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Sustainable Development of Agriculture of Ukraine in the Context of Climate Change

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Abstract: The purpose of the article is to actualize the challenges faced by Ukrainian agriculture in the context of climate change and the impact of the economic activity of enterprises on the state of natural resources, as well as to consider the ways and mechanisms of the post-war transition of Ukrainian agriculture to sustainable development. In the study, we used monographic, comparative analysis, empirical, abstract, and logical methods. The first consequences of climate change in agricultural sectors of the planet are characterized. Increasing temperatures to a maximum level, longer periods of extreme heat, more intense droughts, increased moisture deficit during the growing season, winter thaws, the spread of pests and diseases, and other manifestations of climate change have a negative impact on agricultural production. In the context of climate change, as highlighted in the paper, these negative processes will significantly intensify, requiring an immediate transition from ecologically and socially destructive monoculture to agroecological agriculture, which is recognized as one of the most affordable, low-cost, socially oriented, and environmentally relevant ways to transition to sustainable development of the industry. The principles and institutional support for such a transition are revealed, taking into account the expected climate change and post-war consequences for Ukrainian agriculture.

Keywords: climate change; temperature regime; water supply; environmental threats; food security; agroecology; government policy; post-war restoration of natural resources

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1. Introduction

The conceptual approaches to sustainable development formulated in the UN documents provide for the rational governance of the country's assets. This means preserving and increasing the capabilities of communities where assets are not only traditionally physical, but also natural and human capital. This requires the business entities to integrate with economic, social, and environmental approaches in the governance of the economy (Table 1).

Table 1. Economic, environmental, and social approaches to the concept of sustainable development.

An Approach to Sustainable Development	Meaning
Social approach	Is focused on people and the preservation of the balance of social and cultural systems, including the elimination of conflict at various levels. This approach also includes equitable distribution of benefits and fair opportunities for everyone.

Table 1. *Cont.*

An Approach to Sustainable Development	Meaning
Environmental approach	Involves the coherence of biological and physical natural systems, including the stability of local ecosystems, which affects the overall balance of the biosphere. Ecosystem elements include not only natural but also human-made systems.
Economic approach	Is grounded in J.R. Hicks and E. Lindahl's theory of maximizing the total income that can be obtained while preserving the total capital that generates this income [1].

Source: compiled by authors.

Adjustment in the above approaches with each other in order to achieve sustainable development is the most significant task for modern society. That means that all economic, environmental, and social approaches should be taken into account simultaneously and in a balanced manner [2].

The concept of sustainable development is an alternative to neoclassical economic theory. It is focused on continuous economic growth based on selfishness and self-interest of market participants [3]. The paradigm of continuous economic growth remains dominant in practical activities of people. Growing competition with its inherent overconsumption of natural resources and the pursuit of profit maximization leads to problems caused by significant climate change and global warming [4].

Changes in the Earth's climate are considered as statistical deviations of weather parameters on certain and sufficiently long-term periods of time. This includes both changes in the average values of weather parameters and changes in the frequency of extreme natural events (earthquakes, hurricanes, floods, etc.) [5]. These changes are caused by dynamic processes on the Earth (as in one of the space objects), changes in the level of solar irradiation, and excessive human activity.

The main factors related to economic human activity that have a negative impact on climate change and the environment include:

- The ever-increasing concentration of CO_2 in the atmosphere (due to the combustion of various types of fuel) [6];
- Irrational land use on an industrial scale (in particular, the activities of national and transcontinental agricultural companies and agricultural latifundia) [7];
- Deforestation, etc.

Under the influence of these and other factors, the planet's temperature increased by 0.8–1.2 degrees Celsius since the mid-19th century. According to different scenarios of climate changing, if these factors persist, the projected temperature's increasing in the twenty-first century will reach 2.6–4.8 degrees Celsius [8].

The UN warns that exceeding of the thresholds that already occurred leads to irreversible changes in the ecosystems of our planet [9]. The threatening consequences for humanity are:

- Rise in the level of the world's oceans;
- Changes in the amount and nature of precipitation;
- Increase in the area of deserts;
- Increase in the incidence and scale of extreme weather events (heat waves, droughts, and heavy rains);
- Ocean oxidation and pollution;
- Loss of biodiversity due to changes in temperature regimes;
- Threat to food security due to changes of yields and the amount of arable land;
- Climate-related displacement of people from their traditional locations.

According to Fr. Laloux, "The modern way of doing business has outgrown our planet. The companies are making a huge contribution to the depletion of natural resources, to

the destruction of ecosystems, climate change, the depletion of water and precious arable soils. We are gambling with the future, teetering on the edge of what's allowed, betting that technological advances will heal the wounds inflicted on the planet by a progress. An economic model based on ever-increasing growth with limited resources will inevitably reach a dead end … It is not an exaggeration but a sad reality that very survival of many species, ecosystems and perhaps humanity itself, depends on our ability to move toward more evolved forms of consciousness and thus cooperate together in new ways that can … repair the damage we have done" [10]. That is why large enterprises that have an anthropogenic impact on the environment have to change their approaches of doing business. This implies programs and measures aimed at reducing the negative impact on the environment and adaptation for changing climate conditions in their strategies.

