated 3.1-4.0		High 4.1-5.0		Very high >5.0		Weighted average indicator, %
	thou-sand ha	%	thou-sand ha	%	thou-sand ha	%	thou-sand ha	%	thou-sand ha	%	thou-sand ha	%	
	Polissya												
Volynskaya	39,1	16,5	163,9	69,4	32,2	13,6	1,0	0,4	0,1	0,0			1,54
Zhytomyrska	19,4	4,6	202,7	48,4	90,2	21,5	106,8	25,5					2,08
Zakarpatska	2,1	1,0	56,9	28,1	81,7	40,4	37,4	18,5	15,9	7,8	8,5	4,2	2,73
Ivano-Frankivska			18,4	8,5	79,0	36,6	77,6	35,9	34,4	15,9	6,7	3,1	3,22
Lvivska	2,8	1,6	44,5	26,1	61,4	36,1	37,5	22,0	14,3	8,4	9,8	5,8	2,60
Rivnenska	0,8	0,3	86,3	31,1	139,4	50,2	41,0	14,8	8,7	3,1	1,7	0,6	2,48
Chernihivska	4,4	1,4	95,2	29,3	100,4	30,9	94,1	29,0	29,9	9,2	0,6	0,2	2,71
Total	68,6	3,7	667,9	36,2	584,3	31,6	395,4	21,4	103,2	5,6	27,3	1,5	2,43
	Forest Steppe												
Vinnyt'ska	0,4	0,1	57,7	10,8	233,4	43,5	173,7	32,4	62,4	11,6	8,8	1,6	2,90
Kyiv'ska	10,4	1,6	80,3	12,4	184,4	28,4	276,3	42,5	90,7	14,0	7,8	1,2	3,10
Poltav'ska			11,5	3,1	128,1	34,5	162,7	43,8	67,3	18,1	2,1	0,6	3,29
Sumy'ska	0,4	0,1	31,5	9,6	65,2	19,9	114,1	34,9	102,8	31,4	13,3	4,1	3,48
Ternopil'ska			4,2	1,3	83,8	26,4	213,7	67,3	15,5	4,9	0,1	0,0	3,25
Kharkiv'ska	0,4	0,1	2,4	0,6	18,8	4,4	98,6	23,1	227,8	53,3	79,3	18,6	4,30
Khmelnytska	1,3	0,3	108,0	23,1	173,9	37,3	145,4	31,2	35,8	7,7	2,2	0,5	2,76
Cherkaska	1,7	0,4	49,1	12,0	163,7	39,9	167,0	40,7	25,3	6,2	3,1	0,8	2,98
Chernivetska			25,3	13,9	121,5	66,6	27,2	14,9	5,9	3,2	2,4	1,3	2,70
Total	14,6	0,4	370,0	10,0	1172,8	31,8	1378,7	37,4	633,5	17,2	119,1	3,2	3,20

	Steppe												
Crimea*													
Dnipropetrovska	8,4	1,3	40,9	6,4	74,7	11,6	230,7	35,9	248,9	38,7	39,5	6,1	3,72
Donetska*													
Zaporozhska			4,9	1,0	109,3	23,4	199,9	42,7	145,8	31,2	8,0	1,7	3,63
Kirovogradska			0,7	0,2	19,1	4,7	173,0	42,2	209,9	51,2	7,2	1,8	4,01
Luhanska*													
Mykolayivska	1,3	0,2	31,7	5,7	163,6	29,6	262,1	47,5	87,9	15,9	5,3	1,0	3,28
Odeska			3,4	1,2	86,3	31,7	87,3	32,1	81,4	29,9	13,9	5,1	3,59
Khersonska	57,8	9,0	251,1	38,9	263,1	40,8	71,7	11,1	1,1	0,2	0,6	0,1	2,15
Total	67,5	2,3	332,7	11,1	716,1	23,9	1024,7	34,3	775,0	25,9	74,5	2,5	3,31
Total in Ukraine	150,7	1,8	1370,6	16,1	2473,2	29,0	2798,8	32,8	1511,7	17,7	220,9	2,6	3,07

Notes. * No information is available. Source (State Enterprise "Dergruntohorona", 2023)

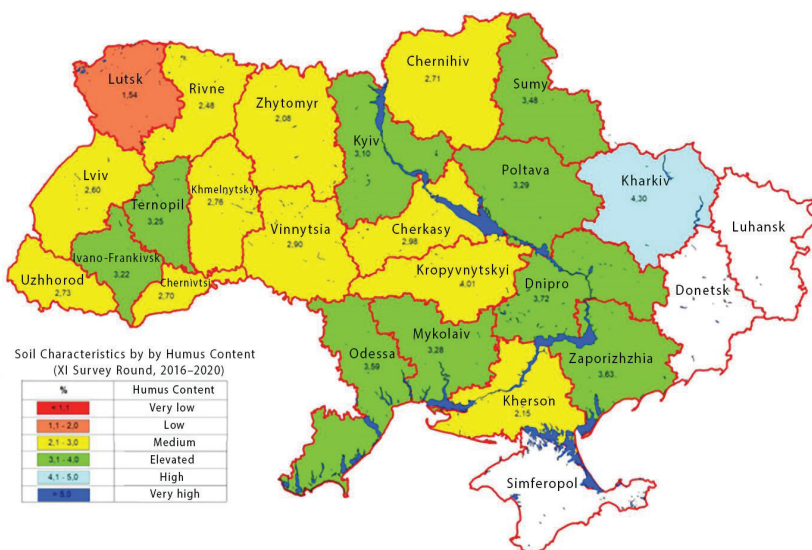


Figure 12. Characterization of soils by humus content. *Source:* Compiled by the authors according to (State Enterprise "Dergruntohorona", 2023)

The process of soil dehumidification leads to genetic processes that gradually turn the soil into unfit for cultivation. If the current trend of decreasing humus in Ukrainian soils continues, it may reach a state of humus starvation, when it becomes impossible to restore the agrotechnical potential of the land.

The unbalanced use of synthetic mineral fertilizers with organic matter leads to soil acidification, while the intensive use of pesticides and herbicides to control pests and diseases pollutes soil, water resources and the environment, and reduces the quality of agricultural products.

Soil *nutrient depletion* is recorded on half of Ukraine's land.

This applies to all macro- and microelements. As for easily hydrolyzed nitrogen, there is a predominance of very low and low nitrogen content in Ukrainian soils. The

percentage of such soils is 86.4% in the Steppe, 92% in the Forest-Steppe, and 90.4% in Polissya.

The weighted average nitrogen content in the country is 110.7 mg/kg of soil. In terms of regions, this figure varies from 89 mg/kg in Zhytomyr region to 138 mg/kg in Dnipropetrovska region (Figure 13).

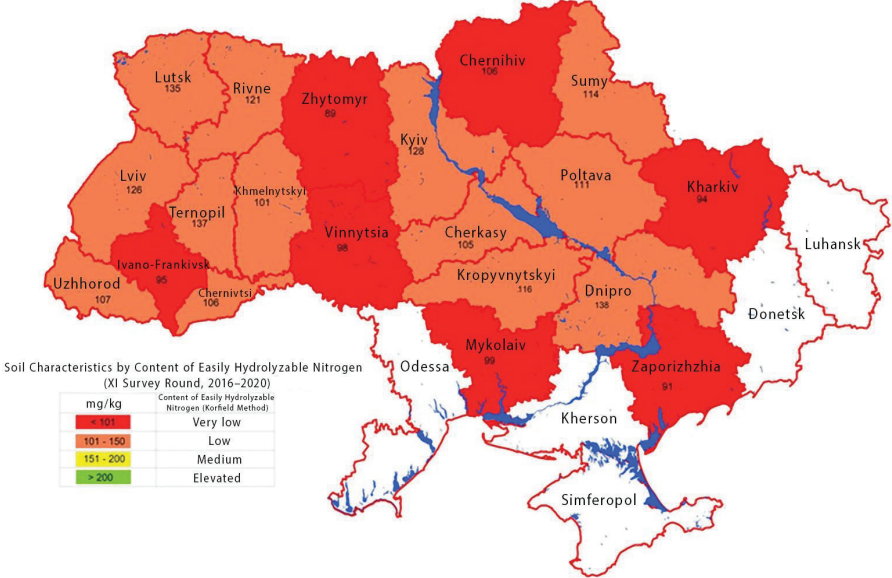


Figure 13. Content of easily hydrolyzed nitrogen in Ukrainian soils. *Source:* Compiled by the authors according to (State Enterprise "Dergruntohorona", 2023)

Between the X and XI rounds (2015-2020) of agrochemical certification of agricultural land, the nitrogen content decreased by 0.4 mg/kg in Kirovohrad region, by 2 mg/kg in Khmelnytskyi region, by 2.4 mg/kg in Lviv region, by 6 mg/kg in Rivne region, by 16 mg/kg in Kharkiv region and by 13.3 mg/kg in Cherkasy region.

The content of mobile phosphorus compounds is somewhat better: 68.1% of the area is characterized by medium and high phosphorus content, 23.8% by high and very high and only 8% by low and very low. On average, this indicator for the country is 116.7 mg/kg of soil: from 56 mg/kg in Chernivtsi to 176 mg/kg in Kherson region (Figure 14).



Figure 14. Content of mobile phosphorus in Ukrainian soils. *Source:* Compiled by the authors according to (State Enterprise "Derguntohorona", 2023)

From 2015 to 2020, the phosphorus content in soils decreased by 4 percent in Volyn region, 5 percent in Chernihiv region, 6.2 percent in Zaporizhzhia region, 9 percent in Sumy and Khmelnytsky regions, 13 percent in Odesa region and 27.8 mg/kg in Lviv region.

The situation regarding potassium content is more favorable - 90% of regions exhibit high, medium or elevated levels of this element. However, declines were also observed. During the analyzed period, the concentration of mobile potassium compounds decreased by 1.7 mg/kg in Volyn region, 9 mg/kg in Zhytomyr region, 10 mg/kg in Odesa region, 11 mg/kg in Sumy region, 14.3 mg/kg in Zaporizhzhia region, and 15.8 mg/kg in Lviv region.

The decrease in nutrients in soils is most observed in black soil regions. Scientists from the Sokolovsky Institute of Soil Science and Agrochemistry confirm that currently, the nutrient content of Ukrainian chernozem soils is 2.5-3 times lower than in European countries (Tarariko, O., Grekov, V. and Datsko, L., 2011).

Soil degradation processes of the pre-war period were significantly intensified by the hostilities.

Mechanical, physical, chemical, physicochemical and biological degradation are observed in lands affected by military operations. Mechanical degradation reveals as intensified erosion, mechanical disruption of the morphological structure of the soil profile. Physical degradation is evident in changes to the soil's granulometric composition and compaction from heavy military vehicles. Chemical degradation includes deterioration of the soil's humus content, salinization and pollution. Physicochemical degradation involves acidification and alkalization, while biological degradation is reflected in reduced biological activity, among other effects.

Black and podzolized chernozems are the most affected by the erosion caused by the hostilities - 34%, sod-podzolic - 16.1%, southern chernozems - 15.1%, typical chernozems - 8.8%, dark chestnut and chestnut soils - 6.5%. Light gray, gray forest, dark gray podzolized soils account for 8.7%, and the rest of the soils are within 10%.

Regarding the consequences of the Kakhovka Reservoir failure, data from scientists from the Institute of Agriculture of the National Academy of Agrarian Sciences indicate that 65,000 hectares were flooded. This area includes 4% arable land, 12% meadows and pastures, with the remainder comprising forested land, fallow land and built-up areas. Although the amount of disturbed land is limited, the decommissioned irrigation system, which originally serving 360,000 hectares of agricultural land, will have a negative impact on soil conditions, potentially intensifying droughts and other adverse climatic effects during the restoration period.

Water resources are a determining factor in influencing the state of other components of natural resources in agriculture.

Ukraine is the poorest endowed with its own water resources among all European countries. Table 14 summarizes the average annual indicators of renewable water resources in Ukraine based on data from the FAO Aquastat global information system.

According to these calculations, Ukraine's total water resources amount to 175.3 km³ per year, of which 97% is formed by surface river flow and the rest by groundwater.

The largest consumers of water in the territorial context, in addition to Kyiv region are Dnipropetrovsk, Donetsk, Kherson, Zaporizhzhia, Odessa, i.e. the southern regions of the Steppe zone, which have the lowest precipitation and the lowest availability of local water resources compared to other regions (Figure 15).

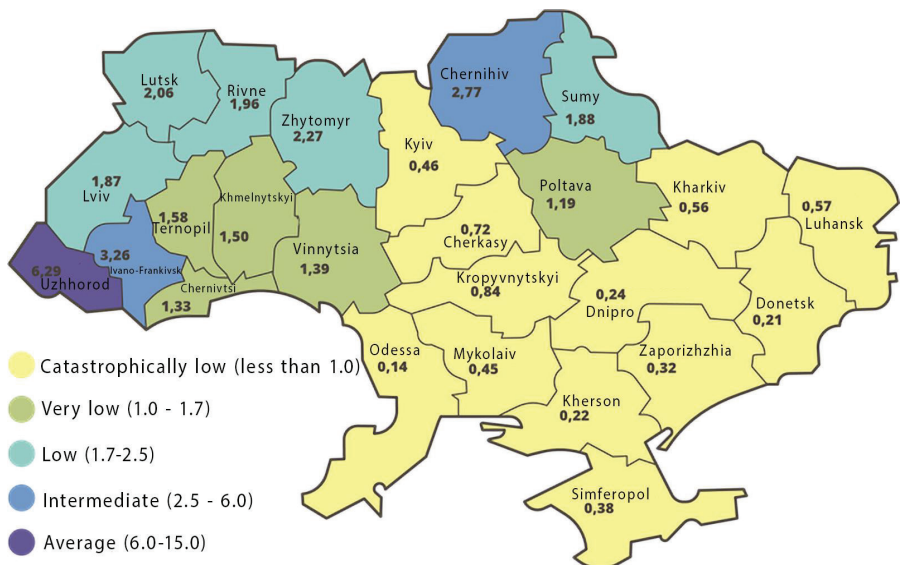


Figure 15. Provision of Ukrainian regions with local water resources, thousand m³/year per person.
Source: Medvedev, V.V., 2003.

The main source of soil moisture is *precipitation*. Until the beginning of this century, Polissya was characterized by a balanced ratio of heat and moisture availability throughout the growing season. The western part of the zone was sufficiently and strongly moistened, while the eastern part was elevated and well moistened.

The Forest Steppe is a more differentiated zone in terms of moisture conditions. This criterion is used to distinguish subzones: western is moderately humid, humid and highly humid, central is highly humid, humid and moderately humid, and eastern is moderately humid subzone.

The Steppe was divided into three parts by climatic conditions. The northern Steppe includes the northern insufficiently moistened, north-central moderately arid and south-central arid subzones.

The Southern Steppe differs from the Northern Steppe by a more arid climate. Finally, the Dry Steppe zone is divided into dry and very dry subzones.

These characteristics of the heat and water supply of the zones are currently being significantly affected by climate change, which is becoming one of the most pressing issues of this century. According to various scenarios of scientists and professional organizations, these changes are occurring at an accelerated pace and will continue to increase in the future. It will have a negative rather than a positive impact on soil conditions, water availability and plant development. Under the conditions of warming, not only the temperature regime is transformed, but also atmospheric precipitation, wind flows and other natural conditions, i.e., all indicators that characterize the state of the climate system and related components of the natural resource of agriculture.

Currently, climate change in all zones of Ukraine is characterized by such signs as long periods of no rain, short-term rainstorms and floods, a drop in the level of groundwater and massive drying up of small rivers and wells. Since 2005, droughts have been recorded across most of the territory. There are three regions of drought distribution: the northern region, where drought is still a rare phenomenon, the central region, characterized by drought of weak and medium intensity and the southern region, where severe drought is observed. Heat waves are expected to last longer and occur more frequently, which will extend drought periods and reduce water content in rivers and lakes and, consequently, river flows.

For plant development, it is important to have moisture in the soil cover at different phases of the growing season - cereals need water the most in the phase of emergence into the tube, earing and flowering phases, corn in the flowering and milky ripeness phases and legumes in the flowering phase. The interphase shift of precipitation leads to the formation of a moisture deficit in the root layer and an increase in climate aridity.

This century has seen several intense droughts that affected large areas of Ukraine in different months of the growing season. In April-June 2002, the Steppe Zone was most affected by the drought, while less intense drought conditions prevailed in the Forest-Steppe and Polissya. The high spring temperatures resulted in early snowmelt, and the lack of precipitation led to rapid drying of the soil surface.

The intense spring drought of 2003 covered all major agroclimatic zones of Ukraine and led to a significant decline in crop yields, down to 11-12 c/ha.

In April-June 2007, the intense drought reached the criterion of severe in the Steppe zone, and was characterized as moderate in the Forest-Steppe zone. In the summer months, the intensity of the drought decreased, but this did not reduce crop losses.

In 2009, drought phenomena began to develop in mid-May, so in the spring the drought was characterized as weak, while in the summer its intensity in the Steppe zone reached the criteria of severe (strong).

The autumn of 2011 was abnormally dry and cool, resulting in atmospheric and soil drought across a large part of Ukraine. In September, precipitation in the central and western regions was 18-42% of normal and in November it was 5% of normal. The number of dry periods between August and November this year ranged from 3 to 5, with the total number of days ranging from 55 in Kharkiv to 87-89 in Odesa and Ter-nopil. As a result, winter crops failed to sprout on one third of the planted areas, which required replanting with spring crops in the spring.

In 2012, all steppe and forest-steppe regions were affected by drought in spring and summer. In the southern regions, it reached the criterion of severe drought, while in all other regions it was moderate. Droughts are often accompanied by windstorms.

According to experts from the Ukrainian Hydrometeorological Center and Meteoblue (Switzerland), the average annual temperature increase in Ukraine is approaching 2°C, the highest in the northern hemisphere. As a result, the movement of agroclimatic zones from south to north reaches 200 km (Snihko, S., Shevchenko, O. and Di-dovets, Y., 2021).

The Eastern Forest-Steppe and Northern Steppe are expected to have a dry climate, the rest of the Forest-Steppe and part of Polissya - a fresh climate, the western regions and surrounding areas of Polissya - a wet climate and the Carpathian region - a humid climate (Figure 16).

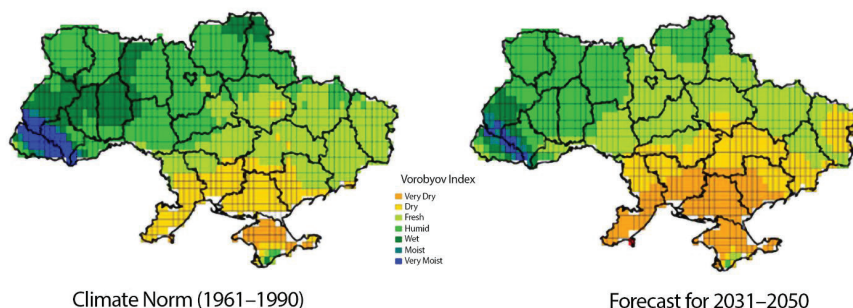


Figure 16. Map of changes in climate humidity zones. *Source:* Churilova, K., 2019

Climate change is associated by researchers with negative rather than positive consequences for agricultural production.

Positive effects include earlier vernalization and a longer growing season, more heat for crops, later autumn frosts, which simplifies harvesting, a longer nutrient period that allows repeated sowing; the possibility of introducing productive late-ripening varieties (hybrids) of crops and earlier first cutting of grasses.

Negative impacts on crop production include:

- frequent extreme and unfavorable hydrometeorological conditions;
- increased maximum air temperature; more frequent and intense droughts;
- more frequent and longer periods of extreme heat (“heat waves”);
- increased fire threats;
- the possibility of frost during the flowering period;
- more frequent and longer winter thaws and the possibility of damage to winter crops;
- moisture deficit during the growing season, lower groundwater levels and deterioration of soil moisture conditions;
- deterioration of conditions for the second grasses cutting due to the dryness of the second half of summer; loss of part of the winter crop yields due to reduced precipitation in September;
- increase in extreme precipitation, soil erosion and damage to plants caused by intense precipitation;
- new pests and plant diseases, improved conditions for overwintering of pests, development of weeds, and their increase;
- weakening of plant hardening, damage due to wetting, temperature changes and diseases;
- increased financial and labor costs for seeds, fertilizers, reseeding and crop insurance.

Positive effects of the drought on livestock and fish farming: increased grazing period; reduced cost of heating livestock buildings in winter; additional opportunities to increase feed production.

Negative impacts on these industries include the threat of heat stress, a drop in productivity, increased water demand, increased costs for ventilation and energy supply of animal facilities, the emergence of new infections, parasites and alien species, changes in temperature and deterioration of fish breeding ponds, reduction of spawning grounds, and changes in the composition of fish fauna.

The expected negative impact of climate change on land and water resources and, consequently, on agricultural production requires significant changes in the structure of sown areas, crop mix, choice of cultivation technologies and other components of agricultural activities.

The level of soil protection, water protection, water regulation and other functions related to agriculture depends on *the forest cover of the territory*. When agronomic forest cover reaches an optimum level, erosion processes are reduced to a practical standstill. Under current conditions, this level is recognized as 20-22% forest cover. Currently, this figure is 15.9% across the country and varies significantly by zone.

Precipitation and soil moisture availability correspond to the forest resources available on their territory. In the driest Steppe Zone, the forest cover is only 5.3%. The Forest-Steppe area, which has more balanced precipitation, is 13% forested. In Polissya, this figure is 26.8%. Forest cover by region is shown in Figure 17.

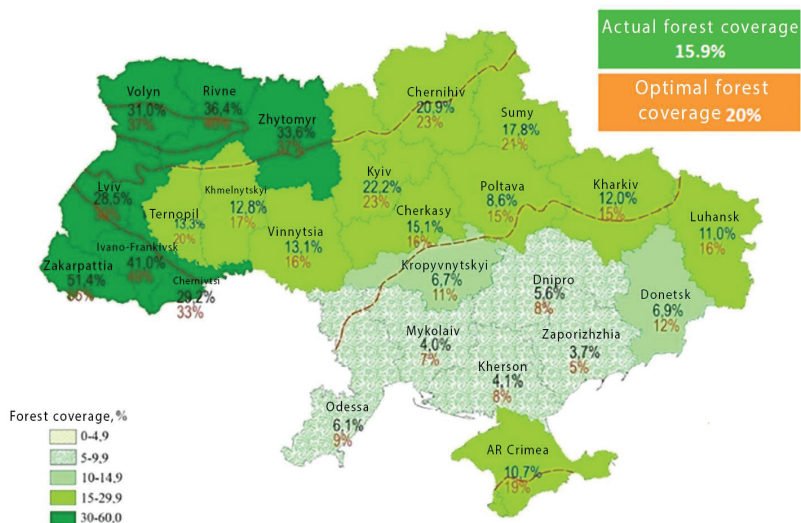


Figure 17. Forest cover in Ukraine. *Source:* National Academy of Sciences of Ukraine, 2024.

The lowest forested areas are in the southern Zaporizhzhia, Mykolaiv and Kherson regions (3.7% - 4.1%) and the highest are in Polissya and western regions of Ukraine (28.5% - 51.4%).

Ukraine is currently the least forested European country. According to the FAO, in Germany, for example, this figure is 32.7%, in France - 31.5% and in Italy - 32.5%.

At the same time, there is uncontrolled deforestation and insufficient restoration, as well as deaths from fires. According to the State Statistics Service of Ukraine, the loss of forest plantations in the country as a result of forest fires as of 2020 is 28 thousand hectares, which is 9 times more than in 2010.

Climate change reduces the resistance of woody plants to pests and diseases. In 2020, 5.5 thousand hectares of forest land were lost to pests, which is 4 times more than in 2010 and in 2015, 7.5 thousand hectares of forest plantations were lost to diseases.

The condition of shelterbelts is even worse. The basis of the modern system of shelterbelt and other forest plantations is formed by the plantations carried out in the 50s-80s of the twentieth century. Their area is approximately 430-440 hectares (no inventory has been conducted in independent Ukraine). They protect about 13 million hectares of agricultural land, which is 30%. Another 10% are protected by the edges of massive forest plantations, roadside and other types of plantations in agricultural landscapes.

In general, the shelterbelt forest cover of agricultural landscapes in Ukraine is again approximately 1.5%, while the scientifically justified figure is 3-3.5%. The figures are even worse in the zonal context.

In the dry Steppe Zone, almost 38% of forest belts need to be completely replaced, more than 23% are in unsatisfactory condition, more than a quarter need sanitary and other felling and 14% need restoration work (Buksha, I., 2018).

Summarizing the assessment of the state of the system of components of the natural resource potential, we can conclude that it is in an unbalanced, destructive state, the key problems of which are:

- erosion processes, soil dehumidification, negative nutrient balance, physical degradation of soil cover;
- the approach of the ecological state of all components of the natural resources of the Steppe Zone and Eastern Forest-Steppe, considering the additional impacts of climate change and hostilities, indicates a threshold beyond which, without significant changes in land use, irreversible ecological processes may occur. These processes, along with their socio-economic implications, could lead to negative consequences for both the agricultural sector and society as a whole;
- aggravation of the problems of soil moisture supply and water supply for agricultural production in general in the context of climate change. The spread of dry periods to the Forest-Steppe and Polissya affects the reduction of water content in rivers and lakes and river flow. According to comprehensive estimates, the increased sensitivity of water resources to an increase in temperature regime in the next 15-20 years could lead to a 3-fold reduction in water resources;
- two times lower forest cover in Ukraine compared to European countries, uncontrolled environmentally destructive deforestation, low level of field protection forest cover (1.5%, while the scientifically justified level is 3.0-3.5%), its neglect, felling, pollution, burning, etc. do not create a forestry complex to fulfill the functions of the ecological framework of the agroecosystem (Lukisha, V.V., 2013).

In order to achieve a neutral level of degradation of the natural resource potential of the agricultural sector of Ukraine, it is necessary to know factors that cause the destruction of the agroecosystem.

2.2. REASONS OF DEGRADATION OF THE NATURAL RESOURCE POTENTIAL OF UKRAINIAN AGRICULTURE AND THE STRATEGY FOR THEIR ELIMINATION.

The ecological degradation and destructive impacts associated with the intensive industrial model of farming, which currently dominates at global agriculture, are further intensified by the expansion of large agro-industrial and commercial enterprises within agricultural production. Transcontinental industrial companies have been steadily increasing their investments in agriculture. While these investments averaged \$600 million annually in the 1990s, by the mid-2000s they had grown to \$3 billion USD (UNCTAD, 2009). On the one hand, this made it possible to increase agricultural production, although it did not solve the problem of hunger and malnutrition.

On the other hand, the short-term gains in productivity are threatened by long-term losses from ecosystem degradation caused by industrial soil-destroying technologies, rural migration, increasing urbanization, growing pressure on public employment services, etc.

Transcontinental agro-industrial companies that have taken a dominant position in defining farming systems are typically export-oriented, highly specialized with a shift to monoculture, which

- simplifies the production process;
- reduces the need for jobs;
- forms large areas of sown areas of homogeneous crops;
- unifies the material and technical base;
- allows to monopolize sales channels to foreign markets and receive higher profits.

However, these benefits are largely offset by the negative consequences that are now fully manifested in national agriculture, namely:

- soil erosion and degradation;
- greenhouse gas emissions;
- reduction of biodiversity;
- contamination of soil cover with chemical elements;
- the appearance of substances hazardous to human health in food.

Intensive industrial agricultural production contributes to climate change and environmental pollution. The irrational, usually monocultural use of land resources and the decline in biodiversity undermine the ability of agriculture to meet the food needs of a growing population in the future.

If it persists in the face of a worsening arid climate and limited fresh water for agriculture, it is estimated that by 2080 the industry's production potential could decrease by 3-16% and at least 600 million people could face the risk of hunger (UNDP, 2007).

An industrial-intensive, deeply specialized type of production with monoculture characteristics was formed in Ukraine in 2000-2010. This happened on the basis of an unprecedented expansion of the area under industrial crops, mainly sunflower, but also partially grain crops. In 2000, the share of these crops in the structure of sown areas was 62.1%. This was in line with scientific recommendations and the practice of countries with crop rotation. However, by 2010, the situation changed dramatically and this

share increased to 81.3%. Over the next 10 years, this figure increased to 87.4% (Figure 18).

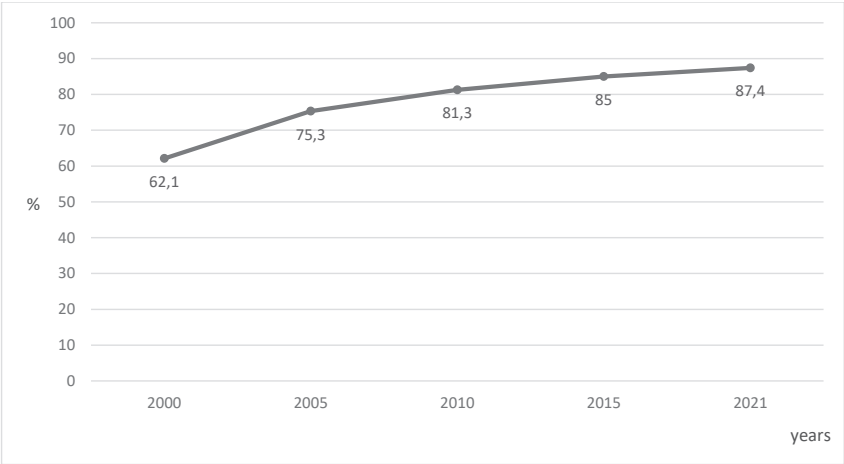


Figure 18. Cereals and oilseeds in the structure of sown areas. *Source:* Calculated by authors based on the statistical collection "Agriculture of Ukraine" for the relevant years. (State Statistics Service of Ukraine, 2024).

Agriholding companies, guided only by market interests, switched to growing 2-3 export-oriented oilseeds and grains. This happened after the creation of new enterprises in the process of reorganization of collective and state farms, division of land and development of lease relations. This did not take into account the natural and environmental conditions, biological, chemical and social factors, as well as the specifics of their cultivation technologies.

During the 2000s, compared to the early 1990s, Ukraine lost 1.5 million hectares of clean and fallow land and almost 10 million hectares of fodder crops (Table 9)

Table 9

Sown areas of agricultural crops by region in 1993 and 2021, zonal aspect

REGIONS AND ZONES	The whole sown area, thousand hectares		Among them							
			Cereals and legumes		industrial oilseeds		potatoes, vegetable and melon crops		fodder crops	
	1993	2021	1993	2021	1993	2021	1993	2021	1993	2021
Total in Ukraine	31264,0	28580,9	14305,0	15994,8	3507,0	9244,5	2165,0	1806,6	11287,0	1535,0
Polissya										
Volynskaya	687,0	622,2	206,0	327,7	55,0	135,7	85,0	93,6	251,0	65,2
Zhytomyrska	1190,0	1165,4	468,0	553,6	88,0	325,8	102,0	116,6	532,0	169,4
Zakarpatska	192,0	176,6	62,0	84,0	3,0	16,4	37,0	41,5	90,0	34,7
Ivano-Frankivska	402,0	383,1	141,0	154,9	30,0	92,8	55,0	70,8	176,0	64,6
Lvivska	806,0	717,6	292,0	318,5	64,0	193,8	96,0	137,9	354,0	67,4
Rivnenska	672,0	632,2	281,0	321,4	56,0	141,8	81,0	86,2	254,0	82,8
Chernihivska	1457,0	1364,1	663,0	858,4	83,0	325,3	145,0	84,0	566,0	96,4
Total	5406,0	5061,2	2113,0	2618,5	379,0	1231,6	601,0	630,6	2223,0	580,5

Forest Steppe										
Vinnitska	1727,0	1633,9	792,0	891,2	248,0	501,0	125,0	127,0	562,0	114,7
Kyivska	1347,0	1219,9	559,0	679,9	126,0	363,2	138,0	117,6	524,0	59,2
Poltavska	1746,0	1741,1	815,0	1016,9	245,0	551,1	86,0	83,5	600,0	89,6
Sumyska	1296,0	1212,7	591,0	722,2	146,0	363,0	97,0	66,5	462,0	61,0
Ternopil'ska	869,0	848,8	379,0	487,9	103,0	252,8	73,0	65,5	314,0	42,6
Kharkivska	1790,0	1836,9	769,0	1061,8	265,0	611,3	107,0	90,3	649,0	73,5
Khmelnytska	1275,0	1212,9	586,0	627,4	142,0	419,1	94,0	71,8	453,0	94,6
Cherkaska	1261,0	1227,5	582,0	709,1	179,0	367,3	95,0	75,0	405,0	76,1
Chernivetska	333,0	307,9	136,0	120,6	30,0	92,7	34,0	49,0	133,0	45,6
Total	11644,0	11241,6	5209,0	6317,0	1484,0	3521,5	849,0	746,2	4102,0	656,9
Steppe										
Crimea	1195,0	-	551,0	-	73,0	-	50,0	-	521,0	-
Dnipropetrovska	1950,0	1984,1	1021,0	1152,7	217,0	698,6	99,0	96,0	613,0	36,8
Donetska	1481,0	1050,2	658,0	597,1	165,0	369,9	93,0	53,4	565,0	29,8
Zaporozh'ska	1655,0	1709,6	780,0	1014,6	207,0	624,7	81,0	32,2	587,0	38,1
Kirovograd'ska	1656,0	1711,4	772,0	900,1	276,0	713,0	81,0	59,4	527,0	38,9
Luhanska	1262,0	872,4	608,0	392,0	137,0	444,7	70,0	17,3	447,0	18,4
Mykolayiv'ska	1527,0	1607,1	726,0	949,5	212,0	570,0	67,0	41,5	522,0	46,1
Odeska	1913,0	1854,8	975,0	1238,2	226,0	545,1	95,0	45,2	617,0	26,3
Kherson'ska	1575,0	1488,5	802,0	815,1	131,0	525,4	79,0	84,8	563,0	63,2
Total	14214,0	12278,1	6893,0	7059,3	1644,0	4491,4	715,0	429,8	4962,0	297,6

Source: Calculated by authors based on the statistical collection "Agriculture of Ukraine" for the relevant years (State Statistics Service of Ukraine, 2024)

The area under perennial grasses remained at 2.5% (700.2 thsd ha) of fodder crops in the period under review. These areas were largely occupied by sunflower - its plantings increased from 1.6 to 6.6 mln ha. Among the grains, the planted areas of corn expanded from 1.5 to 4.5 mln ha.

So, the area of humus-absorbing crops (corn, sunflower) has increased significantly, while the area of humus-forming crops (legumes, perennial grasses) has decreased. The coefficients of organic matter reproduction for soils are -1.15 and -0.53 t/ha for the former, while for the latter they are +0.35 and +1.96 t/ha (Pidlisnyuk, V., 2006). This significantly reduced the humus content in the soil and became a significant factor in the increasing degradation of agricultural land.

The abandonment of "humus creator" crops in favor of humus-absorbing crops has become particularly threatening for the provision of humus to the Steppe and Eastern Forest-Steppe zones. Up to 80% of all sunflower crops are located here, with sunflower occupying 30-40% of the sown area (Table 10)

Table 10

Oilseeds in the structure of sown areas, 2021 , zonal aspect

REGIONS AND ZONES	The whole sown area		Among them					
			Cereals and legumes		industrial oilseeds		fodder crops	
	thsd ha	%	thsd ha	%	thsd ha	%	thsd ha	%
Total in Ukraine	28580,9	100	15994,8	56	9244,5	32	6665,1	23
Polissya								
Volynskaya	622,2	2,2	327,7	1,2	135,7	0,5	39,8	6,4
Zhytomyrska	1165,4	4,1	553,6	1,9	325,8	1,1	154,8	13,3
Zakarpatska	176,6	0,6	84,0	0,3	16,4	0,1	3,6	2,04
Ivano-Frankivska	383,1	1,3	154,9	0,5	92,8	0,3	31,8	8,3
Lvivska	717,6	2,5	318,5	1,1	193,8	0,7	40,5	5,6
Rivnenska	632,2	2,2	321,4	1,1	141,8	0,5	41,0	6,5
Chernihivska	1364,1	4,8	858,4	3,0	325,3	1,1	242,5	17,8
Total	5061,2	17,7	2618,5	9,1	1231,6	4,3	554	11
Forest Steppe								
Vinnyska	1633,9	5,7	891,2	3,1	501,0	1,8	307,6	18,8
Kyivska	1219,9	4,3	679,9	2,4	363,2	1,3	208,6	17,1
Poltavska	1741,1	6,1	1016,9	3,6	551,1	1,9	387,5	22,3
Sumyska	1212,7	4,2	722,2	2,5	363,0	1,3	266,3	22,0
Ternopil'ska	848,8	3,0	487,9	1,7	252,8	0,9	83,2	9,8
Kharkivska	1836,9	6,4	1061,8	3,7	611,3	2,1	582,0	31,7
Khmelnytska	1212,9	4,2	627,4	2,2	419,1	1,4	162,5	13,4
Cherkaska	1227,5	4,3	709,1	2,5	367,3	1,3	257,4	21,0
Chernivetska	307,9	1,1	120,6	0,4	92,7	0,3	21,9	7,1
Total	11241,6	39,3	6317	22,1	3521,5	12,3	2277	20,3
Steppe								
Crimea	-	-	-	-	-	-	-	-
Dnipropetrovska	1984,1	7,0	1152,7	4,0	698,6	2,4	608,1	30,7
Donetska	1050,2	3,7	597,1	2,1	369,9	1,3	357,7	34,1
Zaporozhska	1709,6	6,0	1014,6	3,6	624,7	2,2	535,4	31,3
Kirovogradska	1711,4	6,0	900,1	3,2	713,0	2,5	608,0	35,5
Luhanska	872,4	3,0	392,0	1,4	444,7	1,6	442,2	50,7
Mykolayivska	1607,1	5,6	949,5	3,3	570,0	2,0	518,0	32,2
Odeska	1854,8	6,5	1238,2	4,3	545,1	1,9	415,8	22,4
Khersonska	1488,5	5,2	815,1	2,8	525,4	1,8	348,9	23,4
Total	12278,1	43	7059,3	24,7	4491,4	15,7	3834,1	31,2

Source: Calculated by authors based on the statistical collection "Agriculture of Ukraine" for the relevant years (State Statistics Service of Ukraine, 2024)

With the elimination of perennial grasses and other fodder crops, the number of live-stock has decreased dramatically (cattle - by 8 times, pigs - by 3 times, sheep and goats - by 7 times). Accordingly, the accumulation and use of organic livestock waste has decreased.

The volume of organic fertilizers applied is only from 0.5 to 0.6 tons per hectare of sown area. The minimum rate to ensure a deficit-free balance of humus (depending on the soil and climatic zone) should be between 8 and 14 t/ha (in 1990, the average for Ukraine was 8.6 t/ha) (Table 11)

Table 11

Application of organic fertilizers at enterprises, 1990-2021

	1990	2000	2005	2010	2015	2018	2021
Planted for crops, thsd. tons	257130,8	28410,1	13245,8	9874,1	9636,3	10643,6	10721,0
Share of fertilized area, %	18	3,3	2,7	2,2	2,5	4,4	5,7
Applied per 1 ha, tons of sown area	8,6	1,3	0,8	0,5	0,5	0,6	0,6

Source: Calculated by authors based on the statistical collection "Agriculture of Ukraine" for the relevant years (State Statistics Service of Ukraine, 2024)

The smallest amount of organic fertilizers applied (from 0.1 to 0.2 t/ha) is observed in Zaporizhzhia, Kirovohrad, Luhansk, Mykolaiv, Odesa and Kherson regions. These are the regions with the most degraded agricultural land and the most pronounced monoculture (table 12)

Table 12

Application of organic fertilizers for crops in 2011-2021, zonal aspect

REGIONS AND ZONES	2011		2013		2015		2021	
	ths. tons	t/ha	ths. tons	t/ha	ths. tons	t/ha	ths. tons	t/ha
Total in Ukraine	9845.7	0.5	9602.6	0.5	9598.2	0.5	10745.9	0.6
Polissya								
Volynskaya	428.2	2.3	303.0	1.5	351.3	1.7	408.7	1.6
Zhytomyrska	364.8	0.7	346.8	0.6	363.8	0.6	303.0	0.5
Zakarpatska	8.3	0.4	2.2	0.1	4.5	0.2	0.1	0.0
Ivano-Frankivska	234.7	2.1	278.6	2.0	413.8	2.8	702.3	4.4
Lvivska	177.3	0.8	207.4	0.7	342.4	1.1	98.9	0.3
Rivnenska	182.3	0.8	162.1	0.7	244.0	1.0	273.5	0.9
Chernihivska	704.1	0.8	626.4	0.7	830.3	0.9	643.8	0.6
Forest Steppe								
Vinnyska	513.1	0.4	581.3	0.5	222.6	0.2	600.8	0.6
Kyivska	1319.0	1.5	1100.5	1.3	1224.3	1.4	1542.3	1.9
Poltavska	1271.5	1.0	1566.2	1.2	1404.2	1.1	915.6	0.8
Sumyska	460.6	0.5	384.5	0.4	420.8	0.5	470.4	0.5
Ternopil'ska	257.1	0.5	244.2	0.5	306.9	0.6	445.1	0.8
Kharkivska	403.3	0.3	628.5	0.5	627.7	0.5	585.3	0.5
Khmelnyska	466.1	0.6	555.1	0.7	610.0	0.7	563.6	0.6
Cherkaska	1152.1	1.2	1038.9	1.1	1076.0	1.2	818.2	1.0
Chernivetska	66.1	0.5	88.5	0.7	47.0	0.4	36.1	0.4
Steppe								
Crimea*	339.4	0.6	264.5	0.5	-	-	-	-
Dnipropetrovska	441.6	0.4	372.5	0.3	373.2	0.3	498.4	0.4
Donetska	579.7	0.6	304.9	0.3	277.3	0.4	854.1	1.2
Zaporozhska	90.9	0.1	103.9	0.1	104.4	0.1	260.3	0.2
Kirovograd'ska	105.6	0.1	71.0	0.1	105.2	0.1	184.8	0.2
Luhanska	37.6	0.1	103.3	0.1	72.5	0.1	63.7	0.1
Mykolayiv'ska	102.2	0.1	125.3	0.1	111.3	0.1	206.9	0.2
Odeska	57.3	0.1	87.0	0.1	31.5	0.0	122.3	0.1
Kherson'ska	82.8	0.1	56.0	0.1	33.2	0.0	147.7	0.2

Notes. * There is no information on the application of organic fertilizers in 2015-2021. *Source:* Calculated by authors based on the statistical collection "Agriculture of Ukraine" for the relevant years (State Statistics Service of Ukraine, 2024)

In addition to organic fertilizers of animal origin, plant residues, by-products, green manure etc. are a resource for soil humus reproduction. Their application has a positive effect on agrochemical, physical and water-air properties of soils. However, these sources are used in small quantities. In 2020, 13.0 mln tons of straw were applied to the soil, which is 1.5 times less than in 2015. Green manure with subsequent plowing was grown on an area of only 436 thousand hectares (Table 13)

Table 13

Biologization of agriculture in 2016-2020

REGIONS AND ZONES	2016				2018				2020			
	straw was added		plowed green manure		straw was added		plowed green manure		straw was added		plowed green manure	
	ths. tons	per thousand hectares	ths. tons	per thousand hectares	ths. tons	per thousand hectares	ths. tons	per thousand hectares	ths. tons	per thousand hectares	ths. tons	per thousand hectares
Total in Ukraine	18151,8	5030,4	2366,0	286,9	15769,1	4183,6	2826,3	320,0	13043,5	3942,3	2050,3	435,9
Polissya												
Volynskaya	258,5	83,9	16,3	2,8	325,8	98,2	39,2	8,7	506,4	126,0	31,0	10,6
Zhytomyrska	1266,5	264,0	97,7	9,6	259,2	113,0	119,1	8,5	262,7	115,4	125,5	9,8
Zakarpatska	28,1	9,4	52,1	3,1	27,1	8,5	48,1	2,8	23,7	8,3	45,5	3,0
Ivano-Frankivska	113,3	64,9	173,9	15,7	817,6	92,5	180,9	16,4	862,3	85,0	212,0	18,4
Lvivska	475,1	131,0	0,0	0,0	443,5	137,5	0,0	0,0	503,9	154,2	0,0	0,0
Rivnenska	237,2	103,7	16,7	2,9	253,8	109,8	27,7	6,5	93,6	36,9	3,7	0,8
Chernihivska	1095,3	296,1	218,1	47,5	996,7	268,9	241,6	53,7	1016,8	274,2	246,4	54,2
Forest Steppe												
Vinnitska	1262,3	238,5	37,6	6,7	1272,7	245,2	32,9	6,0	1330,4	255,8	37,1	8,0
Kyivska	2098,0	397,0	159,6	17,8	1628,7	219,6	147,7	13,9	135,5	190,4	94,4	115,6
Poltavska	180,2	196,8	22,5	7,2	153,3	167,5	17,2	4,2	136,5	159,0	12,3	4,0
Sumyska	1262,2	242,3	85,5	6,9	219,3	7,0	216,6	9,4	233,1	13,4	206,3	19,0
Terнопil'ska	1573,1	330,6	667,6	29,7	2475,5	488,9	864,9	41,3	781,6	223,5	120,1	42,3
Kharkivska	356,6	127,8	32,5	1,8	395,3	111,0	32,8	1,6	533,1	188,0	32,2	1,6
Khmel'nytska	1900,0	380,0	128,5	42,0	598,7	112,8	200,1	60,5	592,4	148,2	242,5	73,3
Cherkaska	658,1	340,0	110,1	50,5	189,0	118,6	48,5	4,6	236,1	139,4	25,6	2,5
Chernivetska	238,3	45,2	68,2	2,6	155,8	43,1	73,1	2,7	360,0	68,8	98,3	3,4
Steppe												
Crimea*	-	-	-	-	-	-	-	-	-	-	-	-
Dnipropetrovska	1770,4	426,9	0,0	0,0	2588,0	617,8	0,0	0,0	2678,2	513,1	0,0	0,0
Donetska*	-	-	-	-	-	-	-	-	-	-	-	-
Zaporozh'ska	793,0	249,0	109,0	12,5	677,6	308,0	107,0	13,5	586,8	266,8	125,7	12,3
Kirovograd'ska	928,0	267,4	224,3	15,0	967,8	219,4	260,5	53,3	842,0	324,3	223,2	44,6
Luhanska**	-	-	-	-	-	-	-	-	-	-	-	-
Mykolayiv'ska	176,1	117,2	126,8	6,3	250,1	166,5	127,3	6,3	281,1	187,3	127,5	6,4
Odeska	1333,7	581,0	19,0	6,3	1073,6	529,8	41,0	6,0	1047,4	464,3	41,0	6,0
Kherson'ska***	147,8	137,6	0,0	0,0	-	-	-	-	-	-	-	-

Notes. * There is no information on biologization of agriculture in 2016-2020. ** There is no information on biologization of agriculture in 2016-2018 and 2020. *** There is no information on biologization of agriculture in 2018-2020. Source: prepared by the authors according to (State Institution "Derzhgruntokhorona", 2023)

Non-application of organic fertilizers and the absence of humus-forming legumes and perennial grasses in the structure of sown areas cause an imbalance of humus (Table 14)

Table 14

Humus balance in 2016-2020, zonal aspect

REGIONS AND ZONES	2016			2018			2020		
	humus was formed, in total	lost humus	hu- mus bal- ance, +/-	humus was formed, in total	lost humus	hu- mus bal- ance, +/-	humus was formed, in total	lost humus	hu- mus bal- ance, +/-
	t/ha	t/ha	t/ha	t/ha	t/ha	t/ha	t/ha	t/ha	t/ha
Total in Ukraine	1,12	1,28	-0,16	1,16	1,31	-0,15	1,09	1,30	-0,21
Polissya									
Volynskaya	1,22	1,36	-0,14	1,29	1,40	-0,11	1,24	1,40	-0,16
Zhyto- myrska	1,19	1,13	0,06	1,27	1,11	0,16	1,07	0,87	0,20
Zakarpatska	1,82	1,17	0,66	1,39	1,21	0,18	1,67	1,23	0,44
Ivano- Frankivska	1,32	1,41	-0,09	1,36	1,40	-0,04	1,34	1,43	-0,09
Lvivska	1,23	1,23	0,00	1,28	1,23	0,05	1,42	1,25	0,17
Rivnenska	1,40	1,20	0,20	1,69	1,56	0,13	1,57	1,24	0,33
Cher- nihivska	2,58	1,41	1,17	1,99	1,43	0,56	2,39	1,45	0,94
Forest Steppe									
Vinnitska	1,62	1,39	0,23	1,89	1,41	0,48	1,27	1,42	-0,15
Kyivska	0,44	0,82	-0,38	0,39	0,81	-0,42	0,45	0,80	-0,35
Poltavska	1,70	1,36	0,34	1,80	1,40	0,40	1,45	1,42	0,03
Sumyska	1,33	1,64	-0,31	1,62	1,92	-0,30	1,63	1,82	-0,19
Ternopijska	1,07	0,99	0,08	1,22	1,04	0,18	1,38	0,98	0,40
Kharkivska	1,18	1,39	-0,21	1,02	1,39	-0,37	1,12	1,39	-0,28
Khmelnyn- tska	1,05	1,20	-0,15	1,24	1,27	-0,03	1,22	1,34	-0,13
Cherkaska	0,94	1,36	-0,42	1,02	1,41	-0,39	0,64	1,39	-0,76
Cher- nivetska	0,82	0,86	-0,04	0,76	0,81	-0,05	0,72	0,96	-0,24
Steppe									
Crimea*	-	-	-	-	-	-	-	-	-
Dnipropet- rovskaya	0,79	1,38	-0,59	0,81	1,40	-0,59	0,76	1,39	-0,63
Donetska**	0,72	1,36	-0,64	0,72	1,36	-0,64	-	-	-
Zaporozh- ska	0,75	1,37	-0,62	0,59	1,37	-0,78	0,74	1,37	-0,63
Kiro- vogradskaya	0,83	1,06	-0,24	0,84	1,08	-0,24	0,87	1,13	-0,26
Luhanska**	1,05	1,19	-0,14	1,52	1,33	0,19	-	-	-
Myko- layivskaya	0,86	1,21	-0,35	0,82	1,20	-0,38	0,65	1,19	-0,54
Odeska	0,89	1,29	-0,40	0,94	1,26	-0,32	0,51	1,32	-0,81
Khersonskaya	0,84	1,34	-0,50	0,84	1,34	-0,50	0,92	1,34	-0,42

Notes. * No information on humus balance is available. ** No information on the humus balance in 2020 is available. *Source:* prepared by the authors according to (State Institution "Derzhgruntkhorona", 2023)

Compared to 2015, in 2020, the humus balance deficit increased by 80 kg/ha (62%)

and amounted to 210 kg/ha (Fig. 8).

The largest humus deficit remains in Odesa and Cherkasy regions - 810 and 760 kg/ha, respectively, Dnipropetrovs'k and Zaporizhzhia regions - 630 kg/ha, and Mykolaiv region - 540 kg/ha. A positive humus balance is noted in Zhytomyr, Zakarpattia, Lviv, Poltava, Rivne, Ternopil and Chernihiv regions and varies from 30 kg/ha in Poltava to 940 kg/ha in Chernihiv region.

The decline in organic matter content, combined with monoculture production and intensive mechanical tillage, increases physical soil degradation. This is manifested in the de-structuring of the top layer of the soil surface, clumpiness after plowing, flooding and crusting, the presence of plow treads and over-compaction of subsoil and deep soil layers.

The current systems of machines and methods of tillage compact the soil to a depth of 40-100 cm. Soil density has doubled over the past half century (from 0.8-1 to 1.6-1.8 g/cm³). As a result, the particle size of the solid fraction was changed to 0.25 mm, which characterizes the process of soil destruction and poor moisture absorption and filtration. This, in turn, contributes to the accelerated development of water erosion resulting in the destruction and washing away of topsoil, the formation of ravines and siltation of rivers. Water erosion is particularly destructive when using shelf-type tillage tools, which currently dominate in agriculture.

In the United States and Canada, for example, plow tillage is no longer used on 70% of cultivated land and there are plans to completely eliminate it. At the same time, the tillage methods of Ukrainian producers are not controlled and there are no official measures to encourage them to cultivate their land in a more economical way.

