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Post- and Neo-Industrial Technologies in the Post-War Development of the Agrarian System in Ukraine

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▸ **Abstract.** The study focuses on the identification of directions of innovative development of the agrarian system of Ukraine in the war and post-war periods. The relevance of solving this fundamental scientific and practical task lies in the fact that the agrarian structure of Ukraine in modern socio-economic conditions requires the introduction of new and fundamentally different from the pre-war ways of development, which would make the most of modern science-based methods of development of organisational and legal entities. The purpose of the study is to outline the challenges facing Ukrainian agriculture in the post-war development of the agrarian system and their solutions based on post- and neo-industrial technologies. System-structural analysis and synthesis, monographic, historical methods, methods of abstraction and economic comparisons were used in the investigation. Theoretical and methodological included concepts, provisions, findings presented in the academic publications of Ukrainian and foreign scientists, theories of innovation, communication, information technology. The study considered the substance of technological structures and their influence on economic development in the historical aspect, along with modern models of industrialization and the level of innovative development both in Ukraine and other world countries. The results and challenges of the innovative development of the agro-industrial complex of Ukraine for 2000-2020 are analysed, the branches whose low rates of development threaten the food security of the country and the further development of the agro-industrial complex, in particular the challenges and threats caused by the Russian Federation's full-scale war and occupation of part of the territory of Ukraine, are highlighted. Modern innovative post- and neo-industrial technologies (in particular, technologies of drip irrigation, production of vegetables in the closed ground, precision farming, production of vegetable meat, etc.) were identified and singled out, the broad introduction of which in the post-war period will not only restore the pre-war potential of the agro-industrial comlex, but also ensure its further competitive development. The obtained conclusions and findings can be used in practice: enterprises, rural and urban households – producers of agricultural products and food products on the widespread introduction of drip irrigation technologies, greenhouses, precision farming and robotics, non-animal production of meat and dairy products with high efficiency; specialised scientific institutions and start-ups on the deployment of extensive research towards the creation of new innovative post- and neo-industrial technologies for the production of agricultural products and food; state executive authorities to stimulate the widespread introduction of these technologies to ensure post-war recovery and further competitive innovative development of the agro-industrial complex

▸ **Keywords:** agro-industrial complex, post-war development, innovative technologies, efficiency, agricultural policy

▸ Introduction

As a result of the denationalisation and privatisation of agricultural enterprises by 2010, instead of the collective and state farm system, the agrarian system, which can be defined as "private-rental", was formed in independent Ukraine. Its characteristic features are private ownership of land, property and production results, the introduction of a limited agricultural landsational and legal forms of the market economy [1].

In 2020, agricultural production was carried out by a total of 47,523 agricultural enterprises on an area of 20252,4 thousand hectares, including 31,851 farms on an area of 4280,1 thousand hectares of agricultural land. The majority of agricultural production

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for the needs of the domestic agro-food market has moved to the household sector, which now owns 14418,7 thousand hectares, or 34.9% of the country's agricultural land [2]. The leading export positions were occupied by large transregional integrated corporate agro-industrial associations and groups (so-called agro holdings), which, according to recent estimates, control about 8.7 million hectares (21.1%) of the country's agricultural land [1].

The volume of gross agricultural production (in constant prices of 2016) from 2000 to 2020 increased by 162.6%, including in agricultural enterprises by 246.6% (in particular in farms by 721.6%), in family farms by 110.8%. At the same time, the share of family farms in the production of gross agricultural output, which in 2000 was 61.6%, during this period decreased to 35.4% due to a significant increase in production volumes both in agricultural enterprises and in farms [2].

Exports of agricultural products during this period have increased by over 25 times. Ukraine, which was an importer in the second half of the twentieth century, has become an exporter of agricultural products. According to the data for the year 2020, the foreign trade turnover of agricultural products amounted to $ 28.7 billion, of which $ 22.2 billion accounted for agricultural exports, which accounted for 39.8% of Ukraine's total exports [2]. Ukraine's share in world grain exports is currently about 10%, which makes it possible to feed about 400 million people [3].