This applies most of all to agriculture, the industry where natural resources are the main means of production and human activity is most associated with intervention to the biosphere and is dependent on natural and climatic conditions.

For the development of the industry, extreme and unfavorable hydro-climatic conditions are becoming more and more threatening. As a result, we can observe winter thaws, and in connection with this, there is damage to winter crops, rain increase that has a negative impact on the condition of the soil, the maximum air temperature rises and the threat of fire arises, periods of extreme weather conditions become longer, droughts become hotter, moisture deficit increases during the vegetation period of plant development and soil moisture deteriorates, and new pests and plant diseases appear.

Climate change is a natural and cosmic phenomenon. At the same time, its condition is significantly affected by destructive human activity. Climate change is exacerbated by:

- The expansion of cultivated land at the expense of wetlands and meadows;
- Deforestation (in the last decade of the last century alone, the forest area decreased by 135 million hectares [11]);
- The release of significant amounts of carbon dioxide (CO_2) into the air as a result of imperfect technologies, nitrous oxide (N_2O), and methane (CH_4) (agriculture accounts for up to 60% of total emissions of N_2O and CH_4) [12];
- Intensive use of pastures, up to the point of turning them into semi-deserts (according to research, three quarters of the world's deserts were formed as a result of reckless human activity) [13].

What is mentioned above does not complete the list of impacts of climate change and the contribution of agricultural sector activities to these changes. In general, this has a negative impact on agricultural production. In the current century, the productivity of land is constantly decreasing, the growth rate of crops and gross harvests of major food crops are decreasing, and the profitability of resource-intensive agricultural production systems are declining. Whereas during the first period of the Green Revolution the growth rate of yields of corn, rice, and wheat was 2–3%, today, this figure for corn is 1.5% and for rice and wheat it is 1%. Global grain production decreased by 1.4% and oil production by 1.2%. In the USA, corn production is down, and in China and Japan, rice production is down.

According to various forecasts, the yield of major crops (corn, sunflower, peas, sugar beets, and soybeans) may decrease by 20–55% in the middle of this century compared to 1996–2005. The largest decline is likely to occur in Africa, Latin America, Australia, and a number of Asian countries, where the challenges of climate change are more intense than in other continents. At the same time, in Ukraine, the European country, these higher processes are already gaining certain trends [14].

2. Materials and Methods

The purpose of this article is to actualize the challenges facing Ukrainian agriculture in the context of climate changes and the impact of the economic activity of enterprises on the state of natural resources of the industry and to consider the ways and mechanisms of the post-war transition of Ukrainian agriculture to a state of sustainable (economic, social, and environmentally balanced) development.

The hypothesis of the study is based on the assumption that industrialized, highly specialized agriculture with a transition to monoculture that is focused on profit maximization, on the one hand, generates environmental conflicts that will escalate into environmental crises in the context of climate change, and on the other hand, is unable to fulfill the irreplaceable social functions of the industry that are primarily related to ensuring the country's food sovereignty, as well as preserving and developing rural human potential.

The purpose of the article led to the following tasks:

- To study the social and environmental consequences of the activities of deeply specialized agricultural enterprises with a transition to monoculture;
- To generalize the conceptual approaches of sustainable development in agriculture for the purpose of rational governance of the natural resource potential of agriculture in the context of climate change;
- To substantiate the combination of economic, social, and environmental approaches in order to achieve sustainable development of the industry by transitioning from monocultural nature-destroying to resource-saving agroecological crop rotation agriculture.

The study was based on surveys conducted by the State Soil Protection Agency and data from scientific institutions on changes in the state of agricultural natural resources of Ukraine, and the results of long-term meteorological observations, scenarios of expected global climate changes researched by international organizations and national institutions, also were applied to legislative and regulatory acts, as well as statistical and scientific sources relevant to the research topic.

The following methods were used in the study: monographic (analysis of the zonal distribution of crop areas); comparative analysis (climate change, production, labor productivity, and food consumption in time and space depending on changes in specialization); empirical (as to the environmental and social consequences of non-rotating deeply specialized agricultural production with monoculture features); and abstract and logical (summarizing and formulating main conclusions and proposals on ways to balance the economic, social, and environmental functions of agriculture in the context of expected future climate change).

Elements of scientific novelty. The article proves, based on the analysis of statistical data, documents of international organizations, and the generalization of scientific and own field research, that deeply specialized monoculture and export-oriented agriculture cannot fulfill environmental and social functions. This type of agriculture was formed in Ukraine under the influence of agro-industrial and commercial capital with their inherent violations of the fundamental laws of agriculture. Environmental functions include preserving soil fertility, maintaining biodiversity, protecting local agricultural landscapes, etc. Social functions related to ensuring food security and food sovereignty of the country and the productive employment of the rural population are the main subjects of rural development and environmental protection.