The negative impact of moldboard plow tillage, in addition to increasing erosion processes, increases carbon deficit. Carbon dioxide, as a product of organic decomposition, accumulates in the topsoil, which is the environment for the development of the plant root system. When plowing to a depth of 28 cm, soil CO₂ is released 22-23 times more compared to surface tillage (Figure 19).

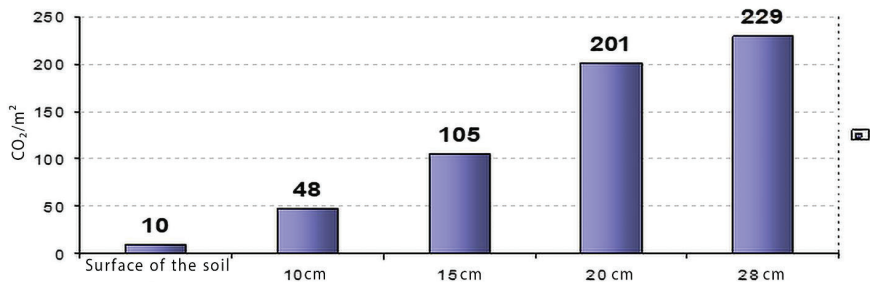


Figure 19. Total carbon dioxide losses depending on the plowing depth in 24 hours. *Source:* compiled by the authors based on the analysis of research literature

As a result, the process of natural synthesis of organic matter and the vital activity of microorganisms is suppressed, with corresponding negative consequences for the physical condition of the soil and plant development.

Erosion processes are exacerbated by the decline of the shelterbelt system. The main

reason for this situation was that before the reform, shelterbelt forests belonged to collective farms, which created them and were responsible for maintaining them in a good condition. In the process of reforming collective agricultural enterprises, they were not subject to division into shares along with agricultural land. As a result, they were left without legal status and became “no man's land”. In the absence of care for forest belts and support for optimization of their structures, their growth has occurred, which has led to an increase in shading of the adjacent forest lands. This also caused competition from the root systems of woody plants, which leads to a decrease in crop yields in the area affected by these factors. At the same time, anthropogenic pressure on neglected forest belts has increased due to illegal logging for fuel, waste pollution, burning of large areas, etc.

This caused the old shelterbelt forests to lose their erosion control functions. New plantations are almost never carried out.

Environmental conditions for growing crops on eroded land are much worse than on non-eroded land. This is due to the fact that eroded lands have a smaller humus horizon and lower moisture reserves. They differ significantly in terms of soil and chemical factors. First of all, eroded soils contain less gross and hydrolyzed nitrogen, which impairs nitrogen nutrition of plants. Erosion reduces the amount of mineral nitrogen by 30-40%. This is due to the low biological activity of eroded soils and the leaching of easily soluble forms of nitrogen.

Erosion processes also reduce the content of phosphorus and potassium. In the soil layer of 0-20 cm of lightly eroded chernozems, organic phosphorus is 16-30% less than in non-eroded counterparts and in medium-eroded chernozems - 38-53% less. The development of erosion leads to losses of not only macro- but also microelements such as copper, zinc, cobalt and manganese. In heavily washed soils, their content approaches the amount of indicators in the soil-forming rock.

Along with the spread of the above factors, the violation of the requirements of the “immutable law of nature” worsens the ecological condition of soils Y. Libikh. This refers to the law of returning nutrients taken out with the harvest.

The application of mineral fertilizers does not ensure a deficit-free balance of nutrients in the soil. Calculations made by regional branches of the State Soil Protection Agency based on statistical data confirm that the main nutrients for crops, phosphorus and potassium, have not been returned to the soil in the amount that is alienated with the harvest for many years. The same trend is observed with the return of nitrogen.

The most deficient balance of nutrients (nitrogen, phosphorus and potassium) is observed in the highly specialized areas of the Steppe zone (Table 15)

Table 15

Nutrient balance in 2016-2020, zonal aspect

REGIONS AND ZONES	2016			2018			2020		
	total re- ceived, kg/ha	re- moval, kg/ha	bal- ance, kg/ha (+/-)	total re- ceived, kg/ha	re- moval, kg/ha	bal- ance, kg/ha (+/-)	total re- ceived, kg/ha	re- moval, kg/ha	bal- ance, kg/ha (+/-)
Total in Ukraine	132	216	-84	159	221	-61	160	216	-56
Polissya									
Volynskaya	187	255	-68	286	250	36	281	247	34
Zhytomyrska	125	167	-42	147	193	-46	133	151	-18
Zakarpatska	142	379	-237	144	304	-159	104	373	-269
Ivano-Frankivska	188	284	-97	213	294	-81	216	311	-95
Lvivska	216	341	-126	369	411	-42	206	318	-112
Rivnenska	193	235	-42	210	251	-41	209	232	-22
Chernihivska	161	195	-34	172	217	-45	192	218	-27
Forest Steppe									
Vinnitska	140	195	-55	166	209	-43	136	146	-10
Kyivska	136	240	-104	161	190	-29	162	227	-65
Poltavska	125	169	-44	90	184	-94	102	156	-54
Sumyska	155	207	-51	184	241	-57	187	229	-42
Ternopilska	170	176	-6	163	220	-57	199	266	-67
Kharkivska	97	168	-70	120	155	-36	75	189	-113
Khmelnitska	131	356	-225	137	281	-144	122	198	-75
Cherkaska	99	249	-150	109	339	-230	158	318	-160
Steppe									
Crimea*	-	-	-	-	-	-	-	-	-
Dnipropetrovska	92	134	-42	123	163	-40	154	142	11
Donetska**	78	168	-90	78	168	-90	-	-	-
Zaporozhska	76	165	-88	111	130	-18	109	160	-51
Kirovogradska	66	116	-50	77	125	-48	88	129	-41
Luhanska**	63	122	-59	120	114	6	-	-	-
Mykolayivska	176	276	-100	209	257	-48	231	215	16
Odeska	108	180	-72	145	183	-39	32	104	-72
Khersonska	75	196	-121	97	192	-95	162	204	-42
Chmielnitska	159	201	-42	195	226	-31	226	216	10

Notes. * No information on humus balance is available. ** No information on the humus balance in 2020 is available. *Source:* prepared by the authors according to (State Institution "Derzhgruntokhrona", 2023)

The balance of nutrients during the XI round of the survey was negative, which was also recorded in previous rounds of the survey. It is an essential requirement to apply mineral fertilizers in the doses necessary for plant nutrition and in the optimal ratio between nutrients. This is important to ensure a deficit-free balance of nutrients. However, their scientifically based ratio is not observed.

In 2016-2020, taking into account the removal of nitrogen with the harvest, almost all regions have a negative nitrogen balance (table 16)

Table 16

Nitrogen balance in 2016-2020

REGIONS AND ZONES	2016			2018			2020		
	total re-ceived, kg/ha	re-moval, kg/ha	balance, kg/ha (+/-)	total re-ceived, kg/ha	re-moval, kg/ha	balance, kg/ha (+/-)	total re-ceived, kg/ha	re-moval, kg/ha	balance, kg/ha (+/-)
Total in Ukraine	87	109	-22	101	116	-14	107	112	-5
Polissya									
Volynskaya	110	125	-15	172	144	28	175	143	32
Zhytomyrska	90	101	-12	105	116	-12	95	89	6
Zakarpatska	99	174	-75	109	144	-35	80	194	-114
Ivano-Frankivska	116	137	-20	133	144	-11	144	154	-10
Lvivska	133	174	-40	189	212	-22	134	161	-26
Rivnenska	131	147	-16	136	159	-23	148	147	1
Chernihivska	106	125	-19	110	140	-30	119	141	-22
Forest Steppe									
Vinnyska	98	122	-25	111	131	-20	92	93	-1
Kyivska	91	129	-38	104	101	4	112	95	17
Poltavska	83	95	-12	76	105	-29	88	89	-1
Sumyska	102	94	8	101	114	-13	117	114	4
Ternopil'ska	117	97	20	105	123	-18	139	151	-12
Kharkivska	63	88	-25	79	83	-4	48	87	-38
Khmelnyska	103	114	-11	127	132	-6	133	134	-1
Cherkaska	87	142	-55	79	110	-31	81	85	-3
Steppe	72	117	-45	74	169	-95	116	146	-30
Steppe									
Crimea*	-	-	-	-	-	-	-	-	-
Dnipropetrovska	63	67	-4	79	89	-10	104	79	25
Donetska**	53	88	-35	53	88	-35	-	-	-
Zaporozhska	58	72	-15	76	57	18	82	72	10
Kirovograd'ska	46	66	-20	50	70	-20	57	73	-16
Luhanska**	49	66	-18	90	75	15	-	-	-
Mykolayiv'ska	84	92	-8	105	86	19	123	75	48
Odeska	80	106	-26	98	111	-13	26	58	-32
Kherson'ska	54	76	-22	69	75	-5	110	79	31

Notes. * No information on humus balance is available. ** No information on the humus balance in 2020 is available. *Source:* prepared by the authors according to (State Institution "Derzhgruntokhrona", 2023)

Eroded soils have worse environmental conditions for plant nutrition with phosphorus. This is especially typical in the southern regions of Ukraine, where the total amount of phosphorus in the tilled layers is lower than in the non-eroded layers. In addition, if the soils in these areas have a calcium-enriched horizon, they form mainly apatite forms of phosphate compounds. These compounds are not readily available to plants. The level of plant nutrition with phosphorus is determined by the presence of its mobile forms. When phosphate fertilizers are applied, the amount of mobile phosphate increases in proportion to the weight of the fertilizer applied. However, the removal of phosphorus from the soil is not compensated by its application (Table 17)

Table 17

Phosphorus balance by zones of Ukraine, 2016-2020

REGIONS AND ZONES	2016			2018			2020		
	total re-ceived, kg/ha	re-moval, kg/ha	balance, kg/ha (+/-)	total re-ceived, kg/ha	re-moval, kg/ha	balance, kg/ha (+/-)	total re-ceived, kg/ha	re-moval, kg/ha	balance, kg/ha (+/-)
Total in Ukraine	19	39	-20	25	40	-15	24	38	-15
Polissya									
Volynskaya	26	65	-39	49	46	3	47	44	2
Zhytomyrska	15	32	-16	18	35	-17	16	25	-9
Zakarpatska	18	58	-40	15	45	-30	8	54	-46
Ivano-Frankivska	31	47	-15	35	48	-13	32	50	-18
Lvivska	36	48	-12	56	58	-2	33	49	-16
Rivnenska	21	42	-21	36	45	-9	23	42	-19
Chernihivska	23	35	-12	26	40	-14	31	40	-9
Forest Steppe									
Vinnitska	17	39	-23	22	43	-21	18	29	-11
Kyivska	20	42	-22	26	33	-7	23	49	-26
Poltavska	19	31	-12	5	36	-31	5	31	-26
Sumyska	24	38	-14	41	46	-6	31	44	-13
Ternopil'ska	25	30	-6	25	42	-17	27	48	-21
Kharkivska	15	33	-18	16	32	-16	11	30	-19
Khmelnitska	22	51	-29	28	58	-30	39	43	-3
Cherkaska	20	51	-31	12	40	-28	19	28	-10
Steppe	15	40	-25	19	54	-35	20	56	-36
Steppe									
Crimea*	-	-	-	-	-	-	-	-	-
Dnipropetrovska	17	28	-11	24	28	-5	29	25	4
Donetska**	14	33	-19	14	33	-19	-	-	-
Zaporozh'ska	12	27	-15	21	21	0	19	26	-8
Kirovograd'ska	11	25	-14	14	27	-13	16	29	-13
Luhanska**	10	27	-17	14	22	-7	-	-	-
Mykolayiv'ska	27	45	-18	35	43	-8	38	36	2
Odeska	17	34	-17	29	34	-6	4	19	-15
Kherson'ska	12	48	-36	17	47	-29	31	47	-15

Notes. * No information on humus balance is available. ** No information on the humus balance in 2020 is available. *Source:* prepared by the authors according to (State Institution "Derzhgruntokhrona", 2023)

A negative phosphorus balance in soils suppresses plant growth, worsens soil energy indicators and its biological activity. As a result, the development of the plant root system is slowed down.

As for potassium, its content and forms of compounds depend mainly on the granulometric composition of the soil. Therefore, there is no significant difference in the ecology of potassium nutrition between eroded and non-eroded soils. In general, our soils are more saturated with mobile potassium compounds than other macronutrients. However, the degree of potassium availability in plants is determined not so much by its total content, but by its readily available compounds in exchangeable and non-exchangeable fixed forms. The ratio between these forms determines the availability of potassium to plants. The removal of potassium with the harvest also exceeds its return to the soil in the form of fertilizers (Table 18)

Table 18

Potassium balance by zones of Ukraine, 2016-2020

REGIONS AND ZONES	2016			2018			2020		
	total re- ceived, kg/ha	re- moval, kg/ha	bal- ance, kg/ha (+/-)	total re- ceived, kg/ha	re- moval, kg/ha	bal- ance, kg/ha (+/-)	total re- ceived, kg/ha	re- moval, kg/ha	bal- ance, kg/ha (+/-)
Total in Ukraine	25	67	-42	33	65	-32	29	66	-36
Polissya									
Volynskaya	51	65	-14	65	60	5	59	60	-1
Zhytomyrska	20	34	-14	25	42	-17	23	37	-14
Zakarpatska	25	148	-122	20	115	-95	15	126	-110
Ivano-Frankivska	40	101	-61	45	102	-57	40	107	-67
Lvivska	47	120	-74	124	141	-17	39	109	-70
Rivnenska	41	46	-5	39	48	-9	39	43	-4
Chernihivska	32	35	-4	36	37	-1	42	37	5
Forest Steppe									
Vinnitska	26	33	-7	33	35	-2	26	23	3
Kyivska	25	69	-44	31	56	-26	27	83	-56
Poltavska	22	42	-20	8	43	-35	9	36	-27
Sumyska	29	75	-46	42	81	-39	39	71	-33
Ternopilska	29	49	-20	33	54	-22	33	67	-34
Kharkivska	20	47	-27	24	41	-17	16	73	-57
Khmelnyska	35	36	-2	41	36	5	53	40	14
Cherkaska	24	163	-139	46	131	-85	22	85	-62
Chernivetska	13	92	-80	16	116	-100	22	116	-94
Steppe									
Crimea*	-	-	-	-	-	-	-	-	-
Dnipropetrovska	12	39	-27	20	45	-25	21	39	-18
Donetska**	11	47	-36	11	47	-36	-	-	-
Zaporozhska	7	66	-59	15	51	-36	8	61	-53
Kirovogradska	8	25	-17	14	29	-15	15	27	-12
Luhanska**	5	30	-24	16	18	-2	-	-	-
Mykolayivska	65	138	-74	68	128	-60	70	104	-35
Odeska	11	40	-29	18	38	-20	2	27	-24
Khersonska	9	72	-63	11	71	-60	21	77	-57

Notes. * No information on humus balance is available. ** No information on the humus balance in 2020 is available. *Source:* prepared by the authors according to (State Institution "Derzhgruntokhrona", 2023)

Potassium imbalance reduces the degree of hydrophilicity and swelling of colloids in plant cells, reduces the flow of water into plants and increases its evaporation. It also reduces the frost resistance of plants and their resistance to diseases, inhibits the movement of organic compounds from the leaves to growth points and reproductive organs and reduces the intensity of photosynthesis, which negatively affects the development and productivity of crops.

Ecological functions caused by physical and chemical fertility factors control such basic soil properties as *the acidity and alkalinity* of the soil solution. They also affect the absorption capacity of the soil. The reaction of the soil solution (the liquid phase of soils) depends on the composition and concentration of chemical components in it. These include free acid, free mineral and organic acids and their salts. Under natural conditions, the pH of soil solutions ranges from 4 to 10, depending on the type of soil and its varieties. The most favorable conditions for plant nutrition are soils with a re-

action close to neutral in terms of the availability of nutrients in forms accessible to plants, nitrification activity, etc. According to the State Soil Conservation Service, more than 19% of soils are acidic and more than 57% are close to neutral and neutral (Figure 20).

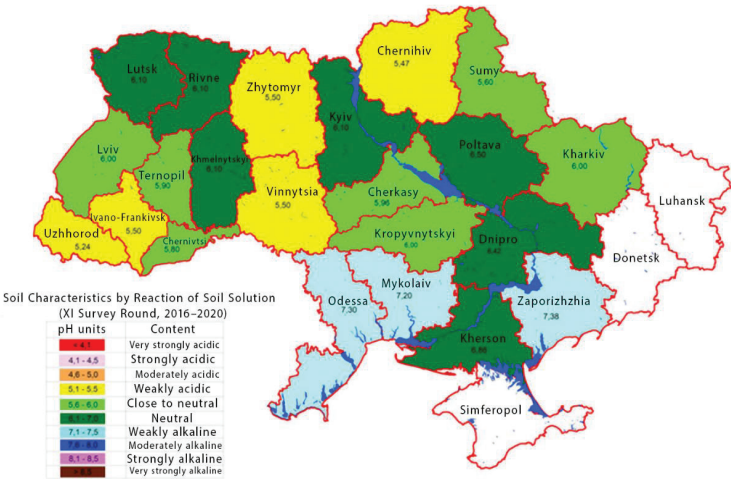


Figure 20. Characteristics of soils by soil solution reaction based on the results of the survey in 2016-2020. *Source:* prepared by the authors according to (State Institution "Derzhgruntokhorona", 2023)

At the same time, under the influence of no-till farming systems, unbalanced application of chemical macro- and microelements, organic fertilizers and anthropogenic loads, the process of secondary soil acidification occurs. This phenomenon is evident even in neutral ordinary chernozems. As a result, 27.2% of acidic soils were found in the Forest-Steppe zone in the last round of surveys. The level of such soils is particularly high in Vinnytsia region is 53.5%, in Sumy region is 41%, in Ternopil region is 32% and in Chernivtsi region is almost 38%.

In the Steppe zone, 47% of the land was found to be slightly, medium and strongly as well as very strongly alkaline.

Meliorated lands are affected by significant degradation. Flaws in the operation of irrigation systems lead to soil erosion, which includes the leaching of nutrients and a decrease in humus content. It also causes the formation of irrigation gullies and other negative consequences. In Dnipro, Donetsk, Mykolaiv, and Odesa regions, the area of saline irrigated land has increased significantly. More than 30% of the area is covered by saline soils (the largest areas of medium and highly saline soils are concentrated in Odesa, Zaporizhzhia and Kharkiv regions).

Out of the 3.1 million hectares of drained land, 1.5 million hectares are in agricultural use, half of which are pastures. About 1 million hectares of drained land require reconstruction of hydraulic structures. Secondary salinization occurred in large areas. These and other negative phenomena of decreased productivity of reclaimed land are the result of violations of irrigation and drainage technologies. They also arise from the

cessation of agrochemical melioration activities, reduced fertilization and other reasons.

In general, up to 10 million hectares of land in Ukraine are salted and saline. This is almost as many hectares as the area covered by acidic soils of various levels. Eliminating such manifestations of chemical soil degradation as acidification and salinity requires liming and gypsumization measures. However, since 1991, the volume of chemical land reclamation decreased tenfold (Table 19)

Table 19

Dynamics of chemical land reclamation volumes

Types of work	1990	2000	2005	2015	2020
Liming of acidic soils, thousand hectares	1548	23,9	41,7	88,1	118,8
Gypsumization of saline soils, thousand hectares	305	5,1	2,4	7,1	11,1

Source: Statistical yearbooks "Agriculture of Ukraine"

Instead of the minimum required 20% liming of acidic soils annually, the work is carried out by 2-3%. As a result, the removal of calcium with plant products leads to the loss of the most valuable part of the soil - the humus. It is also necessary to note the extremely unsatisfactory level of gypsumization of saline soils.

At the same time, monoculture industrial intensive use of agricultural land, increased erosion and high levels of chemicalization reduce soil *biodiversity*. This negatively affects the adaptation of crops to changing climate conditions.

The European Union's Biodiversity Strategy (2020) notes that biodiversity loss threatens healthy, nutritious diets, rural livelihoods and agricultural productivity. It also emphasizes that biodiversity is crucial for food security. Changes in land use, typical of the currently dominant intensive industrial type of management, have been identified as one of the five factors of biodiversity loss (ECEU, 2020).

The process of increasing the rate of destruction of soil biodiversity and certain species of plants as well animals is not related to the law of accelerating evolution. It is caused by anthropogenic activities of people. Thus, biodiversity conservation imposes restrictions on human activities related to the use of natural resources.

Suspending and preventing the occurrence of various types of degradation of the natural resource potential of agriculture requires the development of optimal environmental models of land use. This means creating a set of agronomic and environmental parameters that would ensure a certain crop yield at a given level of farming. Such models should help to realize the potential of varieties, fertilizers and land reclamation measures without harming soil fertility.

Agroecological farming is a model that ensures the environmentally friendly use of intensification factors. It allows for the use of different types of soils and other resources without violating optimal environmental limits.

The development and implementation of optimal ecological models requires the cooperation of farmers and scientists. The synthesis of science and practice will enable the agro-ecological functions of agriculture to be activated and prevent the industry from possible environmental crises.

2.3 POLLUTION AS A DRIVER OF NATURAL RESOURCE DEGRADATION AND A THREAT TO HUMAN HEALTH.

Pollution refers to the introduction of physical, chemical, or biological elements into the environment that are atypical and detrimental to natural ecosystems and human health (Zaverukha, N. M., Serebryakov, V. V., & Skiba, Y. A., 2008). According to scientific sources, pollutants can be of both natural origin, such as volcanic ash and anthropogenic origin, such as industrial waste, wastewater and other human products (Abbasi, A., Haq, N., Rahman, S., Ashraf, M., Misbah, Z.-T., Kazi, A. G., Sajid, A., & Sanober, G., 2013; Ioannidou, V., & Stefanakis, A. I., 2020).

According to the United Nations documents, pollution is the presence of substances and heat that, due to their quantity or location, cause undesirable environmental consequences (UN, 2022).

Environmental pollution is one of the leading causes of disease and premature death in the world, causing more than 9 million premature deaths each year, most of which are the result of air pollution. This number is significantly higher than deaths from diseases such as AIDS, tuberculosis or malaria (World Bank, 2023).

The modern agricultural sector faces significant environmental challenges related to the pollution of natural resources, which poses a serious threat to food security, quality of life of people, sustainability of agricultural systems and long-term preservation of the natural environment (Fyliuk, H., Pimenova, O., Pimenov, S., & Golovanenko, M., 2021). Suffering from pollution coming from the industrial and municipal sectors of the economy, agriculture itself is becoming one of the main factors of environmental pollution, which covers all the main components of ecosystems: air, soil and water. The application of agrochemicals, particularly N and P fertilizers, leads to excessive enrichment of soils and water systems with nutrients, which causes significant environmental issues, such as aquifer contamination and eutrophication of aquatic ecosystems (Abbasi, A., Haq, N., Rahman, S., Ashraf, M., Misbah, Z.-T., Kazi, A. G., Sajid, A., & Sanober, G., 2013; Kumar, P. S., & Yaashikaa, P. R., 2019). This, in turn, contributes to the formation of hypoxic zones in water bodies, which adversely impacts aquatic flora and fauna, as well as the quality of water for human consumption.

According to the UN Food and Agriculture Organization (FAO), approximately 2,250 km³ of wastewater is discharged into the environment each year, of which 330 km³ is municipal wastewater, 660 km³ is industrial wastewater (including cooling water), and 1,260 km³ is agricultural wastewater (FAO, 2021). The ability of soils to preserve, buffer, and decompose pollutants entering water systems is being exceeded by intensive anthropogenic practices in the cultivation of arable land and pastures. This has resulted in widespread increases in N levels, salinity, and biological oxygen demand (BOD) in freshwater ecosystems.

A particular threat to the world's natural resources is currently the growing use of pesticides, which can accumulate in ecosystems and lead to the death of beneficial insects, pollution of water bodies and the creation of persistent pollutants that affect human and animal health (Abbasi, A., Haq, N., Rahman, S., Ashraf, M., Misbah, Z.-T., Kazi, A. G., Sajid, A., & Sanober, G., 2013).

Agricultural pollution is a major environmental problem in many countries around the world. For example, in Europe, diffuse pollution from agriculture covers large areas where NO_3 from fertilizers enter groundwater, posing risks to drinking water quality and public health (Mititelu-Ionuș, O., Simulescu, D., & Popescu, S. M., 2019).

The European agricultural sector is recognized as being at risk. According to the EU LUCAS study, 80% of agricultural soils in the region contain pesticide residues. In addition, high levels of nitrogen in wastewater are recorded, causing eutrophication, affecting 65-75% of agricultural land in the EU. Additionally, the study found that 21% of European soils exceeded regulatory thresholds for heavy metals, such as Cd (ReSoil Foundation, 2024).

Among the various environmental challenges associated with contemporary agriculture, scientists emphasize the risks posed by genetically modified crops. While these crops are known to enhance yields and improve disease resistance, there are significant concerns regarding their potential impact on biodiversity, particularly through genetic drift and unforeseen environmental consequences (Abbasi, A., Haq, N., Rahman, S., Ashraf, M., Misbah, Z.-T., Kazi, A. G., Sajid, A., & Sanober, G., 2013).

These problems are particularly relevant in Ukraine, where additional environmental challenges are exacerbated by the consequences of the Chornobyl nuclear power plant accident and the ongoing military operations in the southeastern territories.

In the territories affected by industrial emissions, degradation of both natural and cultural biocenoses occurs, which leads to a decrease in the species composition and numbers within the fauna are depleted. Additionally, the physical and chemical properties, as well as the biological activity of soils, deteriorate, resulting in acidification, decreased crop yields and the accumulation of toxicants in agricultural products (Robinson, J. M., Liddicoat, C., Muñoz-Rojas, M., & Breed, M. F., 2024). Numerous surveys have demonstrated that within the influence zone of industrial enterprises, the yield of grain crops decreases by 20-30%, while sunflower yields drop by 15-20%, vegetables by 25-30%, and fruits by 15-20% (State Institution "Institute of Soil Protection of Ukraine" SI "Derzhgruntokhorona", 2023).

Industrial pollution in Ukraine is most prominent in the Donetsk and Kryvyi Rih basins, as well as in the Pavlohrad, Nikopol-Marhanets, and Kalush-Drohobych regions. These areas are characterized by the concentration of metallurgical, chemical, coal, and mining industries. The focus on extensive development and the application of outdated technologies became the main reason for their ecological crisis.

Intensive groundwater extraction, combined with the discharge of highly mineralized mine water and contaminated industrial wastewater, has led to a significant inflow of saline water into the rivers of Donetsk and Luhansk oblasts. This situation exacerbates the already negative environmental conditions in the region (Moldavan, L., Pimenowa, O., Wasilewski, M., & Wasilewska, N., 2023).

In western Donbas, mines extract water with a salinity ranging from 2 to 30 g/l, discharging it into the Samara River. The increased salinity in the river threatens soil salinization and the potential decommissioning of the local irrigation system. Similarly, in the Lviv-Volyn coal basin, water with a salinity of up to 3.1 g/l is pumped from mines and discharged into the Western Bug River (State Institution "Institute of Soil Protection of Ukraine" SI "Derzhgruntokhorona", 2023).

In Kryvbas, highly mineralized mine water, with salinity levels ranging from 30-40 to 90-100 g/l, is discharged into the Ingulets River, leading to the salinization of extensive areas of irrigated land in Mykolaiv Oblast. An additional source of pollution in this region is the water generated during the dewatering of sludge ponds, which, in the form of mineralized runoff, enters the geographical grid and infiltrates underground aquifers, resulting in contamination.

Air pollution in mining regions is caused by emissions of solid and gaseous substances into the atmosphere that are generated during the development of mineral resources.

A significant ecological threat is the accumulation of waste dumps, particularly in the Donetsk and Kryvyi Rih basins, the area of which occupies more than 150 thousand hectares. Smoldering dumps release CO, SO₂, H₂S and NO_x into the atmosphere. A substantial portion of the toxic waste generation comes from galvanic industries, which contain heavy metals. Waste in Zaporizhzhya region contains Cr, Ni, Pb and their compounds. In contrast, waste from the Donetsk region predominantly contains Co, Cu, Hg, Mn, and Zn.

Between 2016 and 2020, the State Institution “State Soil Protection”, “Derzhgruntohorona” conducted a survey of approximately 8.6 million hectares of agricultural land in regions not affected by the military operations, specifically assessing mobile Pb compounds. Of the surveyed area, 38.5% exhibited mobile compounds is within background levels (<0.8 mg/kg), while about 52% displayed low to moderate levels of contamination. Additionally, 8% of the area was found to have medium to elevated levels, and approximately 1.5% showed high to very high levels of contamination. The weighted average indicator with concentration of mobile Pb compounds in contaminated agricultural land was 1.59 mg/kg, indicating a moderate level of contamination with this chemical element (Figure 21).



Figure 21. Content of mobile Pb compounds in Ukrainian soils. Source: prepared by the authors according to (State Institution "Institute of Soil Protection of Ukraine" SI "Derzhgruntokhorona", 2023)

Of the surveyed agricultural lands, almost 49% of the land contains mobile Cd compounds that do not exceed background levels (<0.1 mg/kg). The contaminated area is more than 50%. The highest content of mobile Cd compounds of this chemical element is observed in the Steppe zone (0.2-0.27 mg/kg) (Figure 22).



Figure 22. Content of mobile forms of Cd in Ukrainian soils. *Source:* prepared by the authors according to (State Institution "Institute of Soil Protection of Ukraine" SI "Derzhgruntokhorona", 2023)

The survey revealed that agricultural lands exceeding the maximum permissible concentration (MPC) of mobile Pb forms (6 mg/kg) were found in Dnipropetrovska, Odessa, and Mykolaivska oblasts, with weighted average indicators for these contaminated areas were 11.76 mg/kg, 7.16 mg/kg, and 8.05 mg/kg, respectively (State Institution "Institute of Soil Protection of Ukraine" SI "Derzhgruntokhorona", 2023).

Of the more than 8.5 million hectares of agricultural land surveyed, almost 49% of the land has a mobile Cd content that does not exceed background levels (<0.1 mg/kg). The contaminated area is about 4.4 million hectares and the weighted average indicator is 0.2 mg/kg of soil, which corresponds to a moderate level of contamination. The weighted average indicator of the content of mobile Cd compounds in the soils of the Steppe is 0.21 mg/kg of soil, Polissia is 0.2 mg/kg of soil and Forest-Steppe is 0.19 mg/kg of soil. The highest content of mobile compounds of this chemical element is observed in Dnipropetrovska (0.49 mg/kg), Lvivska (0.3 mg/kg) and Cherkaska (0.27 mg/kg) oblasts and is classified as moderate pollution. At the same time, the MPC for mobile forms of Cd (0.7 mg/kg) is exceeded in three regions on 49.3 thousand hectares of agricultural land. The contaminated area in the Dnipro region is 45.47 thousand hectares, in Odessa and Mykolaiv regions it is 3.31 and 0.5 thousand hectares and the weighted average indicators for the contaminated area above the MPC were 0.98 mg/kg, 0.9 mg/kg and 0.71 mg/kg, respectively.

The above-mentioned processes of pollution of natural resources have significantly intensified as a result of military operations in Ukraine, which began in the regions of

the Donetsk basin and currently cover part of the territories of five eastern and southern regions.

In areas of military operations, surface and groundwater, air and soil are subject to chemical contamination due to the release of substantial quantities of combustion products from munitions, as well as the destruction of military and civilian equipment, municipal infrastructure, chemical plants, fuel and lubricant warehouses and liquid chemical fertilizers. The chemical pollutants resulting from these events include oils, heavy metals, nitroaromatic explosives, organophosphorus nerve agents, and radioactive elements, etc.

Pollutants, remaining in the environment for a long time and being mobile, move through the food chains of biological organisms, posing a direct threat to human populations due to their toxicity, carcinogenicity and mutagenicity.

According to the Ministry of Environment of Ukraine, research by the World Bank, Kyiv School of Economics, SavEkoBot and other non-governmental organizations, tens of thousands of fires have occurred since the start of hostilities. The combustion of petroleum products in large volumes releases CO₂, benzopyrene and SO₂, NO_x, gaseous and solid products of incomplete combustion of fuel, V compounds, sodium salts CO₂ and NO_x as one of the most active greenhouse gases contributing to the greenhouse effect (de Klerk, L., Shmurak, A., Hasan-Zade, O., Shlapak, M., Tomlyak, K., & Kortsuis, A., 2023).

CO₂ and sulfur gases interact with moisture in the atmosphere to produce acid precipitation. When combined with precipitation, sulfur is converted into dangerous sulfuric acid, which increases the soil acidity.

Vehicular traffic, the detonation of explosive munitions and other military operations lead to soil compaction, structural damage, reduced water and air infiltration and the development of anaerobic processes, all of which reduce land productivity and adversely affect crop development. Furthermore, the disturbance of the soil surface caused by military actions negatively impacts the biological crust, which plays a crucial role in soil stabilization.

The findings of the scientists' research complement the surveys conducted by non-governmental organizations and projects operating in the combat zone since the onset of the conflict in 2014. Data obtained from the Environment-Law-Human project (Kravchenko, O. (Ed.), 2015) indicate that the concentration of heavy metals in soil samples collected from combat areas frequently exceeded background levels by factors ranging from 1.2 to 12 times. Additionally, according to the Center for Humanitarian Dialogue (IBRD, EU, UN., 2015), Cd levels were 4.4 times higher and Pb levels were 1.2 times higher than the regional average (MTOT., 2016).

Data obtained from a study conducted by the Siverski-Donetsk Basin Water Resources Administration in the conflict area indicated that background levels of Hg, V, Cd, and non-radioactive ⁹⁰Sr were exceeded by factors of 1.1 to 1.3 times.

Flooding of mines due to power outages and damage to equipment, which leads to the shutdown of mine water drainage systems, poses a significant threat to water resources. When mine water mixes with surface water, it contaminates the latter with Fe, chlorides, sulfates and other mineral salts, as well as heavy metals.

Researchers from the Sokolovsky Institute of Soil Science and Agrochemistry and the Semenenko Institute of Geochemistry, Mineralogy and Ore Formation of the National Academy of Sciences of Ukraine are continuously conducting localized studies on the pollution of natural resources. According to the results obtained, all types of pollution caused by chemical, physical and chemical, mechanical, physical, and biological impacts are recorded on the lands affected by hostilities (Sploditel, A., Holubtsov, O., Chumachenko, S., & Sorokina, L., 2023; Balyuk, S., 2023).

The authors of this article have systematized all types of pollution from the territories of hostilities and characterized their expected consequences based on the analysis of the surveys available at this stage (Figure 23).

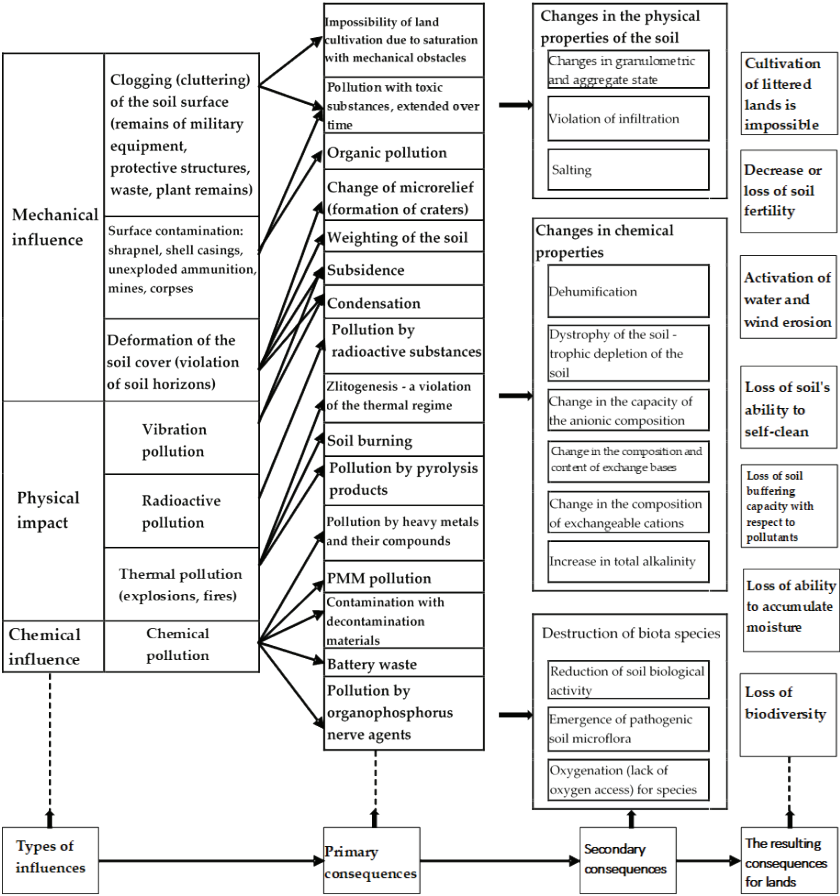


Figure 23. Types of impacts on soil from hostilities and their consequences. *Source:* Developed by the authors with the use of (Sploditel, A., Holubtsov, O., Chumachenko, S., & Sorokina, L., 2023; Balyuk, S., 2003).

The restoration of land contaminated as a result of hostilities requires systematic legislative, regulatory, technological and organizational measures, which is confirmed by foreign experience in implementing an integrated approach that takes into account environmental, social and economic aspects (Fylyuk, G., & Pimenova, O., 2014). Such an approach may include, in particular:

- conservation of contaminated land with its transfer on a lease basis to a state body established by law for the period of restoration;
- reforestation of a part of the affected territories with the state buying them out from the landowner and withdrawing them from agricultural use;
- reclamation of contaminated land with the introduction of ecologically sustainable farming methods.

The proposed technologies for soil reclamation of different types of contamination (Table 20) provide for the transition to agricultural activities based on agroecology, which is based on the imitation of natural processes and thus ensures beneficial biological interaction and synergy between the components of the agroecosystem (Altieri, M. A., 1995; Gliessman, S., 2007).

Table 20

Technologies for soil remediation of various types of contamination

№	Type of pollution	Technology	Content of the technology	Scenarios of land use
1	Subsidence; flooding	Drainage reclamation	Drainage works for groundwater drainage with subsequent treatment	Cultivation of perennial grasses, fodder crops; combination of intermittent furrowing and hollowing along with slotting and mowing; mulching (with manure, straw, forest floor, peat, stubble and post-harvest residues)
2	Drying; sealing	Irrigation reclamation	Water conservation measures and hydro-technical methods of water supply and its transformation into soil moisture	Crop rotation; regular application of manure, compost, straw, other organic fertilizers, open trenches, loosening and watering
3	Water erosion, secondary salinization, salinization and liquefaction; depletion and disruption of the organismal profile (explosion craters); pollution by products of the passage	Agricultural reclamation	Reducing surface runoff and transferring it to intra-soil runoff	Restoration by natural means or reforestation. For shallow craters up to 0.5-1 m, backfill with soil mass close to the natural horizons. Addition of gypsum, application of physiologically acidic and sulfur-containing fertilizers, introduction of perennial grasses into the crop rotation of perennial grasses. Slope terracing, contour plowing, selection of crops, proper tillage during plowing
4	Wind deflation and blowing away	Forestry reclamation	Reducing wind speed in the ground layer, returning lost nutrients to the soil	Sodding, soil-protective crop rotation in multi-depth cultivation (row crops and perennial grasses); tillage with flat cutters and sowing of grain crops with special stubble seeders
5	Threat of geochemical contamination, clogging (littering)	Cleaning of the territory	Mechanical cleaning of the surface, maintenance of sanitary condition	Measures to clean up toxic waste: Use for any crops subject to quality control of agricultural products

Source: Developed by the authors using scientific developments and practice on this issue.

The authors recommend institutional and organizational measures to support environmentally sustainable and socially oriented restoration of disturbed and polluted natural resources. These measures should include:

- Development of a National Strategy for Post-War Soil Restoration of Disturbed Landscapes, taking into account the regional soil and geochemical conditions that affect natural resource use.
- Establishment of a Center for Environmental Management of Post-War Contaminated Areas to set pollutant standards and determine appropriate soil remediation levels.
- Development of zoning plans for post-war landscapes based on contamination levels and the necessary measures for recovery for normal economic activities; creation of a program for ecological and geochemical soil research; development of procedures for environmental and geochemical assessment of territories contaminated by substances of military origin.
- Development of a legal framework to provide a mechanism for the return of contaminated lands (with compensation to landowners) to state ownership for their restoration purposes and to provide investments to landowners for implementing land restoration measures. Establishing a Guarantee of the rights of landowners in cases of temporary land conservation.
- Conducting soil certification of post-military operations landscapes.
- Implementation of pilot projects in contaminated areas to evaluate the effectiveness of rehabilitation measures on specific post-military operations lands.

The problem of contamination of natural resources in the agricultural sector is complicated by the consequences of the Chernobyl nuclear power plant accident. As a result of the explosion, radioactive contamination covered more than 8.4 million hectares, where 10 years later the density of Cs contamination still exceeded 0.1 Ci/km² (Danylyshyn, B., Doroguntsov, S., Mishchenko, V., Koval, Y., Novotorov, O., & Palamarchuk, M., 1999). The largest amount of contaminated land is up to 70% is located in Zhytomyr region. In Kyiv region, contamination has spread to the northern regions (15% of the territory). In Rivne, Volyn, Chernihiv, Vinnytsia, Cherkasy, Ternopil and Ivano-Frankivsk regions, contamination occurred in the form of radioactive spots of different configurations and sizes (Figure 24).

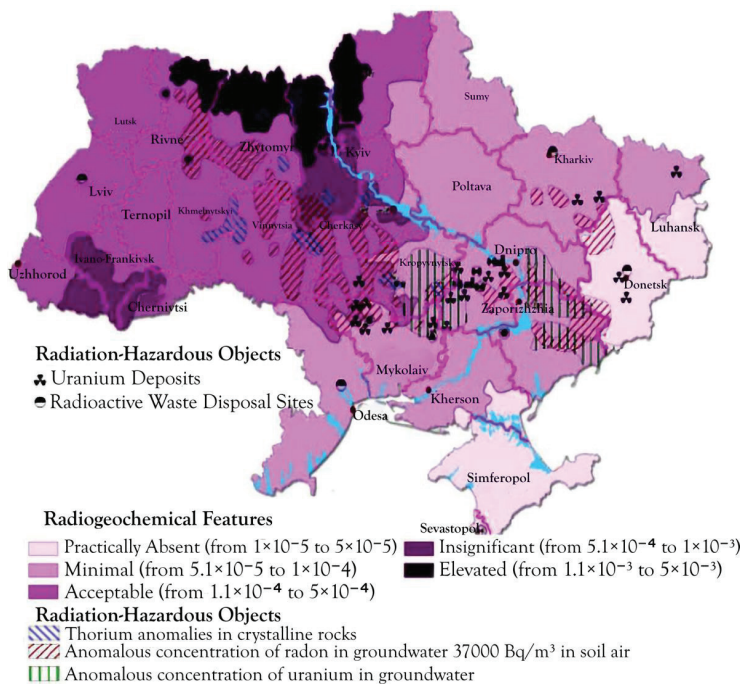


Figure 24. Conventional anthro-ecological risk assessment based on the total density of radiation contamination of the territory (conventional units). *Source:* Tsitsura, Y.H.; Shkatula, Y.M.; Zabarna, T.A.; Pelekh, L.V. *Monograph*; TOV "Druk": Vinnytsia, Ukraine, 2022

Thirty-five years after the Chernobyl accident, the content of ^{137}Cs in crop products in almost the entire contaminated area is balanced on the permissible limit or exceeds it. A certain increase in the level of contamination of products with ^{90}Sr is alarming, which is associated with an increase in its availability to plants (Resolution of the Round Table “Consequences of the Chernobyl Nuclear Power Plant Accident: Current State, Results, and Prospects,” April 21, 2021).

According to the State Soil Protection Agency "Derzhgruntochorna," over 8.1 million hectares of agricultural land have been surveyed, with 99.8% of this area showing cesium-137 contamination at levels up to 5 Ci/km^2 . On 14,800 hectares of the surveyed land, contamination density is from 5 to 15 Ci/km^2 (zone of guaranteed voluntary resettlement).

Nearly 6.2 million hectares of agricultural land were also surveyed for strontium-90 contamination. Of this area, 23,700 hectares (0.4%) showed radio strontium contamination levels ranging from 0.15 to 3 Ci/km^2 , classifying it within the guaranteed voluntary resettlement zone. The remaining 99.6% of the surveyed area is conditionally clean and suitable for agricultural production (Table 21)

Table 21

**Characteristics of soils by the density of contamination of agricultural land
based on the results of the survey in 2016-2020**

REGIONS AND ZONES	Pollution density, thsd ha										
	including cesium-137						including strontium-90				
	Surveyed area, thsd ha	<185 kBq/m²		185-555 kBq/m²		>555 kBq/m²	Surveyed area, thsd ha	<5,55 kBq/m²		5,55-111 kBq/m²	
		<5 Ki/km²		5-15 Ki/km²		>15 Ki/km²		<0,15 Ki/km²		0,15-3,0 Ki/km²	
		total	%	total	%	total		total	Total	%	to tal
Polissya											
Volynskaya	273,1	273,1	100				273,1	273,1	100		
Zhytomyrska	419,1	418,7	99,9	0,4	0,1		419,1	417,0	99,5	2,1	0,5
Zakarpatska	202,2	202,2	100								
Ivano-Frank-ivska	216,1	216,2	100				216,2	215,4	99,6	0,8	0,4
Lvivska	170,3	170,3	100								
Rivnenska	248,3	248,3	100				235,2	228,6	97,2	6,6	2,8
Chernihivska	324,6	324,6	100				324,6	324,6	100,0		
Total	1853,7	1853,4	100,0	0,4	0,02	0	1468,2	1458,7	99	9,5	0,6
Forest Steppe											
Vinnyska	536,4	536,4	100				536,4	536,4	100,0		
Kyivska	653,1	645,9	98,9	7,2	1,1		239,0	228,5	95,6	10,6	4,4
Poltavska	371,7	371,7	100								
Sumyska	327,3	327,3	100				327,3	327,3	100		
Ternopilska	317,3	317,3	100				317,3	317,3	100		
Kharkivska	427,3	427,3	100								
Khmelnyska	466,6	466,6	100				466,6	466,6	100		
Cherkaska	409,9	409,9	100				409,9	406,3	99,1	3,6	0,9
Vinnyska	182,3	175,1	96,0	7,2	4,0		182,3	182,3	100		
Total	3691,9	3677,4	99,6	14,4	0,4	0	2478,8	2464,6	99,4	14,2	0,6
Steppe											
Crimea*											
Dnipropetrovska	643,1	643,1	100				643,1	643,1	100		
Donetska											
Zaporozhska	234,0	234,0	100								
Kirovogradska	410,0	410,0	100				410,0	410,0	100		
Luhanska											
Mykolayivska	551,8	551,8	100				551,8	551,8	100		
Odeska	107,5	107,5	100								
Khersonska	645,4	645,4	100				645,4	645,4	100		
Total	2591,7	2591,7	100				2250,3	2250,3	100		
Total in Ukraine	8137,3	8122,6	99,8	14,8	0,2	0	6197,3	6173,6	99,6	23,7	0,4

Notes. * No information on humus balance is available. *Source:* prepared by the authors according to (State Institution "Institute of Soil Protection of Ukraine" SI "Derzhgruntokhorona", 2023)

As a result of radioactive decay, the activity of alpha-emitting ²³⁸Pu decreased by 24%, while the activity of ²³⁹⁻²⁴⁰Pu remained virtually unchanged. Due to the decay of beta-emitting ²⁴¹Pu, alpha-emitting ²⁴¹Am continues to accumulate, which is added to the ²⁴¹Am emissions of 1986. Today, ²⁴¹Am activity is higher than ²³⁸⁻²³⁹⁻²⁴⁰Ru activity and, according to experts, will increase by 16% over the next 50 years, which is the main radiation hazard for the period up to 2070.

About 91% of the territory remains in exclusion zone with soil contamination density above 1 Ci/km² (37 kBq/m²). During the entire period after the accident, the bioa-

vailability of ^{90}Sr due to its leaching has been increasing and has now reached its maximum value.

Ecosystems are threatened by almost annual phenomena with increased frequency and intensity, such as dust storms, windstorms, heavy rains, forest fires and fire storms, upward atmospheric flows that cause changes in the intensity of radionuclide migration across the country.

Over the period 1993-2020, more than 1800 local and large-scale fires occurred. The area of the “burns” exceeds 100,000 hectares. The radioactive ash formed as a result of the fire is actively involved in the geochemical migration of elements in ecosystems, causing uncontrolled contamination of lands remote from the zone. At the same time, burnt ash contains 600-180000 Bq/kg of ^{90}Sr and from 4100 to 270000 ^{137}Cs . In 2020, forest fires released 700 GBq of ^{137}Cs deposited by wood. As a result, uncontrolled areas with excessive radiation background are created.

With rising temperatures due to climate change and insufficient attention to this issue within governmental structures, there is a risk of large-scale fires in contaminated areas with catastrophic consequences not only for Ukraine, but also for European continent as a whole.

According to the Land Conservation Procedure approved by the Cabinet of Ministers (Cabinet of Ministers of Ukraine. Draft Law on Amendments to Certain Laws of Ukraine on Defining Categories of Radioactively Contaminated Zones and Providing Information to the Population about Their Radiation Status, Reg. No. 6476, dated 28 Dec. 2021), areas contaminated by industrial activities, where it is not possible to produce clean products, are subject to conservation. However, in many radionuclide-contaminated areas, these lands are still cultivated and the products grown are subsequently sold.

The production of agricultural products in private peasant farms in the affected regions remains radio ecologically critical. In the process of privatization of land, the most radioactively affected areas were allocated to the population for livestock grazing, and their condition is currently not being monitored. There is no systematic control of food resources of the forest (mushrooms, berries) obtained in the polluted territories. The current radiation situation in forest ecosystems affected by the consequences of the Chernobyl nuclear power plant accident remains completely undetermined.

Currently, the primary source of collective radiation exposure of the population (up to 95% of the total) is formed as a result of the consumption of food produced on radioactively contaminated land. However, the population is not provided with means of individual protection against radiation contamination, as well as dosimeters and other devices for assessing environmental contamination.

Concurrently, there is a consistent decline in the implementation of radiation protection measures within the affected regions. Efforts related to radioecological monitoring and the assessment of radionuclide content in agricultural products from areas impacted by the Chornobyl disaster are gradually being reduced.

There is currently no effective mechanism for coordination and stable collaboration between central and local executive authorities, as well as between the various agencies, scientific institutions, healthcare institutions, professional associations and representatives of civil society engaged in implementing measures to neutralize radioactive

contamination in affected areas and restore them of safe production und human habilitation.

The above does not exhaust all the problems that have accumulated in the country as a result of radioactive contamination of large areas, which indicates the need for fundamental changes in the management of radio ecologically contaminated land at all levels of the management system.

Scientists indicate that contaminated food will continue to be the primary source of radiation risk for the population in the long term. In this context, the need for effective radiation monitoring and control of radionuclide levels in agricultural products remains critical. Additionally, enhancing the efficiency of resources dedicated to the development and implementation of measures for comprehensive rehabilitation and rational use of contaminated land remains relevant.

The working group of the Committee on Agrarian and Land Policy of the Verkhovna Rada of Ukraine has prepared a draft law entitled "On Amendments to Certain Laws of Ukraine Regarding the Classification of Zones of Radioactively Contaminated Territories and the Provision of Information to the Public on Their Radiation Status" (Cabinet of Ministers of Ukraine. Draft Law on Amendments to Certain Laws of Ukraine on Defining Categories of Radioactively Contaminated Zones and Providing Information to the Population about Their Radiation Status, Reg. No. 6476, dated 28 Dec. 2021).

The purpose of the draft law is to improve legislation in the field of overcoming the consequences of the Chernobyl disaster, while aligning with contemporary international standards for human radiation protection. Specifically, it aims to establish zoning for areas contaminated by the Chernobyl disaster and to create legal mechanisms that promote the sustainable development of agricultural land and the broader affected territories.