These gains were achieved due to the denationalisation and privatisation of agricultural land and property of former collective and state farms and the transparency of the economy of the democratic state of Ukraine, which created conditions for the entrepreneurial initiative of farmers in the implementation of organizational, economic, technical, and technological innovations accumulated in the world practice. Hardworking and educated farmers began to introduce new productive varieties of agricultural plants, new high-performance machinery, widely use plant protection products, other components of advanced technologies of agro-industrial production and elements of precision farming, and the agriculture of Ukraine firmly embarked on the path of innovative development.

The issues of innovation processes, innovations, organisational and technological modes of economic development are studied by renowned scientists: M. Tuhan-Baranovskyi, who formulated the law of investment theory of cycles [4], J. Schumpeter, who introduced the concept of innovation in the theory of economic development [5], S. Glazyev on the evolution of technical and economic systems [6], J. Keynes on the theory of state anti-crisis regulation of the economy [7], V. Vasilenko, L. Gurieva, M. Parkhomets on the evolution of technological devices [8-10], O. Shabluk, L. Antoniuk, O. Datsiy on the development of innovative processes in agro-industrial production of Ukraine [11-13], M. Rudenko on digitalisation of management and precision farming systems in agricultural enterprises [14] et al.

At the same time, the restoration of the economies of countries, minimisation, and elimination of the consequences of military conflicts in the context of globalisation requires conducting scientific research to provide not evolutionary, but revolutionary ways to support the innovative development of agro-industrial production.

In February 2022, Russia waged a large-scale war against Ukraine. The hostilities resulted in the bombing of thousands of apartment buildings in cities and rural households of Ukraine, tens of thousands of agricultural lands were mined, production and social infrastructure (including in rural areas) were completely or partially destroyed, agricultural machinery, grain and fertilisers were stolen from the temporarily occupied territories and taken out of Ukraine, many farm animals were killed, logistics of Ukrainian exports was disrupted due to the blockade of ports on the Black and Azov Seas.

The State Statistics Service is not yet able to record the exact statistics of damage caused by hostilities, but according to rough estimates of the Ministry of Agrarian Policy, in 2022, about 30% of agricultural land will be withdrawn from agricultural turnover, and given the difficulties in providing resources, the expected gross harvest of agricultural crops will be about 40% lower compared to 2021 [3]. And although the country's food security will be generally maintained, the volume of agricultural exports will fall significantly with all the negative consequences for the economy of the state and the threat of hunger for the whole world.

An issue of post-war restoration of agro-industrial production in the country and ensuring further increase of its competitiveness has become apparent. According to the author, the information presented in this investigation can serve as a public search for solving this problem.

The purpose of the study is the formation of avenues and approaches to the modernisation of the agrarian system in the post-war conditions of development of Ukraine on the basis of post- and neo-industrial technologies.

▶ Materials and Methods

The study used:

– system-structural analysis and synthesis for determining the periods of technological modes of production, monographic and historical methods for outlining the evolutionary, process-historical provisions of the formation of the theory and methodology of development of industrialisation models of the world, which made it possible to determine the main directions of further innovative development of agro-industrial production in Ukraine.

– Methods of abstraction and economic comparisons to determine the essential provisions of institutional transformations and develop proposals on ways to improve the institutional environment aimed at establishing conditions for the formation of innovative development of the agrarian sector of the national economy.

– Theoretical and methodological basis: concepts, provisions, conclusions presented in the studies conducted by Ukrainian and foreign scientists, theories of innovation, communication, information technologies

Besides scientific publications [6; 7; 11], a large number of publications on the exchange of leading practices and promotional materials on the Internet [15; 16; 17], data from statistical collections "Agriculture of Ukraine" [2], and also operational data and forecasts of the Ministry of Agrarian Policy for March-April 2022 [3] were used in the study.

▸ Results and Discussion

It was J. Schumpeter who noticed that the development of innovations is discrete in time. He called the periods of time when there is a surge in innovation "clusters" (bundles). Other researchers use the terms "waves of innovations", "technical and economic paradigm" for this phenomenon [8; 18], in Russian literature the phrase "technological way of life" is used [6; 9], in Ukrainian literature the term "technological structure" is used more often in recent years [19]. According to the academic dictionary, the structure is an established social order, a system of organisation. The technological structure is several interconnected and successive generations of equipment and technologies that evolutionarily implement the general technological principle [20]. From a historical perspective, there are 7 technological systems that succeed one another in the process of innovative development (Table 1).