On the basis of the agronomic, economic, and environmental assessment of the structure of sown areas, the directions of bringing it in line with the actual state of agricultural land and projected changes in climatic conditions are determined. The system-forming institutional and legal framework for promoting the transition of Ukrainian agriculture to an agroecological socially oriented type of farming is formulated.

Practical significance of the study. Implementation of the requirements and regulations of EU on rational land and water use, soil fertility, greening of agricultural production, conservation of biodiversity, and local agricultural landscapes into the national institutional and legal framework by adopting the legislative and regulatory acts proposed in the article is a matter of priority. In addition, the implementation of practical recommendations for the transition from deeply specialized monoculture to diversified crop rotation and ecologically oriented agricultural production will enable Ukrainian agriculture to eliminate the current destructive environmental and social processes, to adopt without irreparable losses because of changing climate conditions, provide food for the national market, and maintain export opportunities.

3. Results and Discussion

From 17 Sustainable Development Goals formulated by the United Nations (2015) for the period up to 2030, almost half of them are directly or indirectly related to agriculture. This is, first of all, ensuring the food security of the human community and thus the preservation of its existence. The solution to the problem of eliminating hunger on the planet depends on agricultural production. The industry is directly related to the problems associated with climate change. The preservation of non-renewable land and water resources and the state of the environment depend on it. Agriculture is the main industry that creates jobs for the rural population, ensures their well-being, "ties" them to their immediate workplace, and promotes settling, colonization, and development of rural areas, which is associated with the development of the national home of each country.

This reflects both the economic functions of the industry (competitive production of food products) and irreplaceable social benefits for society as a whole and social values for people who produce and consume agricultural products (production of food products physiologically necessary for humans, creation of jobs for the rural population, education of agricultural producers, health care, etc.) and environmental functions related to the preservation of natural resources. Harmony, balance, and parity of functional relations in the human–economy–nature triad are the basis for sustainable (economic, social, and environmentally balanced) development [15]. However, human economic activity is dominated by the desire to increase profits and the illusion that we live in a world where resources are infinite. At the same time, economic growth is ensured by increasing the intensity of consumption of the productive power of natural resources and ignoring social interests [16], which is confirmed by the processes taking place in the agriculture of Ukraine.

As a result of the absence of a state policy on agricultural organization, more than half of the land cultivated by corporate enterprises moved into the hands of agro-industrial and trading companies. In scientific literature, this process is characterized as "Holdingization" of Ukrainian agriculture [17]. Capital investments in the industry for the sake of profit led to the specialization of production to grow the least labor-intensive and most profitable grain and oilseeds with an export focus. These crops accounted for more than 87% of the sown area and up to 94% in the steppe zone and adjacent areas of the forest steppe, displacing fodder crops, including perennial grasses, taking up fallow land and a significant area of pasture. Currently, the annual sunflower acreage reached 6–7 million hectares, which is almost 2 million hectares more than the acreage of all EU countries combined. In the steppe zone, sunflower accounts for almost 31% of the sown area (Table 2), and in some steppe regions, this figure exceeds 40%.

Table 2. Oilseeds in the structure of sown areas, 2020, zonal aspect.

Areas	All Sowing Area		Including							
			Cereals and Legumes		Oilseeds and Technical		Total Cereals, Legumes and Oilseeds		Share of Sunflower Crops	
	Thousands of Ha	%	Thousands of Ha	%	Thousands of Ha	%	Thousands of Ha	%	Thousands of Ha	%
Total in Ukraine	28,147.5	100	15,392.2	54.7	9223.8	32.8	24,616	87.5	6480.9	23.1
Polissya zone	5026.1	100	2487.1	49.5	1254.3	24.9	3741.4	74.4	520.6	10.4
Forest-steppe zone	11,144.7	100	6204.1	55.7	3468.6	31.1	9672.7	86.8	2261.3	20.3
Steppe zone	11,976.7	100	6701	55.9	4500.9	37.6	11,201.9	93.5	3699	30.9

Source: Calculated by authors based on the Statistical Bulletin "Agriculture of Ukraine" 2020 [18].

The regional crop rotation was carried out without taking into account the law of zonal farming and differentiated crop agronomy, which is determined by objective factors of nature, primarily the amount of heat and light coming from the sun, the amount of

precipitation, their seasonal distribution, the depth of groundwater, soil fertility, and the length of the frost-free and growing season.

The destruction of crop rotation, the displacement of stream crops, leguminous crops, fodder lands, and accordingly, cattle breeding caused a shortage of organic substances, as a result of which the humus imbalance is from −400 to −600 kg/ha.

The spread of less wildlife areas and less crop rotation of agriculture with signs of monoculture is accompanied by a violation of the requirements of the "immutable law of nature" by J. Liebich, which is the law of return of 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, were not 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 [19].

The negative consequences of agroholdings' abandonment of crop rotation, and behind them, the following by other enterprises, are compounded by man-made soil degradation caused by modern machinery and high-powered tillage tools. They worsen the agrophysical condition of the soil and its fertility. Soil-destroying machinery causes over-compaction and pulverization of the soil, which is observed on almost 22 million hectares of arable land [20].