The Cabinet of Ministers of Ukraine should initiate a state-funded program to conduct a comprehensive radiological survey of radiation-contaminated areas. This survey aims to delineate the boundaries of radiation-critical zones, where agricultural production poses a risk of producing products that exceed established radionuclide content standards and to assess the feasibility of land use. Additionally, it is essential to include a separate category for radionuclide-contaminated soils, complete with appropriate coordinate references, in the Public Cadastral Map of Ukraine.

Experts recommend establishing an electronic database of forest survey materials aimed at rehabilitating forests through the assessment of areas within forest blocks that have been designated as unconditional resettlement zones, where all forestry activities were prohibited (Shcherbyna, V., Tretyak, R., & Vashchenko, V., 2021).

The authors concur with the views of several scientists regarding the necessity to standardize the concept of revitalizing agro-food production on remediated radioactively contaminated lands in the Polissya zone. This should be followed by the development of an implementation strategy grounded in scientific justification and multivariate simulation modeling of various scenarios of the development of agricultural production. The goal is to establish cost-effective, naturally regenerating agro-ecosystems that support safe food production.

The task of the Concept is to restore and maintain the barrier function for radiation protection and environmental safety for the population. It also aims to facilitate social, economic, scientific and technical development in the territories of the exclusion zone and the areas of unconditional (mandatory) resettlement, which has experienced the greatest radioactive contamination.

The restoration of farming in radioactively contaminated areas has distinct characteristics, particularly the necessity to minimize individual radiation doses to the population through the production of food products, the content of radionuclide levels in which will not exceed permissible limits (Table 22)

Table 22

Permissible levels of radionuclides in agricultural crops

Corn		Winter wheat		Potatoes		Spring barley		Legumes	
<i>kBq/m²</i>	<i>Ci/km²</i>	<i>kBq/m²</i>	<i>Ci/km²</i>	<i>kBq/m²</i>	<i>Ci/km²</i>	<i>kBq/m²</i>	<i>Ci/km²</i>	<i>kBq/m²</i>	<i>Ci/km²</i>
286	7,7	182	4,9	500	13,6	154	4,1	25	0,7

Source: Avramchuk, A., 2021

The transition to long-rotation grain with the introduction of legumes and green manure will contribute to reducing the accumulation of radionuclides in agricultural products. The planning of the set of crops must be carried out taking into account their characteristics for the accumulation of radionuclides, so that the norms of cesium accumulation do not exceed the permissible. For example, potatoes, which can be grown on sod-podzolic soil, have a low level of “perception” when the density level reaches 15 Ki/km, corn is sown at a rate of up to 7.7 Ki/km and cereals - 2.4-4.1 Ki/km.

Today, biological methods of cleaning the soil from pollution-so-called bioremediation methods, which are characterized by high efficiency and non-toxicity-are attracting a lot of attention. The methods are based on the ability of different groups of living organisms to decompose or accumulate pollutants (heavy metals, radionuclides, N, P and organic compounds, etc.) in their biomass in the process of vital activity (Bilyk, T. I., Shtyka, O. S., Avdeeva, A. O., & Padalka, A. O., 2008). If the viability and species diversity of the natural microbiocenosis of the soil is restored, biological methods are effective, but the process is slow and lengthy (Samokhvalova, V. L., 2014).

According to the conceptual model (Samokhvalova, V. L., 2014) of bioremediation of soils contaminated with heavy metals, the use of a class of biological methods of remediation of contaminated by industrial activities soils with their gradation into groups is envisaged:

- methods of biodegradation of pollutants using microorganisms;
- methods of bioaccumulation by plants and/or redistribution of pollutants in the

soil with simultaneous effect on biological and inorganic (mineral substances that are products of the destruction of rocks and are formed without the participation of living organisms) components of the soil, which leads to the optimization of its ecological state due to the increase in the content of organic matter and its binding by clay minerals as well the improvement of the structural state of the soil, trophic and gas regimes, properties of the soil system as a whole.

Today, there are a sufficient number of patented methods of bioremediation of contaminated soils in Ukraine using: technical oil crops, lawn grass, stress-tolerant trans-

genic plants to the action of heavy metals (Patent for Utility Model 50789 UA; Patent for Utility Model 76416 UA; Patent for Utility Model 45299 UA; Patent for Invention 90279 UA).

For phytoremediation of technogenic contaminated and depleted soils, a biological product of complex action was developed, which was obtained from the culture liquid of *Pseudomonas* sp. PS-17 grown on an optimized nutrient medium, followed by sterilization of the resulting culture liquid and removal of cell precipitate (Patent for Utility Model 77228 UA).

Application of agrotechnical measures to restore the agroecological functions of soils provides additional reduction of the negative impact of radioactive pollution, which creates preconditions for returning part of the polluted lands to production sphere.

Pesticide and NO_3 pollution causes great harm to the environment and human health.

The use of pesticides and agrochemicals in agriculture is a serious problem for most countries where agriculture is the leading sector of the economy. Their use creates a threat not only to soil ecology, but also to water bodies, which are closely interconnected with soils and land. Soil contamination with pesticides and agrochemicals leads to the accumulation of toxic chemicals in groundwater that can pose a threat to human health (Verkhovna Rada of Ukraine. Law of Ukraine "On Pesticides and Agrochemicals" 86/95-VR, 2.03.1995; Draft Law on Amendments to Certain Laws of Ukraine on Improving State Regulation in the Field of Pesticide and Agrochemical Management No. 4558, 30.12.2020). As a result of their use, not only harmful organisms die, but also many useful species, which disrupts the existing balance of species numbers in specific populations.

Ukraine is dominated by rotationless, highly specialized agricultural production with a transition to monoculture, which, in the face of rising climate temperatures, contributes to the spread and accumulation of diseases, pests and weeds and leads to a constant increase in the use of chemical plant protection products (Kaminskyi, V. F., 2015).

The majority of the 1,000 registered pesticides and toxic chemicals authorized for usage are used in violation of the established rules and regulations. At the same time, in many cases, the rules are outdated. For example, spraying of pesticides is allowed, while according to the European Commission Directive 2009/128 EU, all EU member states have to prohibit this method of pesticide application. The European Union is taking steps to reduce and prohibit the use of pesticides in general (European Commission (EC). *Sustainable Use of Pesticides Directive* EC 2009/128; European Commission Wants to Ban Bee-Harming Pesticides. ESPRESO.TV., 2017).

Pesticides can accumulate in agricultural products, with which they enter the body of people and animals. About 90% of all fungicides, 60% of herbicides and 30% of insecticides are carcinogenic.

Critical pesticide pollution is recorded in the soils of Donetsk, Luhansk, Kherson, Sumy and Khmelnytsky regions and excessive pesticide content in crop production is observed in the central regions of the country.

The problem of disposal of prohibited and unusable pesticides, the warehouses of which became "no man's land" in the process of reorganization of collective agricultural enterprises and enterprises that serve them, remains unresolved.

However, the state does not ensure control over their storage and use. The State Service of Ukraine on Food Safety and Consumer Protection, which is responsible for these functions, does not have laboratories that can test the content of pesticides in water, air and soil. Regional laboratory centers, which were previously subordinated to sanitary and epidemiological stations and performed control functions, have now been transferred to the Ministry of Health of Ukraine without specifying their functions. The harmfulness of pesticide use creates the need to adopt appropriate regulations to regulate the limits of their use. It is also important to impose restrictions on the use of these harmful substances. This is aimed at reducing the negative impact on agricultural land. Given the imperfections of the current Law of Ukraine "On Pesticides and Agrochemicals" (Verkhovna Rada of Ukraine. Law of Ukraine "On Pesticides and Agrochemicals" 86/95-VR, 2.03.1995), currently, draft law No. 4558 (Draft Law on Amendments to Certain Laws of Ukraine on Improving State Regulation in the Field of Pesticide and Agrochemical Management No. 4558, 30.12.2020) on the improvement of state regulation in the field of the use of pesticides and agrochemicals has been submitted to the legislative body for consideration. It is assumed that the list of enterprises entitled to carry out state testing for the purpose of toxicological and hygienic assessment is determined by the Ministry of Health of Ukraine, not the State Service of Ukraine on Food Safety and Consumer Protection. The adoption of Draft Law No. 4558 will result in the approval by the Cabinet of Ministers of Ukraine of updated procedures for state testing of pesticides and agrochemicals, their state registration and application in practice.

NO₃ pollution is a painful problem for Ukraine.

Ukraine uses mainly (up to 70%) surface water for drinking purposes, which does not meet the requirements of sanitary legislation. The share of industrial and household waste in NO₃ pollution of groundwater is 47%, agricultural use of land and fertilizers - 30-37%, livestock waste - 10%, and other sources - 7% (State Sanitary Rules and Standards "Drinking Water with amendments and additions by Order No. 400, 12.05.2010).

The use of a growing number of synthetic N fertilizers leads to the accumulation of extremely harmful N in the soil. Part of it migrates within the soil profile and in the NO₃ form it leaches to the upper aquifers and accumulates in the groundwater. Significant levels NO₃ in intensive farming are already found at a depth of 10 meters. At the same time, diffuse pollution is still not systematically measured in the country (Moldavan, L., & Pimenova, O., 2021).

During the study of NO₃ pollution of water supply sources in 9 regions of Ukraine, only 25% of uncontaminated wells were found (Nitrate Pollution of Drinking Water Sources in Ukraine: Research by All-Ukrainian Environmental NGO "MAMA-86", 2009). Environmental pollution of rivers is shown in Figure 25.

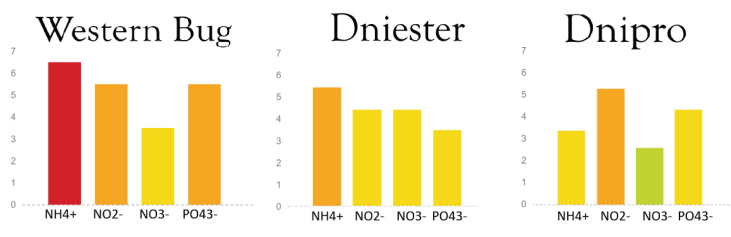


Figure 25. Environmental status of the main river basins of Ukraine by pollutant content. *Source:* Nitrogen Pollution of Water and Agriculture: Problems and Solutions. Ecoaction, 2024

One of the tools to solve the problem of such pollution is the implementation of the EU Nitrate Directive (Directive 91/676/EEC of December 21, 1991 on the protection of waters against pollution caused by NO_3 from agricultural sources). Its implementation, as demonstrated by the experience of EU countries, allows to reduce water pollution caused by NO_3 and other nutrients from agricultural sources, as well as also prevents such pollution in the future.

It provides for the development of a methodology for identifying areas vulnerable to NO_3 pollution and a Code of Best Agricultural Practices that would balance economic needs with the need to ensure good water and aquatic ecosystems.

Vulnerable zones are areas where the safe level NO_3 is already exceeded (over 50 ml/l), there are indications of eutrophication, or there are preconditions for it. Additional monitoring missions are carried out in such areas and Action Plans are applied to reduce risks and occurrences of pollution.

Codes of best agricultural practices include measures that establish rules for the storage of fertilizers, time and space restrictions on their use in crop rotations, etc. Compliance with a set of these measures can prevent or significantly reduce the risks of NO_3 (or biogenic pollution in general) (Moldavan, L., Pimenowa, O., Wasilewski, M., & Wasilewska, N., 2024). According to the European Commission, the implementation of the Nitrate Directive and good farming practices had a positive impact on the environmental situation in most EU member states. As a result, the concentration of pollutants began to decline in 70% of surface water bodies and 66% of groundwater. Simultaneously, in several countries, NO_3 accumulation surpasses permissible limits, as illustrated in Figure 26.

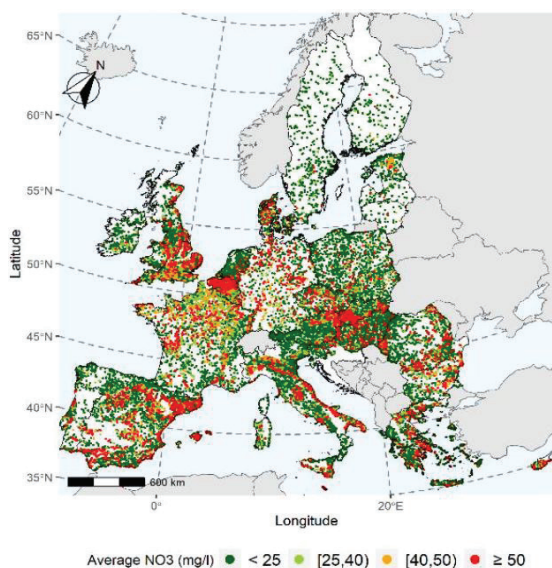


Figure 26. Annual average NO₃ concentrations in groundwater for the reporting period in EU countries. *Source:* European Commission, 2021

The implementation of the Nitrate Directive in Ukraine has already been delayed twice: in 2017 and 2018. There is still no approved methodology for determining vulnerable zones. In this context, the government should revise the timelines for implementing the Nitrate Directive in alignment with the Action Plan for the Implementation of the EU-Ukraine Association Agreement. Responsibility for this process should be assigned to the Ministry of Agrarian Policy and Food and the Ministry of Environmental Protection and Natural Resources of Ukraine, with clear designation of responsible departments and the retention of qualified personnel to ensure continuity of this work.

The ministries should develop a Methodology for identifying areas vulnerable to NO₃ pollution and a Code of Good Agricultural Practice with further legislative regulation.

In the context of restricting pesticide use, the biological method of plant protection against pests, as an alternative to chemical treatments, is gaining strategic importance. The use of biological means increases the level of environmental safety, contributes to a radical improvement of the phytosanitary situation in agrobiocenoses, prevents contamination of agricultural products, which improves their quality and has a positive impact on human health.

According to scientists, in the coming years, it is necessary to increase the level of biologization of crop protection against pests, diseases and weeds to 23-25% of the total rational amount of protective measures, covering 35 million hectares annually (Petik, P., Stankevych, S., Zabrodina, I., Zhulinska, O., Mezentsseva, I., Haliasnyi, I., Hontar, T., Shubina, L., Kotliar, O., & Bondarenko, S., 2023). It is advisable to avoid giving subsidies from the state budget to farms that are environmentally damaged by

pesticides and NO_3 . Instead, support should be focused on helping farms adopt best practices of non-chemical plant protection and optimize the use of mineral fertilizers. Additional attention should be paid to technical equipment that will facilitate the greening of production.

Agriculture is a source of greenhouse gas emissions, which affects climate change (Pimenow, S., Pimenowa, O., Prus, P., 2024). The agricultural sector of Ukraine is dominated by the traditional system of soil cultivation, which is carried out with shelf-type tools (Medvediev, V., 2016). This type of plowing releases ten times more soil CO_2 into the air compared to surface tillage (Figure 27).

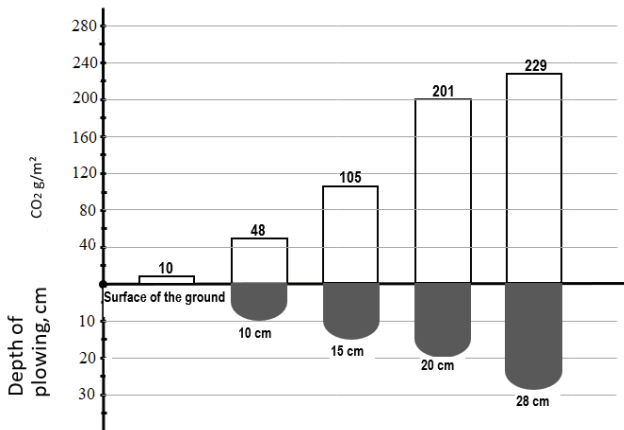


Figure 27. Total CO_2 emissions depending on the plowing depth in 24 hours. Source: compiled by the author

At the same time, agriculture is a source of N_2O emissions - 58%, and CH_4 - 47% of total emissions (Udova, L.O.; Prokopenko, K.O.; Didkovska, L.I., 2014). According to FAO experts, by 2030, N_2O emissions will increase by 35-60% and CH_4 emissions by 60% (Food and Agriculture Organization of the United Nations, 2024).

The main sources of nitrous oxide and methane emissions are livestock and rice farming. In Ukraine, livestock farming is concentrated in small farms with land use of 1-10 hectares - they keep 75% of livestock. There is no control over compliance with organic waste disposal rules on these farms, which is a factor in polluting not only the air but also water resources.

Current pollution studies in regions with high concentrations of industrial activity and ongoing military operations are somewhat fragmented. A complete picture of the level of pollution of natural resources will be provided by research into the post-military period, which will allow to more fully determine the ways of their restoration.

The directions of further scientific research should focus on developing methodological foundations for creating an analytical base to support management decisions in the field of protection against major sources of environmental pollution and human

health. Priority areas include the southeastern regions affected by military operations and the Polissya regions contaminated with radionuclides.

Based on a systematic synthesis of published research on the pollution of land and other resources in agricultural sector, the authors have identified the most threatening types of pollution. The study also takes into account their own observations of these processes. The identified types of pollution are particularly relevant in the current conditions of Ukraine. Understanding the negative impact of pollution on soil fertility, water resources, and product quality, and thus on the health of consumers, is extremely important. This requires adjusting the mechanisms of state control over economic activity. It is necessary to focus on both the restoration of contaminated resources and the prevention of further development of these processes.

As for the first, it concerns the conservation of land contaminated with heavy metals and radionuclides. The land areas subject to conservation in accordance with the laws and regulations are not being withdrawn. The main reason for this is the lack of mechanisms to compensate landowners and tenants for losses due to a temporary reduction in sown areas. In foreign practice, for example, in the United States, such land is transferred for conservation to a state institution with the payment of rent (Johnson, K. A., Dalzell, B. J., Donahue, M., Gourevitch, J., Johnson, D. L., Karlovits, G. S., Keeler, B., & Smith, J. T., 2016). The same problem will arise in the postwar period, when the issue of temporary withdrawal of land affected by hostilities from cultivation will arise. Finding a consensus between the need to preserve the productivity of agricultural land through temporary conservation and supporting the economy of agricultural producers is an urgent task. This issue remains the subject of active discussions.

The transition from chemically intensified to agroecologically oriented agricultural production presents a significant and contentious challenge, particularly in identifying effective mechanisms to influence crop producers. Research suggests that the long-term competitiveness of agricultural enterprises depends on their ability to address the environmental and social impacts of their operations (Pimenova, O., Pimenov, S., & Fyliuk, H., 2020; Mady, K., Battour, M., Aboelmaged, M., & Abdelkareem, R. S., 2023; Yu, Y., Gu, B., Yang, L., Hu, Y., & Reis, S., 2021; Sharma, P., Sharma, P., & Thakur, N., 2024). This issue is especially acute for large agro-trading and industrial companies, which dominate the Ukrainian agricultural sector but frequently resist adopting agroecological principles. This resistance underscores the need for strategic state interventions.

One effective approach is state regulation of agricultural land distribution among business entities, which includes limiting access to land for non-agricultural companies and promoting environmentally sustainable land use (Moldavan, L., & Pimenova, O., 2021). Such measures not only play a critical role in preventing the establishment of an oligarchic-latifundist governance system in Ukraine's agricultural sector but also contribute to reducing pollution. By promoting responsible land management, these actions help mitigate the environmental impact of agricultural activities, enhancing soil fertility, protecting water resources, and improving overall sustainability.

Moreover, the findings and proposed solutions have broader applicability, offering valuable insights for other countries facing similar challenges of land degradation due to armed conflicts. The approaches to land conservation, ecosystem restoration, and

agroecological transformation outlined in this study can serve as a model for addressing post-conflict recovery of agricultural systems worldwide, contributing to global efforts in achieving environmental and food security.

This study assessed the most critical pollutants of natural resources in agriculture. It also analyzed their impact on land productivity, water resources, the environment and human health.

The results show a high level of heavy metal contamination of arable land. This phenomenon is especially typical for the southeastern regions of Ukraine, where metallurgical, chemical and mining enterprises are concentrated. Currently, these regions are covered by military operations, which increase their pollution. The radionuclide contamination of the Polissia zone and localized sites in other regions of the country is alarming. This contamination, caused by the explosion at the Chornobyl nuclear power plant, remains the main source of radiation hazard for the population through the ingestion of radionuclides in food. Pesticides and NO_3 are added to these sources of soil pollution. Their spread is due to the dominance of intensive chemical-oriented agriculture in the agricultural sector of Ukraine. They also act as polluters of water resources. In addition, discharges of highly mineralized mine water and polluted industrial wastewater result in massive flows of saline water into rivers, which exacerbates their negative environmental condition. Air pollutants include smoldering mining dumps, combustion products from ammunition and chemical plants damaged by explosions, and fuel as well as lubricant storage facilities in war zones. Additional sources of contamination are annual local and large-scale forest fires in areas contaminated with radionuclides.

The study confirmed that pollution of natural resources in the agricultural sector is a multifaceted problem. Its solution requires a comprehensive approach that includes policy interventions to strengthen environmental standards of management. It is also necessary to introduce technological innovations aimed at achieving a balance between economic development, environmental protection and human health.

2.4. AGROECOLOGY IN THE CONTEXT OF SUSTAINABLE AGRICULTURAL DEVELOPMENT GOALS.

The main factor in overcoming civilizational crises in human history has always been the emergence of new technologies for using components of the natural environment to meet vital needs. It is believed that there is a regularity according to which, in the face of a global crisis, humanity inevitably generates new knowledge. Based on this knowledge, new paradigms and technologies emerge as the basis for the further development of civilization.

It is now increasingly recognized that a paradigm shift is needed to prevent further development of negative socio-ecological consequences of resource-destroying economic activity that threaten the lives of future generations. This is especially true for industrial-chemical, highly specialized (monocultural) agriculture. The transition to *agroecological agricultural production*, which takes into account the requirements of the natural laws of agriculture, is seen as an important step in this direction.

Agroecology is a branch of science that studies “the application of environmental science to the study, configuration and management of sustainable agroecosystems” (Altieri, M. A., 1995). It is achieved by imitating natural processes, ensuring “beneficial biological interactions and synergies between agroecosystem components” (Gliessman, S., 2007). It provides favorable soil conditions for growing cultivated plants through the rational use of organic matter and increased biotic activity of soils.

Basic principles of agroecology:

- recycling of biogenic substances and energy within the farm instead of using external production resources;
- integration of crop and livestock production;
- diversification of biological species and genetic resources in agroecosystems over time and space;
- focusing on interconnections and productivity within the entire agricultural system instead of focusing on individual species.

Agroecology is recognized as a *tool for increasing the sustainability of food systems* by a wide range of scientists and international organizations, including the Food and Agriculture Organization of the United Nations (FAO), UNEP (Altieri, M. A. & Nicholis, C. I., 2005), and the International Organization for Biodiversity.

Agroecology is based on both science and practice. It incorporates agroecology and ecological agriculture. Agroecology is linked to the ecosystem approach to intensifying sustainable crop production, supported by the FAO Committee on Agriculture (COAG) (COAG, 2010).

Agroecology is one of the most affordable, low-cost and environmentally relevant ways to optimize land use. It includes a whole range of measures that contribute to the formation of sustainable agroecosystems, in particular:

- optimization of the structure of sown areas;
- introduction of crop rotations with their saturation with highly productive crops that improve the environment;
- increasing the biological potential of nitrogen-fixing microflora;
- rational use of organic fertilizers and reduction of mineral fertilizers;

- liming and phosphating acidic soils;
- involvement of plant residues and green manure in the economic and biological cycle of organic matter and nutrients;
- application of energy-saving methods of soil cultivation, spread of zero tillage;
- terracing, mulching and contour cultivation of sloping fields;
- implementation of forest belt plantations and creation of stone fences around the perimeter of agricultural fields;
- use of physical and biological methods of combating weeds, pests and diseases of crops;
- combining livestock and aquaculture with agriculture in farming systems;
- interaction between agroecology and crop breeding to adapt the latter to changing climate conditions.

Table 23 shows the main differences between industrialized and agroecological agriculture.

Table 23

Characteristic features of industrial-intensive and agroecological agriculture

Features	Industrial agriculture	Agroecological agriculture
Investment of anthropogenic energy	Very high	Optimal
General biological diversity	Low	High
A variety of cultivated plants	Low	High
Diversity of animals	Low or absent	Moderate
Crop rotation	Low	Crop rotation, polyculture
Share of arable land in the agricultural system	High	Optimal. Forest and agricultural ecosystems
Disease and pest control measures	Usually chemical	Mostly biological in combination with mechanical
The main direction of plant selection	Increase of product potential	Increasing the adaptive capacity

Source: Developed by the authors based on the results of research of scientific and informational sources

Agroecological systems of agricultural production are currently biodynamic farming, technologies for the use of effective microorganisms (EM technologies); biointensive farming, organic farming. Each system has its own characteristics and can be used in accordance with specific soil and climatic conditions, often complementing each other. At the same time, they have a lot in common.

Biodynamic farming emerged as a backlash to soil degradation - its dehumidification, over-compaction, contamination of agricultural products with all kinds of harmful substances, deterioration of drinking water quality and human health.

The biodynamic farming system involves the reproduction of natural forces in the agroecosystem, restoration of soil self-regulation and its ability to neutralize toxic substances, pathogens and pests. By restoring soil fertility and healthy ecological conditions, it is expected to produce environmentally sustainable, disease-free plants and animals. This will help to produce environmentally safe food and restore human health. The biodynamic method is based on restoring soil fertility at an accelerated pace. This

is achieved through the implementation of one of the main postulates - the need to fertilize not the plants themselves, but the soil itself, for which specially prepared manure composts are used. During the production of composts, as well as for feeding plants, homeopathic preparations are used.

The goal of biodynamic farming is to create and maintain the most closed biological cycle of substances and energy on the farm. It is also aimed at harmonious relations in the soil-plant-animal-human system. Only organic and animal fertilizers are used.

Organic farms also organize their own special seed production system adapted to local conditions. Seeds from farms engaged in conventional agriculture may not be used in bio-agriculture.

To maintain normal soil functioning conditions, optimal conditions for its microflora are created.

The experience of Western European countries shows that when biodynamic farming is used, even for 7-8 years:

- the carbon content of soil organic matter increases;
- the soil is enriched with nitrogen and soluble calcium, which helps to restore the natural soil structure;
- all indicators characterizing the living matter of the soil increase (the total biomass of microorganisms, catalase activity and the number of earthworms increase);
- the index of actinomycetes and streptomycetes, which determine the soil's ability to form humus, increases.

EM technologies are based on the use of effective microorganisms. Having originated in Japan, they have found support in 160 countries. The technology is based on the refusal to use chemicals in agriculture and ensuring a balance between pathogenic and beneficial microorganisms. This has a positive effect on restoring soil fertility and self-regulation in wildlife, strengthens the self-defense of plants and animals and improves food quality and human health.

EM preparations contain a stable association of aerobic and anaerobic microorganisms. They include photosynthetic, nitrogen-fixing, lactic acid bacteria, yeasts, actinomycetes, fermenting fungi and their products. The microorganisms introduced into the soil activate the microflora and produce various physiological substances that improve the health of the soil. This has a positive effect on the growth and development of plants and, entering the body of animals with feed, contribute to their resistance to diseases and the production of healthy livestock products.

Organic and biological farming involves avoiding the use of mineral fertilizers, pesticides and other drugs. Crop rotation is the basis and soil fertility is maintained through organic fertilizers. Mechanical and thermal means are used to destroy weeds.

Organo-biological management of the crop production industry focuses, on the one hand, on the desire to create "living and healthy soil" by maintaining and activating its microflora. On the other hand, it aims to produce products free of harmful impurities. Only organic fertilizers are used (manure, green manure, compost, straw, etc.).

The practical application of this trend is most widespread in Germany, Sweden, and Denmark. Its goal is to grow environmentally friendly crop products. In this case, it is allowed to use special biological products. These preparations should give their plants the necessary strength and activate certain processes in the soil.

Biological (ecological) farming, which is practiced in France, Poland and other countries, requires a strict restriction on the use of pesticides and a flexible approach to the issue of mineral fertilizers. Only organic and non-toxic preparations, such as essential oils, powders, algae infusions, etc., are allowed. These preparations are applied taking into account the mechanical composition of the soil and other conditions.

Organic agriculture can be called the highest level of technology that implements the ecological, socio-economic functions of the industry in a complex. The International Federation for the Advancement of Organic Agriculture (IFOAM) defines organic agriculture as a production system that supports the health of soils, ecosystems and people. It depends on economic processes, biological diversity and natural cycles specific to local conditions, while the use of harmful resources that cause adverse effects is unacceptable. Organic agriculture combines tradition, innovation and science. Its goal is to improve the environment and promote the development of fair relationships and a good standard of living for all involved.

In essence, organic agriculture combines agricultural systems that support environmentally, socially and economically sustainable agricultural production. It ensures the harmonization of agricultural practices and the environment. Its idea is to completely abandon the use of mineral fertilizers, pesticides, antibiotics and, what distinguishes it from other systems, genetically modified organisms.

The FAO/WHO Codex Alimentarius Commission defines organic agriculture as a holistic production management system that promotes ecosystem health, including intensifying biological processes and increasing the biological activity of soils.

Measures that ensure organic production include:

- introduction of soil-protective technologies of basic tillage without rotation of the slice with mulching of the soil surface with post-harvest residues and cover crops and with the use of direct sowing;
- use of materials of plant (straw, chopped stalks of corn, sunflower, sorghum, buckwheat, cover crops), animal (manure) and microbiological (bacterial preparations) origin, which are biodegradable when applied (the use of synthetic fertilizers is allowed only as a supplement to biogenic fertilizers, for example, the application of nitrogen fertilizers on crop residues and green manure, which are converted into organic nitrogen during composting) instead of mineral fertilizers;
- refusal to use genetically modified seeds, planting material and other products of genetic engineering;
- implementation of crop rotation taking into account:
 - a) the peculiarities of different crops in terms of nutrient requirements and their ability to absorb them, which is determined by different root systems;
 - b) the different impact of crops on the physical properties of the soil and the level of its resistance to wind and water erosion, which depends, firstly, on the different mass of organic matter that remains on the field from the harvest and can be used for organic fertilizer and secondly, on different methods of care for row crops and perennial crops, the alternation of which reduces soil degradation;
 - c) the biological characteristics of each crop, which determine the level of weed infestation of fields, the accumulation of pests and diseases in the soil, as

well as the products of vital activity of cultures and microorganisms developing in the rhizosphere;

- use of plant- and animal-based preparations, as well as thermal and physical methods to combat weeds, pests and diseases of agricultural crops; biological control of pests and diseases by increasing the population of beneficial insects, microorganisms and natural parasites; use of post-harvest green manure from cruciferous plants that have an allelopathic effect on weeds to protect crops from weeds;
- implementation of chemical land reclamation and cultural and technical works;
- optimization of water protection forestry;
- formation of a unified system of shelterbelts as a way to improve the productive properties of agricultural land, maintain agricultural landscapes and preserve the ecological balance of the territory.

Adherence to these and other measures, depending on the specific soil and climatic conditions, makes it possible to maintain a sufficiently high yield with a significant reduction in costs. Not only foreign but also domestic practice has proven that soil-protection technologies in organic agriculture take 2-3 times less time and fuel compared to conventional tillage and plant care technologies. In addition, fertilizer costs are reduced by 7-10 times.

Organic farming is designed to maintain and improve the health of the soil, plants, animals, humans and the planet as a whole. This ensures the well-being of current and future generations. Organic agriculture is the most widespread of the above systems in the world. In Australia and Oceania it accounts for 39% of land, in Europe - 21%, Latin America - 20%, Asia - 13% and North America - 4%. Among European countries Italy has the largest area of organic farming (890 hectares), Argentina (2.8 million hectares) among Latin American countries and China (3.4 million hectares) among Asian countries. Australia is the world's leader, with more than 12 million hectares under organic farming.

The development of organic farming in Ukraine dates back to the 2000s. According to IFOAM, in 2002, 31 farms were registered and granted the status of "organic". In 2021, the number of organic operators increased to 528 farms and the total area of agricultural production reached 422.3 thousand hectares.

"Organic" farms have been identified in almost all regions of all zones, with the largest number of them in Kyiv, Odesa, Kherson, Poltava, Vinnytsia, Zakarpattia, Lviv and Zhytomyr regions (Figure 28).

(as of 31.12.2021)



As a result of the implementation of the organic farming system at Agroecology, the yield of all crops and livestock productivity have significantly increased and the financial condition of the farm has improved. The introduction of organic production has significantly increased the average annual yield of grain, sunflower, sugar beet and vegetable crops, which has significantly reduced production costs and positively affected the profitability of production (Pysarenko, V. M. & Antonets, A. S., eds., 2015). This was facilitated by the fact that over the years of using the organic production system, the humus content in the farm's fields has increased. According to the agrochemical survey, this indicator, which is the main indicator of soil fertility and the effectiveness of new technologies, increased by 0.53-1.57%. An important element of the organic farming system is the use of perennial grasses in the crop rotation, which increase soil fertility and improve its structure. They also preserve moisture reserves, counteract erosion, prevent weed infestation, improve field health, are good precursors for grain

crops, valuable fodder crops, and save money (Pysarenko, V. M. & Antonets, A. S., eds., 2015).

Agroecology specializes in the “clean” cultivation of cereals and legumes, including corn for grain, sunflower and fodder crops. In livestock farming, it focuses on dairy cattle breeding, beef production and breeding of young cattle.

Agroecology Farm is certified to produce buckwheat, sunflower, rye, barley, winter wheat, oats, alfalfa and sainfoin. It is also certified for the production of buckwheat, semolina, wheat, pearl barley and meat as well as dairy products. According to the WII-0033-03 certificate, the company's products comply with the requirements of EU Council Regulation W834/2007 and EU Council Regulation W889/2008X (Council Regulation (EC) No 834/2007, 2007).

The new farming system has significantly improved performance in livestock farming: milk yield per cow has increased by 2.5 times and the average daily weight gain of young cattle has increased by 1.5 times. This was greatly facilitated by the strengthening of the feed base of their own production. Abandoning traditional arable farming and switching to a plowless tillage system at Agroecology PE has led to a more than fourfold reduction in fuel consumption. The use of pesticides has also decreased by 5-8 times (only grain seeds are treated), as documented in the farm's annual reports. Gross output per hectare and per employee has increased significantly. The farm employs up to 400 people, thanks to the growing productivity of its crop rotation system in symbiosis with livestock farming.

In the Poltava region, the agricultural firm "Ukraina" has also been successfully engaged in organic production for many years. It annually harvests at least 5 Mt per hectare of grain, even in extreme conditions. All products are environmentally friendly, as evidenced by the relevant state certificates.

As Ukraine increases production of organic products, its consumer market is expanding. In the domestic market, organic products are sold both as raw materials and in processed form. In 2004-2022, the volume of the consumer market for organic products increased from 0.1 to 29.0 million euros. In some years, this figure reached €33.0-38.0 million (Table 24)

Table 24

The volume of the consumer market of organic products in Ukraine, 2004-2022.

Year	EUR million	Year	EUR million
2004	0,1	2014	14,5
2005	0,2	2015	17,5
2006	0,4	2016	21,2
2007	0,5	2017	29,4
2008	0,6	2018	33,0
2009	1,2	2019	36,0
2010	2,4	2020	38,0
2011	5,1	2021	39,0
2012	7,9	2022	29,0
2013	12,2		

Source: Federation of Organic Movement of Ukraine. Organic in Ukraine (2024).

The Sustainable Development Goals of Ukraine for the period up to 2030 (Ministry of Economy of Ukraine, 2017) and the National Economic Strategy for the period up to 2030 (Strategy for Sustainable Development of Ukraine until 2030) envisage an increase in the production of agro-organic products by expanding the “organic” area to 3 million hectares, i.e. up to 3% (currently it is 1%).

EU countries plan to move to organic farming on 25% of agricultural land by 2030. The European Green Deal states that organic agriculture, based on agroecology, provides healthy food and protects agroecosystems from degradation. It also creates 10-20% more jobs per hectare than industrial chemical-based systems (European Commission EU, 2019).

The role of agroecology in solving the problem of preserving the natural resource potential of the agricultural sector and ensuring people’s food security in the long term is significant. It can be systematized as follows.

First, agroecology allows us to *preserve and increase the productive capacity of agricultural land* in the long term. Without a transition to agroecological farming, it is impossible to stop the devastating degradation of land. Today, it covers 33% of the world's agricultural land. Along with land degradation, water bodies and aquatic ecosystems are being degraded: inflows are decreasing, and swamps are drying up. This leads to the depletion of groundwater reserves and a decrease in the level of aquifers, which is classified as a growing risk for global food production. Ignoring agroecological measures will inevitably lead to further loss of soil productivity. This, as the FAO warns, “could seriously undermine food production and food security, increase food price volatility and possibly push millions of people into hunger and poverty” (Soils are under threat, but degradation can be stopped, 2024).

Secondly, agroecology helps to *improve nutrition*. The main principle of the Green Revolution is the narrow specialization of enterprises in the production of grain crops - wheat, corn and rice. However, these food products are mainly a source of carbohydrates. They contain very few other nutrients that are very important for the human body. Humankind needs diverse agroecosystems to provide a more diversified supply of nutrients to meet the needs of the human body (Alloway, B. J., 2008; DeClerck, F. A. J., 2011). In this context, farms that operate on agroecological principles provide a variety of food products of much better quality. This is due to the limited use of mineral synthetic fertilizers and the use of biological methods of pest and disease control.

Third, agroecology contributes to *climate change adaptation*. The use of agroecological methods can significantly increase the resilience of agricultural systems. It also significantly mitigates the negative effects of extreme weather conditions, which are increasingly occurring in different regions of the world. Practice confirms that the physical properties of the soil in agroecological farms significantly improve the resistance of crops to droughts (Eyhorn, F., 2007; Edwards, S., 2007).

Climate change contributes to the emergence of new agricultural weeds, pests and diseases. Agroecological farms are better able to counteract them through the use of genetically diverse varieties of cultivated plants.

Fourth, agroecology contributes to *climate change mitigation* by increasing carbon sequestration in soil organic matter and aboveground biomass. On the other hand, it reduces emissions of carbon dioxide and other greenhouse gases by reducing direct and

indirect energy use. The Intergovernmental Panel on Climate Change (IPCC) has estimated the global technical mitigation potential of agriculture by 2030 at 5.5-6 billion tons of CO² equivalent per year. Most of this potential (up to 89%) can be achieved through agroecological measures (Hoffmann, U., 2010; FAO, 2009).

Fifth, agroecology *reduces poverty in rural areas*. Increasing fertilizer production on organic farms through agroecological measures reduces their dependence on external inputs. The introduction of nutrients into the soil through the use of organic livestock waste and green manure cultivation reduces the need for mineral fertilizers. This has a positive impact on farmers' incomes. The savings can be used for new investments to increase production and improve the welfare of farm families.

Agroecological methods can contribute to both a more productive workload for farmers and the *creation of new jobs* for the rural population. Field reforestation, integration of livestock and aquaculture, production of organic fertilizers and other activities require additional labor. This stimulates the settlement of a part of the rural population and has a positive impact on the preservation of rural settlement, as the scope of labor in rural areas is limited. This is in line with the Sustainable Development Goals (Figure 29).

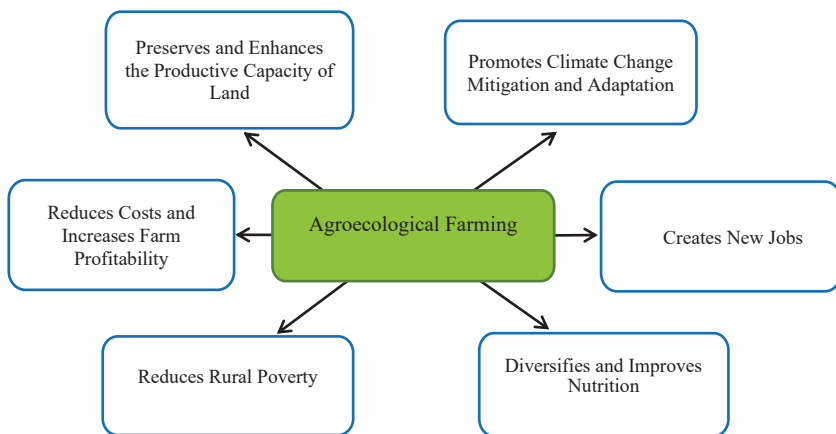


Figure 29. Agroecological farming in the context of the Sustainable Development Goals. *Source:* Compiled by the authors on the basis of generalization of international practice

The transition of the agricultural sector to agroecologically sound sustainable development technologies is, in fact, the beginning of the transition to the second era (wave) of the Green Revolution. This new wave will be based on development factors aimed at eliminating the destructive consequences of the first wave's agricultural production.

The UN Report on the Human Right to Food contains recommendations for governments to implement supportive policies. It is aimed to implement agroecological methods of food production (UN, 2010). It is considered necessary:

- provide references to agroecology and sustainable agricultural development in national strategies for the realization of the right to food;

- include agro-environmental measures to be implemented in the agricultural sector in national climate change action plans adopted by countries as part of climate change mitigation efforts;
- to reorient state support measures to increase production to the formation of organized local markets, development of the material and technical base of marketing and processing cooperatives established by small farms, support for their access to land resources, loans, prioritize public procurement of products produced in agroecological farms, create favorable trade and macroeconomic conditions for them;
- provide support for the dissemination of knowledge among the rural population on agroecological principles of economic activity;
- increase budgetary allocations for scientific research, development of sustainable agroecological systems and systemic measures to increase the profitability of small farms and provide training of scientific personnel in the field of development of agroecological methods of farming.

It should be noted that these recommendations are being introduced in various forms into the agricultural policies of many countries. The EU countries have gained positive experience in this area.

Unlike in European countries, the forms and methods of Ukrainian state control over the protection and restoration of soil fertility, environmental protection, biodiversity and agricultural landscapes are still in their infancy. The system of liability for damage caused to the natural resources of agricultural land is also in its infancy. In this context, Ukraine needs to implement the UN recommendations and EU practices on the legislative and regulatory institutionalization of agro-environmental measures. It is also necessary to ensure responsibility for their observance and incentives for their implementation.

The factors that prevent the process and require targeted work to eliminate them include:

- the need to increase the level of environmental awareness of agricultural producers, their insufficient level of awareness and professionalism regarding the transition to alternative farming systems and overcoming the dominance of stereotypes regarding methods of soil cultivation and crops care;
- supporting the capacity of agricultural producers to promote the benefits of organic production on their own, as well as to organize certification of products for compliance with national standards and international requirements;
- promoting the attraction of primary capital for the replacement of traditional industrial systems with alternative ones, which involves the replacement of a significant part of machinery, equipment, plant varieties and species and livestock breeds;
- eliminating pressure on agricultural producers from transcontinental agro-technical and agro-chemical as well as agro-pharmaceutical corporations that dominate world markets and essentially determine agricultural systems in their own interests;
- bringing the agricultural policy strategy, legislative framework and state support programs for agriculture into compliance with the requirements of the concept of sustainable development of the industry.

The EU-Ukraine Association Agreement obliges Ukraine to work in this direction. In Title V, Chapter 17 “Agriculture and Rural Development”, Article 404 of this chap-

ter refers to “...encouraging modern and sustainable development of agricultural production and rural areas, taking into account the need to protect the environment..., promoting the use of organic farming... by introducing best practices in these areas”.

Chapter VI “Environment”, Article 360 states: “The Parties shall promote the realization of the long-term goals of sustainable development and a green economy. This includes the conservation of natural resources, increased economic and environmental activity and the integration of environmental policy into other areas of public policy”.

The above-mentioned report and other UN materials, as well as scientific works by scientists from different countries, connect the transition from industrialized to agroecological agricultural production with support for small and medium-sized farms. Such farms are the most appropriate for the development of rural areas, the need to preserve land productivity and diversify food production (FAO of UN, 2015).

Such support is especially important during the period of transition to agroecological farming, when certain losses are possible. For Ukrainian small and medium-sized farming, taking into account its real state and the above UN recommendations and the practice of EU member states, it is important to:

- create favorable conditions for access of private peasant households with land use of more than 2 hectares, which identifies them as small farms, to expand their land plots and organize agroecological production by creating a system of preferential credit services adequate to Western European, North American and other countries;
- institutionalize the formation of a national network of local farmers' markets with appropriate infrastructure for the sale of agroecological products;
- introduce a program to support the formation of the material and technical base of marketing cooperatives established by small farms, taking into account the legislation of EU countries on support for producer groups and their associations;
- regulate the priority of public procurement of products produced by small agroecological farms;
- promote the creation of processing cooperatives to ensure that small farms can benefit from economies of scale in terms of value added;
- regulate the state's participation in insuring small agroecological farms against risks associated with adverse weather conditions;
- ensure the organization of training for farmers on agroecological farming.

The transition to agroecological technologies is a complex and long-term process. It requires the consolidation of significant efforts of scientists, legislative and executive bodies as well direct agricultural producers. However, if this work is not done, there may be threats to Ukraine's food security and food independence.

Achieving parity, a balance between the interests of economic entities and nature, or, in other words, achieving an equilibrium state of the system of components of natural resource potential, is the purpose of agroecology.

Agroecological technologies fit into the concept of a “green economy” as technologies designed not to combat the consequences of environmental conflicts, but to prevent their causes. At the same time, they fundamentally change the approach to economic activity, the product obtained as a result of this activity and the consumer behavior of people.

2.5. CROP ROTATION AS A STRATEGY FOR SUSTAINABLE LAND USE.

In agricultural production, crop rotations are considered to be the main cost-free agronomic measure. It affects plant life and all the processes that take place in the soil. Crop rotation is a scientifically based rotation of crops that promotes the accumulation and more efficient use of soil nutrients and fertilizers. It improves and maintains favorable physical properties of the soil, as well as protects it from water and wind erosion. Crop rotation also prevents the spread of weeds, diseases and crop pests.

The need for crop rotation has long been established by farming practices. In agricultural production, crop rotation is one of the most important agronomic measures. The first attempts to scientifically substantiate this approach are associated with the theory of the Swiss botanist Decandol, according to which plants take both necessary and unnecessary substances from the soil. The last ones, being released back into the soil, accumulate in it and delay the development of further crops of this plant. This theory was experimentally tested by Maker. He believed that plants release toxic substances through their roots that are harmful to subsequent crops of the same plants. However, these substances do not harm other plants, but, on the contrary, can serve as food for them.

With the development of the theory of crop rotation, the need for crop rotation began to be justified in terms of the theory of soil nutrition. A characteristic feature of these justifications was the division of plants into different groups according to their impact on soil fertility. Liebig, based on the theory of mineral nutrition, believed that all field crops deplete the soil. He divided crops into three groups depending on which nutrient was predominantly consumed by a particular crop. It could be phosphorus, potassium, or calcium. According to this theory, it is necessary to alternate crops with different needs for ash nutrients. The decrease in yields with unchanged sowing of the same crop was explained by the decrease in one or another nutrient element in the soil. The depletion of certain nutrients had a negative impact on crop productivity.

At the same time, another direction of the theory of alternating cultures began to develop, which was reflected in the works of P.A. Kostichev and W.R. Williams. Followers of this trend believed that the decline in soil fertility during the annual cultivation of grain crops in one field was not due to a change in its chemical composition. They explained this by the deterioration of the soil's physical properties. In particular, it was the loss of a strong soil structure, which negatively affected its fertility. As a result, the water and nutrient regimes of the soil deteriorated, and its fertility decreased. According to this theory, it was concluded that it was necessary to periodically change the culture of annual plants. For this purpose, it was proposed to sow a mixture of perennial legumes and cereal grasses.

Later theories of crop rotation began to take into account the diversity of reasons for the need to rotate crops. D.N. Pryanishnikov grouped these reasons into four groups.

The first group includes chemical causes related to the different nutrient requirements of plants. Some plants require more nutrients, while others require much less. Unchanged crops with high demands on plant nutrition lead to rapid nutrient depletion of the soil.

The need for nutrients depends on the type of plant, its stem, yield and growing conditions. Cereal crops extract approximately the same amount of potassium and nitrogen from the soil to create a crop, and only half of that amount of phosphorus. In the case of sugar beet, the needs are significantly different. It needs 1.7 times more potassium than nitrogen and 4.3 times more phosphorus.

Crops differ considerably in terms of plant residues, both aboveground and soil. These residues are the main material for the formation of organic matter - humus. Perennial grasses leave the most organic residues in the soil. When growing grain crops, some of the substances they take from the soil are returned with the stubble.

Different plants have different properties for utilizing ash substances. Some plants can absorb nutrients from hard-to-reach compounds, while others require readily available forms. Lupine and buckwheat are able to obtain phosphorus from poorly available compounds for their development. At the same time, they leave more readily available phosphorus compounds in the soil for subsequent crops. The alternation of plants with different root systems helps to rationally use the soil layers where it is located. Thus, beans enrich the soil with nitrogen, and buckwheat and hemp increase the amount of phosphorus compounds that are easily absorbed by the next crop. The rotation of these crops helps to use the soil rationally.

The second group of reasons is related to the different impact of crops on the state of the soil cover. Growing these crops also affects the soil's resistance to erosion.

The impact of crops on soil structure and its composition varies. That is why crop rotation plays an important role in the rational use of land. In particular, plants have different requirements for soil moisture. Proper crop rotation helps to preserve and economically use soil moisture. This is especially important in the context of climate change.

Plants also differ in their root systems. To make better use of precipitation moisture, it is important to take into account the degree and depth of soil drying by the previous crop. After plants with deep roots, it is advisable to place shallow-rooted crops. An alternative is to use clean steam, which helps to restore soil moisture.

The composition and rotation of crops, as well as their placement in the fields, are important for protecting the soil from water and wind erosion. Among crops, there are crops with high, medium, weak, and very low soil-protective effect. The basis for this classification is, in particular, the density of the stem and the period of soil coverage by plants. It is especially important to take into account the above on areas with different terrain. On sloping areas, crops with a high soil-protective effect must be present in the crop rotation. These crops primarily include perennial legumes. They effectively prevent soil erosion. Various types of sorghum, horse beans, lupine, soybeans, linseeds, mustard, rapeseeds and peas cover the soil surface well. They are also characterized by high soil protection qualities.

The third group is formed by biological reasons related to the different attitudes of cultivated plants to other plant and animal organisms. Different crops and their cultivation methods create different conditions for weeds to develop. Winter and overwintering weeds are adapted to winter cereals and, if cultivated without interruption, contaminate these crops. Spring weeds are suppressed by rapidly growing winter cereals in spring. When spring crops are sown repeatedly, they become clogged with spring

weeds. Winter weeds, on the other hand, are easily destroyed by autumn tillage and pre-sowing tillage. Thus, alternating winter and spring crops creates unfavorable conditions for both groups of weeds.

The implementation of rational crop rotations with clean pairs and row crops is also an important means of cleaning fields of weeds. Pests and pathogens pose a significant threat to the continuous cultivation of many groups of agricultural plants. Most of them affect only certain crops or groups of crops. This significantly reduces yields and makes it difficult to combat such threats.

In the absence of proper crop rotations, pests that infest the soil multiply greatly. When sugar beet is grown on permanent plantations, nematodes actively multiply. They reduce both the yield and sugar content of the roots.

Many crops are severely affected by various diseases when grown continuously or frequently returned to the same field. These diseases are caused by parasitic fungi, bacteria, and viruses. For example, winter wheat is heavily affected by rust and root rot, flax and hemp by fusarium, potatoes by late blight, etc.

In the course of their life, previous plants release substances that negatively affect subsequent crops. They can also inhibit the development of beneficial microorganisms in the soil. For example, microorganisms that develop in the rhizosphere of cultivated plants release substances that affect subsequent plants. These substances can inhibit their vital activity or interfere with the development of other microorganisms.

The unfavorable combination of these complex processes is the main cause of soil fatigue. It leads to a decrease in the yield of a certain crop and incompatibility of some plants in the crop rotation. At the same time, cultivated plants can suffer from antibiotic substances released by various soil organisms.

According to FAO estimates, soil exhaustion today covers about 1.3 billion hectares of agricultural land and remains the main cause of the loss of almost 25% of the world harvest.

The economic reasons for the need of crop rotation (*the fourth group*) are related to the possibility of optimally organizing the cultivation of different crops. This allows to focus on the demand of both domestic and foreign markets. As a result, the grown products can be sold at maximum profit. Properly selected predecessors for crops can increase their yields. For example, winter wheat sown after legumes, gives a yield of 0,5 -1,0 Mt per hectare more than that planted after sunflower or corn. The alternation of legumes with non-legumes allows for efficient use of the accumulated nitrogen to produce high yields of valuable crops. It also reduces the need for nitrogen fertilizers. As a result, the cost of production is reduced.