Table 1. Periodisation of technological paradigm

No. of tech. of paradigm		Year	Key factor	Core of paradigm
First		1772	The invention of spinning machines	Textile industry, the mechanisation of labour, the establishment of mass production
Second		1825	The invention of the steam engine	Steam shipping, coal mining, railways
Third		1875	Inorganic chemistry (converter, dynamite)	Ferrous metallurgy, railways, shipbuilding, production of explosives
Fourth		1908	The internal combustion engine, conveyor production, wired telephone service,	Automotive industry, aircraft construction, petrochemicals
Fifth		1971	Advancements in microelectronics, computer science, biotechnology, genetic engineering, new sources of energy, materials, space exploration, satellite communications, etc.	Electronic industry, computer engineering, fiber-optic equipment, software, telecommunications, robotics, natural gas production and processing, information technology
Sixth	2004	nanotechnology, cellular technologies	Nanoelectronics, molecular and nanophotonics, nanomaterials and nanostructured coatings, nanosystem engineering, biotechnology, nanobiotechnology, information technology, Cognitive Sciences, socio-humanitarian technologies, convergence nano-, bio-, info- and cognitive technologies	–
Seventh	~2060	The era of cognitive technologies	Cognotropic drugs, cognitive assistants, virtual interfaces that carry out communication of the "human-computer" type, adaptive support systems	–

Source: developed by the authors based on [9; 10; 21]

On the basis of the summary of publications on the evolution of technological structures, the Institute of Encyclopedic Research of the National Academy of Sciences of Ukraine identified the following modern models of world industrialisation [22]:

• traditional industrialization – with a predominance of extractive industries, heavy and low-tech mechanical engineering with technologies mainly of the 3rd and 4th paradigmes, being modernised to meet the modern market challenges;

• necroindustrialisation – the state of the industries with the sectors of the 3rd and 4th paradigmes, which are experiencing the processes of deindustrialisation of the first type, i.e. reduction of production capacities due to their physical deterioration and lack of market demand for products;

• post-industrialisation – transition to technologies of the 5th paradigm, which is accompanied by processes deindustrialisation the second type, that is, the withdrawal of low-tech industries outside the country, the introduction of modern high-tech production facilities focused on the production of products with a high share of added value, informatisation of society, and the development of modern high-tech services;

• neoindustrialisation – transition to technologies of the 6th paradigm, with the production of high value-added products, characterised by individualisation, nanotechnology, biotechnologisation, cognitivisation, development 3D printing, and reindustrialisation that is, an increase in jobs in the national economy based on these technologies, mainly in the small and medium-sized businesses.

In developed countries (USA, Germany, England, France, Japan, China, etc.), 5th paradigm technologies predominate, and 6th paradigm technologies are being formed. The economy of Ukraine is still characterised mainly by technologies of the 3rd and 4th technological paradigm (their share in industrial production is about 96%, the share of industrial products of the 5th and 6th paradigmes is 4%). The volume of production and investment of capital for technical re-equipment and modernisation of the agro-industrial complex is mainly at the level of the 3rd technological paradigm. Therefore, Ukrainian industrial goods and food products cannot compete on the world market, and the Ukrainian economy, including the agro-industrial complex, remains mainly raw materials [12].

It is necessary to introduce innovative technologies of the 5th and 6th technological paradigmes to ensure further development of the country's agro-industrial complex and increase its competitiveness, and, consequently, to carry out post-industrialisation and start neo-industrialisation of agriculture at an accelerated pace.

Thus, rather than restoring the pre-war state of agriculture, it is advisable to address the challenges of its development through the introduction of equipment, technologies and organisation of agricultural production and high value-added food production based on post- and neo-industrialisation technologies.

Based on the summary of the findings of scientific research and world practices [10; 21; 22], the authors of this paper identified the main post- and neo-industrial innovative technologies, the development and implementation of which, along with the post-war restoration of the potential of the agro-industrial complex, will ensure the innovative development of its main sectors [12].

Post-industrial technologies in vegetable production. First of all, we pay attention to the branches of vegetable, berry and fruit growing, since the production of these low-tech industries in the pre-war 2020 was concentrated mainly in family farms (respectively 84.6% and 83.21%), and the level of self-sufficiency of the country's population in agricultural products of these industries, according to the State Statistics Service, was respectively 104.6% and 75.9%, that is, barely met the needs of the country's population [2].