Significant soil damage is caused by the traditional system of the main cultivation of the land with tillage tools of the shelf type. This contributes to the accelerated development of water erosion due to the destruction and washing away of the top layer of soil, the formation of ravines, and siltation of rivers. Almost 60% of the lands that are the subjects of water erosion are located in Luhansk, Donetsk, Odesa, Kharkiv, Kirovohrad, and Mykolaiv regions [21].

Wind erosion (deflation) of the soil that blows away its top layer and transports it over long distances is a threat, especially for the steppe. This is facilitated by traditional methods of soil cultivation that destroy its structure, as well as the lack of perennial grasses and cover crops, insufficient field plantations and forests, and moisture deficit. Dust storms cause great damage, especially to the steppe regions. While in normal years wind erosion covers 6–7 million hectares, in years with dust storms, it can cover up to 20 million hectares of agricultural land. Almost 80% of the land exposed to wind erosion is located in Donetsk, Zaporizhzhia, Luhansk, and Kherson regions, i.e., also in the steppe zone. As a result of economic activity, a 150-hectare desert appeared in the Kherson region [22].

The total area of eroded land in Ukraine increases by 80–100 thousand hectares per year. As a result of erosion, about 500 million tons of productive topsoil are washed away annually and 24 million tons of humus, 1 million tons of nitrogen-containing substances, 0.7 million tons of phosphate, and 1.0 million tons of potassium are lost. The annual damage to agricultural land from soil erosion exceeds UAH 80 billion.

Erosion, caused by degrading of soil fertility, disrupts the complex of the ecological system established over a long evolutionary period and changes the nutrient cycle in the biosphere. In the process of erosion, plant nutrients are removed from the small biological cycle and drawn into the large geological cycle, which means that they are actually lost forever for agriculture.

Deeply specialized, monocultured, export-oriented agriculture is inherently unable to fulfill not only environmental, but also social functions. The latter primarily includes providing the society with physiologically necessary food products of appropriate quality at the level of food sovereignty and productive employment of the rural population.

By expanding of oilseeds and partially grain crops at the expense of fodder lands, enterprises were getting rid of livestock: the number of cattle decreased by eight times and pigs by five times compared to 1990.

Another social problem of monoculture production that scientists and analysts are paying attention to is the deterioration of nutrition. Food products made from cereals, sunflowers, and rapeseeds do not contain very important biological substances for the

human body, which requires a variety of crops with a focus on nutrients according to the needs of the human body. The decline in the consumption of livestock products, vegetables, and fruits had a negative impact on the supply of macro- and microelements. By these indicators, the country did not reach the level of 1990 (Table 3).

Table 3. Consumption of macro- and microelements per person per day.

Macro- and Microelements	1990	2010	2020
Calorie content, kcal	3597	2933	2674
Protein, g	105.3	79.0	83.9
Fats, g	124.0	99.2	92.7
Calcium, mg	1362	893	880
Iron, mg	25.0	20.5	19.7
Retinol, mcg	1863	1088	1055
Beta-carotene equivalent, mcg	1528	2035	2301
Equivalent to retinol and beta-carotene (RET+1/6B-CARQ), mcg	2115	1427	1440
Thiamine, mg	2.30	1.88	1.80
Riboflavin, mg	3.46	2.55	2.60
Niacin, mg	22.4	18.8	18.4
Ascorbic acid, mg	123	121	133

Source: Calculated by the authors according to "Agriculture of Ukraine". Statistical collection for the relevant years [18].

As a result, Ukraine increased imports of certain types of food products for which national enterprises have all the conditions to produce them (Table 4).

Table 4. Production structure of imports of agricultural and food products (in thousands of US dollars).

Product Name	2015	2017	2021
Total	3,484,432.3	4,301,209.0	7,746,968.1
I. Live animals; products of animal origin	548,170.2	731,549.6	1,594,007.5
Including			
Live animals	59,701.1	57,432.5	91,337.5
Meat and edible offal	99,338.4	112,024.7	214,508.2
Milk and dairy products, poultry eggs	79,777.4	84,884.5	384,535.4
Other products of animal origin	18,251.7	21,763.4	28,506.1
II. Products of plant origin	1,146,186.3	1,368,027.1	2,130,534.2
Including			
Vegetables	62,806.6	75,995.2	250,447.6
Cereals	154,707.7	176,756.1	166,099.0
Products of the flour milling and cereal industry	14,028.8	32,240.2	59,130.4
Seeds and fruits of oilseeds	214,991.7	358,269.9	449,314.0
III. Fats and oils of animal or vegetable origin	182,338.9	266,616.4	444,037.8
IV. Prepared food products	1,607,736.9	1,935,015.9	3,578,388.6
Including			
Meat and fish products	42,451.8	82,072.3	182,297.4

Table 4. *Cont.*

Product Name	2015	2017	2021
Sugar and sugar confectionery	34,792.8	47,591.0	171,560.6
Finished grain products	85,551.5	117,821.5	291,033.7
Processed vegetable products	113,989.8	142,355.8	261,807.4
Various food products	339,809.5	363,877.4	561,262.3

The sums of the component and total data for rows and columns may not add up due to rounding. Source: Calculated by the authors according to "Agriculture of Ukraine". Statistical collection for the relevant years [18].