From an economic point of view, crop rotation fertilization is several times cheaper than mineral fertilization. For example, 150-200 kg of free nitrogen is left on 1 hectare after alfalfa, 120-150 kg after red clover, and 50-60 kg after lupine and peas. Adding this amount of nitrogen to the soil in the form of ammonium nitrate will cost from EUR 20 to 70.

The scientific literature does not single out a social group of reasons for the need to diversify plants in crop rotation. It is caused by natural human needs. However, the classics of agro-economic science have been paying attention to this. For example, T. Brinkman emphasized the importance of multi-branch crop rotation for more efficient

use of labor. He also emphasized its role in “the cheapest possible satisfaction of one's own needs with products...” (Brinkman, T., 1926). E. Lauer emphasized the importance of the traditions of the people, which are often stronger than economic calculation.

The formation of modern globalized agricultural markets contributes to the growth of monoculture production. Such production is focused mainly on growing only the most economically profitable types of crops. This necessitates the creation of a set of plants in the crop rotation focused on the needs of the domestic market and strengthening the country's food independence. At the same time, it is important to provide the population with the biogenic substances necessary for the body and to promote rational employment of rural residents as a key factor in the development of rural areas. The importance of this is stated, in particular, in the conceptual documents of the UN, FAO and other international organizations (United Nations, 2010). Taking into account the above objectively determined reasons for the need to rotate crops is a key factor. It serves as the basis for the development of scientifically based crop rotations, which are the backbone of farming systems.

However, the requirements for crop rotation are not limited to these aspects. This is especially true in the context of the chemical-industrial system of agricultural intensification, which is widespread in the world practice and is characterized by growing conflict with nature. The farming system is not isolated; it is in constant interconnection with the environment. This requires taking into account ecological laws and patterns when forming crop rotations.

According to *the law of equivalence of living conditions*, all natural environmental conditions necessary for life play an equal role in the development of living organisms.

Different plants respond differently to physical, chemical and biological indicators of soil quality. They also differ in their sensitivity to precipitation, soil moisture, and the annual sum of effective temperatures. This requires taking it into account both in the zoning of agricultural production and in the development of local crop rotations.

According to the integral resource rule, crop production sectors that compete for the use of specific natural systems have a negative impact on each other. The more they alter the shared ecological component, the more damage they cause. In some cases, this can lead to changes in the entire ecosystem.

According to the law of ambiguous action of factors, each environmental factor has a different effect on different functions of the body. The optimum for some processes can simultaneously be a pessimism for others.

According to the law of optimality, any system functions with the greatest efficiency within certain spatial and temporal limits. It is necessary to search for the best size of agricultural fields, plants, and animals in terms of productivity.

According to Gause's principle of competitive exclusion, two species cannot coexist in the same area if their ecological needs are identical. This means that they occupy the same ecological niche. Under such limited spatiotemporal distribution capabilities, one of the species creates a new ecological niche or disappears.

Long before the theory of crop rotation came into being, farmers noticed in practice that permanent crops reduced grain yields. To restore soil fertility, they left arable land fallow. In some cases, they used clean steam as a way to improve soil characteristics. Three-crop (fallow-grain-grain) or two-crop (fallow-grain) crop rotations have been

practiced for centuries. With the development of capitalism, the growth of the urban population, and other factors, the three-pillar system was replaced by crop rotations with a variety of crops.

The origin of the crop rotation system of agriculture based on the rotation of crops occurred in Belgium and Holland in the 16th and 17th centuries. Later, this system spread to England, France, and Germany. In Europe, the so-called “Norfolk” crop rotation, named after the county of Norfolk in England, was widely used. It included four fields, the presence of red clover in the crops, and forest plantations among the fields. The introduction of the Norfolk crop rotation significantly increased crop yields. It also contributed to the use of natural marl in crop rotation fields to deoxidize soils.

The main scientific principles of the crop rotation system of agriculture were developed in the mid-18th century by German scientists A. Jung and A. Thaer. A. Thaer improved the Norfolk crop rotation by justifying modified 5-field, 6-field, and 7-field variations of the system.

The transition from the grain-based three-pillar farming system to a crop rotation was a significant step in the development of agriculture. Already at the end of the nineteenth century, this approach allowed European countries to increase grain yields from 0,7-0,8 to 1,6-1,7 Mt/ha. The doubling of yields was not due to the widespread use of mineral fertilizers and pesticides. The main role was played by the inclusion of a much larger number of plant species in the crop rotation. In particular, this applies to legumes and cereals, annual and perennial grasses, which helped improve the physical, chemical and phytosanitary properties of soils. This is confirmed by many years of research at the Rotterdam Experimental Station in the UK. There, the yield of winter wheat, rye and oats increased by 1.5-2 times only due to the use of crop rotation. This growth occurred without the use of fertilizers, compared to permanent crops.

The main features of crop rotation were equal proportions of plants with the appropriate alternation of cereals with legumes and row crops. An important principle was the inadmissibility of repeated sowing of crops of the same group on the same field, even for two years in a row. It was also mandatory to rotate crops that enrich the soil and those that deplete it on an annual basis. Obligatory compliance with the crop rotation procedure ensured that crops were protected from pests and diseases. It also created favorable conditions for cleaning the soil from weeds. In addition, it contributed to the uniform use of nutrients from the soil.

The inclusion of clover, alfalfa, and annual legumes in the crop rotation helped enrich the soil with bound nitrogen and humus. The cultivation of row crops improved the physical properties of the topsoil. In addition, row crops helped to clear the soil of weeds.

Crop rotation with various improvements dominated in Western Europe until the 1980s, and in the Soviet Union until the 1990s. With the development of the agricultural industry, chemical and pharmaceutical industries focused on agriculture, signs of crop rotation began to disappear. This was also facilitated by the spread of genetically modified organisms. Traditional approaches have been replaced by intensive, simplified farming systems, including no-rotation, which has had negative consequences for agriculture, rural areas, people and society as a whole.

The dominance of simplified, no-rotation agriculture has become characteristic not only of the countries where the Green Revolution began, it has also spread to the developed world. Crop rotation gave way to the practice of using high doses of mineral fertilizers and chemicals to control pests, diseases, and weeds. Combined with biotechnological advances, this led to higher yields (Andert, S.; Bürger, J.; Stein, S.; Gerowitt, B., 2016); Melander, B.; Munier-Jolain, N.; Charles, R.; Wirth, J.; Schwarz, J.; van der Weide, R.; Bonin, L.; Jensen, P.K.; Kudsk, P., 2013). Priorities of economic interests led to specialization in the cultivation of a limited number of crops. This allowed to reduce waste, simplify sowing, harvesting, and organizing irrigation (International Covenant on Economic, Social and Cultural Rights, 1966); Barbieri, P.; Pellerin, S.; Nesme, T., 2017).

However, after several decades, the negative consequences of this approach became apparent. In order to save costs, they refused to use fallow land, sow perennial grasses and green manure crops. This decision had a negative impact on the humus and biological condition of the soil. Growing a limited number of crops has increased the pressure of weeds on crops. The prolonged use of herbicides to control weeds has led to the development of weed resistance. The mentioned above has led to the need to constantly increase herbicide doses (Panagiotis Kanatas, 2020). The same applies to chemical plant protection products against diseases and pests.

According to FAO experts, narrow specialization has led to soil drought. Today, this process covers about 1.3 billion hectares of agricultural land. Soil loss remains the main reason for the loss of almost 25% of the world's crops (Kaminsky, V.F., 2015). Soil erosion and dehumidification dominate among the types of soil degradation that have affected one-third of the world's agricultural land (Status of the World's Soil Resources, 2015). Erosion on different continents annually loses 25 to 40 billion tons of topsoil. It takes hundreds of years to restore it, and the world's humus reserves are reduced by 1 billion tons annually due to erosion.

Alterations in land use, favoring the cultivation of a restricted assortment of crops, have been identified as one of the top five drivers of biodiversity loss. This decline in biodiversity poses significant risks to healthy and nutritious diets, agricultural productivity and the living conditions in rural areas.

Scientists have documented that within the context of climate change, characterized by rising temperatures and more frequent dry periods, agricultural production in highly specialized systems faces greater risks compared to those utilizing crop rotation systems (Lin, B.B., 2011; Gaudin, A.C.M.; Tolhurst, T.N.; Ker, A.P.; Janovicek, K.; Tortora, C.; Martin, R.C.; Deen, W., 2015).

Both scientific inquiry and practical experience have led to the consensus that resolving the conflict between agricultural activities driven solely by profit and the fundamental principles of agriculture is imperative. This involves finding a balance between the short-term economic interests of individuals and the long-term agricultural productivity (Danilyak, A. Sahara, 2020). Among the various methods to achieve this equilibrium, crop rotation with crop diversification plays a crucial role. This strategy is recommended based on objectively determined reasons for the necessity of alternating crop types to sustain soil health and agricultural viability (Kanatas, P., 2020).

Scientifically informed crop rotation is recognized as a fundamental component in agriculture, crucial for developing and implementing an effective model that enhances soil fertility, facilitates the transformation of organic matter, and establishes a nutrient regime. Additionally, crop diversification within crop rotation schemes is noted for increasing employment opportunities, creating 10–20% more jobs per hectare of sown area compared to traditional and simplified crop rotation methods. Empirical studies have demonstrated that integrating specific crops less susceptible to climate variability into rotation schedules can substantially reduce agricultural production risks. This is achieved by mitigating pest outbreaks and curtailing the transmission of pathogens, which are projected to escalate with advancing climate change (Lin, B.B., 2011). Moreover, crop diversification contributes to reducing the reliance on pesticides and enhancing biodiversity (Strobl, E., 2022; Palmu, E.; Ekroos, J.; Hanson, H.I.; Smith, H.G.; Hedlund, K., 2014), which in turn supports ecological intensification, leading to improved crop quality (Redlich, S.; Martin, E.A.; Steffan-Dewenter, I., 2018).

This underscores the vital role that crop rotation farming plays in achieving the Sustainable Development Goals by 2030, particularly in ensuring soil health, adapting crops to climate change, producing nutritious and high-quality food, and promoting rural employment.

In this context, the authors of this study have concluded that it is imperative to broaden the scope of scientifically established criteria that guide the selection and rotation in crop rotation systems. Furthermore, there is a need to assess the extent to which the practice of highly specialized agriculture with monoculture characteristics in Ukraine aligns with the Sustainable Development Goals. Additionally, it is crucial to devise strategies to address and rectify the problems identified through this analysis.

Objective Analysis of Crop Rotation Necessity. The necessity for crop rotation stems from various factors, primarily the inherent characteristics of the crops and the significance of their diversity for human health, as well as the agroclimatic and soil conditions in which they are cultivated. Key attributes of crop characteristics including chemical causes influencing soil health are closely tied to the varying nutrient requirements of different plants: some species demand a greater quantity of nutrients, while others require significantly fewer. Crops that are permanent and have high nutritional needs tend to deplete soil nutrients swiftly. Furthermore, the cultivation methods and types of crops grown also impact the physical properties of the soil cover, such as its structure and water permeability, which in turn affects the soil's resistance to erosion by water and wind (Dziekański, P.; Prus, P.; Maitah, M.; Wrońska, M., 2021).

Biological reasons are associated with the varied interactions between cultivated plants and other plant and animal organisms. Different crops and their specific cultivation methods establish distinct environmental conditions that influence the development of weeds, pests, and pathogens. Additionally, during their lifecycle, previous crops may release substances that adversely affect subsequent crops or inhibit the development of microorganisms. This phenomenon, known as allelopathy, is a primary cause of soil pestilence, which consequently leads to a reduction in crop yield (Kristine, M.; Sheaffer, C., 2010).

The economic reasons for implementing crop rotation derive from two main factors. Firstly, crop rotation enables the optimal organization of the cultivation of various

crops tailored to meet the demands of both national and foreign markets, thereby facilitating the profitable sale of the products grown. Secondly, crop rotation contributes economically by generating a type of fertilizer that emerges naturally from the sequence of crops. This “crop rotation” fertilizer is considerably more cost-effective compared to the application of mineral fertilizers, offering a significant economic advantage by reducing input costs (Moldavan, L.; Pimenowa, O.; Wasilewski, M.; Wasilewska, N., 2023).

The diversity of crops included in a crop rotation is influenced by the variety required in the human diet to meet physiological needs (United Nations General Assembly, 2010). Additionally, cultivating crops with varying growing seasons, distinct post-harvest processing characteristics for sale, and different usage periods on the farm enhances the productive employment of farmers. These factors collectively provide a social rationale for categorizing and considering social reasons alongside chemical, physical, biological, and economic factors. Together, these diverse reasons impact the selection and rotation of crops within a crop rotation system (Brinkman, T., 1926).

The farming system is not isolated; rather, it continually interacts with the environment. The arrangement of crops within crop rotations is significantly influenced by climatic factors, including average and long-term precipitation patterns, the distribution of rainfall over time, the accumulation of effective temperatures, air humidity, prevailing wind directions, the length of the growing season, the frost-free period, the presence and duration of soil freezing, the availability of productive moisture in the soil in spring, and the frequency of droughts, dry spells, frosts, and other adverse climatic conditions. These factors necessitate careful consideration in both the zonal placement of agricultural production and the development of localized crop rotation plans.

In Ukraine, three primary agroclimatic zones are differentiated based on the ratio of precipitation to accumulated heat: Polissya, Forest-Steppe, and Steppe. Polissya features low-lying terrain and a positive moisture balance, predominantly covered by sod-podzolic soils along with sandy and sandy loam soils. Meadow and sod soils also constitute a significant portion of this region. The Forest-Steppe zone exhibits diverse agroclimatic conditions and complex soil composition, primarily consisting of typical podzolized, degraded, and saline soils, which generally maintain a relatively high fertility level. Conversely, the Steppe zone is characterized by its flat terrain and fertile soils, predominantly black and soddy in the north-central areas, while the southern parts are dominated by southern chernozems and chestnut soils. Before the impact of climate change, the distribution of agricultural land was 19% in Polissya, 35% in Forest-Steppe, and 46% in the Steppe zone, as indicated in Figure 30 of this work.

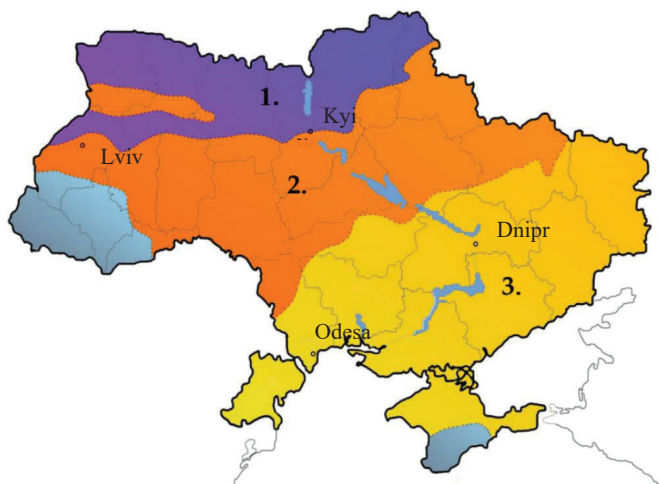


Figure 30. Agroclimatic map before the impact of global warming. 1—Polissya, 2—Forest-Steppe, 3—Steppe. Source: based on: Churylova, K., 2019.

Climate change significantly influences the geographical shifts of climatic zones. According to the Ukrainian Hydrometeorological Center, over the last 25 years, the average annual air temperature in Ukraine has risen by nearly 1.5 °C (Danilyak. A. Sahara, 2020), surpassing the global warming rate observed in the northern hemisphere; in the Steppe regions, the increase reaches 1.6 °C. Historically, the highest effective heat accumulation (+10) reaching 1500 °C was recorded in the Autonomous Republic of Crimea and Kherson region; currently, this figure has escalated to 1600 °C across Ukraine (Adamenko, T.I., 2013). In the southern regions, the average monthly precipitation has a steady downward trend. From 2015 to 2020, a consistent decline in average monthly precipitation has been noted, decreasing by 10% in Kirovohrad, 15% in Luhansk, 17% in Odesa, 20% in Mykolaiv, 23% in Dnipro and Kherson, 24% in Zaporizhzhia, and 25% in Donetsk regions (Levkovska, L.V., 2021).

Additionally, climate change is marked by uneven and increasingly stormy precipitation patterns, exacerbating soil compaction and erosion. The number and severity of drought events during the growing season have doubled over the past two decades. The ongoing climate shifts are expected to intensify these adverse effects, posing significant risks to the grain and sunflower production areas in the Steppe and Eastern Forest-Steppe regions, where average annual rainfall does not exceed 300-350 mm, and soil erosion rates range between 55 and 80%.

As a consequence of these changes, climatic zones have migrated northward by up to 200 kilometers (Figure 31).



Figure 31. Map after the impact of changes. 1: Polissya, 2: Forest-Steppe, 3: Steppe. Source: based on: Churylova, K. 2019.

The Kirovohrad region, traditionally part of the Northern Steppe, is now experiencing conditions more characteristic of the Southern Steppe regions. Meanwhile, the Kherson, Zaporizhzhia, Odesa, and Mykolaiv regions are transitioning from the Southern Steppe to the Dry Steppe zone. This shift is marked by climatic changes, with the Dry Steppe zone nearing dry subtropical conditions in terms of temperature. The Northern Steppe is extending towards the Kyiv region and Polissya is increasingly resembling the Forest-Steppe.

Within the Steppe zone, temperatures are expected to reach $+35^{\circ}\text{C}$ for up to 70 days annually and drought periods can extend up to 90 days per year. Under these conditions, rainfed agriculture becomes highly precarious and in the Dry Steppe zone, it verges on being nonviable.

Given these changes, along with the intrinsic need for crop rotation driven by the legal mandates of crop rotation and the social objectives of crop production, there is a compelling case for developing scientifically grounded crop rotations. These rotations are crucial for adapting farming systems to the evolving climatic conditions.

The study of zonal aspects of crop rotation in Ukraine. With the shift towards a market economy, traditional crop rotation practices in Ukraine have gradually diminished, giving way to the emergence of intensive non-rotational systems. This trend has become particularly pronounced with the entry of large national and international agro-industrial and trading companies into the agricultural sector. For these corporations, as observed in other nations, the key factors driving the selection of crops are the heightened demand in foreign markets for certain products and the economic advantages associated with these demands.

Following the agrarian reforms of the 2000s, Ukrainian researchers have documented significant shifts in agricultural practices (Kaminskyi, V.F.; Sayko, V.F., 2002; Yeshchenko, V.O., 2015). Driven predominantly by market demands, large agricultural enterprises have adopted specialized crop rotations focusing on one or two export-oriented crops. This shift has overlooked several critical factors: biological, physical, and chemical aspects of soil management; natural and environmental conditions pertinent to specific crop cultivation techniques; the agro-ecological classification of soil types according to their suitability for particular crops, which also considers the crops' potential to enhance the resilience of agricultural landscapes; and the social implications associated with the composition of crop varieties. These observations highlight a trend towards a more commercially driven agricultural model that often disregards comprehensive environmental and social considerations.

Grains and oilseeds, particularly sunflower, have dominated the composition of Ukraine's sown areas, accounting for 88.4% in 2021. The annual acreage dedicated to sunflower cultivation in Ukraine is almost two million hectares more than the combined total of all European Union countries. Predominantly, up to 80% of sunflower crops are situated in the Steppe Zone and the adjacent Eastern Forest-Steppe regions. These areas are designated as risky farming zones due to their climatic conditions and represent half of the cultivated land in Ukraine. Within these regions, sunflowers constitute 30–40% of the sown areas, while cereals account for the remaining 50–57%, as detailed in Table 25.

Table 25

Formation of deeply specialized farming with signs of monoculture industrial-intensive agricultural production in Ukraine, %

Regions	Cereals		Technical and Oilseeds				Total Grains and Oilseeds	
			Total		Including Sunflower			
	1993	2021	1993	2021	1993	2021	1993	2021
Polissya Zone	39.1	51.7	7	22.8	0.15	10.7	46.1	74.5
Forest-Steppe Zone	44.7	56.2	12.7	31.3	3.5	20.3	57.4	87.5
Steppe Zone	48.5	57.5	11.6	36.6	10.7	30.2	60.1	94.1
Total in Ukraine	45.8	56.0	11.2	32.4	6.4	23.3	57	88.4

Source: Calculated by the authors based on the Statistical Digest "Agriculture of Ukraine" 1993, 2021.

Pairs that occupied more than a million hectares in these zones before the reform of the agricultural sector have been destroyed and perennial grasses have been reduced to 1.3% in the Steppe Zone.

The implementation of narrow specialization coupled with the abandonment of scientifically grounded crop rotation practices, which characterized Ukrainian agricultural enterprises prior to the transition to a market economy (i.e., until 1991–1992), failed to yield the anticipated increase in crop yields. This observation is evidenced by the performance of the most highly specialized regions within the Steppe zone, as illustrated in Table 26. Despite the adoption of new technologies, the introduction of imported

Western European seeds, and the application of substantial doses of synthetic fertilizers, the anticipated yield improvements did not materialize.

Table 26

Yields of major crops in the regions of the Steppe zone, MT/ha.

Region	Cereals				Sunflower			
	1990	2000	2010	2020	1990	2000	2010	2020
Ukraine	3.51	1.94	2.69	4.25	1.58	1.22	1.50	2.02
Dnipropetrovsky	3.91	2.03	2.53	3.23	1.59	1.31	1.04	1.63
Donetsky	3.78	1.85	2.48	3.47	1.93	1.78	1.38	1.72
Zaporozhsky	3.83	1.55	2.27	3.01	1.49	1.28	1.33	1.57
Kirovogradsky	3.91	1.99	2.89	3.14	1.70	1.28	1.71	1.69
Luhansky	3.09	1.18	1.96	3.45	1.55	1.04	1.05	1.68
Mykolayivsky	3.54	1.47	2.51	2.68	1.53	1.07	1.48	1.35
Odesky	2.98	1.80	2.55	1.85	1.40	1.17	1.44	1.27
Khersonsky	3.50	1.72	1.72	3.50	0.87	0.87	1.23	1.59

Source: Calculated by: "Agriculture of Ukraine". Statistical collection, for the relevant years.

The short-term economic benefits derived from increased grain and sunflower exports, pursued in contravention of scientifically established crop rotation principles, are overshadowed by long-term detriments due to the degradation of agroecosystems. Dehumidification, nutrient depletion, and soil over-compaction and erosion affect up to half of the arable land. Particularly in the highly specialized Steppe zone, between 55% and 80% of the land is vulnerable to erosion, as illustrated in Table 27.

Table 27

The main factors of land degradation in highly specialized cropland areas of the Steppe zone, 2021

Region	Grains and Oilseeds *, % in sown area	Humus Balance **, MT/ha	the Balance of the Lifespan **, kg/ha	Subject to Erosion ***, %
Ukraine	88.3	-0.13	-67	40.8
Dnipropetrovsky	93.3	-0.50	-51	43.8
Donetsky	92.1	-	-	66.3
Zaporozhsky	95.9	-0.61	-123	58.7
Kirovogradsky	94.2	-0.23	-30	50.4
Luhansky	95.9	-0.27	-72	83.9
Mykolayivsky	94.5	-0.39	-96	49.0
Odesky	96.1	-0.54	-69	48.0
Khersonsky	90.0	-0.54	-126	32.0

Source: * Calculated by: "Agriculture of Ukraine". Statistical collection, 2021. ** data from the State Institution "Institute of Soil Protection of Ukraine". *** data from the State Service of Ukraine for Geodesy, Cartography and Cadastre.

The exclusion of perennial grasses and legumes from crop rotations, coupled with the unbalanced extraction and replenishment of organic matter in the soil, leads to a significant humus deficit, amounting to 600–700 kg per hectare. Furthermore, the sole reliance on mineral nitrogen fertilizers contributes to soil degradation, characterized by decalcification and dehumification. Currently, degradation processes impact over 10

million hectares. Consequently, Ukrainian chernozems, which comprise 60% of the land structure, contain 2.5–3 times fewer nutrients compared to nonchernozem soils in European lands (Medvedev, V.V., 2015).

Soil degradation is exacerbated by the proliferation of pests and pathogens affecting plants and weeds. Findings from investigations carried out at the National Research Center “Institute of Agriculture of National Academy of Agrarian Sciences of Ukraine” reveal that diminishing field sizes from 4–5 to 2–3 hectares leads to a notable surge in the presence of pathogenic fungi within the soil, up to 60%. Additionally, an intensified frequency of cereal crop rotations featuring spiked cereals, by up to 75%, corresponds to a 38% escalation in root rot development and a 2.8% increase in the population of bread borers (Rex, D., 2016).

Noncompliance with crop rotation practices and the imbalance within agroecosystems precipitate the swift dissemination of viruses spanning various taxonomic groups. As delineated by A. Boyko (Boyko, A.L., 2015), the agroecosystems of Ukraine currently harbor over 600 distinct viral entities, each adapted to specific plant species. Among these, approximately 25 are disseminated through microscopic fungi, over 30 are prevalent across diverse soil compositions, and roughly 90 phytoviruses are transmitted via seeds.

V. Kaminsky’s investigation revealed that cultivating sunflower within a simplified crop rotation, transitioning towards monoculture, precipitates a notable proliferation of tospovirus (TSV). Analogous to the sunflower mosaic pathogen (SM), TSV poses a substantial threat, potentially resulting in a grain yield reduction of up to 90% (Kaminskyi, V.F., 2015).

When crop rotations are disregarded, pest’s endemic to monoculture proliferate rapidly. For cereals, notable examples include bollworms, thrips, bread beetles, and wireworms, among others. A parallel scenario unfolds concerning weed populations. Under such circumstances, chemical interventions persist as the primary means of weed management (Jabran, K., 2021). However, escalated dosages of chemical plant protection agents engender environmental contamination, exacerbate soil water and nutrient imbalances and introduce substances detrimental to human health into agricultural produce.

The focalization of resources by large agricultural enterprises in Ukraine towards the cultivation of grain and sunflower has not yielded commensurate economic efficiency. Despite encompassing a considerable proportion of the cultivated area within the Steppe and Eastern Forest-Steppe zones, where sunflower occupies over a third of the sown area, the arable land exhibits a superior natural fertility rating compared to other zones. Paradoxically, however, the yield obtained from these regions falls below the national average (Moldavan, L.; Pimenova, O., 2021). Analogously, a comparable trend manifests concerning grain yields, as depicted in Table 28.

Table 28

Assessment of natural soil fertility and yields of major crops, zonal aspect, 2021

Regions and Zones	Natural Fertility Score of Arable Land	Yields, MT/ha			
		Wheat	Barley	Corn	Sunflower
Total in Ukraine	63	4.53	3.82	7.68	2.46
Polissya					
Volynsky	50	4.34	3.39	8.61	2.54
Zhytomyrsky	48	4.65	3.98	8.25	2.40
Zakarpattia	40	3.36	2.93	5.04	1.87
Ivano-Frankivsky	45	4.97	4.35	9.02	2.85
Lvivsky	43	4.93	4.77	9.06	2.52
Rivnensky	51	4.70	3.82	8.12	2.62
Chernihivsky	63	4.97	3.94	8.55	2.91
Forest-Steppe					
Vinnitsky	61	5.57	4.61	9.37	3.20
Kyivsky	59	5.06	4.05	8.67	2.85
Poltavsky	66	4.83	3.64	6.79	2.57
Sumsky	58	4.75	3.91	6.77	2.94
Ternopilsky	57	5.54	4.48	9.87	3.34
Kharkivsky	67	4.80	3.69	5.14	2.44
Khmelnitsky	59	6.01	4.47	10.28	3.14
Cherkasky	65	5.39	4.17	8.95	3.15
Chernivetsky	47	5.01	3.66	7.47	2.84
Steppe					
Crimea	54	-	-	-	-
Dnipropetrovsky	73	4.40	3.25	5.19	2.33
Donetsky	65	4.07	3.01	4.25	2.18
Zaporozhsky	74	3.84	3.52	7.54	2.00
Kirovogradsky	68	4.87	4.04	7.03	2.63
Luhansky	60	3.84	2.77	2.88	1.83
Mykolayivsky	68	4.23	3.77	5.23	2.24
Odesky	64	3.90	4.05	6.10	2.32
Khersonsky	73	4.12	3.88	9.03	1.93

Source: State Statistics Service of Ukraine. Statistical collection, 2021

The social consequences of export-oriented, highly specialized production in the absence of scientifically based crop rotations have manifested themselves in a decrease in rural employment (Lupenko, Y.O., Kropyvko, M.F., 2013). Surveys conducted across agricultural holdings reveal that their subsidiaries and production units, which encompass up to 3000 hectares and have transitioned to cultivating grains and oilseeds—the most mechanized types of crops—can sustain employment for up to five individuals (Nemchuk, V.P., 2011).

Intensified narrow specialization exacerbates the nation's reliance on imported agricultural products that have been supplanted from national production. Consequently, between 2015 and 2021, import volumes surged by 2.9-fold for livestock products, nearly doubled for crop products and increased by 2.4 times for fats and oils. Concurrently, Ukraine's populace experienced a growing deficit in per capita consumption of both micro- and macronutrients, alongside diminished caloric intake (Table 29)

Table 29

Consumption of macro- and microelements per person per day

Macro- and Microelements	1990	2010	2021
Caloric content, kcal	3597	2933	2677
Protein, g	105.3	79.0	82.3
Fats, g	124.0	99.2	95.2
Calcium, mg	1362	893	879
Iron, mg	25.0	20.5	19.4
Retinol, mcg	1863	1088	1051
Thiamine, mg	2.30	1.88	1.80
Riboflavin, mg	3.46	2.55	2.60
Niacin, mg	22.4	18.8	18.1

Source: State Statistics Service of Ukraine. Statistical collection, 2021

The evaluation of detrimental outcomes arising from the disregard of objective factors associated with crop rotation highlights the necessity to restructure cultivated regions by incorporating a diverse array of crops. Such diversification should aim to enhance soil organic matter (SOM) content; facilitate pest management; regulate nutrient equilibrium; ameliorate soil structure; mitigate erosion processes; and foster beneficial effects on food webs and field ecosystems (Rex, D., 2016).

An optimal approach for revising crop selections in rotations must consider climate change, now a global concern. It significantly increases uncertainties and threats in agriculture (Weih, M.; Karley, A.J.; Newton, A.C.; Kiær, L.P.; Scherber, C.; Rubiales, D.; Adam, E.; Ajal, J.; Brandmeier, J.; Pappagallo, S., 2021).

Under the influence of changing climatic conditions, it is essential to restructure cropping areas to halt degradation processes and establish a balance between short-term profitability and long-term productivity of agricultural land (Sue Ellen, J.; Mohler, C.L., 2009).

Possible ways of transitioning to socio-ecologically oriented crop rotations as a factor of sustainable land use. With ongoing climate change in the Steppe Zone, preserving cereal crop structure entails irrigating corn and barley, moisture-loving crops. In the new conditions, it will be advisable to replace some soft wheat with durum wheat to revive Ukraine's role as a durum wheat exporter.

In regions prone to agricultural risks and characterized by extensive land degradation, it is advisable to substitute sunflower cultivation with drought- and salt-tolerant cereal crops. Sunflower, being a moisture-intensive crop with high water absorption and nutrient depletion from the soil, warrants replacement. Priority alternatives for such conditions include sorghum, valued for its dual utility as both a food source and industrial raw material, and millet, recognized for its efficacy as a precursor for winter wheat cultivation.

Incorporating oilseed legumes with nitrogen-fixing capabilities, such as soybeans, chickpeas, and peanuts, offers a dual advantage: ensuring adequate soil moisture reserves for consistent crop germination and revitalizing depleted land while providing crops with valuable nutritional attributes demanded globally. The inclusion of perennial legumes in the cultivated area is pivotal. Additionally, the implementation of post-harvest green manure crops presents a viable strategy for soil enrichment (Table 30)

Table 30

A set of crops for the Steppe zone, taking into account the level of degradation and climate change.

No.	Agricultural Crop	Structure of Crops, %
1	Winter wheat	22
2	Winter barley	20
3	Corn	10
4	Spring barley	5
5	Legumes and pulses	16
6	Cereal crops	16
7	Perennial grasses	11
	Total	100

Source: Compiled by authors based on science-based standards and climate change

The set of these crops with the longest period of return to the previous place of cultivation would allow farmers to switch to 4-plot short-rotation. Field I includes winter cereals; Field II includes legumes; Field III includes spring cereals; Field IV includes perennial grasses for annual use.

The proposed structure of the sown areas allows for the placement of cereals after the recommended best predecessors, which corresponds to scientifically sound standards of crop selection and their rotation.

Such crop rotation practices are commonplace in regions endowed with suitable climatic conditions akin to those found in the Ukrainian steppes, as observed in Canada and the United States. These rotations typically involve the inclusion of perennial grasses and legumes in grain rotations, aimed at mitigating soil lodging and allelopathic effects while enhancing soil phytosanitary conditions. Notably, the United States boasts a significant proportion of global alfalfa acreage, with one in three hectares dedicated to this crop, alongside legumes occupying one in two cultivated hectares. Consequently, the country benefits from an annual influx of approximately 6 MMT of biological nitrogen, with half of this amount being sequestered in the soil, thereby exerting a favorable influence on crop yields and economic viability (Kaminskyi, V.F., 2015).

In the Western and Central Forest-Steppe regions, the restructuring of agricultural production does not necessitate extensive measures as observed elsewhere. The natural resources within this segment of the Forest-Steppe exhibit less depletion, owing to the region's avoidance of narrow specialization and maintenance of polycultural agricultural practices. The proposed structural changes entail rejuvenating the fodder base and bolstering livestock production by partially reducing cultivated areas, particularly those devoted to sunflower and rapeseed cultivation. Concurrently, the expansion of leguminous crop cultivation, notably peas, is advocated. Peas are well-suited to the zone's natural climatic and soil conditions, serving as optimal precursors for sugar beets and spiked cereals.

Based on the above analysis, the tentative set of crops for the Forest-Steppe zone can be structured as follows (Table 31).

Table 31

Set of crops for the Forest-Steppe zone

No.	Agricultural Crop	Structure of Crops, %
1	Winter wheat	16
2	Winter barley	10
3	Spring barley	5
4	Corn	16
5	Soybeans	16
6	Sunflower	10
7	Winter rapeseed, kohlrseed	12
8	Annual grasses	5
9	Perennial grasses	10
	Total	100

Source: Compiled by the authors based on science-based standards and climate change.

Sugar beet and sunflower are crops whose peculiarities determine the longest (7-9 years) period of their return to the previous place of cultivation, which determines the need to switch to long rotation of at least 8 crops. Field I includes annual grasses; Field II includes winter rape; Field III includes winter wheat, rye, and post-harvest crops; Field IV includes corn for grain and silage; Field V includes soybeans; Field VI includes winter barley and post-harvest crops; Field VII includes corn for grain; Field VIII includes sunflower.

In the context of climate change within the Polissya zone, the adoption of long-term crop rotation schemes should serve as the cornerstone for orchestrating structural reforms within commercial agricultural production. The delineation of crop rotations in the Polissya region will be instrumental in reinstating the cultivation of flax and hops, alongside the restoration of fodder lands. Despite its land area being three times smaller than other zones, Polissya previously accommodated 43% of the nation's cattle, a figure that has since halved. However, the projected alterations in climatic conditions do not diminish the conducive environment for fostering the livestock sector's development. Through the reinstatement of forage crop rotations and pastures, the region can emerge as a specialized hub for beef cattle rearing and a net exporter of beef products.

This approach, according to the authors, will allow Ukraine to come closer to the principles of crop rotation farming in European countries by 2030 and achieve a balanced, scientifically sound structure of sown areas. The proposed transformation is presented below in comparison with the current structure of sown areas in France, a country with high food production and at the same time effective environmentally oriented agriculture (Table 32)

Table 32

Possible structure of crop areas in Ukraine focused on restoration of degraded lands and climate change.

Cultures	Ukraine 2020		Ukraine 2030 (Forecast)		France 2020	
	Area KMT	%	Area KMT	%	Area KMT	%
The total sown area	2814.7	100	2450.0 *	100	1787.9	100
Cereals and legumes	1539.2	56	1225.0	50	890.72	50
Oilseeds	893.5	31.7	428.7	17.5	212.11	11.8
Including sunflower	645.7	22.9	245.0	10	77.84	4.3
Technical crops	28.9	1.0	73.5	3	62.48	3.5
Fodder crops	167.7	5.9	490.0	20	472.34	26
Including herbs	86.9	3.1	294.0	12	315.95	17.7
Other cultures	185.4	6.6	159.25	6.5	62.78	3.4
Land temporarily withdrawn from cultivation	-	-	735	3	523	2.9

Notes. * The area of sown land has been reduced by 4 million hectares, which are planned to be withdrawn from cultivation by 2030 in order to reduce plowed land. *Source:* Calculated by the authors according to the recommended zonal crop sets and crop rotation schemes and statistical compilations, Agreste Chiffres et Données Agriculture. Statistique agricole annuelle 2020 and Agriculture of Ukraine. Statistical collection for 2020.

Empirical evidence suggests that the shift from deeply entrenched monocultural practices towards scientifically grounded crop rotation agriculture necessitates robust state intervention, entailing the establishment of a conducive institutional and legal framework. Such a framework should encompass regulations, monitoring mechanisms, incentives, and encouragement strategies. A repertoire of such mechanisms is employed across European Union (EU) member states. These encompass stipulating the proportion of crops from the same biological family within crop rotations, periodic assessment of humus content, promotion of legumes and perennial grasses, and a hybrid approach integrating adherence to established regulations with direct payments under the Common Agricultural Policy.

In Ukraine, a comparable approach is lacking. For instance, the Resolution of the Cabinet of Ministers of Ukraine titled “On Approval of Standards for Optimal Crop Rotation in Different Natural and Agricultural Regions” (2010) stands as an inactive regulatory provision, lacking requisite support from state regulatory and oversight mechanisms. This inert status is mirrored in the implementation of other state decrees addressing similar concerns.

The process of European integration within Ukraine necessitates concerted efforts from governmental bodies and the scientific community to enact legislative frameworks and implement practices aligned with the principles outlined in the European Green Deal. Mandates within the European Green Deal, including initiatives to preserve biodiversity, reduce chemical pesticide usage by 50%, decrease mineral fertilizer application by 20%, and transition 25% of arable land to organic farming, underscore the imperative of adopting agroecological crop rotation systems. These imperatives stem from the adverse environmental and social ramifications associated with non-ro-

tational agriculture, which is poised to proliferate within the Ukrainian agricultural sector amid ongoing climate change. Furthermore, they align with the objectives outlined in Ukraine's Sustainable Development Goals for 2030, particularly those concerning agricultural development (Goal 2) and the preservation and restoration of terrestrial ecosystems (Goal 15). Key performance indicators directly pertinent to crop rotation agriculture include setting targets to achieve a neutral level of land degradation, expanding organic production from 410.6 thousand hectares in 2015 to 3 million hectares by 2030 and ensuring a balanced diet among the populace by augmenting per capita production and consumption of fruits, berries, milk, and meat by specified margins Sustainable Development Goals Ukraine: National Report, 2017).

Implementing a multi-rotation cropping system with varied crop structures and arrangements can ensure quality product production aligned with human needs. This approach supports food independence, rational labor resource use, land productivity, and environmental preservation (Kristine, M.; Sheaffer, C., 2010).

The research carried out by Ukrainian academic institutions and the authors of this study have substantiated the adverse environmental ramifications associated with simplified, highly specialized, non-rotational agricultural practices. These repercussions are notably characterized by the degradation of humus content, proliferation of phytotoxic soil regimes, soil structural deterioration, heightened soil fatigue, amplified erosion rates, and intensified weed, pest, and disease incidences, thereby necessitating escalated chemical interventions, consequently exacerbating risks to both human health and ecological integrity.

The adoption of simplified, highly specialized farming practices engenders an escalation in the nation's reliance on imported agricultural products displaced from crop rotations, precipitating a reduction in the diversity of foodstuffs essential for human physiological requisites. Moreover, this agricultural paradigm shift precipitates a decline in rural employment opportunities, exacerbating poverty rates and fostering migration trends in pursuit of livelihoods, consequently intensifying strain on the labor market and catalyzing rural depopulation alongside attendant social dilemmas.

The findings of this research corroborate the hypothesis that implementing crop rotations that incorporate scientifically rational crop diversification serves as a potent mechanism for restoring soil fertility. This strategy emerges as a primary preventative approach, significantly mitigating the adverse effects of pests and diseases on plant growth. Moreover, it plays a crucial role in enhancing the living conditions of soil microflora, thus augmenting its biological activity and overall ecological health.

This conducted study suggests that modifications in crop assortment and their subsequent rotation necessitate adjustments within the agroclimatic zones of Ukraine. These adjustments are driven by an increase in average annual temperatures, a reduction in precipitation, and heightened evaporation of soil moisture. Consequently, these changes prompt a transformation in the structure of agricultural production, which is increasingly aligned with the demands of both national and international markets.

The approach proposed by the authors, involving a diversified assortment of crops tailored to the agroclimatic zones of Ukraine with corresponding rotation schemes, is identified as a strategic tool to enhance the resilience of agriculture in response to climate change. This approach not only addresses the short-term economic interests of

individuals but also aims to maintain long-term agricultural productivity for the benefit of society at large.

The ongoing exploration and implementation of diversified crop rotation systems, considering their significance in fulfilling the Sustainable Development Goals for Agriculture, continue to be critical tasks for both the academic fields of agrarian and economic sciences and the practical management of agricultural production. This pursuit remains essential in integrating scientific insights with effective agricultural practices to promote sustainable development.

2.6. STRENGTHENING OF THE AGRO-ECOLOGICAL FUNCTIONS OF FOREST PLANTATIONS IN AGRICULTURAL PRODUCTION

Climate change is not just about rising average temperatures. It is also seen in an increase in the number and intensity of adverse events. These include hot days, droughts, floods, tornadoes, sudden thaws and frosts, as well as mudslides and wind-storms. The climate imbalance is expressed in the amplitude of fluctuations of these phenomena. Forest systems are a powerful mechanism of self-regulation of the biosphere. They mitigate climatic events or even prevent them. Forests influence all processes occurring in landscapes, as well as natural geophysical and geochemical processes. Strategies to mitigate the negative impacts of climate change are largely linked to the conservation and expansion of forests. The reduction of forest areas and deforestation of part of the territories is one of the most important environmental challenges. This process negatively affects biodiversity and the economic development of the society as a whole. By worsening the climate, deforestation creates significant problems for people's livelihoods.

The range of ecosystem services provided by forests is extremely important. They include protecting soils from degradation and pollution, providing oxygen and absorbing carbon. In addition, forests contribute to the preservation of landscape and biological diversity and create environmentally safe living conditions for the population.

Forest ecosystems serve as natural water filters. They clean it from various contaminants and heavy metals that enter natural water resources through industrial activities. The air and water cleaning provided by forests has a positive impact on human health. Clean water and clean air ensure a healthy lifestyle (Figure 32).

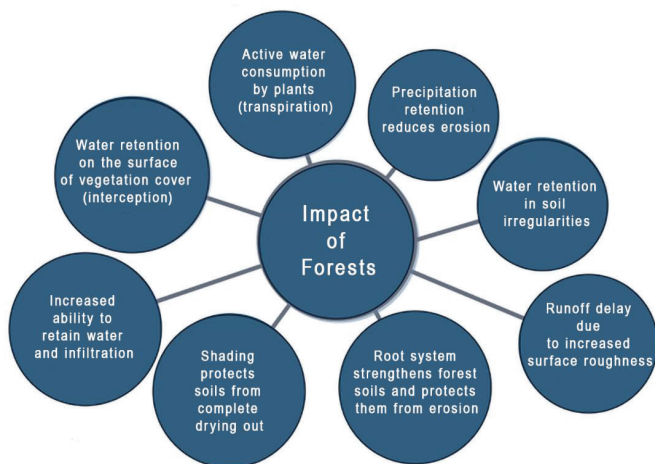


Figure 32. Ecological functions of forest systems. Source: Compiled by authors based on research by various academic institutions

In general, scientists define 100 different groups of forest ecosystem functions, which are grouped into 4 classes: social, economic and ecological, landscape stabilizing, and raw material (Sheinkaus and Sapozhnikov, 1983). These functions of forest systems require the rational use of forest resources. This involves meeting human needs today without harming future generations. This means that along with deforestation, it is necessary to restore forest systems and plant new trees. It is also important to regenerate old growth and maintain natural diversity.

In Ukraine, the total area of forest areas of the forest fund is 10.4 million hectares. Of this area, 9.6 million hectares are covered with forest vegetation, which is 15.9% of the country's territory. Ukraine's forest coverage is 2.3 times lower compared to European countries, which is why it ranks 34th in Europe in terms of forest area to total territory (FOREST EUROPE, UNECE and FAO, 2011). In 2020, there were about 160 million hectares of forest in the European Union (EU), accounting for about 39% of its territory (Eurostat, 2025). Other forested land covered about 20 million hectares. This area, covered by forests and other woodlands, accounts for 45.1% of the EU-27 territory (Eurostat, 2025).

The forests of the European Union are characterized by their extraordinary diversity. They cover a wide range of forest types, characteristics and ownership structures. They provide numerous benefits to society and the economy, being a major source of biodiversity. In addition, they are a key resource for improving the quality of life, well-being and job creation.

Agroforestry plantations play an important role in the composition of forested areas. According to the FAO, agroforestry is a collective name for a system of land use technologies. In these systems, woody perennial plants (trees, shrubs, palms, bamboo, etc.) are purposefully used on the same land as crops and/or animals. This can take place in various forms (Eurostat, 2025). Agroforestry is a dynamic natural resource management system that integrates trees and agricultural production. It increases the diversity and sustainability of agricultural production while providing social, economic and environmental benefits to land users.

According to the FAO, agromelioration covers an area of 1 billion hectares worldwide. More than 1.2 billion people are employed in this sector. Agroforestry systems, in which cocoa is grown under tree canopies, cover 7.8 million hectares. In Central America, forest pasture is spread over an area of 9.2 million hectares (Marie-Laure Augère-Granier, 2020).

In the EU, agroforestry covers more than 15 million hectares, and together with areas where reindeer breeding is developed, it covers 52 million hectares (Eurostat, 2025). In Central Europe, the practice of growing crops and grazing livestock combined with garden cultivated trees is widespread. In the boreal forests of the northern countries there is deer grazing, and in Portugal and Spain there is sheep grazing under cork oaks, etc. Agricultural melioration is recognized at the national and European levels and is supported by the Common Agricultural Policy (CAP). The benefits of agroforestry are recognized by the European Parliament in a number of documents that contain tasks to support it.

Agroforestry is seen as an alternative to intensive farming systems that require significant inputs of mineral fertilizers and other external resources to maintain produc-

tion. It contributes to a more environmentally friendly approach to land use, supporting sustainable development and reducing negative environmental impacts. Agroforestry improves the efficiency of nutrient and water use by reducing their leaching into groundwater. It also improves the physical and biological properties of the soil. Agroforestry helps to increase biomass on farms through the productive use of precipitation. In arid and semi-arid regions, crops productively use less than half of the annual rainfall. The rest is spent in the form of runoff, evaporation or drainage. This reduces the efficiency of water use in agriculture. Agricultural melioration plantations reduce these costs by ensuring the use of water that comes through the rooting zone of crops. This makes it possible to control the groundwater level more effectively. Agroforestry helps to preserve and increase organic matter in the soil, which plays an important role in the biological, chemical and physical aspects of soil fertility.

The peculiarity of agroforestry lies in its synergistic effect - the combination of several components and their dynamic interaction. This makes it possible to increase the overall performance of the system through synergistic effects. A study by the French National Institute of Agricultural Research (INRA) proved that the yield of wheat and walnuts per 1 ha of their joint cultivation is the same as that obtained on an area of 1.4 ha of separate cultivation of these crops.

Agromelioration includes different types of forest plantations (Gold, M.A.). In the United States, for example, there are five categories of agroforestry:

- windbreaks act as environmental buffers, protecting crops, animals, and soil from wind, snow, dust, and odors. They also support wildlife and can be an additional source of income;
- riparian forests are natural or restored areas along rivers and streams that consist of trees, shrubs, bushes and grasses. They perform a buffer function that helps filter water runoff, and their roots stabilize the banks of rivers, lakes, and ponds, which prevents erosion. All areas can support wildlife and provide some income to their owners;
- forest pasture is a combination of trees and fodder in one area. Trees can provide, in addition to wood, fruits, nuts, fodder for livestock, as well as shade and shelter for them, which reduces animal stress from the hot summer sun or cold winds;
- multi-tiered forestry – cultivation of food, botanical or ornamental crops of herbs and grasses under the forest canopy, which provides an ideal level of shade;
- alley cropping (intercropping) are planting crops between rows of trees to provide income while the trees mature. Vegetables, cereals, herbs, bioenergy plants, etc. are cultivated.

Windbreaks have economic, environmental and social functions. The direct economic benefit is the use of timber and non-wood forest products. Trees and shrubs in windbreaks can provide fruit, nuts, fuel, fodder, and materials for crafts. This allows to diversify the farm's income through additional sources of resources for sale or processing. The use of crops does not affect the performance of windbreaks in terms of their ecological functions, which include:

- slowing down the wind, which prevents the development of soil deflation (wind erosion);

- protection of crops as a result of moisture retention and the formation of a favorable microclimate for plants;
- increase of irrigation efficiency;
- even distribution of snow across the field, which increases spring soil moisture;
- increasing biodiversity, creating a favorable environment for wildlife and pollinators;
- intercepting pesticides and chemical-laden dust to protect organic fields.

The ecological functions of windbreaks indirectly have a positive impact on crop yields, enhancing their economic function.

Social (public) functions of windbreaks include:

- opportunities for creating additional jobs;
- improvement of working conditions in nature;
- reduction of heating costs for estates surrounded by forest plantations;
- creation of a visual screen and conditions for aesthetic pleasure and recreation in a protected natural environment;
- clearing roads from snow, which improves traffic safety.

Riparian forest buffers are adjacent to lakes, wetlands, rivers, and other water sources. The main functions of riparian forest buffers are as follows:

- protection of crop lands and settlements downstream of rivers from damage caused by floods;
- generating income from agricultural land that is often flooded;
- filtration of nutrients, pesticides and animal waste from agricultural runoff, and filtration of sediment from runoff;
- stabilization of eroding banks;
- providing shelter and food for fish and other aquatic organisms;
- providing habitat for wildlife and corridors for terrestrial organisms;
- providing a place for recreation;
- diversification of land users' and landowners' incomes through the use of tree species in the buffer zones of coastal forests that provide products such as nuts, fruits and ornamental tree flowers.

The *forestry* category applies to the cultivation of high-value crops under the protection of a managed tree canopy. This approach to growing crops ensures the use of vertical space and the interaction of plants and microclimate. The intensity of such use depends on the goals of the producer and the availability of markets for the products. Also important are the means for cultivating the land and arranging the farm.

Crops grown under forest seeds are called non-timber forest products. The most commonly grown are ginseng, scrofula, golden root, mushrooms, and ornamental ferns used in medicine, cooking, and for decorative purposes. Due to the demand and high value of some of these plants, they can no longer be found in their historical habitats. In addition, harvesting them in the wild is prohibited in most countries to prevent their disappearance. In this context, forestry is an important way to meet the demand for these plants and a source of income for families. Additional benefits of forestry include the fact that it helps to identify and control invasive plants in a timely manner. It also allows us to take the necessary pest control measures in a timely manner.

Forest pastures are created by introducing fodder into forests or planting trees, or, conversely, by planting trees on pastures. To create forest pastures, local nitrogen-fixing legumes and other pasture grasses are used with appropriate fertilization. Trees that can produce edible fruits or fodder for animals, such as acorns, are also used. This ensures income from both livestock production and the sale of fruit trees products. The basis for managing the use of such forest pastures is the organization of rotational grazing with minimal damage to the trees. One of the advantages of forest-pasture systems is the reduction of heat stress of animals, which improves their productivity and well-being. Forest pastures increase the diversity of wildlife (e.g., quail) and improve water quality. In addition, the grass cover enriches the soil with organic matter, and together with trees, it protects the soil from wind and water erosion. Moreover, forest pastures form an attractive agricultural landscape with features of a park environment, which has a positive impact on people's working conditions.

Alley cropping (or intercropping) is defined as planting rows of trees or shrubs to create alleys for growing crops. Trees can be forest species for the production of, for example, timber, or fruit, nut and other specialty tree crops. As they grow, trees and shrubs have a positive effect on light, water and nutrient conditions in the field. A crop rotation is introduced between tree plantings to ensure the production of different types of agricultural products. Growing several appropriately selected crops in close proximity to each other under the cover of tree plantations improves the microclimate. This helps to increase yields.

The creation of all agromelioration systems is considered a part of agricultural activities.

So, in general, the key concept of all categories of agroforestry is to plant trees in the right place for the right purpose:

- to protect soil, animals, crops, houses from extreme weather conditions;
- improve water quality;
- create additional jobs;
- to produce products for additional income (food, fiber, bio-raw materials, flower and medicinal plants, etc.);
- provide habitat for wildlife;
- improve the habitat for pollinators;
- contribute to the reduction of carbon and other greenhouse gases;
- mitigate odors;
- improve agricultural landscapes.

Promoting the development of agroforestry is an important component of US agricultural policy. The Strategic Framework Program for Agroforestry of the Ministry of Agriculture for the 2010-2024 fiscal years is a roadmap for the development of this industry. It aims to improve the science and practice of agroforestry. The program covers all states of the country, ensuring a unified approach to its implementation. The Strategy implementation functions are distributed among several key structures. These include the Executive Steering Committee for Agroforestry, the Interagency Agroforestry Group, and the National Agroforestry Center of the Ministry of Agriculture. Each of these structures performs specific tasks within the overall Strategy (U.S. Department of Agriculture, 2024).

In the European Union, Article 23 of Regulation 1305/2013 defines agroforestry. It is described as “a land use system in which trees are grown in combination with agriculture on the same land”. A broader definition of agroforestry describes it as the practice of deliberately integrating woody vegetation (trees and shrubs) with systems of agricultural crops and/or animals. The aim is to benefit from the ecological and economic interactions that result from such integration (European Union, 2013).

A brief definition of agroforestry in the practical European literature is agriculture with the use of trees. It includes both the cultivation of trees on agricultural land and the use of crops and animals in forest plantations.

Agroforestry covers the area where trees and shrubs are integrated with either crops, livestock or mixed farming (Figure 33).

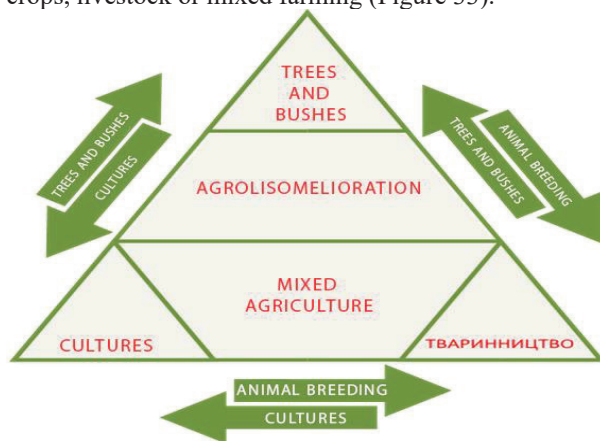


Figure 33. Agromelioration is the integration of trees and shrubs with crop production, livestock production or mixed farming. *Source:* Raskin B., 2019.

In Europe, the classification of agroforestry systems is close to the classification in the United States. In Europe, the classification of agroforestry systems is close to that in the United States. The AGROFORWARD research project (R. Mosquera et al., 2016) also distinguishes five types of agroforestry in European countries (Eurostat, 2025):

- forest-pasture agroforestry: a combination of trees and farm animals;
- forestry agroforestry: a combination of trees and crops;
- protective strips, riparian buffer strips and hedgerows: linear plantations of perennial vegetation (trees, shrubs) bordering arable land, pastures, water sources to protect agricultural crops, livestock, water and soil quality;
- forestry: the cultivation of special crops in the forest environment for medical, decorative or culinary purposes;
- home gardens: a combination of trees and food production for the home.

A similar classification is proposed by Lawso et al. (2016). Agroforestry as a “high social value” is recognized by Council Regulation (EC) No. 1698/2005 on the support for rural development. Since the 2007-2013 program period, agroforestry has been receiving financial support through the European Agricultural Fund for Rural De-

velopment. In addition to direct payments per hectare of agroforestry and compensation for planting different types of forests, farmers can receive additional support. This support is provided through programs aimed at supporting non-productive investments to achieve macro-environmental and climate goals and investments in infrastructure. At the same time, the Common Agricultural Policy provides for the right of additional support for agroforestry measures by national governments of EU countries.

The European Agroforestry Federation (EURAF) has been established in the EU. Its goal is to promote the use of trees on farms, as well as the development of any type of forestry in different ecological regions of Europe. EURAF has more than 500 members from 20 different European countries (European Agroforestry Federation, 2024). For the program period 2021-2027, increased attention is paid to agroforestry due to the growing negative impact of changes in climate conditions on the development of agriculture and the state of the environment. Out of the eight strategic measures of the new CAP, three are related to support for agroforestry.

Agroforestry is given an important place in the European Green Deal. In particular, the biodiversity conservation strategy envisages the active use of measures to support agroforestry as part of rural development. This is due to the great potential of agroforestry to provide many benefits for biodiversity, people and the climate.

The “Farm-to-Fork” strategy, which aims to build a healthy and environmentally friendly food system, emphasizes that the CAP will provide a “major funding stream” to stimulate sustainable agricultural practices in the allotted period. This includes practices such as precision agriculture, agroecology (including organic production), carbon farming, and agroforestry (Eurostat, 2025).

In Ukraine, the history of agroforestry dates back to the 18th century, when V. Y. Lomikovsky, the owner of an estate in the village of Trudolyub in the Myrhorod district of Poltava province, afforested all uncultivated land and lowlands. He also enclosed the boundaries of the fields with forest strips and organized the local river, hayfields and pastures. There is information in the magazine “Forestry” of the time that in the dry years of 1831 and 1833, V. Lomykowski's farm, thanks to agroforestry work, received good grain harvests. In 1836, 37 bales of spring wheat were harvested per tithe, while this crop did not grow at all in the county (Lomikovskiy V.Ya., 1837).

The scientific justification of the role of shelterbelts in agricultural landscapes is related to the ideas of V.V. Dokuchaev on the harmonious balance of arable land, forests, meadows and water bodies. According to these ideas, the creation of a system of shelterbelts is one of the most radical ways to ensure the sustainability of agroecosystems.

The science and practice of the 20th century and the present confirm that by changing the microclimate, water regime and soil trophicity in agrocenoses, field protection plantations thereby contribute to increasing their productivity (Table 33).

Table 33

Changes in wind speed in forest protection belts and adjacent areas

TYPE OF FOREST BELT	WIND FORCE (REVOLUTIONS / MIN)						
	BEFORE THE FOREST BELT			IN THE FOREST BELT	BEYOND THE FOREST BELT		
	30 m	20 m	10 m	0	10 m	20 m	30 m
PINE	138	115	96	61	70	80	83
BIRCH	134	120	102	74	76	82	90
POPLAR	135	130	120	96	110	120	125

Notes. The wind strength is noticeably weakened: in the pine belt - by 56%, in the birch belt - by 45%, in the poplar belt - by 25%. *Source:* State Statistics Service of Ukraine. Statistical collection, 2021

Compared to open areas, wind speed decreases by 26% behind the pine forest belt, by 25% behind the birch forest belt, and by almost 10% behind the poplar forest belt, which reduces wind erosion and, consequently, preserves soil productivity. The same trend is observed in the impact of shelterbelt plantations on the moisture of adjacent areas (Table 34)

Table 34

Air moisture in the forest belt and the adjacent area

TYPE OF FOREST BELT	MOISTURE (%)			
	IN THE FOREST BELT	IN THE ADJACENT AREA		
		10 m	20 m	30 m
PINE	89	82	74	70
BIRCH	85	82	76	71
POPLAR	82	80	72	70

Source: State Statistics Service of Ukraine. Statistical collection, 2021

Compared to open areas, moisture increases by 22% in the pine forest belt, by 18% in the birch forest belt, and by 15% in the poplar forest belt.

At a height of 150 cm in the inter-belt space, the relative air moisture is 8-10% higher than in the open steppe.

In the area influenced by protective and other forest plantations, moisture reserves in the one-meter soil layer increase by 30-50 mm. Forest belts promote the accumulation of biogenic elements in the soil profile and enhance soil humification processes. Over 30-50 years of positive impact, shelterbelts in the chernozem steppe can improve soil quality by 25% (Pylypenko, O.I., Yuhno, V.Yu. & Vedmid, M.M., 2004).

In inter-belt fields, the average crop yield increase is 13%. Increasing the forest cover of agricultural landscapes by 1% can result in a grain yield increase of 0,5 Mt or more per hectare (Gladun, H.B., 2005).

In the Bug-Dnipro forest reclamation district, when the area of arable land protected by field forest plantations increased from 18% to 42%, the grain crop yield almost doubled (Stadnyk, A.P., 2008; Furdychko, O.I. & Stadnyk, A.P., 2008).

The ecological functions of agroforestry reclamation plantations are difficult to assess using traditional economic indicators. This is because these functions lack a tangible material essence and are not products. At the same time, this goal can be achieved by determining the extent of their impact on improving labor efficiency.

This includes preventing losses and fostering the development of agricultural production. In other words, the economic assessment is based on the effect of using agroforestry plantations as a means of labor in agricultural production.

In scientific literature, the following formula is used to evaluate this effect (Danylyshyn, B., Droguntsov, S., Mishchenko, V., Koval, Y., Novotorov, O. & Palamarchuk, M., 1999, p. 386-388):

$$R_{pf} = \left[\frac{bS_m(C_m K_p - C_i)}{E_c} \right], \text{ where} \quad (1)$$

R_{pf} – Economic value of the *protective function* of forest plantations, UAH;

C_m – *Marginal costs* of producing 0,1Mt of crop production depending on the influence of forest plantations;

C_i – Individually aggregated costs for producing 0,1Mt of crop production;

b – Average weighted yield of agricultural crops per 1 hectare of land area, 0,1 Mt;

S_m – Area of land *subject to melioration*, hectares;

K_p – *Productivity* (efficiency) *coefficient*;

E_c – *Capitalization coefficient equal to 0.12*.

The *marginal costs* (C_m) consist of expenses related to restoring *soil fertility* (S_f) lost due to erosion, technological costs for cultivating *protective plantations* (Z_o), and costs from withdrawing agricultural lands for creating forest plantations (P_o):

$$C_m = F_s + P_p + P_f \quad (2)$$

Determining the costs of restoring soil loss due to erosion methodologically involves establishing the cost of compensation by adding fertile soil or fertilizers in amounts equivalent to the value of the eroded substances. The costs of these measures are calculated using the following formula:

$$R_s = \sum_i^m C_i * Q_i, \text{ where} \quad (3)$$

C_i – the cost of compensating for the i -th resource (soil, organic fertilizers, etc.), including delivery and spreading expenses, UAH/ton..

Q_i – the quantity of the i -th resource (soil, fertilizers, etc.) equivalent to the losses on eroded lands, tons.

Technological costs for the creation and cultivation of protective plantations consist of capital investments and operational expenses (thinning, reconstruction, soil preparation, planting of crops). All expenses for growing forest plantations typically occur periodically rather than as a one-time cost. Therefore, in calculations, these costs are adjusted to a base period in accordance with the recommendations of the *Temporary Standard Methodology for Determining the Economic Efficiency of Environmental Protection Measures and Assessing Economic Damage to the National Economy Caused by Environmental Pollution*, using the following formula:

$$C_t = \sum_{t=t_0}^T \frac{K_t + C_t}{(1+K_{OC})^{t-t_0}}, \text{ where} \quad (4)$$

K_t – capital investments for the creation of protective plantations, UAH/ha;

C_t – operational costs for cultivating plantations, UAH/ha;

K_{OC} – standard coefficient for adjusting costs occurring at different times, equal to 0.03;

t_0 – the base period to which the costs of year t are adjusted;

T – the operational period of protective plantations, years;

t_0 – year of establishment (planting) of forest plantations.

The base period is considered to be the year of the establishment of protective plantations, the execution of thinning, and other forestry activities. All technological costs are calculated per 1 hectare of agricultural land, per 1 hectare of protective plantations, and per the production of 0,1Mt of crop products.

Losses associated with the withdrawal of productive lands for protective plantations (belts) are determined by the amount of profit that could have been generated from their use in agricultural production. These losses are calculated using the following formula:

$$P_0 = S_p b_i (P - C), \text{ where} \quad (5)$$

S_p – the area of productive land withdrawn for protective plantations, hectares;

b_i – the average yield of the i -th crop per 1 hectare, 0,1Mt;

P – The purchase price of undifferentiated crop products, UAH;

C – The cost price of undifferentiated products, UAH.

More complex formulas and calculations are also used. In other words, the established approach to the economic assessment of the ecological functions of agroforestry plantations is still in the development stage.

Research has shown that the average increase in yield on fields protected by forest belts ranges from 0,5 to 1,0 Mt per hectare. The following formula, proposed by V. Dmyterko and I. Medvedev, is used:

$$V_i = V_{sh} S_i - V_{wp}, \text{ where} \quad (6)$$

V_i – Increase in yield per hectare of shelterbelts depending on their height in the i -th year, in feed units;

V_{sh} – the average yield increase from the reclamation effect of shelterbelts, measured in feed units;

V_{wp} – the average crop yield per hectare without the protection of agroforestry plantations, measured in feed units;

S_i – the area of land influenced by 1 hectare of shelterbelts of the i -th age, hectares.

The latter is calculated using the formula:

$$S_i = \frac{H_i R (L_1 K_1 + L_2 K_2)}{(L_1 + L_2) W}, \text{ where} \quad (7)$$

L_1, L_2 – The length of main and auxiliary forest belts, respectively, in meters;

R – the range of effective protection provided by forest plantations, meters;

K_1, K_2 – correction coefficients for field protection from winds of various directions corresponding to main and auxiliary forest belts (for the Steppe zone, for example $K_1 = 0,8$; $K_2 = 0,3$);

W – the width of the forest belts, meters;

H_i – The height of the forest belts in the i -th year, meters.

Ukrainian scientific literature and legislative acts distinguish two types of agroforestry reclamation measures: the creation of water-regulating field forest belts and protective forest plantations along the shores of water bodies. The purpose of the first is to protect soil from water erosion. The second aims to prevent shoreline flooding, reduce siltation of water bodies, and decrease water surface evaporation (Holian, V., Sakal, O. & Holub, O., 2015). The essence of agroforestry reclamation lies in the creation of protective forest plantations to safeguard agricultural landscapes from wind erosion through shelterbelts and their systems (Shum, I., 2013).

According to Ukrainian legislation, field forest plantations include areas that serve the function of protecting the environment. They also ensure the protection of engineering structures from the negative impacts of natural and anthropogenic factors. The creation of shelterbelts forms the foundation of agroforestry reclamation.

The "Strategy for the Prevention and Adaptation to Climate Change in Agriculture, Forestry, Hunting, and Fisheries until 2030" was developed in accordance with the decree of the Cabinet of Ministers of Ukraine dated December 6, 2017. It aims to increase the area of linear forest plantations on agricultural lands, particularly field shelterbelts. Additionally, the strategy includes measures to prevent forest degradation, support forest cover resilience, and increase the overall forested area of the country.

To adapt shelterbelts to global climate change, the following strategic measures have been identified:

- supporting the sustainable shelterbelt cover and increasing its area by incorporating tree and shrub species with enhanced resilience to changing climatic conditions;
- ensuring the preservation of existing and growth of potential biodiversity in shelterbelts;
- rationally combining natural and artificial methods for forest regeneration and afforestation of shelterbelts to ensure the stability of the formed forest species;
- increasing the proportion of mixed forest species within shelterbelts.

However, the proposed measures are not supported by specific tasks with appropriate funding. A similar situation occurred with other previously adopted documents. Among them are the Law of Ukraine "On the National Program for the Formation of the National Environmental Network for 2000–2015," the "Concept for the Development of Agroforestry Reclamation in Ukraine" (2013), and the "Action Plan for the Implementation of the Concept for the Development of Agroforestry Reclamation in Ukraine" (2014). As a result, since the late 1990s to early 2000s, the creation of new shelterbelts has virtually ceased. The network of old shelterbelts in Ukraine's agro-landscapes covers only 30% of agrocenoses, including all other types of adjacent forest

plantations, this figure increases to about 40% (Furdychko, O.I. & Stadnyk, A.P., 2008).

Under changing climate conditions, the functioning of shelterbelts is significantly altered. Their resilience, as individual elements of agroecosystems, is also undergoing changes. This impacts their ability to perform protective functions. During the period of rising average annual temperatures, significant changes in natural and hydrological conditions have occurred. These changes have led to the rapid degradation of shelterbelts. Previously, the decline of field forest plantations was characterized by the dieback of individual trees or small groups of trees. However, the situation has now changed. Sudden dieback of plantations, especially pine and oak, is observed. This phenomenon occurs regardless of their age, type, or location conditions.

The area of shelterbelts is decreasing. This is due to trees being affected by pests and diseases, which are spreading more intensively as a result of climate change. Diseases significantly reduce the resilience of trees to adverse environmental conditions. They also cause plant dieback, which negatively impacts the overall condition of the shelterbelts. Shelterbelts that are located individually perform their functions in agro-landscapes with low efficiency. This is particularly true for those that exceed scientifically justified distances between them.

Anthropogenic depletion and vulnerability to global climate change lead to the formation of gaps in shelterbelts, which become overgrown with natural regeneration, undergrowth, and saplings, among others. Such processes of spontaneous renewal of shelterbelts lack significant ecological importance for preserving the agroecosystem and contribute to degradation processes within the shelterbelts themselves (Tarariko, O.H. et al., 2012).

The increase in average annual temperatures and the shift of agroclimatic conditions from south to north negatively affect the functioning of certain tree species in shelterbelts. This impact is also observed in crop production. The reduction in precipitation during winter months critically affects shelterbelts with shallow root systems. Under these conditions, soil moisture in the one-meter layer decreases by 15–30%. Rising winter temperatures lead to milder climates. This results in a significant expansion of the range of certain forest pest insects and tree disease pathogens, causing the death of a substantial portion of trees. The decrease in the amount and frequency of precipitation impacts the soil water balance. Consequently, the sanitary condition of shelterbelts deteriorates.

All the mentioned factors reduce the environmental protection function of shelterbelts. This exacerbates soil degradation processes and negatively affects the yield of agricultural crops.

The existing shelterbelts are degrading not only due to the aforementioned factors related to climate change and the degradation of land and plantations. Additionally, the situation is exacerbated by the legal uncertainty surrounding property and land use rights for agricultural areas (Storchius, O., 2017).

A large part of the existing shelterbelts were established in the postwar period of the last century by collective and state farms and were on the balance sheet of these enterprises. Shelterbelt projects were developed as part of on-farm land management projects. The Ministry of Agriculture financed the creation of shelterbelts on farmland

through the Ministry of Agriculture. At the same time, measures to create anti-erosion forest plantations in ravines, gullies, and along the banks of rivers and water bodies were financed through ministries and state forestry committees.

With the beginning of land reform, collective and state farms were transformed into collective agricultural enterprises (CAEs). As a result, these enterprises became the collective owners of agricultural land, including shelterbelts. However, the Land Code of Ukraine of March 13, 1992 (Article 5) classified shelterbelts, as well as on-farm roads, as public lands of the CAE. The violation of the legal unity of agricultural land and shelterbelts intended to protect it has created a number of problems. In the process of dividing agricultural land among the members of the CAE, shelterbelts as public land were transferred to the jurisdiction of local councils (Kulinich, P.F., 2005).

Thus, they became strangers to the new business entities created as a result of the reorganization of the CAE. The legislation did not oblige them to take care of the field forest plantations, and they began to deteriorate. At present, more than 90% of the field forest protection belts are destroyed.

The Law "On the Ecological Network of Ukraine" of June 24, 2004, No. 1864-IV defined the special status of field protection strips and other protective plantations that do not belong to the forest fund. These plantations were included in the ecological network of Ukraine. Thus, they acquired the status of objects of environmental law.

An important issue is the designated purpose of the land plots on which the forest belts are located. Art. 22 of the Land Code of Ukraine, which established the definition of agricultural land, does not include shelterbelts in its structure. According to Article 55 of the Code, the land under shelterbelts is classified as forestry land. In other words, part of the agricultural land occupied by shelterbelts and other protective forest plantations was transferred to another forestry category. As a result of the unclear and contradictory legal regime of shelterbelts, a significant part of them ended up in different spheres of administrative control. About a quarter of shelterbelts remained under the jurisdiction of the Ministry of Agrarian Policy, mostly shelterbelts of farms that retained their property complex after the reorganization of the CAE and did not sublease land to agricultural holdings. Approximately 70% of the forest belts are located on reserve lands or lands not transferred for permanent use, while the rest are managed by the State Committee of Forestry and Range Administration. Additionally, while Articles 90 and 96 of the Land Code of Ukraine obligate landowners and users to preserve and protect their land plots, they do not provide for the maintenance of shelterbelts located on them. Such obligations are also not established by the Law of Ukraine "On Land Protection".

The legislation does not assign any of the entities responsible for shelterbelts the function of organizing of field protection afforestation. A similar situation applies to other protective forest plantations. Virtually all agroforestry reclamation stations (specialized state organizations responsible for establishing shelterbelts) have now been dissolved.

Due to such an improper approach by the legislator to agricultural land use relations, shelterbelts have been devalued. They are no longer considered a critical factor in protecting agricultural lands from wind and water erosion or in combating climate change. Moreover, their role in preserving soil fertility has diminished, and they are

not treated as an object of state intervention. This has resulted in the destruction of existing shelterbelts and the complete absence of new ones being established. The main issues concerning the condition of shelterbelts, which require immediate measures for resolution, include:

- lack of systematic maintenance;
- gradual dieback of tree stands (poplar, birch, acacia, etc.);
- spread of pests and diseases;
- shading near windbreak belts, which can cause stunted growth and delayed development of plants in the fields;
- littering (glass, plastic, construction debris);
- pollution (pesticides, mineral fertilizers, emissions of harmful substances from vehicles and trains);
- hazardous zones resulting from military actions;
- climate change, including the aridification of climatic conditions and an increase in the frequency of hazardous weather events.

The Concept for the Development of Agroforestry in Ukraine (2013) outlined measures aimed at solving the problem of agroforestry development. It provides for the improvement of the forestry and melioration condition of protective forest plantations of linear type and the creation of scientifically based technologies on their basis. In the context of low forest cover in Ukraine and EU practices in this area, the priority areas for climate change prevention and mitigation in forestry should be:

- increasing the area of forests, forest belts, and green spaces in general, optimizing the structure of land use by reducing arable land and increasing forest cover by 20% in accordance with the Sustainable Development Goals for the period up to 2030;
- improving business practices based on climate-oriented forestry methods (Climat Smart Forestry);
- development and implementation of the national forestry development program, taking into account the priorities of low-carbon development, climate change and cross-sectoral cooperation.

The following measures are also important for climate change mitigation (Buksha, I., 2018) and adaptation as well as forestry development in this context:

- formation of a positive image of forestry activities as a basis for stabilization of the rapidly changing natural environment;
- promoting the popularization of the principles of “green” economy and climate-adapted forestry;
- promoting scientific research on the interaction between climate change and forestry;
- dissemination of publications in the mass media on the topic of “Forest and Climate Change”;
- revision of regulations on the selection of forest tree and shrub species, timing of forest planting and the implementation of forest protection measures;
- institutionalization of financial support for climate mitigation measures in conjunction with forestry development.

Regarding the latter, it is important to study the experience of the European Union. The EU supports forestry, particularly through the Common Agricultural Policy (CAP). Under Pillar II of the CAP, financial support is provided for the development of rural areas. EU countries can choose to fund forestry interventions through their national strategic plans. These measures are aimed at protecting forests and enhancing their resilience to climate change. They also ensure the preservation of the numerous functions of forests, including the provision of ecological services. Additionally, they provide support for investments, innovations, and training to benefit the rural economy.

In the forestry sector, these measures can support investments aimed at:

- afforestation or the creation of forested areas and reclamation plantations, including both their establishment and maintenance;
- creating and maintaining new agroforestry reclamation systems or regenerating and reconstructing existing ones (where trees and agricultural crops or pastures occupy the same land);
- preventing damage to forest systems caused by fires, natural disasters, or catastrophes, as well as restoring damaged forests;
- investing in enhancing the climate resilience and ecological value of forest ecosystems;
- investing in forestry technologies, mobilization, processing, and marketing of forest products;
- land management agreements for forest-ecological-climatic services and forest conservation;

For these purposes, €8.2 billion was allocated between 2014 and 2020. Additionally, European structural and investment funds play an active role in financing climate change adaptation measures. This approach continues under the New CAP framework until 2027.

Based on the practices of Western European and other countries, agroforestry reclamation should be regulated within the Ukrainian legal framework. It is an essential tool for supporting sustainable long-term agricultural production. Different categories of agroforestry reclamation provide opportunities for agricultural and forestry enterprises to diversify their production. This helps increase profitability and reduce risks associated with market instability and extreme weather conditions. At the same time, agroforestry reclamation improves the ecological environment for human livelihoods.

Agroforestry reclamation should become part of a national approach to protect agricultural lands. It is also aimed at improving their productivity, safeguarding the environment, and promoting human health. The expansion of agroforestry reclamation in the 21st century will greatly depend on the combined efforts of various stakeholders. Active participation by state institutions, scientists, landowners, and land users is particularly important. Other entities involved in agriculture should also contribute to this process. The practice of agroforestry reclamation demonstrates the potential to combine profitability and productivity in agricultural production with the conservation of natural resources. This contributes to the creation of healthy and sustainable agricultural systems. Such systems meet the needs of the current generation while serving future generations.

2.7. FORMATION OF ECOLOGICALLY SUSTAINABLE AGRO-LANDSCAPES.

Agricultural landscapes were formed by humans as a result of the transformation of natural landscapes for the production of agricultural products. At the same time, they continue to develop in accordance with natural laws and constitute one of the genetic series of natural landscapes. Failure to recognize or ignore the natural patterns of agrolandscape functioning by humans creates a conflict between their natural and economic components. This causes significant negative environmental and social consequences. The ability of agricultural land to withstand water erosion and deflation is decreasing. There are changes in the balances of organic matter and chemical elements in soils, and climate aridization is intensifying. In addition, the groundwater level is changing, and natural components are losing their ability to regenerate themselves.

The damage that humans cause to the natural components of the agricultural landscape turns into a boomerang for the human. Hence, the urgency of transitioning to the formation of productive and sustainable agricultural landscapes. They should be able to withstand water and wind erosion, flooding and salinization. Such agricultural landscapes should maintain soil fertility, not disturb balanced ecological systems and contribute to their stabilization. It is important that they ensure the overall ecological balance of agro-landscape areas. In addition, such systems should be able to be restored in the course of economic activity with minimal operating costs. The creation of such agro-landscapes fits into the paradigm and goals of sustainable development and the tasks for their achievement, as defined by UN documents (UN, 2018; UN, 2015).

In the scientific literature, agro-landscape is defined as an anthropogenic-natural territorial system. It is an integrated natural and production structure adapted to agricultural production. Such production should be scientifically sound, environmentally rational and economically viable. It should ensure the preservation and development of the natural foundations of agriculture, not contradict environmental protection and maintain the organization of the biosphere (Burakov, V.I., 1997; Dubinsky, H.P. & Burakov, V.I., 1985).

As a type of landscape, agro-landscape is a geographically separated area of the earth's surface, characterized by the unity and close interconnection of its components (Bulyhin, S.Yu., 2005, p.167). According to the European Landscape Convention (European Landscape Convention, 2006), a landscape is defined as a territory as perceived by people, the character of which is the result of the action and interaction of natural and/or human factors. Hence, an agro-landscape is a certain territory that includes, in addition to agricultural land, other natural components located on this territory.

The main difference between agroecosystems and natural biogeocenoses is the openness of the nutrient cycle (circulation of biogenic elements). This is due to the alienation of crops, which leads to the loss of nutrients. As a result, there is a need for active human participation in compensating for these losses. At the same time, it is important to observe the regularities of the functioning of natural components.

Agricultural landscapes include arable land, hayfields, pastures, perennial plantations, natural meadows, bogs, peatlands, forest plantations, etc. Tarariko, O.H. & Lobas, M.H., 1998). Arable land is intensively used and is a destabilizing factor in the

agricultural landscape. In contrast, extensively used lands such as hayfields, pastures and forests are a stabilizing factor (Babmindra, D.I., 2004, p.20). The state of the agricultural landscape as a self-organizing system depends on the ratio of factors that stabilize and destabilize it. With an increase in the level of agricultural development and plowing of land, which is not justified by science, the ecological sustainability of landscapes is significantly reduced (Sokhnych, A.Ya. & Tiblyova, L.M., 2005, p.22). To preserve it, i.e. to achieve ecological balance in agricultural landscapes, it is necessary to adhere to scientifically determined and practically proven ratios of arable land and stabilizing lands at the local, regional and national levels (Babmindra, D.I., 2004, p.22; Babmindra, D.I., 2001, p.28). This is the basis of the landscape approach to the organization of agricultural land use. The essence of the approach is to create a system of cultural agricultural landscapes throughout the country. In these agricultural landscapes, the structure and ratio of components should exclude anthropogenic processes of natural resource destruction.

One of the main principles of building agrolandscapes is also the compatibility of agrolandscape elements with the structure of natural complexes, which requires compliance with laws and regulations of ecology. According to the law of necessity of biodiversity, no natural system can be formed from identical elements. The ecological stability of natural systems is directly proportional to biodiversity. Decreasing biodiversity leads to a simplification of the natural system and a decrease in its environmental stability. This is important to take into account, as agricultural activities are associated with the transformation of natural landscapes into agricultural landscapes, which is accompanied by a decrease in biodiversity.

According to the law of equivalence of all living conditions (Liebig's Law of the Minimum), all conditions necessary for life play an equally significant role. This necessitates the comprehensive regulation and maintenance of the functioning of all components of agro-landscapes.

The law of geographical zonation defines the basic principles of the relationship between system-forming factors and the properties of landscape components. Changes in the structure of natural landscapes, plowing of land, irrigation and drainage of land, and other human activities are accompanied by disruption of historically established heat, water, geochemical and biological balances. This leads to an increase in climate aridity, soil erosion, soil deflation, acidification, and salinization. According to the law of successive phases of development, natural landscapes evolve from relatively simple to complex. Agricultural landscapes, on the other hand, change from complex to simpler. The consequence of this law is the chain reactions that occur in landscapes. Changes in one component of the landscape lead to changes in all the others and, ultimately, to the transformation of the entire agro-landscape system.

Landscapes in natural settings use available energy, matter, and information to maintain and develop themselves. In agricultural landscapes, a significant part of energy and matter is alienated with the harvest. As a result, the balance of organic matter and chemical elements is disturbed, which, according to the rules of basic metabolism, leads to degradation of agricultural landscapes. According to the rule of ecological duplication, when natural landscapes are transformed into agricultural landscapes, certain species of living things necessarily disappear or are destroyed. They are replaced at the

same time by other species that correspond to a certain ecological scheme. In particular, a small organism replaces a large one, an evolutionarily less organized one replaces a more organized one. A more genetically modified species replaces a less genetically modified one. As a result, a new ecological niche is emerging that can be epidemically threatening to humans.

The rule of ecological optimization of agricultural landscapes involves the creation of an ecological framework consisting of three main components. The first component is formed by natural areas such as forests, meadows, hayfields and pastures. The second component is agricultural land, primarily arable land. To create a unified structure of the ecological framework, the natural environment is being restored in these areas through the restoration of hayfields and pastures. The third component is formed by artificial elements necessary to maintain ecological balance. These include field protection and water protection forest strips.

According to the law of optimality, every natural system functions normally within its characteristic structural and temporal limits. The more the natural structure of landscapes is disturbed, the more they are affected by external factors and the more strongly the processes of destruction of agricultural landscapes develop.

The problem of creating sustainable agricultural landscapes is extremely important for Ukraine. According to experts (Voloshenko, S.I., 1991), the anthropogenic load with the corresponding negative consequences is 7-9 times higher than in neighboring and other countries.

Excessive anthropogenic pressure leads to a violation of the natural properties of soils, water bodies and the biotic component of ecosystems. It also causes a loss of their self-healing capacity.

Agricultural landscapes are degraded, which negatively affects soils and biodiversity. In addition, the quality of surface and groundwater is deteriorating, which generally reduces the productivity of agroecosystems.

The current agricultural landscape of Ukraine is characterized by a deformation of specialization and concentration of agricultural production. It is accompanied by the formation of unbalanced land uses in terms of size and ratio. There is also an imbalance in the organizational orderliness and territorial structure of agricultural landscapes. This destroys their components and leads to a deterioration in the environmental and economic conditions for production activities and human life.

The natural ecosystems of modern agricultural landscapes have lost their state of constant balance. This is a result of the deep specialization of agricultural production, expansion of sown areas, and reduction of ecologically stabilizing lands. An additional factor is the growing anthropogenic load. As a result, natural ecosystems have acquired other characteristics, including the dominance of certain species and populations of flora and fauna. The structure of biomass has become unstable, with a depleted species composition characteristic of monoculture production. The natural and industrial components of agricultural landscapes in large areas have been disrupted by military operations.

An effort to implement a landscape approach to the organization of agricultural land use was made by a legislative initiative. In 1998, the Verkhovna Rada of Ukraine adopted the Resolution "On the Main Directions of the State Policy of Ukraine in the

Field of Environmental Protection, Use of Natural Resources and Preservation of Environmental Safety”. This document laid the groundwork for the introduction of new approaches to land use. Its goal was to combine environmental and economic interests in agricultural production. It aimed to optimize the structure of land and create highly productive, environmentally sustainable agricultural landscapes at the national level by:

- reducing the plowing of arable land to 50%;
- increasing the share of meadows, hayfields and pastures to 17-20%;
- increasing the country's forest cover to 20%;
- increasing the area of the nature protection fund to 5%.

However, in the process of land reform, the problem of forming sustainable agricultural landscapes fell out of the legislators' sight, so none of the above provisions of the Resolution was implemented.

In the Concept of Balanced Development of Agroecosystems in Ukraine for the period up to 2025, approved by the Order of the Ministry of Agrarian Policy of Ukraine No. 280 of August 20, 2003.

This resolution provided for a scientifically based transformation of the structure of agricultural land. Its goal was to form a balanced relationship between the individual components of agroecosystems and to ensure ecological safety and balance of the territory. Among the tasks was to increase the share of agricultural land for extensive use, such as hayfields and pastures, in accordance with scientifically sound indicators. It was also planned to reduce the area of arable land to 37-41% of the country's territory. This involved the withdrawal from arable land with slopes of more than 3 degrees, the territories of water protection zones, as well as degraded, unproductive and technologically polluted land (Ministry of Agrarian Policy of Ukraine, 2003).

This policy was specified in the State Target Program for the Development of Ukrainian Rural Areas for the period up to 2015, approved by the Cabinet of Ministers of Ukraine on September 19, 2007, No. 1158. This document states that the Program aims to address key issues of land protection, soil fertility and environmental safety in rural areas. This had to be achieved by implementing a set of measures. All measures are carried out in accordance with land management projects that provide for specific actions to achieve these goals:

- optimization of the structure of sown areas and crop rotation to increase the productivity of agricultural land, prevent erosion processes and restore soil fertility;
- improving the balance of humus and basic nutrients by increasing the use of mineral ... and organic fertilizers, including peat composts and organic plant residues;
- stimulating the withdrawal of degraded, unproductive and technologically contaminated agricultural land from intensive use;
- formation of an ecological network as an effective mechanism for the conservation of landscape biodiversity” (Cabinet of Ministers of Ukraine, 2007, p. 16).

However, these measures have not been transformed into concrete actions for their practical implementation and have remained unfulfilled.

This problem was returned to in connection with the adoption of Ukraine's Sustainable Development Goals for 2015-2030. It was assumed that the area of arable land would decrease from 32.5 million ha to 28.3 million ha, which will lead to a decrease

in their share in the total territory of Ukraine from 53.9 to 47.0. At the same time, it is planned to increase the share of hayfields, pastures, and other extensive use lands from 13% to 15.8%. These tasks are also not being fulfilled without any mechanisms.

As a result, from 2000 to 2020, the area of plowed land increased, while the area of hayfields, pastures and fallow land decreased (Table 35)

Table 35

Dynamics of the structure of agricultural land in Ukraine, 2000-2020

LAND RESOURCE POTENTIAL	YEARS					
	2000		2010		2020	
	area, th/ha	%	area, th/ha	%	area, th/ha	%
Land Fund	60400,0	100	60400,0	100	60400,0	100
Agricultural Lands	41827,0	69,3	41576,0	68,8	41310,9	68,4
including: arable land	32563,6	77,9	32541,3	78,3	32757,3	79,3
meadows	2388,6	5,7	2410,9	5,8	2283,9	5,5
pastures	5521,3	13,2	5481,9	13,2	5250,3	12,7
fallow lands	421,6	1,0	310,2	0,7	166,7	0,4
perennial plantations	931,9	2,2	896,5	2,2	852,7	2,1

Source: State Statistics Service of Ukraine. Official website

The highest agricultural development is in Vinnytsia, Kirovohrad, Cherkasy, and Kherson regions, with the highest levels of land development ranging from 84 to 88%. The level of plowing of the land fund in Ternopil, Zaporizhzhia, Mykolaiv, and Dnipropetrovsk regions is 80-83% (Table 36)

Table 36

Level of plowing of the land fund of Ukraine by administrative-territorial units

Region	Total area, th. ha	Share of arable land in the total area, %	
		of all lands	of agricultural land
Ukraine	60354,9	53,9	76,1
Polissya			
Volynskaya	2014,4	33,4	62,3
Zhytomyrska	2982,7	37,3	70,2
Zakarpatska	1275,3	15,7	42,6
Ivano-Frankivska	1392,7	28,4	61,4
Lvivska	2183,1	36,4	61,5
Rivnenska	2005,1	32,8	68,5
Chernihivska	3190,3	44,4	66,7
Forest Steppe			
Vinnyska	2649,2	65,1	83,6
Kyivska	2812,1	48,2	75,6
Poltavska	2875,0	61,7	79,7
Sumyska	2383,2	51,5	70,5
Ternopilska	1382,4	61,9	79,8
Kharkivska	3141,8	61,5	78,1
Khmelnyska	2062,9	60,7	78,1
Cherkaska	2091,6	60,8	85,5
Chernivetska	809,6	40,9	68,7
Steppe			
Crim	2608,1	48,8	68,6
Dnipropetrovska	3192,3	66,6	82,4
Donetska	2651,7	62,3	78,9
Zaporozhska	2718,3	70,0	82,8
Kirovogradska	2458,8	71,8	84,8
Luhanska	2668,3	47,9	65,3
Mykolayivska	2458,5	69,1	82,7
Odeska	3331,4	62,3	78,0
Khersonska	2846,1	62,5	87,5

Source: According to Form no 6L of the State Geocadastr of Ukraine.

In terms of soil types, black soil is characterized by the highest plowed area, which occupies more than 60% of the agricultural land in Ukraine, -89-92%, followed by chestnut and gray-forest soils, which are within 80% (Table 37)

Table 37

Level of plowed land by soil type

No	Soils	Agricultural land, th. ha	Arable land
1.	Podzolic Chernozems	3418,7	91,6
2.	Typical Chernozems	5279,6	91,8
3.	Ordinary Chernozems	10488,6	88,3
4.	Southern Chernozems	3639,9	88,8
5.	Light-gray forest, gray forest, and dark-gray podzolic soils	4333,4	80,5
6.	Various Chestnut soils	1382,9	80,0
7.	Brown soils	1110,0	43,9
8.	Sod-podzolic and other sandy soils	505,5	24,2

Source: Polupan, M.I., Solovey, V.B., Kysel, V.I., and Velychko, V.A. (2005) *Determination of the ecological-genetic status and fertility of soils in Ukraine*. Kyiv: Kolooobig. 296 p.

The plowed land is shown in Figure 34.

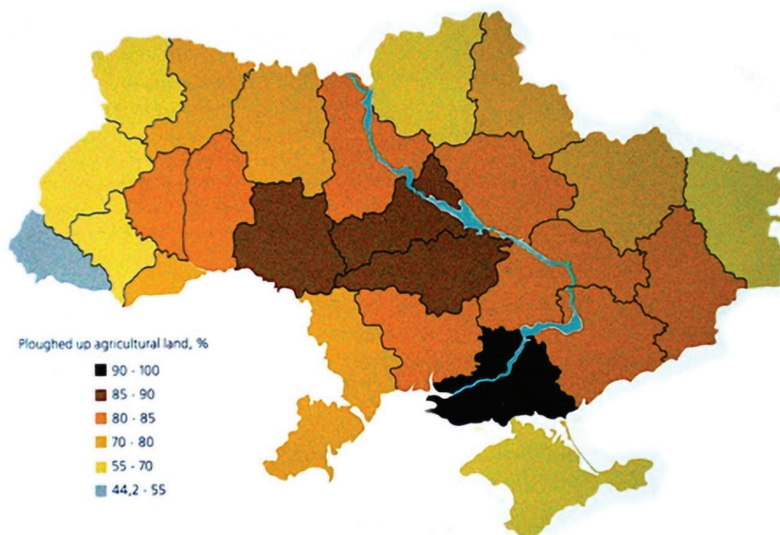


Figure 34. Plowing of agricultural land, %. Source: Compiled by the author based on data from the State Soil Conservation Service DI "Derzhgruntochorona"

The ratio between arable land and pasture and hayfields in Ukraine is 4:1, while in France and Canada, for example, it is 1.6:1, Spain 1.3:1, and the United States 0.7:1. Ukraine's forests and plantations occupy a much smaller area (15.9%, which is almost half as much as compared to France, for example). The ratio of the area of conditionally stable land (forests, shrubs, hayfields, pastures, etc.) to the area of arable land reflects the level of soil vulnerability to anthropogenic stress, expressed as the land stability coefficient.

The calculations show that the former include land resources of the northern and western regions, and the latter - of the southern and eastern regions.

Improving the resilience of land to anthropogenic pressure lies in changing the ratio between arable land and pasture, hayfields and forested land in favour of conditionally stable land, as is the case in Western European countries.

Intense erosion and other degradation processes have become a significant problem. This is especially true in the context of incomplete land reform. There is a need to reconstruct the existing agro-landscape disorganization of the territory. It is important to move to a scientifically based anti-erosion organization of the territory.

The main stage in the transition to such an organization of the territory is the creation of a *soil-protective contour-meliorative spatial structure of the agricultural landscape*. The main elements of such a system are permanent measures that help protect the territory. These include field protection forest belts and drainage earthworks. These elements guarantee the contour and reclamation organization of the territory. They are also the structural and spatial basis for the formation of erosion-resistant agricultural landscapes. Reconstruction involves:

- allocation of crop rotation areas, taking into account the steepness of the slope, soil erosion, and the intensity of modern erosion processes;
- selection and development of crop rotation schemes;
- determining the size of fields and their location on the territory;
- correct placement of field protection forest belts and other linear boundaries;
- selection of the location of hydraulic structures and alkalization areas (Barabanov, A.T., 1993).

Optimization of the structure of sown areas is considered the main, cheapest and most environmentally friendly measure to increase the productivity of the agroecosystem and soil erosion protection (Tarariko, O.G. & Lobas, M.G., 1998). In the system of contour ameliorative agriculture, the optimization task is carried out, first of all, by determining the ratio of the area of crop rotations of different types of land in ecological and territorial groups. The general principle of forming the structure of any group is to assess the ability of crops to restrain erosion processes. An important aspect is their role in restoring soil fertility. This includes maintaining a deficit-free humus balance. In addition, crops should ensure the highest productivity of agrophytocenoses based on a system of scientific standards.

The soil-protective capabilities of crop rotations are supplemented by strip crops. They also include alkalization of "beams" with intermediate crops and a number of other measures (Bezruchko, I.N., Milchevskaya, L.Ya. & Moskalenko, V.M., 1990). Strip cultivation is the easiest and cheapest way to protect arable land from melt and storm water. It is carried out by alternating strips of annual and perennial grasses, or alternating dense cover crops with strips of row crops. This method reduces the air flow rate by 20-25%, and the reserves of productive moisture increase by 10-18 mm.

A variation of strip cropping is buffer strips on pairs of annual and perennial grasses sown under the cover of the black fallow predecessor. In this case, soil washout is reduced by 10 times (Sazonov, I.N., Shtofel, M.A. & Pilipenko, A.I., 1984).

Afforestation is an important component of the anti-erosion organization of the territory and cultivation of agricultural landscapes. Forest ecosystems are superior to other

terrestrial ecosystems in terms of sustainability and quality of their impact on the environment. They have a positive impact on the climate and hydrological regimes of the area. They also contribute to soil formation and the development of flora and fauna. These ecosystems act as a kind of framework for natural landscapes in general and agricultural landscapes in particular. They are the main stabilizing element of their sustainable development. Forest ecosystems also play a crucial role in the strategy of ecological survival.

The combination of protective plantations, such as field protection, drainage control, riparian forest belts and massive forest plantations, plays an important role in agricultural landscapes. If they are created and function as a single system, they form a forest reclamation complex. This complex serves as the ecological framework of agroecosystems. In it, elements and subsystems interact, providing a synergistic effect (Stadnyk, A.P., 2008).

The expansion of forested areas is of great importance for Ukraine. This is due to the historical decline in the country's forest cover as a result of the expansion of arable land. It is estimated that Ukraine's forest cover has decreased by almost three times. Currently, it remains the least forested country in the EU (Table 38)

Table 38

Forest cover by natural zones of Ukraine, %

NATURAL ZONE	FORESTS IN THE PAST	CURRENT FOREST COVER	OPTIMAL FOREST COVER
Ukraine	44,4	15,9	20
including: Polissia	72,8	26,8	32
Forest-Steppe	52,0	13,0	18
Steppe	20,0	5,3	9,0
Carpathians	76,0	42	45

Source: Compiled by the author based on data from: Danilyshyn, B.M., Doroguntsov, S.I., Mishchenko, V.S., Koval, Ya.V., Novotorov, O.S. & Palamarchuk, M.M., 1999; State Forest Resources Agency of Ukraine, 2022

Deforestation, combined with high levels of plowing, non-crop rotation, and soil-destroying technologies, are the reasons that have led to a high level of land degradation. Scientists agree on the need to increase zonal forest cover to an optimal level. This implies the removal of highly fertile and unproductive lands from cultivation. In addition, it is proposed to withdraw land located on slopes with a steepness of more than 5°. Subsequently, these territories should be subjected to reclamation or afforestation (Babich, A.O., 1992; Burakov, V.I., 1992; Lidov, V.P., Setunskaya, L.E. & Khmeleva, N.V., 1956; Novakovskiy, L.Ya., Kanash, O.P. & Leonets, V.O., 2000; Saiko, V.F., 1997). In the Steppe zone, the area of such lands is 250-300 thousand hectares. A significant number of them are now additionally affected by military operations, which increases the need to withdraw them from cultivation.

In the Steppe zone, more than 900 thousand hectares of land are affected by erosion processes. These areas are located on slopes with a steepness of 3-5°. It is recommended to withdraw these lands from cultivation. Temporary conservation for a period of up to 10 years is proposed for their restoration. Some areas are subject to temporary conservation in the Forest-Steppe zone and Polissya.

Conservation of heavily eroded land is a well-established practice in Western European countries. It is widely used to preserve land productivity. In the United States, this practice is regulated by law. The Farm Bill, which has been passed every 6 years since 1985, sets a nationwide limit on the amount of land that can be conserved at any one time. This figure for 2022-2023 was 6.2 and 6.3 million hectares of agricultural land, respectively (U.S. Department of Agriculture, 2022). This is approximately 3% of arable land. In France, 450-500 thousand hectares are conserved annually, which is also close to the US figure.

Soil scientists believe that it is necessary to implement a similar program in Ukraine. It will help to restore valuable plant cover on eroded land. The program will help to improve water resources and prevent further development of soil erosion. In addition, its implementation will reduce the loss of favorable environment for the habitat of wildlife (Dobryak, D.S. & Kuzin, N.V., 2016).

The legislative act should implement the most effective practices of Western European and other countries in terms of:

- determination of the state structure to which land plots are transferred for conservation;
- rules for the transfer of land plots on the basis of lease and lease payments;
- mechanisms of partial state compensation to landowners for agro-environmental measures implemented on conserved lands: creation of meadows and pastures, reforestation, and wetlands;
- conditions for preserving the right of landowners to graze cattle, mow hay, collect grass seeds, and apply other methods of optimal use of the land transferred to temporary state management on the lands under conservation.

The conservation of lands should be carried out in stages. The first stage involves conservation of land in the Southern and Central Steppe regions. These areas have the largest share of eroded land, which reaches 50-80%. In addition to this, lands disturbed by military operations are subject to conservation. The national limit of eroded areas of land that can be conserved annually should be set at 500 thousand hectares. The program should become an important tool for restoring agricultural land and play an important role in mitigating the negative effects of climate change.

All components of agroecosystems of agricultural landscapes are significantly damaged by modern intensive farming systems. They include the use of large doses of mineral fertilizers for growing crops. In addition, the use of chemical plant protection products against weeds, diseases and pests also causes damage. Moreover, an additional factor is the use of soil-destroying machinery that negatively affects the soil structure. The use of pesticides leads to a loss of natural soil fertility. It also contributes to an increase in the species composition of pests that become resistant to chemicals. This process negatively affects the quality and preservation of agricultural products. Finally, it affects the health of people who consume such products. Nitrates, sulphates, chlorides and other elements migrate from mineral fertilizers into the soil in large quantities, posing a threat of toxic substances entering the environment.

The use of high-powered energy tools causes over-compaction and pulverization of the soil. This reduces its ability to absorb and retain moisture and air. Such changes contribute to the development of anaerobic processes that worsen the conditions for

microorganisms and soil fauna. This results in a significant decrease in the productivity of the soil cover of agricultural landscapes.

The solution to these problems lies in the transition to alternative agricultural systems developed by science and tested in practice. One of these systems is biodynamic farming, which combines the organization of production with the skillful use of biological cycles of plants and animals. Another approach is EM technologies, which are based on ensuring a balance between pathogenic and beneficial mechanisms. This helps to restore soil fertility, self-regulation in wildlife, and changes the self-defense of plants and animals. Organic farming also plays an important role, as it implements the ecological, socio-economic functions of agricultural landscapes in a complex.

All alternative technologies have common features. First, they involve minimal tillage and the replacement of chemicals with organic materials of plant and animal origin, as well as bacterial preparations. Secondly, the use of chemicals is limited, and the main emphasis is placed on integrated plant protection systems. These systems are based on the use of pest- and disease-resistant crop varieties, as well as on the application of biological, agronomic and other non-chemical control methods. Finally, biodiversity conservation and environmental health are key goals of such approaches.

In soil cultivation, agrotechnical measures play an important role in runoff regulation and erosion control, including:

- techniques aimed at improving water absorption - deepening the topsoil (non-dumping loosening), shielding, mowing.
- techniques aimed at surface water retention - transverse and contour plowing, creation of artificial nanorelief (hollowing, berming, etc.)
- methods that ensure high erosion resistance of the soil - surface and no-till tillage of the soil, mulching of the soil surface).

Correctly selected crop rotations, the use of strip crops and agrotechnical measures are most effective when applied in an integrated manner. These measures should be implemented simultaneously with permanent measures. Such measures include the creation of runoff-regulating field forest belts and the construction of anti-erosion hydraulic structures. They are an important component of the formation of a soil-protective farming system with contour reclamation organization of the territory. Performing reclamation functions, such as snow retention, transferring surface runoff water into the soil and reducing moisture loss through evaporation, these measures are essential for the strengthening soil fertility. They ensure that the contour boundaries of ecological and technological groups of land are rigidly fixed. This includes defining the boundaries of crop rotations, fields and fertile areas on the ground.