According to the Global Food Security Index (GFSI), Ukraine is inferior not only to all European countries, but also to those countries to which it actively exports food, including Egypt, Tunisia, and Morocco [23] (p. 22).

The export orientation of large agricultural enterprises, the increase in the acreage of fast payback and less labor-intensive grains and oilseeds, and the monopolization of regional sales channels led not only to an insufficient supply of certain types of products to the national market, which led to rising food prices, but also to the constant layoffs of employees. According to various sociological studies (there are no statistics on this issue), agricultural holdings, which lease a third of agricultural land, provide employment for only a one fifth part (1/5) of the able-bodied rural population and reduce wage payments. The share of the annual wage bill in the cost of production of agricultural enterprises with a profitability of up to 50% is within 5% and above 50% is up to 10%. The number of employees during the period of formation of highly specialized production (2000–2010) decreased from 2.5 million to 595 thousand people and from 2010 to 2020 decreased to 443.7 thousand people.

Due to the deep specialization of enterprises in the cultivation of the most mechanized types of crops, the problem of using female labor became particularly acute. This is one of the main reasons why internal and foreign migration has a female face.

The number of people employed in agriculture is declining in all countries. The promotion of scientific and technological progress to replace labor with labor-saving equipment and reduce the number of people employed directly in agricultural production is an objective process. However, in Western European, North American, and other countries, a significant proportion of rural residents find work in agricultural cooperatives (in French cooperatives, for example, there are more hired workers than in farms who are members of these cooperatives). The material and technical base of cooperatives is usually located in rural areas, which contributes to the sedentarization of the rural population and the preservation of rural settlements. In Ukraine, the development of agricultural cooperatives is not a part of state agrarian policy.

Overall, Ukraine's economic benefits from exporting grain and sunflower products do not cover the country's environmental and social losses caused by the existing monoculture–industrial type of agricultural production.

The above-mentioned negative processes in agriculture are exacerbated by active climate change. While the change in annual temperature in the Northern Hemisphere approached 1 °C over half a century, in Ukraine it increased by 1.4 °C. The upward trend in average annual temperature significantly intensified since the 1980s. At that time, the largest amount of effective heat was observed only in the Autonomous Republic of Crimea and Kherson region and today this figure is reached throughout the country [24].

In each region, the temperature has been rising by 0.3–0.4 °C over the past 10 years. If the trend continues, in the 2030s in the steppe zone, crops will be grown only under irrigation, and by 2050 desertification can be expected in the southern regions [25]. According to scientists at the Institute of Botany of the National Academy of Sciences of Ukraine, this trend could lead to the shifting of Ukraine's natural zones by 160 km or more [26]. The reproduction and distribution area of crop pests is changing and will continue to change: their amount may increase by 1.5–2 times [27].

At the same time, the water regime changes with the temperature. Although the average annual precipitation rate in Polissya and the forest-steppe varies little, their efficiency decreases under the influence of higher temperatures. This is characterized by evaporation of moisture, which leads to an increase in the water demand of agricultural plants by 10–20%. In the southern regions, the average monthly precipitation has a steady downward trend from 2015 to 2020:

- In Kirovohrad region decreased by 10%;
- In Luhansk region decreased by 15%;
- In Odesa region decreased by 17%;
- In Mykolaiv region decreased by 20%;
- In Dnipro and Kherson region decreased by 23%;
- In Zaporizhzhia region decreased by 24%;
- In Donetsk region decreased by 25% [28].

Seasonal variations in precipitation underwent significant changes, with an increase in winter and a decrease in summer. In the face of rising temperatures, these changes lead to an increase in moisture evaporation and as a result, the need for water consumption in irrigation increased by 1.3–1.4 times compared to the 1980s [29]. This, combined with heat and water stress and erosion, increases the risks for agricultural production in these regions [30,31]. Eliminating this problem is not easy, as Ukraine is a water-scarce country. There are about 15 million hectares of arable land in the zone of insufficient moisture, which is half of the sown area, and the need for irrigation will increase. Water reserves of rivers and lakes will be scarce and additional water sources will be needed, which Ukrainians will have to learn from the practices of arid climate countries [32].

The evaporation of soil moisture speeds up the traditional method of plowing with a layer turnover. At the same time, the release of soil CO_2 increases, which negatively effects the climate change.

The environmental and social problems of the agriculture on the one hand, and climate change with its expected negative consequences on the other, require fundamental changes in agricultural activities towards the transition to the principles of sustainable development of the industry.

A wide range of scientists and international organizations, in particular, the Food and Agriculture Organization of the United Nations (FAO) and the International Organization for Biodiversity, recognize agroecological agriculture as a tool for increasing the resilience of food systems in changing climate conditions.

Agroecology studies "the application of ecological science to the study, configuration and management of sustainable agroecosystems" [33] by imitation of natural processes and thereby ensuring beneficial biological interactions and synergies between agroecosystem components [34].