The contouring of a territory through the use of linear boundaries (borders) is a prerequisite for agriculture. This is a kind of "price" that human civilization has to pay for the opportunity to engage in agricultural activities. This necessity arose due to the disturbance of the natural balance as a result of land development (Barabanov, A.T. and Garshinev, E.A., 1993). The placement of linear boundaries on agricultural land is an important part of agrotechnical measures. These works are aimed at creating the basis for a soil-protective reclamation spatial structure of the agricultural landscape. This is especially relevant in conditions of active water erosion.

Field forest belts provide environmental protection of the territory at a distance of up to 6-7 meters up and 8-11 meters down. To enhance water absorption, it is advisable to combine forest belts with simple hydraulic structures. This may include bunding, intermittent ditches and water retention swales. Such measures are especially effective in gully areas. Field forest belts in combination with hydraulic structures absorb up to 700-1000 mm of runoff on ordinary chernozems. The system of forest belts and hydraulic structures retains 90% of moisture, and their influence on field areas is up to 60%. As a result, an average of 16-18 mm of moisture is additionally accumulated, which provides a yield increase of up to 5-6 units per hectare.

The use of permanent soil conservation measures in agricultural landscapes prevents soil and nutrient losses (Table 39)

Table 39

Environmental effect from the use of anti-erosion terrace shafts and beam lintels

Indicator (per 1 ha)	Terrace ridges	Cross-dams in gullies
Prevented annual soil loss from erosion, t	3,90	2,000
Including: humus, t	0,18	0,094
nitrogen gross, kg	9,30	4,750
phosphorus, kg	6,40	3,300
potassium, kg	34,70	17,800
Prevented annual energy potential loss of soil, GJ	4,21	2,160

Source: Compiled by the authors based on research by various academic institutions

The National Land Protection Program for the period up to 2010 envisaged large-scale land management measures. In particular, it was planned to carry out contour reclamation of the territories of newly created enterprises on an area of 25.3 million hectares. The program also envisaged the construction of 98 thousand kilometers of earthen berms of various designs. Additionally, it was planned to establish 191 thousand hectares of field protection forest belts. However, in the context of the emergence of new business entities with a change in land use in the process of desoldering former collective farm lands, the identified tasks remained unfulfilled.

The conservation of degraded and unproductive land is an important step to improve the environmental situation. The transition to crop rotation and ecologically oriented agriculture also has significant potential. Together with protective forest belt systems, these measures will contribute to the development and spread of biodiversity. The conservation of landscape diversity depends on the degree to which landscape ecosystems deviate from their natural standards. The smaller this deviation, the greater the chances of preserving natural diversity.

In the context of highly specialized and monoculture production with up to 90% of the land plowed, the situation for natural vegetation is critical. The development of natural vegetation is significantly limited. The number of beneficial soil organisms has also been significantly reduced. They are preserved mainly in areas inaccessible for growing crops. On limited areas of pastures, about 10 species of phytodiversity are threatened with extinction due to their intensive use. In waterlogged and wetlands, this figure reaches up to 20 species.

The way out is to balance the areas of natural and artificial ecosystems in the agricultural landscape. The more species of flora, fauna, and other diversity there are in a given area, the higher its ecological value. Differences within each species and ecosystem also increase the value of the territory. Such an agro-landscape becomes especially important for human needs.

The agricultural landscape is not only an object of agricultural activity, but also an environment of human life. In addition to the arrangement of agricultural land, an important factor in the formation of sustainable agricultural landscapes is the organization of ecological arrangement of rural settlements bordering them. Equally important is the creation of recreational areas for people by diversifying the location and interrelationships of natural and artificial components. It is also necessary to preserve historical natural monuments of ecological and cultural value. This work is a necessary condition for maintaining the spatial organization and aesthetics of the agro-landscape environment.

Negative destructive trends in Ukraine's agricultural landscapes require an urgent response. This necessitates turning to the scientific principles of organizing the formation of sustainable agricultural landscapes. To do this, it is advisable to use best practices that ensure efficiency and environmental sustainability. This applies primarily to EU regulations that form national "Crosse compliance" systems. These regulations set standards for compliance with environmental and agricultural regulations. The experience of EU countries in implementing codes of good agricultural practices is also important (Informationsbroschüre über die einzuhaltenden anderweitigen Verpflichtungen – Crosse Compliance, 2021; Cross-compliance. Linking income support to respect for European Union rules, 2021).

There are several factors that drive compliance with the established rules and requirements for conducting agricultural activities without harming local agricultural landscapes. On the one hand, there is the control exercised by government agencies based on standardized criteria. This is accompanied by measures of responsibility for non-compliance with these rules and requirements. On the other hand, there are programs to support measures to protect ecosystems and efficiently use natural resources in the agricultural sector. They cover areas such as agro-environmental and climatic activities, transition to organic agriculture, support for farms with natural constraints, and reforestation and forestry.

Agro-environmental and climate activities include sustainable agriculture. It is aimed at protecting soil and water. Another important aspect is the preservation of plant and animal biodiversity. Polish farmers receive 400 PLN/ha under the program to support sustainable agriculture. To promote soil and water protection, subsidies are provided for intermediate crop planting at 650 PLN/ha and for protective strips of perennial grasses on sloping arable lands at 450 PLN/ha.

To preserve biodiversity, the following measures are supported:

- conservation of traditional fruit orchards and specific fruit tree varieties at 1964 PLN/ha;
- preservation of plant genetic resources in agriculture that are at risk of extinction, with subsidies of 750 PLN/ha for crop cultivation and 1000 PLN/ha for growing seeds of these plants;

- conservation of genetic resources of endangered animal breeds, including cattle at 1600 PLN/ha, horses at 1500 PLN/ha, sheep at 360 PLN/ha, pigs at 1140 PLN/ha, and goats at 580 PLN/ha;
- protection of endangered bird species and their habitats, with support ranging from 642 PLN/ha to 1199 PLN/ha, depending on the bird species.

Support of organic farming is provided during the transition period and the period of stable farm management (Table 40)

Table 40

Support of organic agriculture

CROPS	TRANSITION PERIOD	PERIOD OF SUSTAINABLE DEVELOPMENT
Field agricultural crops	966 PLN/ha	792 PLN/ha
Vegetable crops	1557 PLN/ha	1310 PLN/ha
Fruit crops	1882 PLN/ha	1501 PLN/ha
Forage crops	787 PLN/ha	559 PLN/ha
Grass cultivation	1325 PLN/ha	1325 PLN/ha
Sown pastures	428 PLN/ha	428 PLN/ha

Source: Ministerstwo Rolnictwa i Rozwoju Wsi (2014).

Farmers and local governments that own land receive support for afforestation and forest creation. Afforestation is supported by a one-time payment ranging from 4,984 to 7,624 PLN per hectare, depending on the composition of the afforestation, soil characteristics, and the type of planting material used. Additional assistance is provided for potential protective measures.

From 794 to 1,628 PLN is allocated annually for the maintenance and care of forest plantations over a period of 5 years, depending on the characteristics of sloping lands and forested soils. In addition, assistance in the amount of 424 PLN/ha is provided for the possible protection of plantations from animals by using repellents.

To cover the costs of farming activities related to afforestation of land plots, farms receive an annual premium. The premium amounts to 1,215 PLN and is paid over a period of 12 years. The maximum area of land a farmer can withdraw from cultivation for afforestation is 20 hectares. This constitutes 7% of the legally regulated maximum land use allowed per farmer (Zubov, A.R., Zykov, I.G. & Tarariko, A.G., 2009).

The formation of environmentally sustainable agricultural landscapes is impossible without strengthening the regulatory and legislative function of the state. This involves the use of organizational, environmental and economic instruments. In the context of Ukraine's potential membership in the EU, it is necessary to introduce rules and requirements for conducting agricultural activities on an environmentally friendly basis. These rules should ensure the preservation of natural components of agricultural landscapes. At the same time, the system of inventory and monitoring of compliance by business entities should be legally regulated. This system should include certification of land with the subsequent issuance of permits for the sale of commercial production of certain types of crops. It also provides for penalties and recommendations on a set of land protection measures to be implemented (Figure 35).

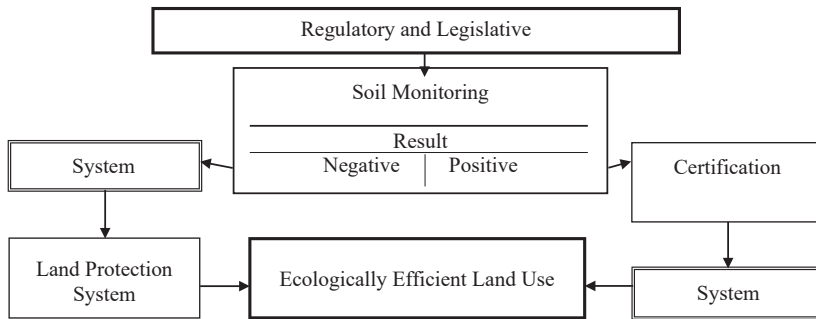


Figure 36. Scheme of organizational and economic support for the implementation of activities to ensure land fertility in agricultural landscapes. Source: own research.

The starting point of this system is the results of the monitoring assessment. If the results of the soil quality assessments meet the established requirements, the certification body issues the relevant permits. These permits have a limited validity period. In Western European countries, such permits are usually valid for four years. They allow land use activities for the commercial production of plant products by crop groups.

If the results of monitoring assessments are below the established regulatory thresholds for soil quality characteristics, permits are not issued. The land user receives a list of recommendations for implementing appropriate measures aimed at restoring agro-ecological balance. These measures may include, for example, expanding the area of hayfields, pastures, and perennial plantations, i.e., ecologically stabilizing lands. Penalty payments are imposed for the deterioration of the quality characteristics of soil cover on agricultural land. Such sanctions are applied in the event of a negative impact on commercial crop production.

The set of economic incentives should be closer to the programs of the EU member states discussed above.

All artificially created ecosystems in agriculture can function successfully with human support. Such cenoses are not stable in the nature and are not capable of self-regeneration and self-regulation. Therefore, the main strategy for creating a sustainable agricultural landscape is to preserve and enhance each of its components, which requires appropriate policies and costs.

Economics and ecology should collaboratively and interdependently align the values produced by human activity with those generated by the natural environment. This approach enables the establishment of a consensus between limiting the economization of human activities and promoting the rational use of natural resources for the future benefit of the planet and humanity.

2.8. NATURAL RESOURCE POTENTIAL IN THE ASSESSMENT OF SUSTAINABLE ECONOMIC DEVELOPMENT.

The negative impact of human economic activity on the condition of soils and other components of the natural resource potential necessitates the use of *new approaches to assessing the efficiency of their use*. Scientists in the countries with the most industrialized agriculture came to this conclusion back in the 1980s. France has developed the IDEA (Indicateurs de durabilite des exploitations agricoles) methodology (La methode IDEA, 2008; Ryzu, B., 2010; Publications propres à la méthode IDEA, 2024; Zahm, F., Girard, S., Alonso Ugaglia, A., Barbier, J.-M., Boureau, H., Carayon, D., Cohen, S., Del'homme, B., Gafsi, M., Gasselin, P., Gestin, C., Guichard, L., Loyce, C., Manneville, V., Redlingshöfer, B. and Rodrigues, I., 2023; Zahm, F., Alonso Ugaglia, A., Boureau, H., Del'homme, B., Barbier, J.M., Gasselin, P., Gafsi, M., Girard, S., Guichard, L., Loyce, C., Manneville, V., Menet, A. and Redlingshofer, B., 2019; Zahm, F., Girard, S., Rodrigues, I., Alonso Ugaglia, A., Gasselin, P., Angot, J., Boureau, H., Buys, C., Barbier, J.M., Bockstaller, C., Carayon, D., Del'homme, B., Follet, D., Fourest, A., Gafsi, M., Gestin, C., Larbi, X., Laxalde, S., Manneville, V., Peltier, C., Saillard, C. and Viel, J.-A., 2024), and Germany has developed the KSNL (Kriteriensystem Nachhaltige Landwirtschaft) system (KSNL, 2022). Studying them makes it possible to identify the conceptual basis for assessing the model of development of environmentally healthy, socially oriented and economically viable agriculture.

The IDEA methodology was developed under the auspices of researchers at the National Research Institute for Agriculture, Food and the Environment (INRAE). This institute is engaged in a variety of research. Among the main areas are climate change mitigation and adaptation, food and nutrition security. It also studies the transition to agroecological agriculture, conservation of natural resources, biodiversity restoration, and risk prediction and management.

The IDEA method includes all aspects of the sustainable development strategy: preservation of natural resources (water, air, soil, biodiversity, landscapes and minerals); social values that characterize a certain level of development of social relations (ethics, quality, citizenship); and economic aspects. The 17 agro-ecological goals identified are based on the agronomic principles of integrated agriculture (Vijo, 1999). (Table 41)

Table 41

Seventeen goals of the IDEA method

1. Consistency	10. Product Quality
2. Autonomy	11. Ethics
3. Conservation and Management of Biodiversity	12. Human Development
4. Landscape Protection	13. Local Development
5. Soil Conservation	14. Quality of Life
6. Conservation and Management of Water Resources	15. Citizenship
7. Atmospheric Protection	16. Adaptability
8. Efficient Use of Non-Renewable Natural Resources	17. Employment
9. Animal Welfare	

Source: La methode IDEA (2008). Educagri editions, Dijon. Available at: <https://methode-idea.org>

They should enable the farm to achieve economic efficiency with the least possible environmental damage.

1. Consistency (COH)

While intensive systems often demonstrate a very high degree of technical consistency, primarily aimed at achieving maximum short-term efficiency, they frequently result in environmental pollution and resource depletion. Moreover, sustainable agriculture embodies an entirely different set of values, leading to a broader and more integrated form of coherence. This coherence encompasses the responsibilities of farmers in their roles as agronomists and business managers, as well as their role as individuals integrated into the rural environment and society at large.

This perspective recognizes the interdependence between short- and long-term goals and across different scales, from the plot and the farm to the territory and the planet. It is crucial to distinguish technical coherence from "civic" coherence. Technical coherence refers to a combination of agricultural practices that, when formulated together, amplify each other and produce effects greater than the sum of their parts. For example, the choice of crop variety, crop rotation, and sequencing leads to specific technical pathways that may or may not reconcile profitability, production quality, and environmental protection.

On the other hand, "civic" coherence pertains to socio-economic behaviour that supports the sustainable development of agriculture and rural areas. It is particularly characteristic of sustainable agricultural systems, focusing on integrating economic viability, environmental stewardship, and social responsibility.

2. Autonomy (BT)

Autonomy reflects, on one hand, the ability of a farm to be self-sufficient with respect to its primary production factors, and on the other hand, its capacity to contribute to the sustainable development of the region it belongs to. This inclination toward autonomy in production systems is not a regression to autarky. On the contrary, it often entails increased risks and requires more time from the operator due to technical decisions or more complex organizational systems, for which recommendations or advice may still be limited or inadequately supported.

This autonomy should be analyzed at both the farm and regional levels (Godard and Hubert, 2002; Gafsi, 2006):

- egocentric autonomy at the farm level refers to the farm's ability to sustain production in the future by adapting to major climatic, political (e.g., Common Agricultural Policy reforms), and economic changes (e.g., shifts in relative competitiveness among major global producers).
- territorial autonomy encompasses the farm's integration into its surrounding region, enabling the development of local resources and products to foster regional sustainability and resilience.

3. Conservation and Management of Biodiversity (BIO)

Biodiversity, in all its forms, is vital for the long-term maintenance of the planet's food production potential. As such, it represents a fundamental goal of sustainable agriculture. Biodiversity is also essential for the self-regulation of ecosystems, which depends on a balance among all trophic levels (plants, herbivores, carnivores, and de-

composers). Furthermore, it is an integral characteristic of living organisms, enabling them to evolve and adapt to continuous environmental changes.

In agricultural systems, biodiversity is categorized into two types: domestic biodiversity, consisting of breeds and varieties directly involved in the production process, and wild or spontaneous biodiversity, comprising species that colonize marginal spaces such as hedgerows, embankments, groves, ponds, and other areas with minimal or no human intervention. These two components of biodiversity complement one another and are indispensable.

Agricultural lands are never entirely isolated from the broader living ecosystem, which brings about competition, predation, and parasitism while simultaneously ensuring organic matter recycling and the demographic regulation of pests.

4. Landscape Protection and Management (PAY)

The protection and management of landscapes have not traditionally been explicit objectives of agriculture. However, as landscapes are collective resources that are significantly shaped by human activities, managing their heritage has become a key goal of sustainable agriculture.

The quality of landscapes serves as an indirect economic resource for various stakeholders, including farmers, who enhance collective heritage through hospitality and tourism. Furthermore, well-managed landscapes contribute to the distinct identity of regions and improve the overall quality of life.

5. Soil Protection (SOL)

Soil is a natural resource that is practically non-renewable within the timescale of human activity. Erosion represents an irreversible loss that significantly reduces the food potential for future generations. Consequently, an agricultural system that depletes its fertility each year through practices that increase the risk of erosion and humus depletion is inherently unsustainable.

The same applies to the accumulation of pollutants, such as persistent pesticides or trace metal elements (TME) like copper, zinc, and cadmium. These pollutants often result from frequent treatments, large-scale emissions of industrial sludge, or suspensions, which locally poison the soil ecosystem.

6. Water Conservation and Management (H2O)

Water is a renewable natural resource, and its management depends on maintaining a proper balance between extraction and replenishment rates. Hundreds of kilometres of rivers and streams dry up annually due to extensive irrigation, even as other legitimate water uses compete for the resource. Beyond the immediate interests of farmers, the development of irrigated areas should involve collective consideration of watershed-scale dynamics to ensure a sustainable balance between water resources and demands.

Rivers are more than just channels directing water to the sea; they are delicate ecosystems that suffer severe damage when flow rates drop below critical thresholds. Consequently, extraction rates must be limited to levels that support self-cleaning and regenerative functions of aquatic ecosystems. Failure to adhere to this balance can lead to the gradual transformation of these environments into simple open sewers, evacuating waste into the sea.

Water quality is another critical concern. In certain contexts, agricultural systems significantly impact water quality. Whether affecting surface water or groundwater, the quality of water continues to deteriorate. Thus, agricultural production free of contamination – or minimizing contamination risks – is a fundamental requirement for sustainable farming practices.

7. Air Protection (AIR)

Protecting air quality may seem an unexpected goal for an activity more commonly associated with impacts on water and soil. However, various agricultural practices significantly contribute to air degradation. The suspension of pesticide-laden soil micro-particles during tillage, the volatilization of pesticides, ammonia emissions, and unpleasant odors accompanying manure spreading – particularly in overproducing regions – are all factors that diminish air quality.

Additionally, the high energy consumption of certain technical systems in agriculture can account for a substantial share of global greenhouse gas emissions, further emphasizing the sector's role in air quality challenges.

8. Efficient Management of Non-Renewable Resources (NRR)

This goal emphasizes the importance of rational and careful management of natural resources on a global scale, including oil, phosphates, potassium, and others. It closely aligns with the objectives of autonomy and coherence, ensuring a balanced and sustainable approach.

By integrating long-term considerations, this goal supports the preservation of natural capital for future generations, safeguarding essential resources against depletion.

9. Animal Welfare (BIE)

The goal of ensuring animal welfare is an integral part of all agricultural practices. It is a matter of both ethical principles and zootechnical considerations.

10. Product Quality (QLP)

The production of high-quality food is a task situated at the intersection of agronomic or zootechnical challenges and social or territorial concerns. It represents the logical outcome of an agronomic approach grounded in ethical values, ensuring that the agricultural food function poses no health risks to consumers. High-quality agricultural products also play a role in safeguarding industries or regions against standardized and easily transferable mass production. Finally, it is a fundamental condition for fostering dialogue between consumers, taxpayers, and producers.

11. Ethics (ETH)

Ethics refers to a set of principles governing life and behaviour that define a specific level of civilization. It encompasses the responsibility for practices evaluated not only in terms of their immediate and localized impacts but also their distant and delayed consequences. Without ethics integrated into the production function, sustainable agriculture cannot exist.

12. Human Development (HDD)

Indicators targeting the goal of human development focus on self-fulfillment and professional realization within the farming profession. These aspects play a critical role in the sustainability and transferability of agricultural practices.

13. Local Development (LDD)

For centuries, agricultural activity was the heart of rural life. Today, farmers have become a significant minority, even in rural areas. Nonetheless, they can contribute to local development and rural revitalization through their social engagement. By fostering connections among individuals within a shared territory, conditions for dialogue are created, promoting greater cohesion and responsibility.

14. Quality of Life (QLV)

Quality of life results from complex interactions among private, social, and economic spheres. Enhancing quality of life is a central goal of sustainable development at both individual and collective levels. However, certain agricultural practices either improve or degrade the micro-regional living environment and/or influence the daily work quality, aligning to varying degrees with this objective. Consequently, technical management that is environmentally sound and economically viable but leads to a decline in the quality of life for the farmer and their family would neglect a critical aspect of sustainable development.

15. Citizenship (CIT)

Citizenship and eco-citizenship are expressed through social significance, collective and solidarity-based engagement, and efficient, waste-free social action. This represents a distinctive dimension of sustainable agriculture.

16. Adaptability (ADA)

Sustainable agricultural systems are never fixed in an unchanging technical configuration, as the economic and social context tends to change rapidly. Therefore, adaptability and technical flexibility are essential conditions for the economic resilience of these systems. Diversification of production facilitates this adaptation.

17. Employment (EMP)

This objective addresses a critical demand of modern society. Sustainable agricultural systems cannot base their profitability on accumulating quotas or production rights at the expense of other, more vulnerable enterprises. Thus, certain practices of division of labour through collective employment of workers or self-imposed limitations on expansion strengthen this goal.

Achievement of this objective is supported by 41 indicators that reflect the sustainable (economically, socially, and environmentally balanced) development of the farm.

The Environmental Health of the Sector

The environmental health of the sector is assessed through a system of indicators that reflect the conservation of soil, water, air, biodiversity, and landscapes. This system includes, among other factors: the diversity of annual and perennial crops, animal diversity, preservation of the gene pool, crop rotation, return of organic matter removed with the harvest, application of mineral fertilizers, conservation of natural biological resources, preservation of forage lands, use of pesticides and veterinary drugs, level of technogenic overload, animal welfare, use of water resource, and energy dependence (Table 42)

Table 42

Agroecological Sustainability Scale

Components		Indicators	Maximum Values	
Internal Diversity	A1	Diversity of annual or temporary crops	14	The total is limited to 33 units
	A2	Diversity of perennial crops	14	
	A3	Diversity of animals	14	
	A4	Preservation and enhancement of genetic heritage	6	
Spatial Organization	A5	Crop rotation	8	The total is limited to 33 units
	A6	Parcel size	6	
	A7	Organic matter management	5	
	A8	Ecological control zones	12	
	A9	Contribution to addressing regional environmental issues	4	
	A10	Expansion of ecological space	5	
Agricultural Practices	A11	Forage area management	3	The total is limited to 34 units
	A12	Fertilization	8	
	A13	Liquid organic waste management	3	
	A14	Pesticide use	13	
	A15	Veterinary treatment practices	3	
	A16	Soil resource conservation	5	
	A17	Water resource management	4	
	A18	Energy dependency	10	

Source: La methode IDEA (2008). Educagri editions, Dijon. Available at: <https://methode-idea.org>

Social Orientation of Agriculture at the Farm Level

The social orientation of agriculture within the farm includes a system of indicators that reflect social benefits intended for society as a whole and social values for individuals who produce and consume agricultural products. These indicators encompass:

- The structure of commodity production aimed at supporting the national food balance;
- The quality of feed produced for in-house livestock;
- The quality of agricultural products intended for sale in raw or processed forms;
- Diversification of activities;
- Preservation of existing and creation of new jobs;
- Collective work of those involved in agricultural production;
- Stability of the farm workforce;
- Education of agricultural producers;
- Labor intensity;
- Quality of life of working people;
- Health, hygiene, and safety. (Table 43)

Table 43

Scale of Social and Territorial Sustainability

Components		Indicators	Maximum Values	
Quality of Products and Territory	B1	Approach to Quality	10	The total is limited to 33 units
	B2	Enhancement of Architectural Heritage and Landscape	8	
	B3	Management of Non-Organic Waste	5	
	B4	Accessibility of Space	5	
	B5	Social Activity	6	
Employment and Services	B6	Evaluation through Short Supply Chains	7	The total is limited to 33 units
	B7	Autonomy and Development of Local Resources	10	
	B8	Services and Multifunctional Activities	5	
	B9	Contribution to Employment	6	
	B10	Collective Work	5	
	B11	Likelihood of Sustainability	3	
Ethics and Human Development	B12	Contribution to Global Dietary Balance	10	The total is limited to 34 units
	B13	Animal Welfare	3	
	B14	Formation	6	
	B15	Work Intensity	7	
	B16	Quality of Life	6	
	B17	Isolation	3	
	B18	Reception, Hygiene, and Safety	4	

Source: La methode IDEA (2008). Educagri editions, Dijon. Available at: <https://methode-idea.org>

Economic Viability in Agriculture

Economic viability in agriculture is shaped by indicators related to the entrepreneurial activities of economic entities, reflecting their efficiency. These include: net profit per unit of area; net profit per animal; level of economic specialization; operational costs as a proportion of product value; financial autonomy; share of government support in profit; production profitability (Table 44)

Table 44

Economic Sustainability Scale

Components		Indicators	Maximum Values	
Viability Economic	C1	Economic Feasibility	20	30 units
	C2	Level of Economic Specialization	10	
Independence	C3	Financial Autonomy	15	25 units
	C4	Sensitivity to Support under the First Pillar of the Common Agricultural Policy	10	
Transmissibility	C5	Capital Transmissibility	20	20 units
Efficiency	C6	Efficiency of the Production Process	25	25 units

Source: La methode IDEA (2008). Educagri editions, Dijon. Available at: <https://methode-idea.org>

To achieve a balance among the three functions (ecological, social, and economic) the indicators for each function are assigned an equal total number of points. The scoring of each individual indicator is carried out by specialists (agronomists, soil scientists, ecologists, sociologists) based on the role the indicator plays within the system of indicators that reflect the performance of a particular function of agriculture. This eval-

uation is also aligned with the level of impact of the indicator on the achievement of the desired outcome.

For instance, in the ecological orientation of agriculture, the indicator "diversity of annual and perennial grasses," which influences organic matter accumulation in soil and its physical condition, is assigned significantly greater importance compared to the use of mineral fertilizers. Similarly, in ensuring the economic viability of the sector, net profit is given much greater weight compared to, for example, the role of direct government support.

To ensure correct assessment of each indicator, the methodology developers rely on such disciplines as soil science, plant and animal physiology, organic chemistry, as well as the specific socio-economic and agro-climatic conditions of each natural zone.

The analysis results are presented as various graphical representations of score evaluations across indicator groups. This approach enables the assessment of the balance between the agroecological, social, and economic components of agriculture. Based on these findings, strategies for achieving their equilibrium can be identified, serving as the foundation for ensuring the long-term development of the sector.

In the IDEA method for assessing the multifunctional nature of agriculture, economic indicators are primarily considered as derivatives of indicators reflecting the use of soil, water resources, and natural and cultural biodiversity. This approach is scientifically justified, as agricultural production is a process of natural synthesis of organic matter conducted by billions of soil-dwelling organisms. Interacting with one another, these organisms transform plant residues and animal waste into accessible nutrients and create a favourable environment for the development of new plants. This process results in the formation of humus, carbon dioxide, accessible nutrients, phytoncides, vitamins, enzymes, and other substances. These elements collectively establish soil fertility, defined as the soil's ability to meet plant needs for nutrients, water, to provide their root systems with air, heat, and other conditions essential for growth. Essentially, it is not the land itself that serves as the primary means of production, but rather the fertility of its soil cover – the productive layer of its surface capable of self-development and self-renewal (INRAE, 2024).

The process of organic residue decomposition, along with the energy released during this decomposition, serves as the primary driver for plant growth and productivity. In essence, the organic matter from the previous harvest, combined with the plant's use of solar energy and moisture, generates a new harvest and new organic matter.

In Germany, the German Institute for Sustainable Agriculture deals with a problem of using indicators for the analysis and optimization of agricultural operations focused on sustainable development (Deutsches Institut für Nachhaltige Agrarkultur, DINAK) (Kraft, C., 2021; Breitschuh, G., Eckert, H., Matthes, I., and Strümpfel, J., 2008; Breitschuh, G., Gernand, U., Jäkel, L., Geyer, M., and Breitschuh, T., 2019). The main areas of activity of DINAK include:

- Consultation. The institute provides comprehensive advisory services aimed at optimizing agricultural operations in line with sustainability principles. These consultations help enterprises develop long-term plans and strategies that promote sustainable development.

- Sustainability Certificates. DINAK offers sustainability certification, allowing agricultural enterprises to demonstrate their commitment to sustainability. These certificates serve as both an internal management tool and an external indicator of responsibility to society and the market.

- Support for Adaptation and Transformation. DINAK assists enterprises in adapting to changing conditions and transitioning to more sustainable practices. This support may involve the implementation of new technologies, methods, and strategies.

- Measurability. The institute emphasizes the importance of measurability in evaluating sustainability. Only what can be measured can be assessed and subjected to targeted improvements. This approach enables enterprises to more accurately identify areas for improvement and achieve specific results.

The core idea of DINAK is that sustainability can be achieved through specific steps and changes, grounded in objective data and measurements. This approach enables agricultural enterprises to work more effectively toward sustainable development and adapt to changing conditions.

To evaluate the sustainability of enterprises, relevant indicators are developed to characterize impacts on ecological, economic, and social spheres (Table 45). Specific requirements for these indicators include:

- Reproducibility. Indicators must reflect the system's ability to regenerate resources and maintain its functionality over the long term.

- Reasonable cost-benefit ratio. Indicators should account for the balance between the costs invested in the system and the benefits derived, ensuring efficient resource use.

- Reactivity to behavioural changes. Indicators should clearly respond to changes in behaviours and practices, enabling the tracking of effects from implemented decisions.

- Methodological verification/justification. Indicators should be supported by methodological justifications and verification to ensure reliability and objectivity.

- Relevance and ease of use. Indicators should be relevant and pertinent to the concept of sustainable development, as well as easy to use for analysis and decision-making.

- Utility as a "regulation tool". Indicators should also serve as tools for adjusting and correcting activities to achieve sustainable development goals.

Table 45

Indicators of sustainable development of agriculture (Germany)

Environmental Sphere	Economic Sphere	Social Sphere
Soil erosion	Exhaustion of the long-term debt servicing limit	Wages
Humus balance	Cash-flow margin	Working hours
Phosphorus balance	Return on equity	Education and employment
Nitrogen balance	Relative remuneration of factors	Share of female employees
Plant protection intensity	Net investments	Gender equality
Greenhouse gas balance	Equity ratio	Vacation days utilized
Biodiversity potential	Profit share	Age structure
N-efficiency in animal feeding	Risk management	Occupational safety and health
P-efficiency in animal feeding	Compliance with Cross Compliance requirements	Social integration
Animal welfare		

Source: Compiled by the authors independently, based on German Institute for Sustainable Agriculture (DINAK). Available at: <https://dinak.info/>

The assessment of the significance of integral indicators for the ecological, economic, and social components of agricultural activities is carried out using a scoring system and depends on the specific characteristics of each enterprise (Eckert, H., Breitschuh, G. and Sauerbeck, D., 2004).

The indicators of the environmental sphere in agriculture include the following:

1. *Humus Balance*. The humus balance plays a crucial role in shaping soil properties and their functions due to the influence of organic matter. The humus content in arable soils affects crop yields and holds significant ecological importance, including its impact on greenhouse gas balance. The measurement of humus balance is expressed in humus units. The humus requirement depends on the diversity of fruit varieties, growing conditions, and yield levels. Most importantly, a balanced ratio of humus demand to availability in the long term leads to an optimal humus level. This can result in either soil enrichment or depletion, depending on the initial conditions and previous management practices. The indicator is calculated at the level of separate field and subsequently summed up for the entire enterprise.

2. *Nitrogen Balance*. Nitrogen plays a critical role in supporting agricultural yields. However, its application can lead to challenges such as groundwater and habitat pollution, as well as nitrous oxide emissions that contribute to climate change. Effective nitrogen management is calculated by balancing all relevant material flows, following the Hülshbergen methodology (Hülshbergen, K.-J., 2003). Unlike simplified nitrogen balances, this approach accounts for nitrogen emissions that affect both income and environmental sustainability. The indicator is calculated at the level of a separate field and then summed up for the entire enterprise.

3. *Phosphorus Balance*. Phosphorus, as a key nutrient, plays a critical role in agricultural production. To maintain soil fertility in the long term, its removal should be adequately compensated. The calculation of the phosphorus balance incorporates relevant farm management data. Phosphorus inputs from mineral and organic fertilizers (considering their type and quality) are compared to its removal through harvested crops. In cases where livestock is present, the quantity and quality of manure are ac-

counted for individually for each farm. The indicator is calculated for each field and subsequently summed up for the entire enterprise.

4. *Plant Protection Intensity*. Chemical crop protection, despite public criticism, plays a vital role in achieving high agricultural yields. It not only contributes to increased productivity but also ensures profitability and product quality by effectively managing energy and material flows. The plant protection intensity indicator evaluates the extent of chemical protection use by comparing the actual application levels with typical protection intensity standards for a specific region and crop. This indicator is calculated for each field and then summarized for the entire enterprise.

5. *Water Erosion*. The importance of soil conservation as a non-renewable resource stems from its numerous functions and social significance. The Federal Soil Protection Act establishes preventive measures to avert negative changes and threats to soil. Among these threats, water erosion holds a prominent place, involving the displacement of soil material and nutrients into local ecosystems via surface runoff from rainwater. The degree of soil erosion is assessed using the Universal Soil Loss Equation (USLE), developed by Schwertmann and Vogl (Schwertmann, U. and Vogl, W., 1987), which integrates geographic information through GIS. The assessment is conducted for each field, and the results are subsequently summarized for the entire enterprise.

6. *Energy-Intensive Crop Production*. With the intensification of agriculture, energy consumption for fertilizers, pesticides, machinery, and equipment increases significantly. This highlights the growing importance of developing energy efficiency and managing energy intensity. The analysis of energy intensity in crop production evaluates the use of fossil energy within the context of production processes. Both direct and indirect energy uses (fuel, electricity, equipment, and machinery) are considered, excluding costs for drying, storage, transportation, or solar energy. Human labour is also not included. The indicator is calculated for each field and then summarized for the entire enterprise.

7. *Greenhouse Gas Balance in Crop Production*. The global agricultural sector is a significant source of anthropogenic greenhouse gas (GHG) emissions, accounting for approximately 7% of total emissions. In Germany, agricultural emissions in 2021 amounted to 54.8 million tons of CO₂-equivalent, representing 7.6% of the country's total emissions. Calculating CO₂ and N₂O emissions in crop production requires analysing nitrogen, carbon, and energy flows based on field-specific and management conditions. Sources of GHG emissions include nitrous oxide emissions from soils due to processes and the application of nitrogen fertilizers, as well as changes in soil humus balance that influence carbon sequestration and release. Emission indicators are calculated for each field and summed up for the entire enterprise. Additionally, GHG emissions per unit of production can also be evaluated.

8. *Biodiversity Potential*. The contemporary cultural landscape of Central Europe is shaped by historical and current land use, including millennia of agricultural influence on biological diversity. However, intensification and structural changes in agroecosystems have led to a decline in species, negatively impacting biodiversity. Environmental impact factors are divided into three domains: structures, resources, and practices. These domains include sub-indicators that allow for the analysis and evaluation of effects on agroecosystems, thus determining the "biodiversity potential." The overall

indicator comprises 11 sub-indicators. Calculations are carried out at the level of individual fields, and the results are summarized for the entire enterprise.

9. *Nitrogen Use Efficiency in Feeding.* The issue of nitrogen enrichment in the environment due to agricultural livestock has garnered public interest. Nitrogen plays a critical role in the metabolism of livestock, but the majority of nitrogen compounds from feed are not used for the formation of animal tissues or products, for example, for the production of milk. This non-use of nitrogen significantly affects the composition of manure and contributes to unwanted emissions that are harmful to both the environment and the climate. The nitrogen use efficiency indicator compares the amount of nitrogen supplied through feed with the amount of agricultural output generated on the farm over a year. A low value for this indicator reflects effective nitrogen use.

10. *Phosphorus Use Efficiency in Feeding.* Phosphorus, as a key nutrient, plays a central role in agriculture, particularly in its essential functions for plant growth and physiology. In Germany, significant amounts of phosphorus are introduced into soils, primarily through livestock production and imported feed. The phosphorus use efficiency indicator compares the amount of phosphorus supplied through feed with the volume of agricultural output produced on the farm over a year. Therefore, a lower value for this indicator indicates more efficient phosphorus use.

11. *Energy-Intensive Livestock Farming.* Modern livestock systems in agriculture requires the use of non-fossil energy resources. In the conditions of the shortage of fossil fuel shortages and the observed climate changes, conserving energy resources and ensuring their efficient use are of critical importance. High energy consumption and insufficient energy balance negatively impact both the economy and the environment. The energy intensity indicator is calculated by analysing technological modules within livestock farming, where each stage of the process systematically examined and studied. Each stage is assigned specific energy inputs and outputs, enabling the identification of potential for improvement in various production systems and the detection of possible weak points.

12. *Greenhouse Gas Emission Balance in Livestock Farming.* Globally, the agricultural sector is one of the leading sources of anthropogenic greenhouse gas emissions, accounting for approximately 7% of total emissions. In Germany, livestock farming contributed about 40.4 million tons of CO₂-equivalent emissions in 2021, representing a significant share. Strategies to reduce greenhouse gas emissions and mitigate their impact on climate and the environment often start with changes in animal feeding practices. By optimizing feeding methods, the production of harmful compounds that negatively affect the environment can be minimized.

The greenhouse gas emission balance for livestock farming considers the following emission sources:

- CO₂ emissions resulting from technological processes, including direct and indirect energy use;
- CH₄ emissions caused by animal digestion, barn conditions, and manure storage;
- N₂O emissions originating from barns, paddocks, pastures, and manure storage facilities;
- NH₃ emissions generated in barns, on paddocks, and in manure storage facilities.

13. *Animal Welfare.* Animal welfare efforts are directed at ensuring livestock owners actively self-monitor the well-being of their animals, as mandated by the Federal Animal Protection Act adopted in 2014. The "Animal Welfare" indicator encompasses various sub-indicators, such as housing conditions, productivity, health, and animal behaviour. These metrics enable a comprehensive assessment of the overall state of animals within livestock farming operations.

Economic Dimension of Sustainable Agricultural Development Indicators

1. *Exhaustion of the Long-Term Debt Service Limit.* This indicator reflects the liquidity and financial stability of an enterprise, particularly its ability to service long-term obligations over an extended period. The financial stability coefficient can be calculated using the following formula:

KFS= (E+LTL) /TB, where:

E = Equity capital

LTL = Long-term financial liabilities (loans and borrowings with a repayment term exceeding 12 months)

TB = Total balance (sum of liabilities)

For calculating the current liquidity ratio, the formula is as follows:

KCL=CA/CL, where:

CA = Current assets

CL = Current liabilities

This indicator is essential for financial planning and managing an enterprise's debt obligations effectively.

2. *Cash Flow Margin.* The "Cash Flow Margin" indicator provides insight into an enterprise's financial ability to generate its own cash resources from current operational activities. This metric allows for the assessment of how effectively a company manages its finances and whether it can cover its current expenses, key obligations, and investment needs.

The calculation of the cash flow margin is based on an analysis of annual financial statements, such as the income statement. This indicator highlights the amount of cash remaining after deducting operating expenses and tax payments, demonstrating the enterprise's capacity to generate free cash flows for debt repayment, investments, and other financial goals.

3. *Return on Equity (ROE).* Return on Equity (ROE) is a key metric that evaluates the efficiency of a company's use of its equity to generate profit. This indicator allows investors and managers to assess how successfully the company uses its capital to create added value. The formula for calculating ROE is:

Return on Equity (ROE)=(Net Profit/Equity)×100, where:

Net Profit is the profit of the company after deducting taxes and other expenses.

Equity refers to funds invested in the company by its owners or shareholders.

ROE provides insights into how effectively a company uses its internal resources to generate profit. A high ROE typically indicates strong management and the company's

ability to generate income, while a low ROE may signal inefficient use of capital or other financial challenges.

4. *Return on Investment (ROI)*. The Return on Investment (ROI) metric is a key indicator used to assess the efficiency of capital investments. ROI helps determine the profit a business earns from its investments relative to the costs incurred. The formula for calculating ROI is:

$$ROI = (\text{Profit from Investments} / \text{Investment Costs}) \times 100$$
, where:

Profit from Investments is the net profit generated from investments after deducting all associated expenses.

Investment Costs refer to the total amount the company has allocated to its investments.

ROI is expressed as a percentage, indicating the return gained for each unit of capital invested. A high ROI signifies that investments are successfully generating income for the business. However, the indicator has some limitations as it does not account for the time horizon of investments or their long-term implications.

ROI is also useful for comparing the performance of different investment opportunities or analysing profitability trends over different periods. Additionally, this metric is important for benchmarking against other businesses in the same industry or evaluating the company's profitability dynamics over time.

5. *Relative Factor Remuneration*. The "Relative Factor Remuneration" metric measures the ratio between factor remuneration (e.g., wages, equipment depreciation, and other production factors) and the factor costs required to produce goods or services. This indicator assesses resource efficiency and determines whether an entrepreneur or farmer receives additional remuneration beyond the costs of production. The formula for calculating Relative Factor Remuneration is:

Relative Factor Remuneration = Factor Remuneration / Factor Costs, where:

Factor Remuneration represents the total payment for production factors, including wages, depreciation, rent, and other related expenses.

Factor Costs refer to the total resources and expenditures needed to produce goods or services.

This metric is expressed as a percentage and indicates how effectively resources are used to achieve operational income. A higher value for Relative Factor Remuneration signifies that the entrepreneur or farmer generates additional profit beyond production costs, reflecting strong management efficiency and enterprise competitiveness.

6. *Net Investments*. Net investments represent the difference between the increase in the value of business assets and the reduction in value due to depreciation and asset disposal over a specific period. This concept is critical for evaluating how effectively a business or farm invests its resources to create long-term value. Net investments help identify changes in the asset composition of a business or farm and how these changes impact its financial position.

Positive net investments may indicate that a business or farm is actively investing in new assets or equipment, which could support future growth. Conversely, negative net investments might suggest that existing assets are becoming obsolete or are being dis-

posed of, potentially putting the agricultural enterprise at risk of losing competitiveness.

Net investments can be positive or negative, depending on the dynamics of asset changes and the associated maintenance costs. This indicator is a key metric for analysing the efficiency of capital utilization within an agricultural enterprise and assessing its investment strategy.

7. *Equity Ratio*. The equity ratio is a key indicator that measures the proportion of an agricultural enterprise's own funds in its total financing. This metric serves as a critical indicator of financial stability and assesses the extent to which a business or farm depends on its own funds in its activities. A higher equity ratio indicates that the agricultural enterprise is primarily funded by its own resources and is less dependent on external debt. This can be a sign of a more stable and resilient financial position, as equity provides a buffer in times of financial difficulties or crises.

However, an excessively high equity ratio may also suggest inefficient use of borrowed funds, which could have been effectively used for expansion and growth. Therefore, analysing the equity ratio helps investors, analysts, and managers evaluate the financial health of a business or farm and its capacity to navigate potential financial challenges.

8. *Profit Margin*. The profit margin is a financial indicator that expresses the ratio of a business or farm's net profit to its revenue (income) over a specific period. This metric evaluates what portion of an agricultural enterprise's revenue remains as profit after accounting for all expenses, including operating costs, taxes, and other obligations. The formula for calculating the profit margin is:

$$\text{Profit Margin} = (\text{Net Profit} / \text{Revenue}) * 100\%$$

A higher profit margin indicates that the agricultural enterprise retains a larger share of its profit relative to total revenue. This reflects efficient cost management, optimization of business processes, and the ability to generate profit despite market competition and changes. However, a high profit margin may also suggest limited investments in enterprise or farm development, potentially restricting growth over the long term.

Conversely, a low profit margin may point to high operating costs, tax liabilities, or inefficient resource utilization. Therefore, analysing the profit margin in conjunction with other financial indicators provides a more comprehensive understanding of the financial stability and performance of the enterprise or farm.

9. *Risk Management*. Risk management is an integral component of any company's operations, including agricultural enterprises. Given the unpredictability of future events and the outcomes of entrepreneurial activities, the goal of risk management is to ensure the sustainable functioning of the enterprise or farm by identifying, assessing, managing, and controlling potential sources of risk. In agricultural companies, risk management involves the following key stages:

- **Risk Identification**. This involves analysing potential and actual sources of risks that may affect the enterprise's operations. In agriculture, risks may include weather conditions, plant and animal diseases, market fluctuations, and other factors.

- Risk Assessment. The likelihood of each risk and its potential impact on the enterprise or farm are evaluated. This process helps prioritize risks that are most significant and require special attention.
- Risk Management. Strategies and plans are developed to address identified risks. These may include implementing preventive measures, reducing the impact of risks, and selecting alternative strategies to mitigate their effects if they materialize.
- Control and Monitoring. Continuous monitoring of risks and their impact on the enterprise is carried out. Risk management strategies are adjusted as necessary to respond to changing circumstances.
- Risk Management Tools. These tools include insurance, diversification, financial reserves, and the development of contingency plans. A structured questionnaire can be used to systematically collect information about existing risks and evaluate current risk management measures.

The operational manager assesses risks, takes preventive or mitigating actions, and ensures the effective implementation of risk management tools.

The primary goal of risk management in agricultural enterprises is to minimize the adverse effects of risks and ensure the resilience of operations in a dynamic and unpredictable environment.

10. *Compliance*. The concept of "compliance" refers to an enterprise's adherence to legal regulations, standards, and internal policies in its operations. The compliance indicator reflects the extent to which an agricultural enterprise conforms to laws and standards in its activities. This includes compliance with legal norms, regulations, and rules at both local and international levels.

Providing accurate data on how an enterprise or farm uses compliance management systems can be facilitated through a structured questionnaire, allowing for an assessment of the effectiveness and scope of compliance measures. Regulatory authorities and auditors monitor the proper and reliable functioning of these systems.

The primary goal of maintaining compliance is to prevent violations, reduce the risks of legal issues, preserve the enterprise's reputation, and ensure the long-term sustainability of the business.

Social Indicators for Sustainable Development in Agriculture

1. *Wages*. The analysis of wage indicators in the social sphere of sustainable agricultural development assesses how an enterprise ensures fair and adequate compensation for its employees. Wages are a critical indicator of social sustainability, as they not only provide a decent standard of living for workers but also influence their motivation, productivity, and job satisfaction. The wage indicator is evaluated based on several key criteria:

- Fair Compensation. This criterion considers whether wages align with the level of responsibility, qualifications, and workload of employees. Fair pay incentivizes workers and fosters motivation for high-quality performance.
- Equity and Transparency. Enterprises must maintain transparent wage determination procedures, avoiding discrimination and unfair practices. Employees should have a clear understanding of how their wages are calculated and distributed.

- Ratio to the Minimum Wage Standards. Maintaining wages above the legally mandated minimum wage ensures that employees receive sufficient income to meet their needs.
- Motivation and Productivity. Adequate wages can serve as an incentive for employees to improve their skills, enhance productivity, and invest greater effort in their work.
- Standard of Living. Wages should provide employees and their families with a decent standard of living, including basic needs such as food, housing, healthcare, and education.

Providing wages that exceed minimum levels promotes a sustainable and socially responsible work environment, enhances employee satisfaction, and increases their contributions to the enterprise's development.

2. *Working Hours.* The analysis of the working hours indicator within the social dimension of sustainable agricultural development assesses labour schedules and their compliance with regulatory requirements. Working hours are essential for ensuring employees' long-term productivity, health, and quality of work life. This indicator evaluates the following aspects:

- Compliance with Legislation. Established working hour standards, as defined by labour laws, serve as a benchmark for enterprises. Exceeding these limits should only occur in exceptional circumstances and under specific conditions.
- Health and Well-Being. Work schedules should consider employees' physiological and psychological needs. The duration of working hours must allow sufficient time for rest and recovery to prevent negative impacts on employees' health.
- Work-Life Balance. An appropriate work schedule supports the balance between professional responsibilities and personal interests, which is crucial for employee satisfaction and efficiency.
- Consideration for Part-Time Employment. For employees working part-time, it is essential to ensure working hours align with their job conditions and agreed-upon responsibilities.
- Monitoring and Reporting. Enterprises analyse data on actual working hours to calculate this indicator. Monitoring and reporting enable compliance with established standards and provide transparency.

Adherence to working hour norms promotes the sustainable development of agricultural enterprises, supports employee health and productivity, fosters a positive working environment, and enhances the quality of work life.

3. *Training.* The analysis of the training indicator in the context of the social sphere of sustainable agricultural development evaluates how a company provides training, education, and professional development opportunities for its employees. Training is a key mechanism for maintaining competencies, enhancing professional skills, and fostering both individual and organizational growth.

The training indicator considers the following aspects:

- Skill Enhancement. Professional training and continued education equip employees with the necessary skills and knowledge to perform current and future tasks effectively.

- **Satisfaction and Motivation.** Training impacts employee job satisfaction by offering opportunities for personal growth and development. This can increase motivation and commitment to the organization.

- **Progress and Innovation.** Skilled and competent employees can contribute to the technical, scientific, and social progress of the company. Their knowledge and skills foster the development of new ideas and innovations.

- **Leadership Development.** Training can support the development of leadership qualities among employees, which is essential for effective team management and coordination.

- **Social Responsibility.** Providing training demonstrates the company's social responsibility toward its workforce and society at large.

- **Lifelong Learning.** Given the rapidly changing environment and advancements in technology, maintaining a system of continuous learning ensures employees stay updated on the latest developments and requirements.

Analysing the training indicator helps enterprises assess the extent of their investment in employee development and growth, which positively influences organizational sustainability and productivity.

4. *Proportion of Women.* This indicator reflects gender equality within the organization and influences the dynamics of innovation and decision-making. Analysing the proportion of women in an enterprise or agricultural operation provides the following insights:

- **Equality.** A balanced representation of women promotes a more equitable and inclusive work environment.

- **Diversity.** Diverse perspectives and experiences brought by women contribute to more creative and varied approaches to problem-solving.

- **Innovation.** The presence of women in agricultural enterprises can enhance the emergence of new ideas and innovations, as diversity in experience often leads to diversity in thought.

- **Leadership.** Promoting women to leadership positions fosters a variety of leadership styles and approaches, enriching the management structure.

- **Corporate Culture.** Greater gender representation supports the development of a more inclusive and tolerant corporate culture.

- **Partnership.** Increasing the proportion of women at all management levels encourages the development of collaborative relationships among team members.

Analysing the proportion of women in agricultural enterprises enables companies to assess their efforts in providing equal opportunities for employees, regardless of gender, and to evaluate the diversity of the team in terms of experience, perspectives, and approaches.

5. *Gender Equality.* The concept of gender equality serves as a critical indicator of social sustainability and management in agricultural enterprises. Analysing gender equality metrics, such as the gender pay gap, helps identify the presence or absence of equal opportunities for employees regardless of gender. The analysis of gender equality includes the following aspects:

- **Equal Pay.** Disparities in wages between women and men can indicate violations of the principle of equal pay for equal work. Such disparities may arise from a lack of transparency in compensation systems, biases, or discrimination.

- **Career Opportunities.** Gender equality entails equal opportunities for career growth and advancement, regardless of gender. Limited career progression opportunities for women may signal inequality.

- **Equality in Training.** Gender equality also encompasses access to education and professional development. Restricted access for women to training and skill enhancement programs can negatively impact their career prospects.

- **Representation in Management.** Equal representation of women and men at various management levels demonstrates an inclusive and diverse corporate culture.

- **Work Environment.** Gender equality includes creating a workplace free from discrimination, stereotypes, and unequal treatment.

Analysing gender equality metrics enables agricultural enterprises to assess how well they adhere to gender equality principles in their operations. It also helps evaluate whether the organization fosters diversity, supports development, and ensures fair compensation for all employees, regardless of gender.

6. *Utilized Vacation Days.* This indicator reflects the extent to which employees utilize paid vacation time to restore their productivity and maintain physical and psychological well-being. The analysis of the "Utilized Vacation Days" indicator includes the following aspects:

- **Health and Well-Being.** Vacation provides employees with the opportunity to rest, recover, and reduce stress. Regular vacations can have a positive impact on their health and overall well-being.

- **Productivity.** Employees who have taken sufficient rest tend to perform their duties more efficiently and productively upon returning to work. This can positively influence the overall productivity of the enterprise.

- **Satisfaction Levels.** Offering opportunities for rest and vacation can enhance employee satisfaction with their jobs and the enterprise as a whole.

- **Work-Life Balance.** Vacation time allows employees to maintain a balance between work and personal life, which is crucial for their resilience and long-term productivity.

The "Utilized Vacation Days" indicator can be used to assess how well the agricultural enterprise facilitates proper use of vacation time by its employees. This, in turn, promotes their resilience, health, and overall well-being.

7. *Age Structure.* The analysis of the age structure within an agricultural enterprise serves as a critical analytical tool for identifying long-term workforce requirements and planning personnel policies. This indicator assesses how well the enterprise balances experience and younger talent while accounting for projected demographic changes. Key aspects of age structure analysis include:

- **Succession Planning.** Analysing the age composition helps identify how many employees are approaching retirement age or planning to retire soon. This enables the enterprise to develop strategies for replacing experienced employees and ensuring a smooth transfer of knowledge and skills across generations.

- Development and Training. Understanding the age structure aids in identifying the training and development needs of younger employees, allowing them to effectively replace departing personnel and contribute to the enterprise's long-term growth.
- Innovation and Experience. A diverse age group fosters the integration of senior employees' experience with fresh ideas from younger employees, potentially driving innovation within the enterprise.
- Performance Management. The age structure influences team dynamics, motivation, and the effectiveness of collaborative processes.

The analysis of the "Age Structure" indicator provides the enterprise with a more strategic and long-term perspective on workforce management. It allows the organization to adapt its plans and strategies to changes in age composition, ensuring resilience and successful development in the future.

8. *Occupational Safety and Health*. Ensuring occupational safety and health is a critical indicator in the sustainable development of agricultural enterprises, in view of the increased risks associated with this sector. Working with machinery, animals, chemicals, and other factors can pose potential hazards to employees' health and safety. Active attention to workplace safety and health helps mitigate risks and creates a favourable working environment. Key aspects of occupational safety and health in agriculture include:

- Training and Awareness. Employees must be trained and informed about safety regulations, occupational health measures, and the correct use of equipment and substances.
- Protective Equipment. Workers should be provided with essential personal protective equipment (PPE), such as safety goggles, masks, gloves, and other protective gear.
- Inspections and Audits. Regular inspections of equipment, machinery, and work environments help identify potential hazards and implement measures to eliminate them.
- Compliance with Regulations. Agricultural enterprises must adhere to occupational safety and health standards outlined by legislation to ensure safe working conditions.
- Context-Specific Measures. Safety measures should account for the unique risks of working with animals, chemicals, and other specific aspects of agriculture.

Additionally, analysing the indicator "Number of Workplace Accidents" allows companies to assess the effectiveness of their safety and health measures, identify areas requiring further effort, and take action to improve working conditions and reduce risks for employees.

9. *Social Integration of an Enterprise*. The social integration of an enterprise can be implemented through various actions:

- Education and Awareness. Proactively informing the community about the enterprise and its activities fosters better understanding and recognition of its significance.
- Engagement with Society. Participation in events, exhibitions, seminars, and other activities aimed at exchanging experiences and information with the community.

- **Social Programs.** Implementing and supporting programs aimed at societal well-being, such as initiatives promoting health, education, social protection, and more.

The evaluation of social responsibility is conducted through surveys using questionnaires that assess various aspects of the enterprise's activities in social integration. The results from the surveys allow to categorize the enterprise's actions and the assessment of their impact, ultimately forming the *Social Commitment Indicator*. This indicator reflects the level of the enterprise's involvement in social and community issues and serves as a metric to evaluate its societal impact and recognition.

The indicator system for assessing the sustainable development of agricultural enterprises enables an in-depth analysis of enterprise activities, identification of vulnerabilities, determination of areas for improvement, and effective risk management. Using indicators fosters a deeper understanding of the interconnections between various sustainability domains and the operational activities of the enterprise. Through systematic data collection and indicator analysis, enterprises can optimize operations, implement innovations, and strive for high sustainability standards. The use of indicators also enhances transparency and openness for society, investors, and partners. Sustainability assessment through the indicator system highlights the responsible and purposeful approach of agricultural enterprises toward sustainable development. Overall, such assessments facilitate informed and systematic management, help achieve a balance between economic, environmental, and social indicators, and promote the adoption of practices that support long-term operations aligned with the goals of sustainable development.

To promote the farmer's commitment to achieving economic, social, and environmental balance in agricultural activities, French legislation has established the Farm-land Contract (Contrat Territorial d'Exploitation, CTE) (Contrat territorial d'exploitation, 2002). This contract is concluded between the authorities and farming enterprises and encompasses three key areas of commitments:

- **Production commitments.** The farmer undertakes to manage specific cultivated areas for agricultural production and ensure its efficiency.
- **Employment commitments.** The farmer agrees to support the employment of family members and hired workers, create additional jobs, and promote diversification of agricultural activities, including the development of integrated food supply chains.
- **Environmental commitments.** The farmer pledges to improve the ecological environment by maintaining soil fertility, preserving water quality, and protecting natural landscapes and biodiversity (Code rural, 2022).

In order to support measures under obligations stated in the Territorial Farming Contract (CTE), a dedicated funding mechanism has been established, operating within the budget of the French Ministry of Agriculture.

Economic Measures. The government funds initiatives aimed at:

- Reducing production costs;
- Diversifying agricultural activities;
- Structurally reorienting production.

Environmental Measures. State assistance is provided to compensate farmers for expenses or losses incurred while implementing environmental actions. Eligible measures include:

- Preservation of the environment;
- Conservation of biodiversity;
- Proper care and management of livestock and poultry;
- Transition to organic farming;
- Afforestation of degraded agricultural lands withdrawn from cultivation;
- Reconstruction of field shelterbelts.

Social Measures. Farmers may receive government support for social-oriented initiatives such as:

- Improving product quality;
- Producing low-margin but essential goods for public health and nutritional needs;
- Participating in collective marketing associations;
- Enhancing professional qualifications.

Compensation Rates. Compensation is calculated based on the type of farm:

- For general farms: 30% of expenses;
- For farms in disadvantaged areas: 40% of expenses;
- For young farmers: 45% for general farms and 55% for those in disadvantaged areas.

Financial Limitations. The average total amount allocated for all measures over a five-year period range from €20,900 to €25,000 per farm.

In this regard, national agro-economic science is taking its first steps. Ukrainian scholars such as Tykhonov A.G., Grebenyuk N.V., Tykhonenko O.V., and Fedenko V.P. have proposed a system of agricultural land-use indicators that includes over 30 groups of indicators across economic, environmental, and social dimensions (Tykhonov, A.G., Grebenyuk, N.V., Tykhonenko, O.V. and Fedenko, V.P., 2002). A comparison of this system with international methodologies highlights the need for further refinement of the system's classification criteria (such as the number of dimensions, their designations, and the principles of indicator systematization) as well as the selection and substantive development of indicators to adequately reflect the multi-functional purpose of agriculture.

Scientists from the National University of Life and Environmental Sciences and the State Institution "Institute of Environmental Economics and Sustainable Development of the National Academy of Sciences of Ukraine" (D. Dobriak, V. Budziak, O. Budziak) have proposed a transition to environmentally safe land use principles. This approach is implemented through the development of a comprehensive assessment system for evaluating land use efficiency. The assessment employs relevant indicators based on approximately 150 primary representative macro- and meso-level metrics identified through expert analysis, which characterize the development of land use systems. The assessment incorporates environmental, social, and economic indicators of environmentally safe land use.

The *environmental indicator* reflects the ecological load on land resources, the degree of preservation of the natural state of the land, and the level of land protection, among other factors. The *social indicator* measures the accessibility and suitability of land for habitation and the level of population support provided by land resources. The

economic indicator characterizes the efficiency of land use in economic activities and the overall level of economic development of land use.

Further calculations enabled scientists to determine the average values of the environmental, social, and economic indicators. Differences in the trends of these indicators indicate a current positive dynamic in land use efficiency based on economic and social indicators. However, the trend in land use efficiency based on the environmental indicator is generally negative (Figure 37) (Dobriak, D., Budziak, V. and Budziak, O., 2013).

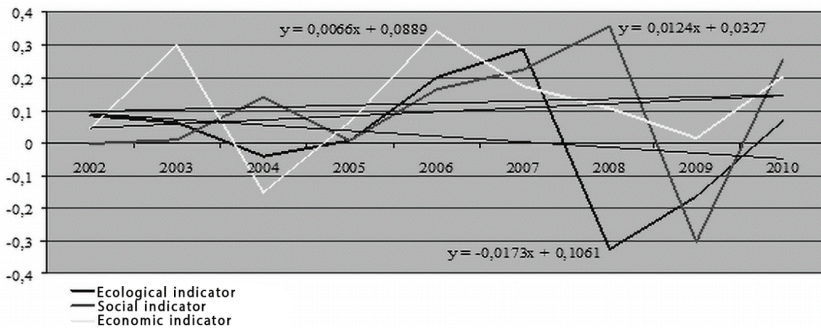


Figure 36. Trends in Indicators of Environmentally Sustainable Land Use. Source: Authors' calculations

A comparative analysis of the proposed methodology for evaluating land use and the approaches used in France and Germany highlights the need for further development in this area. Specifically, the social indicator requires refinement, as it does not incorporate several metrics employed by international research, including:

- The structure of commercial product output aimed at supporting national food balance and food security;
- The quality of feed produced for own livestock operations;
- The quality of agricultural products intended for sale in raw or processed form;
- The diversification of activities by agricultural producers;
- The preservation of existing and creation of new jobs;
- Education and training of agricultural producers;
- Labor intensity;
- The quality of life of workers.

Incorporating these metrics would likely reveal less positive trends in the use of domestic agricultural lands, considering their specific characteristics and multifunctional purposes.

The authors of this monograph have also tried to propose their perspective on assessing the sustainable development of agricultural enterprises. Indicators have been suggested for evaluating sustainable development across three spheres: economic, environmental, and social (Table 46). Additionally, a methodology (model) for indicative evaluation of the sustainable development of agricultural enterprises has been proposed (Olena Pimenova, Serhii Pimenov, Halyna Fyliuk, 2020).

Table 46

Indicators for Sustainable Development of Agriculture (Ukraine)

Environmental Sphere	Economic Sphere	Social Sphere
Soil erosion	Rate of production growth	Ratio of average worker income to the national average income
Humus balance	Productivity per unit of land area	Employee turnover rate
Phosphorus balance	Labor productivity	Percentage of young workers (under 35 years old)
Nitrogen balance	Financial stability ratio	Percentage of women in the workforce
Intensity of plant protection	Production profitability	Share of employees with higher and specialized secondary education
Greenhouse gas balance	Sales profitability	Employment rate of workers
Biodiversity potential	Investments in technological modernization	Wages and working hours
N-efficiency in animal feeding	Compliance with norms and regulations	Education and employment
P-efficiency in animal feeding	Automation of production	Days of vacation utilized
Animal welfare	Green investments	Occupational health and safety

Source: Pimenowa, 2023. Strategy of sustainable development of agriculture of Ukraine in the context of European Integration. Monograph. Bulgarian Academy of Science, 405 p.

This model for indicative assessment of sustainable development in Ukrainian agricultural enterprises assumes that the significance (or weighting) of the economic, social, and environmental dimensions should be equal.

Simultaneously, the weights of various indicators within each sphere were determined based on the relative weight of each indicator within its respective sphere. The method of pairwise comparison by independent experts was employed for this purpose. As part of the process, five experts evaluated each pair of indicators and selected the one they deemed most important. This comparison was conducted for every possible pair of indicators.

A specific scoring scale was used for the comparisons: 3 points were assigned to the more important indicator, 1 point to the less important one, and 2 points to both indicators if they were deemed equally important.

Next, the relative weight of each indicator within the sphere was calculated using Formula 1:

$$\text{Relative Weight of the Indicator} = \frac{\text{Sum of the Indicator's Scores}}{\text{Total Sum of Scores for All Indicators in the Sphere}}$$

The calculation of relative weights was performed separately for each of the three spheres. Subsequently, the arithmetic mean of the relative weights assigned by all experts was calculated. The resulting relative weights of the indicators were then integrated into the assessment model.

The scoring scale for each indicator comprises nine levels, where a score of 1 represents the highest rating, and 9 represents the lowest. In general, the assignment of scores to indicators follows these guidelines:

- 1 point is awarded if the company is close to the ideal.
- 2 points signify a "very high level."
- 3 points indicate a "high level."
- 4 points represent a "level above average."
- 5 points denote an "average level."
- 6 points reflect a "satisfactory level."
- 7 points indicate a "low level."
- 8 points signify a "very weak level."
- 9 points represent a "zero level."

The methodology for assessing an agricultural enterprise in terms of sustainable development across all three spheres includes four stages:

1. Assigning weights. Each indicator is assigned a score on a scale of 1 to 9. This evaluation is performed by an analyst (expert) using the scoring scale.
2. Calculating the integral indicator. This is achieved by multiplying the weight of the indicator by its relative weight within the sphere.
3. Summing up integral indicators. The total of all integral indicators within a sphere is calculated to determine the integral indicator for that sphere.
4. Calculating the overall integral indicator. This is obtained by summing up the integral indicators of all three spheres.

By applying the indicative assessment model for the sustainable development of Ukrainian agricultural enterprises, the following can be determined:

- Balance or imbalance. The model reveals the enterprise's balance or imbalance in its economic, social, and environmental aspects. This provides a clear understanding of how well the enterprise is aligned across all three spheres.
- Comparative analysis. The integral indicator of any given enterprise can be compared to the integral indicators of other enterprises within the region and across the country. The absolute value of the integral indicator reflects the enterprise's competitive position relative to others in the market.

An example of the matrix for comparing economic spheres is presented below in Table 47.

Table 47

The example of Estimation of the importance of indicators of the economic component

Economic Indicators	The growth rate of production	Volume of production per 1 hectare of land	Volume of production per one worker	The dynamics of the volume change of output per hectare of land	Productivity	Dynamics of changes in labor productivity	The level of self-sufficiency	Profit of 1 hectare	Profit for: 1 person	Profitability of production	Dynamics of change of profitability	Sum in grades
The growth rate of production	x	3	2	3	3	1	1	1	1	1	1	17
Volume of production per 1 hectare of land	1	x	3	3	3	2	3	1	2	1	1	20
Volume of production per one worker	2	1	x	3	3	3	3	1	1	2	1	20
The dynamics of the volume change of output per hectare of land	1	1	1	x	3	1	2	1	1	1	1	13
Productivity	1	1	1	1	x	2	2	1	1	1	1	12
Dynamics of changes in labor productivity	3	2	1	3	2	x	3	1	1	1	1	18
The level of self-sufficiency, a measure of independence from third-party resources	3	1	1	2	2	1	x	1	1	1	1	14
Profit of 1 hectare	3	3	3	3	3	3	3	x	1	3	2	27
Profit for: 1 person	3	2	3	3	3	3	3	3	x	1	3	27
Profitability of production	3	3	2	3	3	3	3	1	3	x	2	26
Dynamics of change of profitability	3	3	3	3	3	3	3	2	1	2	x	26

Source: own research

The total weight of all indicators in the economic component amounted to 220 points (each comparison allocates 4 points, resulting in 55 comparisons in total). Then we calculate the specific weight of each individual indicator by the formula.

$$\text{Specific weight of the indicator} = \frac{\text{The sum of grades of the indicator}}{\text{The sum of grades of all indicators of the sphere}}$$

For example, for the indicator "The growth rate of production", the weight is: $17/220 \times 100\% = 7,7\%$. In a similar way we received specific weights for indicators of ecological and social spheres.

Social Component. For social component we make 21 pairs of comparisons for 7 indicators. The total weight of all indicators of social component is 88 (in each comparison is distributed 4 grades, we have total of 21 significant comparisons, that is, $21 \times 4 = 88$). The pairwise comparisons revealed that the most significant indicators in the social component were:

- "Employee Turnover Rate" (the ratio of employees leaving the company to the average number of employees) and
- "Share of Youth in the Company" (the proportion of employees under 35 years old), both scoring 19.0%.

Environmental Component. For ecological component, we make 36 pairs of comparisons for 9 indicators. The total weight of all indicators of ecological component is 144 (in each comparison is distributed 4 grades, we have total of 36 significant comparisons, that is $36 \times 4 = 144$). The pairwise comparisons identified the most significant environmental indicators as:

- "Land Affected by Soil Erosion" (as a percentage of the total land area), scoring 16.7%, and
- "Extent of Anthropogenic Impact from Enterprise Activities" (impact on water, soil, air, and biodiversity), scoring 14.6%.

Thus, the relative weights for each indicator across all three spheres were determined. The model's application was demonstrated using the example of an agricultural cooperative. Table 48 presents the scoring process (using a scale from 1 to 9) for each indicator in each sphere.

The integral indicator was calculated using the formula:

$$\text{Integrated indicator} = \text{The specific weight of the indicator} \times \text{Weight (in grades)}$$

For example, Table 48 presents the results of the cooperative's evaluation by an analyst, using the economic assessment scale.

Table 48

Estimation of the importance of indicators of the economic component

Indicator	Specific weight	Indicator weight	Integrated indicator
The growth rate of production	7,7%	4	0,31
Volume of production per 1 hectare of land	9,1%	2	0,18
Volume of production per one worker	9,1%	3	0,27
The dynamics of the volume change of output per hectare of land	5,9%	7	0,41
Productivity	5,5%	5	0,28
Dynamics of changes in labor productivity	8,2%	6	0,49
The level of self-sufficiency, a measure of independence from third-party resources	6,4%	2	0,13
Profit for 1 hectare	12,3%	5	0,62
Profit for: 1 person	12,3%	5	0,62
Profitability of production	11,8%	4	0,47
Dynamics of change of profitability	11,8%	5	0,59

Source: own research

The sum of all integral indicators of one component is an integral indicator of a component. Thus, the integral indicator of economic factors is 4.36, social is 4.45, ecological is 3.53. The overall integral indicator of the cooperative is 12.34. Figure 37 shows the network of integral indicators of the cooperative.

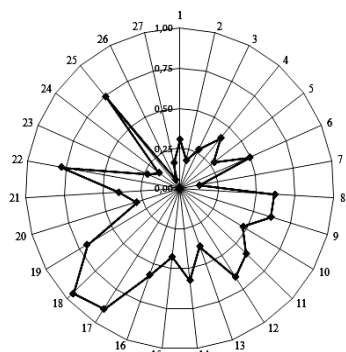


Figure 37. Network of integral indicators of the cooperative. Source: own research. *Notes:*

- 1 The growth rate of production
- 2 Volume of production per 1 hectare of land
- 3 Volume of production per one worker
- 4 The dynamics of the volume change of output per hectare of land
- 5 Productivity of labor
- 6 Dynamics of changes in labor productivity
- 7 The level of self-sufficiency, a measure of independence from third-party resources
- 8 Profit for: 1 ha
- 9 Profit for: 1 person
- 10 Profitability of production
- 11 Dynamics of change of profitability
- 12 The ratio of the average income of the employee to the average income of the country
- 13 The level of fatigue
- 14 The share of women in production
- 15 The share of specialists with higher and secondary specialized education
- 16 Workplace Warranties
- 17 Employee employment rate
- 18 The share of young people in the enterprise
- 19 The area of land with a high man-made load in the total area
- 20 The size of man-made load on the ground from the enterprise
- 21 The level of soil fertility relative to the average in the region
- 22 Variety of cultivation of crops, in number of species
- 23 Land area, which is processed by heavy c / g cars in the total area
- 24 The lands prone to soil erosion in the total volume of land
- 25 The level of compliance of the landscape with the recreational area
- 26 Area of uncultivated land in the total land area
- 27 Area of land "under the steam" in the total area of the enterprise's land

It should be noted that the lower the integral indicator of the enterprise so the more it corresponds to the concept of sustainable development and as we see an enterprise is competitive. The best value for an integral indicator of an enterprise is 3 (when all the indicators get in the assessment of 1 grade), the worst value is respectively 27 (when each indicator receives 9 grades). That is the integral index of the enterprise varies from 3 to 27.

As indicated above the requirement for sustainable development and high level of competitiveness is the balance of three components: economic (100%), social (100%) and ecological (100%). For example, Romualdas Ginevicius wrote about country region's competitiveness: «country region's competitiveness depends on how it is adjusted their economic, social and ecological development. It's important because it could be that some of the development components are developing at other compo-

nent's expenses.» (Ginevicius, 2019). For visualization authors proposes to use the equilibrium triangle. Three sides must be equal, so we have an equilateral triangle. If sides are different in size then the triangle will not an equilateral. That indicates on the imbalance.

According to the cooperative's data each of the components turned out to be less than 100%, and the triangle turned out to be not equal, indicating the imbalance and the predominance of ecological component (71.9%). The social and economic components are balanced between themselves, but their absolute values are not high enough (61.6% and 62.7%). All this indicating that there is a potential for development (Figure 38).

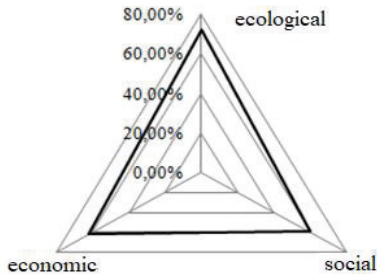


Figure 38. Triangle of balance between economic, social and environmental components of agricultural activities. Source: own research

A standardized methodology of assessment of the sustainable development of agricultural enterprises, ready for practical implementation, is not yet available in Ukraine. This represents a significant gap in the contributions of agronomic, agroecological, agroeconomic, and other agricultural sciences to the agricultural sector and society.

Chapter III THE ROLE OF THE STATE IN RESOURCE SECURITY FOR FOOD SECURITY OF FUTURE GENERATIONS.

3.1. SOCIALISATION OF LAND RELATIONS AS A FACTOR OF SUSTAINABLE AGRICULTURE.

Land is a social good by its very purpose. Therefore, within the framework of land relations, unlike other property relations, the interests of owners and users of land are aligned with the interests of society.

The social function of land relations is manifested in ensuring

- food security, food sovereignty of the society;
- profitability of small and medium-sized agribusinesses;
- promotion of employment of the rural population;
- preservation of the rural population and rural settlements;
- Increasing the productivity of the agricultural land fund of the society in the long

term.

Food security and food sovereignty imply the availability and sufficiency of food. Physical accessibility means access to food for all categories of people at the local, regional and national levels, while sufficiency means meeting the physiological needs of the human body for healthy, safe food through domestic production.

Support for the profitability of small and medium-sized agribusinesses is associated with the creation of favorable conditions for their access to land and agricultural activities. This is a necessity, as small and medium-sized farms are the organizational backbone of global agriculture. Without taking this into account, it is impossible to meet humanity's food needs.

Small and medium-sized agribusiness is an important area of employment for the rural population, which contributes to its settling down and reduces migration processes. Its development preserves local agricultural landscapes and rural settlements, which is an important factor in the development of rural areas.

The responsibility for realizing the interests of society lies primarily with the state. According to the Constitution of Ukraine (Article 13), land, like other natural resources, is subject to the ownership rights of the Ukrainian people. On behalf of the people, the owner's rights are exercised by state authorities and local self-government bodies, to which the state delegates a part of its powers within the limits defined by the Constitution. It follows that the state, as a representative of the interests of society, should redistribute property rights in such a way that the use of land is consistent with the ideology of sustainable (economic, social and ecologically balanced) land use with a focus on the future needs of society (Hrytsenko, A.A., 2019).

The main legal means of influence on participants of land relations in the context of implementation of the public function of land use are legal restrictions, legal prohibitions, legal obligations and legal incentives.

The review of land legislation in different countries shows a high level of regulation of all aspects of land relations, starting with the recognition of persons entitled to pur-

chase (lease) agricultural land and ending with the regulation of functions of state institutions controlling the movement of land plots on the market. The analysis allows us to identify the most general ones.

1. *The right to acquire a land plot for farming by purchase and/or lease is granted by the law to individuals residing in the territory of their location or at a short distance from it (in Denmark - 10-25 km). Often, requirements are also set for the period of residence in rural areas (Denmark - at least 8 years).*

In some cases, a legal entity may also acquire the right to purchase (lease) a land plot if it is a non-profit form of association of peasants-landowners for joint agricultural activities (e.g. GAEC and EARL in France, production cooperatives in Italy).

2. *Buyers (tenants), both individuals and each member of the association, are obliged to work directly on the farm in agricultural operations.* They cannot be limited to management activities. If it is not possible to combine managerial and technological functions in a large farm, an executive director is hired to perform the former.

3. *An important legislative provision is the qualification requirements for buyers (lessees) of agricultural land plots.* They must have:

- an agricultural diploma or other professional document;
- a set period of professional experience (France - at least 5 years);
- certain means of production, including livestock, etc.

It is compliance with these requirements, rather than the price or rent offered, that are the priority criteria for assessing applicants participating in a tender (auction) for the sale (lease) of agricultural land plots. At the same time, family members, neighbouring farmers, tenant farmers and their heirs have a privileged right to purchase (lease) a land plot.

Farm heirs must also meet the above requirements. If there are several of them, the one with the highest qualifications acquires the right to land. If his or her training does not meet the requirements of the law, the inherited farm should be temporarily leased until he or she acquires the necessary qualifications.

4. *Another peculiarity of the world's legislative practice is the prohibition or restrictions that make it virtually impossible for foreigners to purchase (lease) agricultural land.* In some countries, this is ensured by national legislation (EU countries, Japan, Australia), in others - by regional legislation (USA, Canada).

The most common restrictions for foreigners are:

- residence of a foreigner in the country for a specified period of time and acquisition of citizenship (France - 7 years, Kentucky, USA - 8 years);
- qualification requirements, as discussed above;
- access only to free land for the purpose of its agricultural development (New Zealand);
- purchase (lease) of land plots only for research and development (Minnesota, USA);
- limitation of land plots (in France, only a foreigner - a citizen of the EU countries who meets the qualification requirements - can purchase or lease a land plot (except for vineyards) that does not exceed the cost of the total area of an average-sized farm; in the US state of Wisconsin, no more than 640 acres (≈ 267 ha), which is close to the size of the land use of an average farm).

5. At the same time as securing the right to purchase (lease) agricultural land for farmers, *legislation promotes the formation of viable farms by regulating their minimum and maximum sizes and mechanisms for avoiding overcropping, introducing incentives for owners (tenants) to unite to cultivate land and conduct business together.* In Germany, the minimum plot (owned or leased) should be 1 hectare, the maximum - 400-500 hectares, depending on the conditions of the federal states, in Poland - from 1 to 300, and with inheritance - up to 500 hectares. In Spain, the limit is 50 hectares for irrigated land and 100 hectares for extensive pastures. In Denmark, the upper limit for land use (owned or leased) is 150 hectares. Cases of increasing the area of land are allowed by special decision only in the case of specific production requirements and provided that no one claims the land. In the US, the concentration of land in the hands of a single farm has been restricted since the 1970s by a ban on its purchase and lease by non-farmers. Land use restrictions are regulated by state laws. In the western states, for example, the limit in the 70s and 80s was 130 hectares for individual farms and 260 hectares for family farms.

6. In many countries, *land use regulations are linked to the effective employment of farm workers.* In Switzerland, the minimum size of a farm must ensure that one person is employed by 75%, or 2,100 hours per year. The minimum size of leased land is calculated for full-time employment of 1.5 people. The maximum size is a plot (owned or leased) that provides a level of income that satisfies 2.5-3 people working on it.

In France, the minimum optimal farm is a farm that provides full employment for 2 people and an income that meets their needs and keeps them from moving to other areas of employment. The national average size of such a farm is 25 hectares. Depending on the zone, an upward and downward deviation coefficient of 30% is set. The law does not set a maximum level of land use for a farm. At the same time, if farmers are united in non-profit associations for joint farming (CAEC, EARL, etc.), the total area of their plots cannot exceed 6 minimum sizes.

7. *It is a common practice to introduce regulations that discourage the fragmentation of farms.* In France, Sweden, Italy, and other countries, it is not allowed to split up a land plot for the purpose of sale, lease, or donation - it is included in the circulation. When a land plot is inherited, the right to it is assigned to only one family member, who is determined by agreement, through the court or by special authorities. Other heirs receive payments for their shares. In order to prevent the monetary compensation from becoming a burden for the designated heir, a certain payment period is set (in France - up to 10 years), or the mechanism of "preferential valuation of agricultural land" is legalized, according to which inherited land is valued at significantly lower than market prices (in the Netherlands - by 50%, in Denmark - by 60%). In several countries, the law establishes a mechanism of "deferred salary", according to which the applicant for inheritance is paid a salary working on the farm, the accumulated amount of which at the time of entry into rights is deducted from the value of the inherited land plot, which reduces payments to the co-heir.

8. *The ideology of pricing and rent regulation* is aimed at a balanced solution of two tasks - to prevent price dumping in the interests of a farmer who sells (leases) his land, on the one hand, and, on the other hand, to prevent speculative transactions in the agricultural land market in the interests of their buyer (lessee), who takes over the "ba-

ton" of the producer. There are various mechanisms for balancing the interests of the buyer and seller, lessee and lessor. In many countries, this is achieved by regulating a "price corridor" within which the purchase and sale price is formed. In case of exceeding the "corridor", intervention activities of state institutions to regulate the market are triggered.

In the UK, for example, a tenant and a landlord may agree on the amount of rent. However, such an agreement will only be notarized after it has been reviewed and approved by the local authorities if it (the rent) meets the standards set by the country. France and other countries have a similar approach. In the Netherlands, Spain, Belgium, Portugal, and Japan, the authorities control rents by setting standard or maximum rents. The rent is calculated in monetary terms, based on the potential harvest and prices for agricultural products over the past year.

In the US, Canada, Australia and New Zealand, the agricultural land lease market is more liberal. At the same time, the central executive bodies of the countries approve possible options for calculating the rent to choose from (in the US, the relevant ministry has recommended 8 such options).

9. Institutionalization of the "rules of the game" in the agricultural land market is accompanied by the creation of structures that monitor compliance with legislative norms. In France, these powers are exercised by SAFER, an institution "that regulates and guides the agricultural land market" in order to facilitate the start of professional farming, especially for young farmers; increase the area of land use of farms to the optimal (reasonable for each zone) size; regroup land plots between farms and eliminate gaps; prevent speculation in agricultural land, etc.

To perform its functions, SAFER has the following rights

- Priority purchase of land plots put up for sale, carrying out land reclamation works on them, if necessary, and selling them within 5 years, choosing the option that best meets the above objectives of the law
- examination of all land sale and purchase projects from the point of view of their compliance with the law to prevent excessive concentration of land in one hand or, conversely, fragmentation of land plots, purchase of land at a far distance from residence.
- cancellation of the sale and purchase agreement, including through the courts, if it goes beyond the minimum and maximum prices established in the region;
- creation of land reserves for public needs through the purchase of land plots, etc.

Specialists of the grassroots (district) SAFER structures "monitor" the turnover of land plots; conduct land property expertise; assess the potential of the farm where the land is sold and the farm that acquires the land plot; solve problems of land exchange; negotiate the price with the seller; and endorse the sale documents. However, the transaction based on the certified documents will only be carried out after it is approved by the government (prefecture).

SAFER is funded 50% by the government and 50% by fees from land buyers. SAFER receives a concessional loan (at 2%) from the cooperative bank Credit Agricole for the purchase of land plots and their conservation.

In Poland, the Real Estate Agency is responsible for regulating the agricultural land market and carries out such operations as leasing, purchase, lease, sale, transfer to management, etc. The 1991 law gave it the same powers as SAFER.

In Canada, until almost the 1990s, the Land Bank acted as a regulator of the agricultural land market, with *monopoly rights* to buy, sell, lease and other transactions. The acquired plots were immediately leased or sold to persons who met the requirements established by law.

10. *The above regulatory policy is complemented by state financial support.* Farmers, as a rule, do not have the necessary one-time capital to purchase land to start or expand their farms due to the specifics of agricultural production. And here the state also becomes their partner. In other words, the socialization of land relations through the redistribution of property rights in the interests of farmers and the state is complemented by support for the financial capabilities of certain agricultural producers.

In EU countries, lending for the purchase of agricultural land is usually provided through *a system of cooperative banks* formed with the participation of the state. In France, this is the Credit Agricole network of cooperative banks, in the Netherlands - Rabobank, in Romania - Creditcoopbank, in Spain - Coopérative de Credito, and in Germany - the Deutsche Genossenschaftsbank system. Poland's rural cooperative credit system includes 596 cooperative banks with 3.3 thousand local branches, which meet 80% of the credit needs of their member farmers, including long-term loans for land purchase (Ustawa, 1958). India's cooperative system of long-term land purchase loans, which includes 67% of farmers (880,000 farms), includes 2841 district cooperative banks and 20 state cooperative banks (National Cooperative Union of India, 2016).

The system of preferential long-term cooperative credit services for farmers' purchases of agricultural land is complemented by *state non-bank credit structures*. In the United States, the Farm Service Agency (FSA) of the US Department of Agriculture forms such a "tandem" with the Farm Credit System, a cooperative farm credit system (Farm Service Agency, 2025).

In Canada, the agricultural credit co-operative system is complemented by the government-owned Farm Credit Canada (FCC) (Farm Credit Canada, 2025). The purpose of the corporation is to provide specialized and personalized business and financial services for the purchase of land by farms, including family farms.

In the UK, in addition to cooperative lending institutions, the Agricultural Mortgage Corporation (AMC) (The Agricultural Mortgage Corporation Plc, 2025), established under the Agricultural Credit Act to provide long-term mortgage loans to revive land tenure, especially for young farmers, lends to farmers to purchase real estate.

Specialised institutions use a range of mechanisms to improve the financial capacity of farmers to acquire agricultural land, including: *long-term* (up to 50 years) lending for the purchase of land plots *at low* interest rates; *larger* loan amounts than commercial banks in relation to the value of the land plot to be acquired and *higher* liquidity *ratios* of the pledged land plot (up to 75%); *protection of the value of* land real estate transferred by the farmer as collateral for the loan received. To facilitate the acquisition of land plots by small farms, the EU countries have made it common to sell state-owned land plots at prices *lower than* those for private plots, etc. (Kolyubakin, V., 2018; Demianenko, S.I., 2002).

An analysis of the legislative practice of regulating land relations shows that all transformations in land relations were subordinated to the farming type of management. This direction had to be chosen even in those countries where the latifundist-landlord model of agriculture seemed to be unshakable. Thus, until almost the 1960s, the dominant latifundist economy in Latin America was actively involved in large-scale capitalist production with its inherent monocultural character, displacement of tribes and small farmers from rural areas with the participation of foreign campaigns (under the influence of these processes in Argentina, for example, the rural population decreased to 7%).

The concentration of land in agro-trading and financial companies, landlessness, poverty, pressure on urban labour markets and other social phenomena have necessitated radical changes in land use. These changes are based on the mechanism of land redistribution through *nationalisation and purchase of* land and its sale to peasant families at an affordable price and preferential lending from the state. In this way, Mexico, Cuba, Bolivia, and Venezuela completely switched to the farming type of economy. In Mexico, by the early 1970s, about 30 million hectares of land had already been distributed.

In Chile, according to the 1967 Agricultural Sector Reform Law, expropriated and purchased land was transferred to rural families with *payment in instalments*. With the help of the state, the peasants who acquired the land plots were initially required to unite in production cooperatives (assentamentos) for joint farming for a period of 3-5 years, after which the land was transferred to family-individual farms. During the first 6 years of the reform, 3.6 million hectares were expropriated, and 916 assentamentos were organized on them with the participation of 29,000 families (on average, a cooperative accounted for 3,736 hectares of land, and a family farm for 117 hectares).

In Brazil, this process has been developing more widely since the 1980s. In the second half of the 1990s alone, 18.0 million hectares of land were expropriated and purchased, on which 285 thousand farms were established. The conversion of agriculture to a farming type of management is associated with high costs. The Brazilian state budget provides preferential lending for the purchase of land and means of production, the creation of new rural settlements on depopulated land from families previously displaced to cities, financing of social infrastructure, primarily housing construction, etc.

The fact that the world's science and practice recognizes the farming type as the dominant one is objectively justified by the fact that it considers the peculiarities of land as the main means of agricultural production and the multifunctional nature of agriculture to the greatest extent compared to others. *Farming has proven to be the economic unit that is able to work most productively in harmony with nature.*

The peculiarities of agriculture and the specifics of land are reflected in the organizational and legal forms of farming, which are individual and corporate family farms: partnership farms (simple partnerships in Germany), social corporations (EARL in France, S-corporation in the United States), joint farming associations (GAEK in France), and production cooperatives for joint land cultivation (Italy, Spain). Industrial, commercial and financial capital in any organizational and legal form is not allowed to independently conduct agricultural activities and use land in the EU countries.

In all forms of farms, ownership and labor relations are not separated, which ensures the most complete and effective implementation of the multifunctional value of agriculture and cultivated land: all types of farms, including collective farms, retain the status of their member as the owner of the land plot, produced goods and proceeds from their sale; work on the farm guarantees a job, and life on the farm encourages a frugal attitude to land, flora and fauna, other natural resources.

Most countries in the world, including the most developed ones, demonstrate optimal land use through the support of farming. In Germany, for example, after the agrarian reform, the following land use was formed in the eastern states (Table 49)

Table 49

Structure of agricultural enterprises in Germany by size of land, 2017

Size of the enterprise,	Number of enterprises		Land area		Average enterprise size
	th.	%	thousand ha	%	ha
up to 10	654	24,3	359,3	2,2	5,5
10-20	55,5	20,8	831,4	5,0	14,9
20-50	64,9	24,0	2170,0	13,0	33,4
50-100	46,8	17,4	3324,0	19,0	71,0
100-200	24,6	9,1	3330,6	20,0	135,4
200-500	8,8	3,2	2554,4	15,2	290,3
500-1000	2,3	0,8	1599,0	9,6	695,2
more than 1000	1,5	0,6	2528,6	15,2	1686
Total:	269,8	100	16687,3	100,0	62

Source: Situatiausberidit Z018/19 des deutsdien Bauerystoandes

The same trend in land use is observed in the USA (Table 50)

Table 50

Land use in the USA by organizational and legal forms

Farms	Number of farms		Area of land		On average per 1 farm, acres/ha
	th.	%	th.	%	
Individual and family farms	1829	86,7	562000	61	307.3 acres = 129.0 ha
Partnership farms	138	6,5	156000	17	1130.4 acres = 475.0 ha
S-corporations	107	5,1	131000	14	1224.2 acres = 514 hectares
including family land	95	4,5	11880	12,8	1250 acres = 525 ha
Co-operatives, ranches, etc.	36	1,7	73000	8	2027 acres = 851 ha
Total	2109	100,0	929209	100,0	437 acres = 184 ha

Source: Compiled by the author according to ProQuest Statistical Abstract of the United States: 2016. - P.555-557.

The economic, social and environmental orientation of agriculture is supported by legislative and regulatory acts on land protection, rules of its use in accordance with the laws of agriculture and the needs of society, and measures of responsibility for their violation. Compliance with the established rules is ensured by a set of legal actions of

regulatory authorities, ranging from warnings to withdrawal of licences to engage in agricultural activities.

In Ukraine, transformational processes in land relations from the very beginning of the land reform were not and are not associated with the concept of multifunctional use of agriculture and, accordingly, its basis - land. Multifunctionality is not legitimized as a tool for developing agricultural policy for sustainable development. A haphazard approach to land reform has given rise to many contradictions, which has led to negative consequences in land use.

The contradictory nature of the transformations in agricultural land use is, in particular, as follows: lease of agricultural land has been legalized, but the absence of any restrictions on access to it has led to the concentration of land in the hands of big capital; private peasant farms have been granted the right to annex land plots received as part of shares without registering a legal entity, but their status in the economic structure of agricultural production is not legally defined; a contradictory system of land taxation has been introduced.

As a result, two new dominant diametrically opposed, but equally disastrous for the village and the country, models of management have emerged in the agricultural land use of the economy: *latifundist-oligarchic and parcel-based*. The former was formed through the absorption of successor farms by industrial, commercial and financial capital. It is characterized by a significant concentration of leased land in the hands of individual companies. While in the USA, according to Table 50, one fifth of the land is cultivated by the largest farms with an average land use of 500 to 850 hectares, in Germany - from 695 to 1686 hectares (Table 49), in Ukraine the same share of land is used by enterprises with an average size of 20-23 thousand hectares (Table 51)

Table 51

Distribution of agricultural enterprises in Ukraine by area of agricultural land

Group s of agri- cul- tural enter- prises by the area of land in their use	Number of enterprises						Area of agricultural land						Area of agricultural land per enterprise, ha		
	2003		2010		2020		2003		2010		2020		2003	2010	2020
	Number of sub-units, units	in % to the total of the total	Number of sub-units, units	in % to the total quantity	Number of sub-units, units	in % to the total number	Area of agricultural land, thousand ha	in % of the total area	Area of agricultural land, thousand ha	in % of the total of the total area	Area of agricultural land, thousand ha	in % of the total of the total area			
Up to 5	6850	11,4	5784	10,2	1975	4,2	22,5	0,1	18,3	0,1	6,4	0,0	3,3	3,2	3,2
5,1-10	4881	8,1	4038	7,1	1877	3,9	38,8	0,2	31,9	0,1	14,7	0,1	7,9	7,9	7,8
10,1-20	5787	9,8	4925	8,7	3061	6,4	90,8	0,4	76,3	0,4	47,7	0,2	15,6	15,5	15,6
20,1-50	16251	27,1	13707	24,3	9395	19,7	614,5	2,6	519,8	2,4	353,3	1,7	37,8	37,9	37,6
50,1-100	5279	8,8	4831	8,6	4626	9,7	355,9	1,5	345,2	1,6	333,0	1,6	67,4	74,5	72,0
100,1-500	6512	10,9	7181	12,7	7889	16,6	1589,2	6,7	1743,1	8,1	1928,1	9,5	244,0	242,7	244,4
500,1-1000	3119	5,2	2667	4,7	2716	5,7	2282,5	9,6	1919,4	8,9	1957,9	9,7	731,8	719,7	720,9
1000,1-2000	3927	6,6	2661	4,7	2409	5,1	5645,5	23,9	1822,8	17,7	3458,9	17,1	1437,6	1436,6	1435,8
2000,1-3000	1873	3,1	1347	2,4	1030	2,2	4543,4	19,2	3295	15,3	2500,3	12,4	2420,7	2446,5	2427,5
3000,1-4000	942	1,6	666	1,2	473	1,0	3234,2	13,7	2293,0	10,6	1629,9	8,1	3433,3	3442,9	3445,9
4000,1-5000	435	0,7	376	0,7	247	0,5	1931,2	8,2	1670,5	7,6	1099,2	5,4	4439,5	4442,8	4450,2
5000,1-7000	356	0,6	332	0,3	263	0,6	2052,6	8,7	1919,6	8,9	1535,9	7,6	5765,7	5781,9	5859,9
7000,1-10000	91	0,2	178	0,2	132	0,3	743,3	3,1	1479,6	6,9	1107,0	5,5	8168,1	8312,4	8386,4
More than 10000	34	0,1	131	0,3	184	0,4	495,8	2,1	2450,9	11,4	4280,1	21,1	14582,3	18709	23261,4
Total	56437	94,2	48824	100	36277	76,3	23640,2	100	21585,7	100	20252,4	100	418,8	226,3	558,3

Source: Statistical Yearbook "Agriculture of Ukraine" for the relevant years.

The average figure hides dozens of companies that lease 300 to 500 thousand hectares or more of land.

According to the magazine "TOP-100 Agricultural Companies", 16 agro-industrial structures began to control 100 thousand hectares or more. In 2012, each such company accounted for an average of almost 203,000 hectares, while now it is about 240,000 hectares.

According to research conducted by the Institute of Agrarian Economics, these structures have taken over or subordinated more than 6,000 agricultural enterprises, control up to 40% of the land used by enterprises and produce up to a third of agricultural products (Table 52)

Table 52

Companies with the largest land use in the agricultural sector in Ukraine

№	Name of the company	Area, ha
1.	"Kernel Group Company	524 000
2.	"UkrLandFarmihg	500 000
3.	"Myronivsky Hliboproduct (MHP)	380 000
4.	"Agroprosperis (NCH)	300 000
5.	"Astarta-Kyiv	240 000
6.	"Continental Farmers Group	195 000
7.	"Epicentre Agro	160 000
8.	"Harveast	132 000
9.	"Industrial Milk Company (IMC)	123 000
10.	"Ukrminvest-Agro	120 000

Source: Top 10 largest agricultural holdings in Ukraine 2021 (Baker Tilly, 2024).

The concentration of agricultural land is accompanied by the abandonment of crop rotation and the transition to monoculture export-oriented production, the destruction of local agroecosystems and traditional employment sectors of the rural population, increased migration and depopulation of rural settlements.

The second model is formed by individual peasant farms, which account for more than 80% of rural households engaged in agricultural production. Of these, 3.7% have formed land plots of 5 to 10 hectares or more through the annexation of land plots received as part of sharecropping, while almost 78% of households have up to 1 hectare of land in use (Table 53)

Table 53

Distribution of rural households by land area

Area of land, ha	Number of rural households		Land area	
	ths.	%	ha	%
up to 1	1401	77,8	11670	27,0
1,01-5,00	1571	18,5	2775	30,2
5,01-10,00	671	2,3	345	12,9
more than 10.0	1555	1,4	210	29,9

Source: Calculated by the author according to the statistical collection "Agriculture of Ukraine"

The number of forcedly employed people in this group of farms increased by 2 million people who were forced out of the first model enterprises as a result of the destruction of livestock and other labor-intensive products. Smallholder farms cannot compete with large companies in the land lease market, which makes it impossible to expand their land use to increase profitability and increase effective employment, they do not have access to state support and loans, and they are not able to access profitable markets monopolized by traders.

We attribute the basic miscalculation in the implementation of land reform in Ukraine to the fact that in its concept such an important "pillar" of its foundation as the organization of land use on the basis of farming, which would then be the basis for agrarian reform and rural social policy, has fallen out of sight of reformers, despite both international experience and recommendations of many domestic agricultural scientists.

Academicians V.V. Yurchyshyn, O.M. Onyshchenko, and P. Haidutskyi defended in their works back in the 1990s the thesis that land reform *"...is intended to revive agricultural dynasties and strengthen the social roots of the peasant"* (Yurchyshyn, V.V., 2013). At the same time, production and organizational transformations in collective agricultural enterprises in the most general form should be aimed at deepening and strengthening *the cooperative principles of management* (Yurchyshyn, V., Onyshchenko, O. and Haidutskyi, P., 1994). The above-mentioned practically focused on the development of the farm type of management through individual, family and socially oriented (non-commercial) corporate farms at the level of production and their cooperative and other associations for joint actions at the level of markets for the sale of products and the purchase of means of production. However, Ukrainian legislation has not yet determined the dominant agricultural system.

The mechanism of transferring land shares (plots) to CAE members free of charge and the principles of rent formation proved to be ineffective. They did not inspire peasants' confidence in privatization and did not "awaken" their sense of ownership. More effective, as practice shows, would be the purchase of land plots at a reduced price, affordable to the least solvent part of the peasantry. This conclusion is also confirmed by a sociological survey conducted by us in the 1990s in 8 districts of all zones of Ukraine, covering 10,000 respondents from various professional and social groups of the rural population. The respondents preferred the purchase of land plots to all other methods of acquiring land ownership. The peasants argued that such an act is more reliable for the owner ("the purchased land is more mine than the gift", "if they gave it for free, they can take it away"); that what is received for free is usually less valuable; that the land plot will be bought primarily by those peasants who seriously plan to link their fate with agriculture, resulting in natural selection and settlement of the most capable people in the agricultural sector (Moldavan, L.V., 1991).

The biggest miscalculations in the institutionalization of conditions for rational land use were made in legislative regulation of the turnover of agricultural land. The long-term moratorium on the sale and purchase of land has provoked uncontrolled sales of land under various shadow schemes, such as preliminary agreements between tenants and landowners when concluding future sale and purchase agreements with notarization; potential buyers providing a "loan" to the landowner with subsequent "forced" collection of the outstanding "debt" through the court by entering into an amicable agreement, as a result of which, with the consent of the "debtor", the debt is covered by the land plot, etc.

The chaos in land use was compounded by the imperfection of the Law of Ukraine "On Land Lease" (1998) (Verkhovna Rada of Ukraine, 1998), which does not contain any restrictions on the size of land plots that can be leased by one business entity, does not link lease to qualification requirements for tenants and to the preservation of employment of peasant landlords, does not orient the use of land to the needs of the domestic market for food and other social functions of land use common in world practice.

The Law of Ukraine "On Amendments to Certain Legislative Acts of Ukraine on the Turnover of Agricultural Land" (Verkhovna Rada of Ukraine, 2020) adopted in 2020 did not eliminate the above problems but rather consolidated them and created new

ones. This act granted the right to buy and lease agricultural land to any citizen and any legal entity. There are no requirements for professional education, work experience, or residence in the area where the land is located. The lease of land remained unrestricted, and the purchase of a land plot by one person is limited to 10,000 hectares, which is incomparable to the land use of any European or North American corporate farm.

The law provides for the auction sale of state-owned land plots, which makes it impossible for small and medium-sized farms to acquire them in this way, as the competitive financial capabilities of large companies are an insurmountable barrier for them.

The government-approved conceptual guidelines for reducing the cost of loans to agricultural producers provide for conditions that small and medium-sized agribusinesses cannot meet. The same applies to partial state guarantees for loans to purchase agricultural land.

Commercial banks remain the lenders, and under no circumstances do they agree to serve farms with land use of less than 500 hectares.

The Law "On Banks and Banking" (2000) does not provide for the creation of a state fund like Canadian or US institutions for farmers' credit services, nor does it regulate the network of cooperative banks in the country.

The above requires amendments to the current legislation on the rules of turnover of agricultural land, considering its social functions and international experience, that of Western European countries. The real processes that have deeply penetrated the "fabric" of land relations in the domestic agricultural sector will obviously preserve the possibility of leasing agricultural land not only to individuals but also to legal entities, if they are registered at the location of these lands, provide employment to the local population (primarily landlords) and pay taxes to the local budget, which is of great social importance.

Failure to take this into account leads to the concentration of land in the hands of national and transnational companies, whose interests are not related to the welfare of society, but to the use of land to increase their profits by growing the most profitable crops for export.

Legislative legalization of their access to the agricultural land market is a way to landlessness of peasants, increased unemployment of the agricultural population and migration processes, depopulation of rural settlements and environmental degradation of rural areas, which threatens future generations of our society with a decrease in food sovereignty and loss of the country's main wealth - fertile agricultural land.

To prevent the development of such processes, the priority measures in line with Western European practice should include the introduction of generally accepted restrictions on the ownership and lease of agricultural land; a ban on non-agricultural companies and foreigners from acquiring agricultural land in any way; setting an upper limit on land use for individuals (up to 500 hectares) and for corporate enterprises (up to 5,000 hectares); identification of private farms; and

The European integration orientation and the situation in land use oblige Ukraine to make fundamental changes in the regulation of socialization of land relations by harmonizing domestic and European legislation in this sphere of human activity. Justification of these changes is an important mission of the national agronomy.

3.2. STATE REGULATION OF RESOURCE USE AND RESOURCE CONSERVATION IN THE AGRICULTURAL SECTOR

The constitution of each country recognizes that land is the main national wealth that is under special protection of the state. This wealth is the only source of agricultural production and food security for society. Land is a backbone resource of agricultural landscapes - the habitat of rural and urban populations and a means of ensuring biodiversity. In this regard, the essence of control over the use and protection of agricultural land is to monitor those parameters that determine the quality of agricultural land, its fertility and ecological functionality.

With the development of policies aimed at eliminating the negative processes that accompanied the industrialization and chemicalization of agriculture, the functions and forms of state control methods have changed, as shown by their analysis in developed countries, which are covered by scientific and technological progress. Until the 1990s, Western Europe was dominated by control over farmers' compliance with environmentally sound management rules related to soil and water pollution with nitrates, violations of the rules for storing chemical plant protection products, mineral fertilizers and organic livestock waste. At the same time, violations related to the use of land for other purposes were controlled.