The peculiarity of agroecological agriculture is to provide favorable soil conditions for growing cultivated plants through the rational use of organic matter and increasing the biotic activity of soils. Basic agroecological principles are:

- 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 their individual components.

Agroecological farming contributes to climate change adaptation. The use of agroecological methods can significantly increase the resilience of agricultural systems and significantly mitigate the negative effects of extreme weather conditions, which are increasingly occurring in different regions of the planet. The practice confirms that physical properties of the soil in organic farms significantly improve the resistance of crops to

droughts. Climate change is contributing to the emergence of new agricultural weeds, pests, and diseases, which agroecological farms are better able to counteract through the use of genetically diverse varieties of cultivated plants [35].

Adherence to agri-environmental measures helps mitigate climate change by increasing carbon sequestration in soil organic matter and aboveground biomass on the one hand, and reducing carbon dioxide and other greenhouse gas emissions by decreasing direct and indirect energy use on the other. The Intergovernmental Panel on Climate Change (IPCC) estimated the global technical mitigation potential of agriculture by 2030 at 5.5–6 billion tons of CO_2 equivalent per year, most of which (up to 89%) can be achieved through agroecological measures [36].

Agroecological agricultural production contributes to improving the nutrition. Humankind needs diverse agroecosystems to provide a more diversified supply of nutrients to meet the needs of the human body. In this context, farms operating on agroecological principles provide a variety of food products and much better quality due to the limited use of mineral synthetic fertilizers and the use of biological methods of pest and plant disease control [37].

Agroecology reduces poverty in rural areas. Increasing the fertilizer production of ecological 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, which has a positive impact on farmers' incomes. The savings can be used for new investments to increase the production and improve the welfare of farm families.

Agroecological methods can contribute for a more productive workload for farmers, as well for the creation of new jobs for rural population. Field reforestation, integration of livestock and aquaculture, production of organic fertilizers, and a number of other measures require additional labor, the scope of which is limited in rural areas, which stimulates the sedentarization of a part of the rural population and has a positive impact on the preservation of rural settlements.

UN documents assign a key role to state policy in creating favorable conditions for agroecological and crop rotation models of agricultural development. For example, the Report on the Human Right to Food contains recommendations for governments of UN member states to implement policies to support the introduction of agroecological methods of food production. In particular, it is considered as necessary:

- To include references to agroecology and sustainable agricultural development in national strategies for the realization of the right to food;
- To include agri-environmental measures, which should be implemented in agriculture in national climate change action plans, as well as adopted by countries as part of their climate change mitigation efforts and sustainable development goals;
- To reorient state support measures to increase production to the formation of organized local regional markets for the successful sale of products, the development of the material, and technical base of sales and processing cooperatives established by small farms for the promotion of products to consumers without numerous intermediaries;
- To prioritize public procurement of products produced in agroecological farms and create favorable trade and macroeconomic conditions for them;
- To support the dissemination of knowledge among the rural population on agroecological principles of farming;
- To increase budget allocations for research, development of sustainable agroecological systems, and systemic measures to increase the profitability of small farms and provide training of scientific personnel in the development of agroecological methods of farming [38].

The state is responsible for the food security of their society and employment of their citizens. This obliges it to intervene in the activities of private food producers if these activities do not meet the needs of people for the food necessary for life and the health of the population. Government levers of influence should play a dual role: on the one

hand, to create conditions under which the producers will be interested in improving the environmental safety of their production, and on the other hand, to encourage compliance with environmentally friendly technologies in the context of social responsibility for the country's food security and preservation of the favorable environment for human life. We can see the experience of this approach in Western European countries.

At the pan-European level, regulations provide the mechanisms to encourage the implementation of measures that shape agroecological agriculture. Crop rotation, for example, is required by certain rules of the pan-European Crose Complianse system, which are specified in the Codes of Good Agricultural Practice and other regulations of the EU member states in accordance with national conditions. In Germany, for example, such an act regulates the share of each crop of the same biological family in the crop rotation at 15% of the sown area. This is complemented by requirements to implement measures to preserve and accumulate humus in soils, to protect them from erosion, and others. The established norms are controlled by state authorities and their violation leads to economic and administrative penalties. Sanctions are complemented by economic incentives to preserve soil fertility, carry out rational use of soil, as well as to protect water and forest resources in compliance with environmental functions [39].

An attempt to begin legislative and regulatory support for the creation of an ecologically balanced structure of agricultural land was made in the Concept of Balanced Development of Agroecosystems in Ukraine for the period up to 2025, and approved by the Order of the Ministry of Agrarian Policy of Ukraine No. 280 of 20.08.2003. It is provided for: " . . . to carry out a scientifically based transformation of the structure of agricultural land in order to form a balanced ratio between individual components of agroecosystems and ensure environmental safety and balance of the territory, in particular, to increase the share of agricultural land of extensive use (hayfields, pastures) in accordance with scientifically based indicators and reduce the area of arable land to 37–41% of the country's territory by withdrawing from arable land slopes with a steepness of more than 3 degrees, lands of water protection zones, degraded, low-productive lands." However, these measures were not transformed into specific mechanisms for their practical implementation and as a result, remained unfulfilled [40].