The main regulatory tool was state standards, which were subject to penalties for violations.

The expansion of exhausting and environmentally hazardous land use has led to the development and implementation of a new approach to state regulation, which considers all factors of anthropogenic impact on soil degradation and reduction of its productive capacity. *To implement this new approach, Western European countries have recognized environmental protection and resource-saving activities in the field of land use as one of the most important functions of the legislative, executive and judicial branches.* The policy of protecting and restoring land fertility is based on the concept of multifunctional use of agricultural activities, i.e. the integration of its economic, environmental and social aspects. Overcoming the degradation of land resources is the basis for preserving the country's main national wealth, which requires an appropriate level of administrative, legal, financial and resource support.

The standardized objects of assessment of farms' activities in the context of compliance with the new approach are nutrient and humus balances in cultivated soils, animal health, crop and animal diversity, crop rotation, and preservation of natural pastures, conservation and reforestation of degraded land, the level of pesticide, veterinary medicine and mineral fertilizer use, the availability of field shelterbelts, the quality of feed for own livestock and the quality of products for sale, etc.

At the pan-European level, the legislatively regulated requirements for creating conditions for preserving soil fertility, protecting the environment, water and forest resources form the system of "mutual consent (Crosse Compliance)" (European Commission, n.d. Cross-compliance. Linking income support to respect for European Union rules, 2025). The name is derived from the EU Regulation No. 73/2009, according to which payments under direct support programmes for agriculture are linked to established standards for the protection of the natural environment, animal health and

welfare, feed and food safety, and other requirements. The farmer's access to subsidies, compensation payments, and benefits becomes dependent on the obligation to rationally use and reproduce the natural resources of agriculture. Violation of the established rules leads to a reduction in payments due to farmers under existing state support programmes.

EU Regulation No. 1122/200 sets out the main rules and obligations for soil protection and fertility restoration. Commission Regulation (EC) No. 1698/2005 is aimed at supporting the development of agro-landscape rural areas. It is supplemented by Regulation (EC) No 1698/2005. Regulation (EC) No 1234/2007 provides rules for farms in the wine sector. The rules for the identification and registration of cattle and the labelling of beef and beef products are set out in Regulation (EC) No 1760/2000. General principles and requirements for food products are set out in EU Regulation 178/2002.

The regulations are supplemented by more than a dozen EU Council Directives. National laws and regulations of the EU member states implement, specify and expand the rules of the pan-European Grosse Compliance system and communicate them to producers through governmental acts, in the form of Codes of Good Agricultural Practice. The Codes, which are common in EU countries, specify what is permitted or prohibited to prevent crimes against natural resources in agriculture, shape the right attitude of farmers to the requirements of the law and teach them how to reduce the negative impact of agriculture on natural resources.

The Codes contain rules on environmental protection, land protection, soil fertility, water quality requirements, the economical use of chemicals, and other guidelines that are regulated by EU regulations and directives.

The main objective of the Polish Code of Good Agricultural Practice is to create a system of recommendations aimed at preserving and restoring soil fertility, preventing soil degradation and maintaining ecological balance. The main principles of sustainable agricultural management set out in the Code include:

1. *Preservation of soil fertility.* This is achieved through the balanced application of organic and mineral fertilizers, the use of green manure, composting of organic residues and other methods that increase the organic matter content of the soil. These measures help to improve the soil structure, its water-holding capacity and activate soil microflora.

2. *Prevention of soil erosion,* as soil erosion is one of the main threats to the sustainability of agro-ecosystems. Therefore, the Code recommends the implementation of agrotechnical practices aimed at reducing erosion processes, such as contour farming, use of cover crops, mulching and creation of protective forest belts. These measures help to reduce the rate of water runoff, prevent soil washout and preserve soil structural integrity.

3. *Effective nutrient management in agricultural systems,* which helps to reduce the risk of environmental pollution and more efficient use of resources. The Code provides recommendations for optimizing the use of mineral fertilizers, including their precise dosage, timing and application methods. Particular attention is paid to preventing the leaching of nitrates and phosphates into water bodies, which is achieved through the

introduction of buffer zones and precise application of fertilizers depending on the agrochemical analysis of the soil.

4. *Reducing the impact of agricultural machinery on the soil*, as excessive soil compaction by agricultural machinery leads to reduced aeration, deterioration of water permeability and root-bearing environment. The Code proposes measures to reduce soil pressure, such as the use of wide-cutting equipment, tire pressure regulation and minimizing the number of times machinery passes through fields. These measures are aimed at preventing soil degradation and maintaining its physical condition.

5. *Regulation of soil pH*. One of the key aspects of soil protection is maintaining an optimal pH level, which improves nutrient availability and reduces the toxicity of certain elements. Regular liming of soils, especially in acidic areas, helps to stabilize the pH and improve conditions for plant growth.

6. *Organic farming*, which is based on the rejection of synthetic chemical fertilizers and pesticides, is an important strategy for soil conservation. An important element in this context is *composting* organic waste, which helps to return essential nutrients to the soil and improve its structure.

Measures envisaged by the Polish Code of Good Agricultural Practice aimed at protecting groundwater are based on the principles of pollution prevention through rational use of resources, implementation of environmental technologies and continuous monitoring. Their implementation contributes to the preservation of groundwater quality, which is crucial for maintaining ecological balance and sustainable agricultural development.

1. *Rational use of fertilizers*. The Code provides recommendations on the use of mineral and organic fertilizers to minimize the risk of nitrate and phosphate leaching into groundwater. It is important to carry out agrochemical soil analysis to determine the optimal doses of fertilizers, as well as to choose the appropriate timing and methods of their application. This includes the introduction of precision farming systems that reduce the amount of fertilizer used while increasing its effectiveness, thereby reducing the risk of water pollution.

2. *Create protective buffer zones* along water bodies and near water sources. Buffer zones are areas of natural vegetation that act as filters that trap pollutants, such as pesticides and nitrates, and prevent them from entering groundwater. The Code emphasizes the need to establish and maintain such zones on all vulnerable agricultural land.

3. *Control over the use of pesticides*. To prevent groundwater contamination by pesticides, the Code imposes strict restrictions on the use of chemical plant protection products. It recommends the use of an integrated plant protection system (IPM), which involves minimizing the use of chemical pesticides and switching to safer alternatives, such as biological pest control methods. In addition, the Code prescribes compliance with the rules of storage and disposal of pesticides to prevent their uncontrolled release into the environment.

4. *Water management*, covering measures to prevent over-irrigation and optimize water consumption on agricultural plots. Excessive irrigation can lead to the leaching of harmful substances from the soil into groundwater, so special attention is paid to the use of water-saving technologies such as drip irrigation and mulching. These measures

help to reduce the water load on agricultural landscapes and minimize the risk of groundwater contamination.

5. *Water quality monitoring.* The Code provides for regular monitoring of groundwater quality, which allows for timely identification and elimination of sources of pollution. An important aspect is the creation of a monitoring system that includes both periodic analyses of water samples and the use of automated monitoring systems that ensure continuous collection of data on the state of water resources.

The Polish Code of Good Agricultural Practice is a comprehensive system of recommendations aimed at preserving and restoring soil resources. Its implementation and compliance not only increase the sustainability of agro-ecosystems but also reduce the negative impact of agricultural activities on the environment. Ultimately, the implementation of sustainable agriculture principles contributes to the long-term food security and environmental sustainability in the country.

The criteria for assessing compliance with the requirements and rules are:

- frequency of violations: sanctions are imposed and increased for repeated failure to comply with warnings of non-compliance;
- scope of violations - the area of land on which the conditions are not met, the volume of incorrectly performed technological operations, etc;
- severity of violations - the level of losses incurred because of non-compliance with the established requirements.
- the period of validity of the consequences of the violations - the period of restoration of the lost humus content, the period of cleaning up the pollution, restoration of natural pasture, etc.

The level of sanctions depends on the assessment of violations according to the above criteria, which can range from 1 to 100% of the total amount of direct payments due. Each country develops rules of good agricultural practice and sanctions for their violation, depending on the state of agricultural natural resources in specific conditions.

Agricultural ministries, as well as governors and local authorities, are responsible for the rational use of land. If land users violate the rules for the protection and restoration of soil fertility set out in the laws and regulations, the commune and the governor may impose a ban on activities that cause soil degradation. The commune determines the measures to be taken by the land user to stop the negative processes. Ministries of Agriculture may issue orders to create cultivated agricultural landscapes on degraded land to be used for agritourism development or to convert them into forests, hayfields, etc. If the recommendations are not implemented within the established timeframe, the ministries are empowered to:

- conclude an agreement with the land user to lease the degraded land to the ministry for a period of 10 years to organize measures to ensure the rational use of degraded land;
- to take measures for the compulsory transfer of the most affected lands into lease to other persons who agree to the terms and recommendations of the Ministry;
- to confiscate completely degraded both leased and owned land for further use in accordance with the requirements of the law (Kresnikova, N., 2006).

An important feature of the new approach is the addition of economic incentives to sanctions to preserve soil fertility, rational use of soil, protection of water and forest

resources, and compliance with environmental functions. For example, farms that switch to organic farming receive a reward over five years in the amount ranging from 30% in the first year to 10% in the last year of total costs. Remuneration (compensation) is set for various measures to protect land from wind and water erosion, conserve degraded land, alkalize it, reforest it, etc.

With the expansion of the functions of control over the rational use of land, its protection and restoration of fertility, restoration of agricultural landscapes, protection of water and forest resources, a new approach to the formation of professional controlling bodies, which are special agricultural, environmental, veterinary and other state institutions, has arisen.

The UK has a clear system for assessing anthropogenic impact on the environment, which includes 150 agronomic, environmental, economic, social and other indicators (White Achieving a Better Quality of Life). The use of farmers' performance indicators is aimed at improving the structure of agricultural land and agricultural production, reconstructing crop rotations, and switching to organic farming and soil-protective tillage technologies. Biological indicators involve monitoring the quantity and diversity of soil ecological conditions.

There are 11 NGOs in the country whose work is aimed at preserving and restoring soil cover. Popular and informational materials on this issue are published, farmers are educated, and television programmes are broadcast about soils, their structure, micro-organisms and their role in soil formation, and the need and ways to protect land from degradation, erosion, chemical pollution and other negative processes.

In Germany, the protection and reproduction of the natural potential of agriculture is institutionalized in the Federal Soil Protection Act and the document "Informationbroschüre über die einzuhaltenden anderweitigen Verpflichtungen - Cross Compliance". The introduction of soil protection technologies for cultivating land, mulching the soil cover, ensuring a balanced soil nutrient regime and other regulated measures to maintain and restore agricultural land fertility are supported by subsidies of 25-100 euros/ha.

In Norway, measures to protect and maintain land fertility and the environment have been supported since the late 1980s. Farmers receive financial subsidies for reducing the use of chemical plant protection products and mineral fertilizers (up to EUR 40/ha), and for refusing autumn ploughing with a layer turnover, which increases surface water runoff and erosion processes during spring snowmelt (up to EUR 125/ha).

In Greece, Italy, and Spain, where a large share of small farms operate, mechanisms have been institutionalized to support the introduction of new soil conservation technologies and the transition to conservation agriculture by compensating these farms for the purchase of necessary machinery and equipment, etc.

Compared to European countries, the forms and methods of domestic state control over the protection and restoration of soil fertility, environmental protection, biodiversity and agricultural landscapes, and the system of liability for damage to the natural resources of agricultural land are in their infancy.

According to official statistics, only the violations established by land legislation are controlled, such as unauthorized occupation and use of land plots without relevant documents, failure to comply with legal orders and instructions, and use of land for other

purposes. In other words, agricultural land is subject to control only as an operational basis and real estate. Violations in relation to land as a means of agricultural production and an environmental resource are not subject to state control, and therefore there are no liability measures in place.

Formally, the current land legislation considers actions or omissions of farms that lead to a decrease in the fertility of agricultural land to be an offence. Article 254 of the Criminal Code of Ukraine provides for criminal liability for mismanagement of land that has led to a decrease or loss of fertility, withdrawal of land from agricultural turnover, washing away of the humus layer, and disruption of soil structure.

However, no one has been held accountable for the catastrophic degradation of soils over the past 20 years, the decline in their humus and nutrient content, and other violations. These phenomena have not been subject to control by government agencies responsible for monitoring land protection, land use and fertility restoration.

This was the result of imperfect institutional and legal support for control activities. The state control over the use of land as a means of agricultural production, in the process of which their main production value - fertility - is realized, is technological in nature. It cannot be carried out in isolation from the regulation of the process of growing crops. However, the controlling institutions lack soil analytical laboratories, relevant units and qualified personnel on the ground. Consequently, inspectors of land use and protection do not have appropriate methods for identifying those factors of activity that damage soil fertility and assessing the level of losses incurred as a result.

In France, Germany, Denmark, Norway and other EU countries, ministries of agriculture are responsible for monitoring the rules for the use and restoration of agricultural land fertility. The structure of the People's Commissariat of Agriculture of the USSR (the predecessor of the Ministry of Agriculture) included a service of land surveyors who carried out state audits of land use in collective and state farms, monitoring compliance with the established procedure for land use, crop rotation, erosion control measures, etc.

With the creation of the Ministry of Agriculture, its structural unit was the main department for land use, land management, shelterbelt forestry and protection of agricultural land, with corresponding units in regional and district departments of agriculture.

The Ministry's land management service monitored problems in agricultural land use and prepared draft legal acts to address them. The Ministry directly managed the activities of agricultural enterprises as land users, controlling their compliance with the legislation on the protection and proper use of agricultural land. Thanks to the land management service, the country has developed scientifically based crop rotation farming, and a significant amount of forest reclamation work has been carried out (reforestation of ravines and steep slopes, planting of field anti-erosion forest belts, regulation of surface runoff, etc.) The Service initiated and managed the introduction of new technologies aimed at radically improving soil fertility and ecological conditions (in particular, the introduction of contour-meliorative farming systems).

In 1991, with the start of the land reform, the service was separated from the Ministry and the State Committee of Ukraine for Land Reform was established on its basis, which was transformed into the State Committee for Land Resources in 1993. In 2002,

the State Inspectorate for Control over Land Use and Protection was spun off as a governmental body of state administration, but with a significant limitation of functions that would correspond to the name of the institution. By 2010, these structures had been reformed several times. The functions of controlling the use and protection of land were redistributed between the State Committee for Land Resources and its Agency, the Ministries of Environmental Protection and Agrarian Policy and Food, and the State Inspectorate of Agriculture of Ukraine, which was subordinated to it. However, all these reforms did not comply with the provisions of the Law of Ukraine "On State Control over Land Use and Protection" adopted in 2003, although they did not fully implement foreign practices in this area.

This is demonstrated by a comparative description of the functional responsibilities of the bodies controlling land use in the United States and Ukraine. The U.S. Soil Conservation Service, for example, carries out:

- researching the causes of soil erosion, its nature and consequences, and developing practical measures to combat erosion.
- regional soil and erosion surveys and mapping to identify locations and areas where measures are needed to prevent erosion and preserve soil moisture;
- wide practical demonstration of the effectiveness of the practice of using agricultural land with erosion control and wide promotion of erosion control techniques through the application of erosion control measures on agricultural land;
- dissemination of information on soil erosion and means of combating it among the rural population;
- co-operating with various federal and state agencies in the field of soil protection, regulation of land use, territory organization and determination of the relative position of individual fields for erosion control;
- cooperation with local soil protection groups organized in accordance with the laws of individual states (Konke, G. and Bertrand, A., 1962).

The State Inspection of Agriculture of Ukraine is responsible for controlling:

- the accuracy of information on the availability and use of land;
- compliance with the conditions of removal, preservation and use of fertile soil layer during mining, construction and other works related to soil disturbance, timely reclamation of disturbed lands
- compliance with the requirements of land legislation when acquiring ownership of land plots, etc.

The State Inspectorate for Control over Land Use and Protection, which is subordinated to the State Committee on Land Resources, is also responsible for implementing state policy in the field of land relations and for summarising the practice of applying legislation on these issues. The controlling functions in relation to soil fertility are not the main ones and are vague.

The dispersion of control functions among many agencies, their concentration outside the powers of the main state body responsible for managing the development of agriculture and the food sector, together with the unclear content of these functions, has essentially removed state bodies from responsibility for the proper use of agricultural land.

Under the current land legislation, the functions of ensuring the protection and rational use of land are assigned only to their owners, while in international practice, some of these functions are performed by the state through land policy, land law and public administration. Businesses in market conditions cannot solve the problem on their own due to, first, the high cost of resource-saving technologies and the threat of losing price competitiveness, second, the limited free funds that are typical for agricultural farmers, and third, the non-commercial nature of environmental and social benefits. Thus, only joint activities of producers and state institutions with levers of influence on business entities can yield positive results in solving the problem of land use and protection, preservation and reproduction of their productive capacity to meet the food needs of future generations. This is achieved on a contractual basis. Such agreements between the authorities and owners or lessees of agricultural land are a means of extending legally binding control activities to agricultural use of land that is subject to protection as a national treasure.

At the same time, these agreements are not only prohibitive but also have the nature of obligations in the public interest, which is one of the important social features of multifunctional agriculture.

The above-mentioned Law of Ukraine "On State Control over the Use and Protection of Land" was supposed to create a single State Service for Soil Fertility Protection with appropriate legislative support for its activities, but this has not been done to date. Merging all inspections of the agricultural sector into one structure, as is done today in the context of deregulation of its development, does not solve the problem.

The scientific literature suggests creating such a public service with a special status based on the State Technological Centre for Soil Fertility Protection of the Ministry of Agrarian Policy and Food (the Centre for Soil Fertility) (Kulinich, P.F., 2011).

Another drawback of the current land legislation in terms of preserving and restoring land fertility and using it in a rational and environmentally sound manner is that the legal mechanism does not include reasonable fertility indicators, legal obligations to comply with them and liability for failure to comply with these obligations.

The territorial heterogeneity of soils also necessitates that land legislation reflects the natural characteristics of specific types of agricultural land, which differ in their slope, which requires a different set of legal means to regulate their protection, use and reproduction. However, the legislation does not establish any criteria for assessing the level of proper use and restoration of soil fertility.

Article 165 of the Land Code of Ukraine (Verkhovna Rada of Ukraine, 2024) defines the general provisions of land use regulation. Part 2 of this article provides a list of standards: optimal ratio of land; quality of soil; maximum permissible soil pollution; indicators of land and soil degradation. There are no specifics on standardization. The article states that regulatory documents on standardization in the field of soil protection and restoration of its fertility are adopted by the Cabinet of Ministers of Ukraine.

In terms of their content, standards are regulatory documents that define the concept, content, structure, stages, methods, and qualifications of activities aimed at ensuring the protection, use and restoration of soil fertility. According to Art. 29 of the Law of Ukraine "On Land Protection" (Verkhovna Rada of Ukraine, 2003), such regulatory documents include:

- requirements for the collection, recording, processing, storage, analysis of information on land quality, and forecasting changes in soil fertility.
- requirements for the rational use and protection of land.
- technical specifications for processes and services in the field of land protection.
- metrological norms, rules and requirements for work organization.

Standards ensure the organization of the necessary work, but they do not determine the results of such activities, nor do they form their quantitative and qualitative outcomes. In other words, standards define the content of the activity as a means of achieving results, but do not define the indicators of maximum permissible levels of soil pollution, their qualitative condition, the optimal ratio of land, or soil degradation. Legislation establishes only types of standards.

Article 31 of the Law of Ukraine "On Land Protection" sets out the maximum permissible soil pollution standards, including:

- maximum permissible concentrations of chemicals, residual amounts of pesticides and agrochemicals, heavy metals, etc. in soils
- maximum permissible levels of soil contamination with radioactive substances.

Pursuant to Article 32 of the Law, the standards for controlling the quality composition of soils are:

- pollution levels;
- optimal nutrient content;
- physical and chemical properties.

According to Art. 33, the standards for the optimal ratio of land holdings include

- the optimal ratio of agricultural, nature reserve and other nature protection, health, historical, cultural and recreational land, as well as forest and water fund land;
- the optimal ratio of arable land and perennial plantations, hayfields, pastures, as well as land under shelterbelts in agricultural landscapes.

Art. 34 of the Law provides for the following standards of land degradation indicators:

- maximum permissible deterioration of the condition and properties of land resources because of anthropogenic impact and negative natural phenomena;
- intensity of agricultural land use.

Most of the above standards have not been approved in quantitative terms, while some of the legally regulated ones have been suspended. The latter concerns, first, the Law of Ukraine "On Amendments to Certain Legislative Acts of Ukraine on Soil Fertility Preservation" of 4 June 2009, which establishes the mandatory use of scientifically based crop rotation, and the Resolution of the Cabinet of Ministers of Ukraine of 11 February 2010 "On Approval of Crop Rotation Standards in Different Natural and Agricultural Regions". The Resolution approved the norms of crop ratio in the five main natural and agricultural regions of Ukraine, as well as the norms of agronomic-based frequency of crops growing in the same field depending on their characteristics.

Representatives of big business organized their opposition to the transition to crop rotation, presenting these regulations as restricting the rights of owners and users of agricultural land to use the latter, and therefore demanded compensation for losses caused by these restrictions.

The legal nature of crop rotation in foreign legislation is that its introduction is not a legal restriction, but a means of specifying the rights and obligations of owners and users of agricultural land to preserve and restore the quality of land through a scientifically sound alternation (rotation) of crops grown on it.

The establishment of standards for the protection of the use and reproduction of soil fertility is inextricably linked to the rules of liability for non-compliance with these standards and the incentives for their successful application. The need to apply legal incentives in the field of organizing the protection and rational use of agricultural land is due to objective factors. Implementation of environmental protection measures in agricultural land use requires a significant amount of work and, accordingly, costs, which drain farmers' working capital and put them in an unequal competitive position with farms that do not spend money on soil protection measures. Therefore, the state should become a partner of agricultural producers in reproducing the productive power of land as a national wealth of society by providing for legal incentives for agricultural producers in the structure of land policy using a system of compensatory incentives.

The situation with the development of the incentive system in Ukrainian legislation is the same as with the development of regulations for the protection and use of agricultural land. According to Art. 205 of the Land Code of Ukraine, economic incentives for rational use include:

- provision of tax and credit benefits to citizens and legal entities that carry out measures envisaged by national and rational land use and protection programmes at their own expense;
- allocation of funds by the state or from the local budget to citizens and legal entities to restore the previous state of land disturbed through no fault of their own (tornadoes, dust storms);
- exemption from payment for land plots undergoing agricultural development or improvement in accordance with state and regional programmes;
- compensation from state funds for the reduction in income of landowners and land users because of temporary conservation of degraded and unproductive land.

Art. 27 of the Law of Ukraine "On Land Protection" details and supplements the provisions of the Land Code of Ukraine with the following provisions:

- granting tax and credit benefits to individuals and legal entities that carry out measures at their own expense to protect land from erosion, improve soil fertility and other measures provided for by national and regional programmes;
- application of accelerated depreciation of fixed assets for land protection and environmental purposes;
- exemption of landowners and users from payment for land plots where land reclamation, recultivation, conservation, etc. are carried out.

However, none of these provisions is applied, as the regulatory framework for such incentives for the rational use and protection of agricultural land has not been established.

The norms of rational use, protection and restoration of land fertility declared in legislative acts and not supported by financial support programmes are legally and economically null and void. Ukraine needs to implement the EU practice of legislative and

regulatory support for the protection and rational use of agricultural land in its national legislation. First, we are talking about the Codes of Good Agricultural Practice.

The need for this act in Ukraine is driven by two main factors. The first is the catastrophically destructive soil-depleting processes that are developing in the agricultural sector, as discussed above.

The second important factor is the implementation of the EU-Ukraine Association Agreement (Verkhovna Rada of Ukraine, 2023) in terms of the introduction of sustainable agricultural production principles, which is particularly specified in Title V, Chapter 17 "Agriculture and Rural Development". Article 404 of this chapter calls for "...encouraging modern and sustainable development of agricultural production and rural areas, taking into account the need to protect the environment..., spreading the use of organic farming... by introducing best practices in these areas".

Chapter VI "Environment", Article 360 states: "The Parties shall promote the implementation of long-term goals of sustainable development and green economy, which includes the conservation of natural resources, increased economic and environmental activity, and the integration of environmental policy into other areas of state policy."

The Order of the Cabinet of Ministers of Ukraine of 15 April 2015 No. 371-r "On Approval of the Implementation of Certain Acts of EU Legislation Developed by the Ministry of Ecology and Natural Resources" (Cabinet of Ministers of Ukraine, 2015) provides for an Implementation Plan only for Council Directive 91/676 of 12 December 1991 on the protection of waters against pollution by nitrates from agricultural sources, as amended by Regulation (EC) No. 1882/2003 (Annex XXX to Chapter VI above).

As for the implementation of the bulk of the regulations and directives whose norms form the Grosse Compliance system and the Codes, no decisions have been made yet.

Familiarization with the regulations and implementation of the above EU acts allows us to formulate the basic principles of the National Code of Good Agricultural Practice (or the National Code of Sustainable Agriculture). The main section of such a document should be "Preservation of agricultural land and the environment in good agricultural condition".

The main rules and requirements of this section are aimed at preventing land degradation. The Polish Code explains the priority of this choice by the fact that the process of soil formation is slow, occurring at a rate of 1 cm of produced soil per 100-400 years. For this reason, soil is considered a non-renewable resource in practice and should be subject to special protection (Ministerstwo Rolnictwa i Rozwoju Wsi, 2004).

Land use requirements should prevent physical, chemical and biological soil degradation. Physical degradation is the loss of a certain mass of soil because of water and wind erosion, as well as deterioration of the properties of the soil's water-air regime (crust, density, soil levelling). It is particularly dangerous because the loss of soil mass is irreparable and is only partially compensated for by the process of soil creation. It is believed that the loss of soil mass because of erosion processes in the amount of 1 tone per hectare per year can lead to complete soil degradation in 50-100 years.

Chemical degradation involves the loss of plant nutrients, the accumulation of harmful substances, and the acidification and salinization of soils. These processes lead to a decrease in soil fertility.

Biological degradation includes the processes of reducing the content of organic matter (organic carbon), as well as adverse changes in the composition of soil microflora and microfauna. Microorganisms harmful to plants begin to predominate over beneficial microorganisms (e.g., bacteria that bind nitrogen from the air).

All of the above degradation processes lead to a decrease in soil fertility, i.e. its ability to produce large yields with the required quality characteristics. The ecological role of soil, which is to store water and minerals, as well as to prevent the negative impact of the accumulation of substances harmful to plants, animals and people, is also diminishing. Soil protection is a special duty of the farmer, for whom it is his job and source of livelihood.

In this context, this section should include rules on:

- prevention of soil erosion;
- preservation of organic matter in the soil and protection of soil structure;
- development of agricultural areas and protection of landscapes;
- implementation of water protection directives;
- compliance with nitrate directives;
- compliance with plant protection regulations.

Erosion control requirements should include a set of mandatory rules, such as:

- land on slopes of more than 20 per cent (12°) should be permanently sown with perennial grasses (grassed) or planted with forests;
- land with an angle of 6°-12° can be used for economic activities, but with regular application of technologies and procedures to reduce erosion,
- rainwater runoff paths should be sown with grasses and the turf should be mowed at least twice during the growing season;
- gullies that appear on arable land should be reforested and landscaped to prevent their further expansion;
- to prevent erosion, apply anti-erosion crop rotation, which should include legumes and mixtures of grasses and winter crops - the so-called "green fields";
- after the harvested predecessor, provide for the cultivation of post-harvest intermediate crops and leave them unploughed for the winter in the form of mulch;
- cover unseeded soil surfaces of arable land in autumn and winter with all materials available on the farm, such as straw, tops, leaves, which also serve as mulch and protect the soil from destruction by raindrops, retain snow and limit soil washing away by spring water;
- on arable land located on slopes, cultivate in the direction transverse to the slope and avoid ploughing;
- on soils prone to severe erosion, carry out loosening, which increases the moisture capacity of the soil and facilitates the penetration of water into its deeper layers;
- terracing slopes as a way to reduce the threat of water erosion;
- planting forest belts perpendicular to the main wind directions (in Germany, at least 2.5 m wide at a distance of at least 100 m).

The accumulation of organic matter in the soil is an important factor in maintaining its structure and fertility. Controlling the availability of the required amount of organic matter is determined by calculating the humus balance or by analyzing the humus content per unit of soil (at the farmer's option).

Humus is the end product of soil life. A high humus content indicates that the soil contains a significant amount of organic matter, the circulation of which is the main factor in soil fertility.

The humus balance is calculated by the difference between the total weighted average of the humus created by the humification of plant residues and the mineralized humus, considering erosion losses within its permissible limits. *The humus balance* is the ratio of "inflow and outflow" (input and output) of organic substances. The farmer must strive to ensure a positive balance of this ratio. The results of the humus balance must be kept on the farm for at least 4 years and submitted annually to the state authorities together with an application for state support.

To maintain the humus balance, farms are required *to observe crop rotations with scientifically based crop rotation* and the presence of fields of perennial grasses and legumes with high organic matter reproduction rates ("creators" of humus). Optimally, crops of the same biological family should occupy a crop rotation of 15% (in Germany). A common requirement for all farms is that straw should not be burned - it, like other organic residues, should be returned to the soil to enrich its organic matter content.

The areas temporarily withdrawn from agricultural use must be either arable or under pasture. In the first case, the land should be occupied by annual cover crops (various mixtures of green manure), which at the first stage of their vegetative development are subject to chopping to mulch the arable land surface. The areas occupied by perennial grasses are subject to mowing 1-2 times during the agricultural year with shredding of green mass. These measures are carried out in such a way as not to harm wild birds, which is regulated by EU Directive 2009/147 on the conservation of wild birds and EU Directive 92/43 on the conservation of natural habitats for wild fauna and flora.

Degraded soils are subject to temporary withdrawal from cultivation in order to restore their natural fertility. Upon expiry of the period of such withdrawal (5 or 10 years), the land is returned to agricultural use.

The protection of permanent pastures, which include cultivated (sown) or natural pastures used for at least 5 years and not included in crop rotations, is since they form the ratio between arable and non-arable land, which, together with forests, is an important agroecological and agrolandscape factor. These ratios must be maintained both at the level of an individual farm and within an agricultural area, and EU member states report annually to the European Commission.

The area of permanent pasture cannot be changed for 5 years. A decrease of 5% compared to the baseline period does not entail liability. Under certain conditions, this figure may be 8-10%. If the established limits are exceeded, the farm is obliged to create a new pasture equal to the ploughed one within one year, otherwise its actions are subject to sanctions.

Pastures in river floodplains are prohibited from being ploughed at all. The same applies to pastures located in designated nature conservation areas. On all permanent pastures, farms must comply with the prescribed rules for the protection of wild animals and birds.

Landscape elements shall be maintained in view of their important environmental protection functions and the enrichment of biodiversity on agricultural land. Farms are prohibited from destroying them in whole or in part:

- fences made of greenery with a length of 10 m (linear structural elements formed by trees);
- planting along the plots of at least 5 non-agricultural trees with a length of at least 50 m
- virgin forests with a minimum size of 50 m² and up to 2000 m² or more (this does not include areas temporarily withdrawn from cultivation and occupied by undergrowth, which are subsequently to be included in agricultural cultivation);
- wetlands with a size of more than 2000 m² of any origin;
- individual trees protected as natural monuments;
- stone fences and land covered by natural formations (rocks, ledges, stone surfaces of various rocks) with an area of more than 2000 m² located on the territory of the farm;
- natural stone walls and remains of walls made of earth or clay and natural stone;
- historical mounds and fragments (remains) of rocks;
- protective strips of at least 2 meters in width, which are located on the border of the farm or have historically been on its territory;
- natural water sources (water intake is possible only with the permission of the competent authority).

Compliance with the requirements for the protection of these landscape elements is monitored by authorized state bodies.

The Code sets out the rules and obligations that farmers must comply with to protect water from pollution by harmful substances in accordance with EU Directive 80/68. These requirements are related to the use of nitrogen fertilizers, storage and application of liquid organic fertilizers and solid manure. This regulatory and methodological document establishes a set of measures aimed at preventing the pollution of water resources, in particular groundwater, which is important for both ecosystems and economic needs.

Significant attention is also paid to plant protection rules, which restrict the use of chemicals.

The section "Requirements in the field of animal husbandry" includes:

- rules for the identification and registration of animals (registration of cattle, pigs, sheep and goats, their labelling);
- standards of livestock density per unit of land (the standard is 1.5 heads per 1 ha);
- animal welfare standards;
- obligations to report animal diseases;
- requirements for feed safety and hygiene;
- prohibition of the use of certain ingredients in feed;
- special requirements to produce milk and eggs;
- requirements to produce safe food products.

The Code contains a system of control over compliance with the established rules and obligations and sanctions for their violation

The functions of continuous control are performed by a designated control body. In addition, agricultural and veterinary inspections and other institutions are involved in this work. The systematic ongoing control is carried out both on a documentary basis and selectively on the ground at farms that have applied for participation in government programmes under which payments are due. Reports on the inspection results and their assessment are submitted to the state authority for sanctions.

The assessment considers criteria such as the frequency of violations, their scope, severity and duration, as discussed above.

In accordance with these criteria, the supervisory authority assesses the offence as minor, medium or serious. The Code should provide for a reduction in the total amount of state support payments for each type of offence, as well as a methodology for determining penalties.

The State Budget of Ukraine needs to establish a fund for economic incentives to improve soil fertility, which could be funded by fines for non-compliance with the requirements for the rational use of agricultural land.

The development and implementation of the Code of Good Agricultural Practice will contribute to the achievement of the four goals set out in the above-mentioned FAO Report of 4 December 2015, which should be the focus of the efforts of all parties interested in preserving the productivity of land, from the government to farms, namely:

- minimizing further soil degradation and restoring productivity of already degraded soils. Erosion can be stopped by minimizing deep tillage, covering the soil surface with crop residues, introducing crop rotations with perennial legumes, etc;
- stabilizing global soil organic matter stocks, such as organic carbon and soil organisms;
- stabilizing or reducing the global use of nitrogen and phosphorus fertilizers;
- raising public awareness of soil conditions and the main trends in the development of negative processes in this area.

The achievement of these goals should be ensured by appropriate state policy aimed at:

- supporting the development of information systems for soil monitoring;
- improving education and raising people's awareness of soil protection and reproduction of soil fertility, integrating these issues into formal education and curricula from geology to geography, from biology to economics;
- investing in research and development to promote sustainable technologies and methods of soil cultivation and efficient use of agricultural water potential;
- introduction of effective regulation and incentives for compliance with the requirements for the protection and reproduction of natural resources in agriculture (introduction of taxes that discourage the use of large amounts of mineral fertilizers, herbicides and pesticides; provision of subsidies to producers for certification of environmentally friendly products, etc;)
- strengthening local, regional and international food security, considering the soil resources of the countries and their potential to manage natural agricultural resources on a sustainable basis.

Currently, the Government recognizes the low level of institutional capacity of public authorities to strategically plan and implement specific effective actions and systemic measures to overcome the problems with the state of land and other natural resources, aggravated by climate change (Cabinet of Ministers of Ukraine, 2021). However, the current situation in Ukrainian agriculture, as well as in the global agricultural sector, requires an early awareness of the threats to food security in the absence of effective measures to preserve land productivity and adapt to a changing environment.

According to FAO estimates, by 2050, countries will need to allocate a total of up to USD 160 billion to protect and maintain land productivity. In Ukraine, soil scientists estimate that about UAH 60-80 billion is needed annually to overcome the negative balance of humus and NPK alone. If this is not done today, the cost of restoring degraded land will be even higher in the future.

3.3. THE EUROPEAN GREEN DEAL IS A STRATEGY FOR PRESERVING THE NATURAL RESOURCE POTENTIAL OF THE AGRICULTURAL SECTOR IN THE LONG TERM.

The European Green Deal (EGD) is one of the most ambitious strategies of the European Union aimed at achieving sustainable development and combating climate change. This initiative envisages radical changes in all sectors of the economy, including the agricultural sector, which plays a key role in ensuring food security and preserving natural resource potential. The EGD emphasizes the need to move to more environmentally friendly farming practices, which is an important element of a long-term strategy for biodiversity conservation, sustainable resource use and carbon footprint reduction.

The relevance of the study of the impact of the European Green Deal on the agricultural sector is driven by the need to ensure sustainable development in the face of global environmental challenges. The agricultural sector, as one of the most important for human life, faces the need to adapt to new environmental standards, preserve natural resource potential and introduce innovative approaches to production. Mastering the objectives of the European Green Deal will allow not only to assess the current situation in the context of their implementation, but also to determine the prospects for further development of the agricultural sector on the way to a sustainable (economic, social and environmental) future.

The European Green Deal (EGD) is a comprehensive strategy of the European Union (EU) aimed at transforming the EU into a climate-neutral economy by 2050. An important component of this strategy is the achievement of intermediate targets, particularly the reduction of carbon dioxide emissions by 55% by 2030. The EGD covers a wide range of policies and measures implemented in various sectors of the economy, including energy, agriculture and finance, aimed at combating climate change and reducing negative environmental impacts. The initiative envisages a fair and inclusive transition for all EU member states, ensuring equal opportunities for all.

It is worth noting that the EGD's impact goes far beyond environmental sustainability. It will have significant geopolitical implications affecting global trade and relations with non-EU countries. In addition, the EGD emphasizes the importance of active citizen participation in achieving its goals, recognizing the important role of individuals and communities in achieving sustainable development. The initiative is also harmonized with other EU policies, such as the Integrated Maritime Policy, and has encouraged EU candidate countries such as Ukraine and Turkey to develop relevant action plans.

As we can see, the European Green Deal represents a significant commitment by the EU to address the challenges posed by climate change and environmental issues through a systematic and ambitious approach. It integrates environmental objectives with economic and social policies, seeking to set global standards for sustainable development and climate action. At the same time, the EGD considers the complexities of international relations and domestic policy integration. The success of this initiative will depend on its effective implementation at all levels of government and society, as well as on its ability to adapt to the changing global context.

One of the central components of the European Green Deal in agriculture is the development and implementation of a system that will allow the agricultural sector to adapt to the new challenges posed by climate change while maintaining productivity and economic viability. This includes a gradual transition to more environmentally friendly farming practices that reduce reliance on chemical fertilizers and pesticides and promote biodiversity conservation.

However, the implementation of this ambitious strategy faces a number of challenges. One of them is the development of unified criteria and methods for assessing the sustainability of agricultural practices. Currently, there are many approaches to defining sustainable development in agriculture, which causes difficulties in assessing the effectiveness of policies and programmes implemented under the EGD (Chami, 2020). This, in turn, complicates the process of monitoring and adjusting the strategy in response to changing conditions or new challenges.

In addition, the CAP tasks member states with supporting farmers in transition. Such support may include financial incentives, training in new farming methods, and access to innovative technologies that contribute to climate resilience (Ataseven, 2022). At the same time, countries should develop their own national action plans that are consistent with the EGD's overall objectives but consider the specifics of local conditions and challenges.

The European Green Deal also requires close cooperation between EU member states and countries seeking integration into the European community. The implementation of EGD principles in the agriculture of the associated countries is an important aspect for achieving the pan-European goals of sustainable development. However, the success of this cooperation depends on the ability of these countries to adapt their policies and practices to the EGD requirements (Baştürk, 2022).

In addition, the European Green Deal is an integral part of the EU's strategy to combat climate change and promote sustainable development in agriculture. However, to achieve its ambitious goals, a number of challenges need to be overcome, including the development of clear criteria for sustainable development, effective implementation of national action plans, and close international cooperation. The success of the EGD will largely depend on the ability of the EU and associated countries to adapt to change and effectively coordinate their efforts to achieve common sustainable development goals (Streimikis & Baležentis, 2020).

The Organic Farming Action Plan proposed under the European Green Deal is an initiative aimed at transforming the agricultural sector in the European Union. The main goal of the plan is to increase the share of organic farming in total agricultural production, which should contribute to the environmental sustainability of agroecosystems, reduce environmental pollution and improve public health.

One of the key features of this plan is to stimulate the transition to organic production methods, which involve minimizing the use of synthetic fertilizers and pesticides, replacing them with organic analogues, such as natural fertilizers, green manure and compost (Singh, 2021). This approach ensures the preservation of soil fertility, reduction of greenhouse gas emissions, and maintenance of biodiversity, which are important components of a sustainable development strategy.

An important aspect of the successful implementation of this plan is the development of clear and accessible criteria for the certification of organic products, as well as ensuring transparent control over their compliance. In addition, it is necessary to create conditions for increasing the demand for organic products among consumers, which will help to expand the market for organic farming and ensure the economic sustainability of farms that switch to organic production methods (Ghulati, 2004).

The plan also envisages the development of research and innovation in organic farming. This includes the introduction of new technologies and practices that increase the productivity of organic farms, conserve natural resources and improve product quality. Research institutes and universities have a key role to play in this process, providing scientific support and developing effective strategies for the implementation of organic methods (Chami, 2020).

However, despite the significant benefits of organic farming, there are challenges associated with its large-scale adoption. These include ensuring the competitiveness of organic products on the market, the need for farmers to adapt to new conditions, and the challenge of defining and measuring sustainability criteria in organic farming (Streimikis & Baležentis, 2020).

Therefore, the Organic Action Plan is an important step towards sustainable agriculture in the European Union. Its success depends on a comprehensive approach to the implementation of organic production methods, integration of innovations and creation of favorable conditions for the development of the organic sector, as well as on the ability to balance the environmental, economic and social aspects of sustainable development (Chami, 2020; Ghulati, 2004; Singh, 2021).

After reviewing the overall objectives and conceptual framework of the European Green Deal, it is necessary to elaborate on its key initiatives that form the basis for the practical implementation of the EU's ambitious climate and environmental objectives. These initiatives cover a wide range of legislative, economic and social measures to ensure sustainable development and environmental transformation of the European economy. So, let's analyze the main initiatives underlying the European Green Deal, including the Ready by 55 package, European climate legislation, the Climate Change Adaptation Strategy, the 2030 Biodiversity Strategy, and others.

The Ready by 55 package. One of the main initiatives of the European Green Deal is the Ready by 55 package. This package is an ambitious set of legislative proposals aimed at implementing the EU's climate goals, including achieving a reduction in greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels. This package covers a wide range of measures related to energy, transport, industry, and sustainable energy innovations. It aims to ensure a socially just transition to a climate-neutral economy, while maintaining the competitiveness of European companies on the global market.

European climate legislation. The adoption of the European climate legislation was an important step in the implementation of the Green Deal. This legislation transforms the EU's climate ambitions into legal obligations. The main elements of this legislation are the establishment of a binding goal of achieving climate neutrality by 2050, as well as the obligation to reduce greenhouse gas emissions by 55% by 2030. The legislation

also provides for the development of a monitoring and reporting system to ensure transparency and predictability for all market participants.

Climate change adaptation strategy. To strengthen resilience to the effects of climate change, the EU has developed a Climate Change Adaptation Strategy, which was approved in 2021. This strategy aims to ensure that EU society becomes climate resilient by 2050. It includes measures to improve data collection, nature-based solutions for resilience, and the integration of adaptation measures into macro-financial policies.

Biodiversity Strategy until 2030. The 2030 Biodiversity Strategy is an important element of the European Green Deal, which aims to restore natural ecosystems and protect biodiversity across Europe. It envisages an increase in protected areas, restoration of degraded ecosystems, and reduction of pesticide use and damage. This will help preserve nature and create sustainable conditions for human development in the face of climate change.

Farm to Table Strategy. The Farm to Table strategy aims to transform the EU's food system so that it becomes environmentally sustainable, ensuring an adequate supply of healthy food within the planet's capacity. It also aims to ensure sustainable food production and consumption, which will reduce the environmental impact of the agricultural sector.

European Industrial Strategy. The European Industrial Strategy aims to encourage industry to switch to climate-neutral technologies. It includes measures that support the innovation, competitiveness and growth of European industrial sectors, while promoting the environmental and digital transformation of the economy. The strategy also considers the need to recover from the COVID-19 pandemic by integrating the principles of sustainable development.

Circular Economy. The Roadmap for a Circular Economy is another key element of the Green Deal, which aims to decouple economic growth from resource use. It envisages the transition to circular production and consumption systems, which will reduce the environmental impact and contribute to achieving climate neutrality by 2050. The strategy includes more than 30 measures aimed at sustainable product design, support for innovative production processes and consumer empowerment.

A mechanism for a just transition. Achieving climate neutrality will require significant efforts from Member States and regions, especially those dependent on fossil fuels or carbon-intensive industries. The Just Transition Facility provides financial and technical support to such regions, mobilizing at least €55 billion for the period 2021 to 2027. The Just Transition Fund aims to support job creation, energy efficiency, clean technology development and worker retraining, which will reduce the socio-economic costs of the transition to a green economy.

Farm to Table Strategy

The European Union's food system provides more than 400 million citizens with fresh and safe food, which is not only a basic service but also an important source of income for many Europeans. The EU's agri-food chain is an important economic sector, but it also has a significant environmental impact. According to a report by the Intergovernmental Panel on Climate Change (IPCC), food systems account for approximately one third of global greenhouse gas emissions. In addition, the current model of

food production and consumption has a negative impact on public health, as evidenced by the fact that more than 50% of European adults are overweight.

In this regard, the European Union is actively working to transform the food system to reduce its environmental impact, strengthen its resilience to crises and ensure the availability of healthy food for future generations.

The Farm to Table strategy was presented by the European Commission in May 2020 as a key element of the European Green Deal. The main objective of this strategy is to contribute to achieving climate neutrality by 2050 by transforming the EU food system into a sustainable model.

Food security remains the top priority of the strategy, but it also sets ambitious targets to ensure that healthy food is available within the limits of the planet's capacity. The main objectives of the strategy include:

- reducing the use of pesticides and fertilizers by 50%;
- reducing the sale of antimicrobials;
- increasing the area of land allocated for organic farming to 25% by 2030;
- promoting healthy eating and more sustainable food consumption;
- reducing food losses and food waste;
- combating food fraud in the supply chain;
- improving animal welfare.

These measures are expected to not only help achieve food system sustainability but also create new business opportunities and have a positive impact on the agri-food sector's revenues. The main initiatives under the strategy are:

- **Action Plan for Organic Agriculture.** The European Commission presented this plan in March 2021, with the aim of increasing the share of organic farming to 25% of agricultural land by 2030. The Council of the EU endorsed the conclusions of the action plan, emphasizing the importance of organic agriculture for the sustainability of the European agricultural sector and the need to balance supply and demand in this sector.

- **Food Security Plan.** In response to the Covid-19 pandemic, the European Commission has developed a contingency plan to ensure food security during crises. The plan envisages the establishment of a European Mechanism for Food Security Crisis Preparedness and Response, as well as the formation of an expert group to enhance the EU's preparedness for future challenges.

- **Global food safety standards.** The EU is actively working to improve food safety standards in international trade. Particular attention is paid to the sustainability of the Commission's work on the Codex Alimentarius, which is the main global body for discussing food standards.

- **Renewable agriculture.** This initiative aims to introduce agricultural practices that promote the absorption of carbon dioxide from the atmosphere and its storage in soil or biomass. The EU Council has supported the provision of financial support to encourage farmers and foresters to adopt such practices.

- **Sustainable aquaculture.** The EU aims to develop a sustainable and competitive marine and freshwater aquaculture sector to reduce dependence on imports and create new opportunities for the development of this sector in Europe (European Commission, 2021).

The Farm to Table strategy is a comprehensive initiative that integrates different aspects of food security, health, environment and economic sustainability. It plays a central role in the implementation of the European Green Deal, helping the EU to move towards a more sustainable and environmentally responsible food system that can provide healthy food for present and future generations.

European Union Biodiversity Strategy

The European Union's 2030 Biodiversity Strategy for Europe, entitled "Putting Nature Back in Our Lives", was published by the European Commission on 20 May 2020. This document is an important milestone in the EU's efforts to protect the environment and conserve natural resources.

The strategy is a comprehensive, ambitious and long-term plan aimed at protecting nature and preventing further degradation of ecosystems. The main goal of the strategy is to restore Europe's biodiversity by 2030 through the implementation of specific actions and commitments. The plan includes numerous measures aimed at halting the loss of natural habitats, improving the condition of natural ecosystems and ensuring their resilience in the face of climate change and other human impacts.

In particular, the strategy includes measures to expand and improve the network of protected areas, restore degraded natural areas, ensure the ecological integrity of landscapes, and integrate biodiversity issues into all policies and sectors of the economy. It emphasizes the need to reduce the use of pesticides and fertilizers, support sustainable agriculture and develop new approaches to water management.

Raising public awareness and engaging the public in biodiversity conservation is also an important aspect of this strategy. The European Commission calls for active cooperation between Member States, scientific institutions, businesses and NGOs to achieve the goals.

Thus, "Bringing Nature Back into Our Lives" is a strategic document that sets out priorities and measures for the conservation and restoration of biodiversity in Europe, noting the importance of preserving natural resources for future generations (Polish Government, 2020).

EU strategy for climate change adaptation

The European Commission adopted a new EU strategy on climate change adaptation on 24 February 2021. This strategy sets out how the European Union can adapt to the inevitable effects of climate change and become climate resilient by 2050.

The strategy has four main objectives: to make adaptation smarter, faster, more systematic, and to step up international action on climate change adaptation.

- Smarter adaptation implies that adaptation measures should be based on reliable data and risk assessment tools. This will allow all actors, from individuals building homes to businesses in coastal regions to farmers planning their crops, to use accurate information to make informed decisions. To achieve this goal, the strategy proposes expanding the frontiers of adaptation knowledge, improving data collection on climate change risks and losses, and strengthening the Climate-ADAPT platform as a European hub for adaptation knowledge.

- Faster Adaptation focuses on the need to accelerate the pace of adaptation in response to the already tangible impacts of climate change. The strategy focuses on the

development and implementation of adaptation solutions that will help reduce risks, enhance climate protection and ensure the availability of fresh water. This includes both infrastructure upgrades and improved management practices in a changing climate.

- More systemic adaptation considers that climate change will affect all levels of society and all sectors of the economy. Therefore, adaptation measures should be systematic and integrated into all relevant policies. The European Commission plans to actively mainstream climate resilience considerations into all policy areas and support the development of adaptation strategies and plans at all levels of government. Three cross-cutting priorities in this context include integrating adaptation into macro-financial policies, applying nature-based solutions for adaptation, and supporting local adaptation measures.

- Enhanced international action focuses on supporting global climate resilience through the provision of resources, prioritization of actions, increased international financing and enhanced global participation and exchange of experience on adaptation. This will ensure the integration of adaptation efforts at the international level and contribute to the overall effectiveness of the global fight against the effects of climate change (European Commission, 2021).

The development of this strategy began with the European Commission's announcement of an ambitious new Adaptation Strategy in December 2019 as part of the European Green Deal. The strategy builds on the 2018 assessment and the previous EU Adaptation Strategy of 2013. The preparation of the new document included open public consultations with the public held from May to August 2020, which allowed for a variety of views and suggestions to be considered in shaping the final strategy.

The European Green Deal (EGD) is an ambitious strategy of the European Union aimed at transforming Europe into a climate-neutral continent by 2050. In the context of the agricultural sector, this course envisages significant changes aimed at preserving natural resource potential and ensuring sustainable development in the face of global environmental challenges.

The EGD aims to transition the agricultural sector to environmentally friendly farming practices. This includes reducing the use of chemical fertilizers and pesticides, introducing organic farming and protecting biodiversity. These measures are intended not only to reduce the carbon footprint but also to ensure the long-term preservation of land productivity, improve product quality and protect the environment.

At the same time, the implementation of the EGD in agriculture faces a number of challenges, such as the need to develop common sustainability criteria, provide financial support for farmers to switch to new production methods, and adapt policies to different national contexts. One important element of this transition is to support innovation and research that will improve the efficiency of organic methods and climate resilience.

It is also important to note that the EGD has not only environmental but also significant socio-economic impacts, including on global trade and geopolitics. The successful implementation of this strategy will require the active participation of all members of society and close cooperation between EU member states and countries seeking integration into the European community.

Thus, the European Green Deal is an important step towards the sustainable development of the agricultural sector in the EU. However, its success will depend on effective implementation at the local level, adaptation to regional conditions, and the ability of the agricultural sector to respond to new challenges posed by climate change.

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