The same situation with the implementation of the current tasks is envisaged by the Sustainable Development Goals of Ukraine until 2030. It provides for the reduction in arable land from 32.5 million hectares to 28.4 million hectares by 2030, i.e., the withdrawal of 4 million hectares from cultivation [23]. At the same time, the area of agricultural lands of extensive use (hayfields, pastures) should be increased from 7.8 million hectares to 9.5 million hectares, bringing their share in the total territory of the country to 15.8% and in relation to agricultural lands up to 23% (Goal 15 "Protection and restoration of terrestrial ecosystems"). The document also recognizes the urgent need to introduce "such sustainable land use practices that do not deplete or pollute soils and on the other hand, that clearly restore degraded and eroded land". However, the recommendations for achieving the goals do not include mechanisms of state influence on solving these problems. They do not appear in other government documents either, although half of the allotted time was left before the results of the planned tasks were summed up.

In this context, it is urgent to adopt a program for the conservation of degraded and war-damaged agricultural land with a state structure. It should include the governance of land plots for conservation, mechanisms of interaction between the state and owners of these plots, the period of their stay in conservation, etc. In the USA, for example, such a program remained in place since 1985. The national limit on the area of land that can be conserved at the same time is set by the agricultural law (6.3 million hectares in 2023) [41]. It is also necessary to use the practice of temporary withdrawal of eroded land from cultivation in Western European countries. Approaches for solving the problem are proposed by scientists from the Institute of Agriculture of the National Academy of Sciences and other institutions [42,43].

The conditions for the transition to agroecological agriculture should be set out in the Code of Sustainable Agriculture. It should implement the provisions of the EU regulations on the economical use of the natural resource potential of agriculture, which form the cross-compliance system and acts to regulate the adaptation of the agriculture to climate change. The study of the codes of good agricultural practices in Poland and other EU countries is useful for the development of this document [44].

For Ukraine, the most difficult adaptation to the new economic conditions will be in regions with the most disturbed lands and the most expected climate change in the steppe and eastern forest-steppe zones. According to the FAO, short rotation of crop rotations in combination of wheat and corn with drought-resistant legumes and cereals (soybeans, chickpeas, millet, sorghum, and peanuts) are the most suitable for similar soil and climatic conditions. Realization of the full benefits of wheat and maize–legume rotation is ensured by conservation agriculture [45]. Short grain rotations are common, for example, in arid regions of Canada and the USA.

The peculiarities of such crops as sunflower, sugar beet, and flax require ecologically oriented long crop rotations, which should be adopted by farms in the western and central forest-steppe and Polissya. Fodder crops, and consequently, livestock production should be restored in the crop rotations of all zones, which will largely eliminate the social problems outlined above.

In this context, the structure of Ukraine's sown areas can be transformed accordingly (Table 5).

Table 5. Structure of sown areas in Ukraine, 2021–2030.

Cultures	2021		2030 (Forecast)	
	Area Thousand Hectares	**%**	**Area Thousand Hectares**	**%**
Total sown area	28,581	100	24,500 *	100
Cereals and pulses	15,995	56.0	12,250	50
Including				
Wheat	6908	24.2	6125	25
Barley	1337	4.7	6125	6
Corn	5522	19.3	1470	10
Millet	83	0.3	2450	1
Buckwheat	90	0.3	245	1
Leguminous crops	314	1.1	245	5
Oilseeds	8939	31.3	1225	17.5
Including				
Sunflower	6622	23.2	2450	10
Soya	1006	3.5	857.5	3.5
Rapeseed	1311	4.6	980	4
Technical crops	305	1.1	735	3
Including				
Sugar beet	227	0.8	269.5	1.1
Flax	-	-	147	0.6
Other industrial crops	78	0.3	318.5	1.3
Potatoes, vegetables, etc.	1807	6.3	1592.5	6.5
Fodder crops	1535	5.4	4900	20

Table 5. *Cont.*

Cultures	2021		2030 (Forecast)	
	Area Thousand Hectares	%	Area Thousand Hectares	%
Including				
Annual fodder	660	2.3	1960	8
Perennial grasses	819	2.9	2940	12
Temporary withdrawal from land cultivation	-	-	735	3

* Reduction in sown areas in line with the 2030 Sustainable Development Goals. Source: Agriculture of Ukraine. Statistical Digest 2021 Forecast calculations based on expected climate change [18].

One of the most important areas of transition to agroecological agriculture is the development of organic farming, which is designed to maintain and improve the health of the soil, plants, animals, people, and the planet as a whole. Ukraine should follow the example of EU member states and adopt a program to support organic agriculture. In Poland, for example, such support is provided during the transition period and in the period of established farming. Payments are made for field, vegetable, fruit, and fodder crops, as well as for growing grasses and sowing pastures [46].

The above does not exhaust all the work that needs to be conducted by legislative and executive bodies, scientists, and commodity producers for a transition to sustainable agriculture in the face of expected climate change, but only highlights the systemic directions of this work. Adoption of programs for the conservation of disturbed lands and support for the transition to organic farming, development, and implementation of crop rotations with an appropriate structure of sown areas, different set, ratio, and placement of crops should be subordinated to ensuring the production of quality products, taking into account the country's food independence and food security, and rational use of rural labor resources, maintaining the productivity of arable land and preserving the environment for current and future generations.

4. Conclusions

(1) The results of the study confirm the hypothesis that agriculture is unable to perform environmental functions in the context of a deeply specialized type of agriculture with a transition to monoculture, which was formed in Ukraine as a result of the entry of large agro-industrial and trading companies into the agricultural sector in order to make profits, as well as to perform environmental functions in accordance with the requirements of the laws of functioning of natural resource potential and irreplaceable social functions (ensuring food security, employment of the rural population, etc.). Large specialized export-oriented agribusinesses are characterized by increasing the economic component of agricultural activity, ignoring their environmental and social components [17].

(2) The successes of monoculture exports create an atmosphere of false prosperity. Negative environmental consequences (soil damage, erosion, loss of soil fertility and biodiversity, etc.) are being ignored by agriholdings and will be the problems of future generations of agricultural producers. The remoteness of repayment of the debt to nature entails an increase in conflict and its escalation into environmental disasters.

Practice confirms the basic theoretical principles of classical agroeconomics, according to which profit maximization cannot be the only criterion for the efficiency of an agricultural enterprise, because in the agricultural process, human activity involves nature, whose laws are "foreign" to human economic interests [47]. The aggregate effect of agricultural production should be assessed not only by special (economic) indicators, but also by social indicators [48]. To obtain a truly comprehensive tool for assessing agricultural activities, economic results in agriculture should be correlated with the environmental balance [49,50].

(3) The social consequences of the deep specialization of agriculture with the transition to monoculture are manifested in the country's growing food dependence on imports of agricultural products that were displaced from production, a narrowing of the range of food consumption baskets, and a decrease in the calorie content of the average daily diet and consumption of macro- and microelements (all of which is confirmed by official statistics of Ukraine). Hundreds of thousands of jobs were eliminated, unemployment, poverty, migration processes, and the depopulation of rural areas increased due to the reduction in 3–8 times of a number of different types of livestock compared to the pre-reform period, the abandonment of potato cultivation, the reduction in vegetable crops, and the destruction of large areas of gardens at enterprises.

The production of agricultural products is a masterpiece of nature and human labor, and at the same time, an indispensable source of energy for human life. Therefore, these products should be available to everyone in the required quantity and quality, regardless of whether they are profitable or unprofitable for business. The importance of this social function of agriculture will grow in the face of climate change.

(4) The complex of environmental and social problems of Ukrainian agriculture are compounded by negative climate change. Over the past 25 years, the average annual temperature exceeded the climate norm by 1.4 °C. Every 10 years, the temperature rises by 0.3–0.4 °C. If this rate of warming continues from the 1930s onwards, the steppe zone, where the average monthly precipitation has a steady downward trend, will become semi-desert, a significant part of the forest-steppe will acquire steppe-like characteristics, and Polissya will become forest-steppe. In these conditions, the combination of economic, social, and environmental approaches to achieve sustainable development of the industry is ensured by the transition from monoculture nature-destroying to resource-saving agroecological crop rotation of agriculture with the introduction of short-term grain crop rotations with legumes and a set of crop varieties adapted to new conditions in arid regions, as well as fruitful long crop rotations in other regions in combination with crop and livestock production.

(5) The practice of Western European, North American, and other countries accumulated a significant arsenal of mechanisms for organizing resource-saving crop rotation farming. With institutional and legal support, 100% of cultivated land in the EU is covered by crop rotation and 85% of cultivated land in the US. A range of measures is in place to maintain soil fertility, preserve biodiversity, and protect the environment. For Ukraine, the implementation of this practice in national agrarian policy is the only way to preserve the country's natural resources and food sovereignty.

In this context, the basis of the course towards crop rotation and agroecologically oriented agriculture should be formed by:

- A state program for the conservation of degraded land and land affected by military operations, with appropriate organizational, legal, and financial support;
- Adoption of the Code of Sustainable Agriculture as an analogue of national codes of good agricultural practice, taking into account the state of natural resource potential of national agriculture and expected climate change;
- A long-term program to promote the development of organic farming using the practices of European countries;
- Scientific and human resources support for the transformation of zonal crop rotations and the structure of production in the post-war period, taking into account the state of agricultural land, expected climate change, and the needs of society for adequate nutrition.

Without such an approach, the Sustainable Development Goals of Agriculture and the Protection of Natural Resources set for 2030 will not be achieved.

(6) The main strategy for the formation of productive agroecological agriculture is to preserve and enhance each of their natural components, which requires appropriate

policies and costs. The economy and ecology should jointly and interconnectedly compare the values produced by people with the values created by the environment, which allows for finding a consensus between limiting the economization of human activity and the rational use of nature for the sake of the future of the planet and humanity.

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