During the First and Second World Wars the project "VICTORY GARDENS" was implemented in the USA, Great Britain, Canada, Australia, and Germany and which included vegetable, fruit and herb gardens planted in private residences and public parks. They helped these countries to survive in the most difficult times. A similar picture is observed in Ukraine, where the industrial production of tomatoes, onions, fruit, and melons is concentrated mainly in the South, which is temporarily occupied. Therefore, the Ministry of Agrarian Policy and the Ministry of Community Development have started implementing such a project in Ukraine. According to project experts, due to military operations in 2022, Ukraine may lose about 68% of the tomato crop. As a result, if big and family farms fail to cover domestic demand, Ukraine will have to raise imports. Experts also report disappointing estimates for the production of onions, eggplants, fruit and melons [15].

As for the production of cucumbers, berries, leafy greens, cabbage, etc., the industrial output of these products to supply urban residents is concentrated around the cities, and due to the specifics of the hostilities for their defense, a significant part of private farms and agricultural enterprises in the combat zone are looted, contaminated, mined, and the agricultural land is subject to reclamation. And if rural farms and a small part of urban farmers will be able to satisfy the basic needs for berry and vegetable products through their cultivation on their backyards and summer cottages (gardens), the majority of urban residents will face a significant increase in demand over supply with all the financial and quality consequences. The most rational solution to this issue is to develop drip irrigation, greenhouse, and greenhouse farming, including vertical farms in urban environments.

Drip irrigation is a method of rationed watering of all types of garden and vegetable plants. It consists in supplying water in small portions directly to the roots. The liquid enters through droppers located above the soil near each plant. Thus, only the soil covered by the root system remains moist, and water is supplied directly to the roots.

Drip irrigation technology was invented in the 1950s in Israel, when the young state began to develop its desert lands. Having used it in the most acute water shortage, the Israelis have developed a powerful agricultural industry and achieved a high level of greening of arid territories in 10 years. This made it possible to increase crop yields by 50% and save up to 40% of water. Today it is widespread in the Middle East, Israel, India, Spain, South and North America [23].

Climate change in recent years has exacerbated this particular problem in Ukraine. Therefore, rational use of energy and water is relevant in all regions. Drip irrigation systems allow [16]:

* increasing the yield by 2-3 times;
* saving water, fertilisers, and electricity;
* reducing labour costs;

* getting higher early yields;
* limiting weed growth;
* avoiding burns and mechanical damage to the leaves;
* minimising the development of fungal and bacterial contamination;
* applying active substances directly to the soil;
* eliminating erosion of the topsoil;
* maintaining air permeability of the soil;
* watering with minimal working fluid pressure.
* automating the irrigation process;
* providing water to all types of plantings – beds, bushes, large-sized trees, and greenhouses.

Pioneering farmers and rural farm owners in Ukraine are already actively using drip irrigation technologies in their operations, and equipment for drip irrigation systems is widely available in online stores and construction markets. The next step is to encourage farmers and rural communities to adopt these technologies on a large scale.

Greenhouse farming and production of indoor vegetables. Vegetables and other products grown with these technologies are kept in special cultivation facilities:

– greenhouses with solar, biological or technical heating, intended mainly for growing seedlings and vegetable products;

– tunnels on film shelters or insulated soil for heating plants in early spring, growing mushrooms;

– greenhouses equipped with heating, lighting, water supply and ventilation systems;

– greenhouses for the cultivation of exotic fruits, flowers and equipment of places for recreation.

Greenhouse vegetable growing is an intensive form of production, characterised by a high degree of technological development and allows growing vegetables and other greenhouse products throughout the year, providing 25-40 kg of products from 1 square meter of winter or block greenhouses. Spring greenhouses have fewer heating devices and can be made of film. In these facilities, vegetables are grown from April to October, using the sun, biofuels, and electric energy as heat sources. The productivity of spring film greenhouses is 15-25 kg of vegetables per 1 sq. m [16].

Greenhouses in the Netherlands, which cover almost 10 thousand hectares, have increased the production of agricultural products by 15 times. Half of these greenhouses are vegetable greenhouses, the rest are used for growing flowers and fruits. Despite the high cost of indoor production, its output due to a much higher price in the winter-spring period allows receiving guaranteed profits. In addition, the influence of soil and climatic conditions on the final cropping result is thus minimised [23].

Vertical farms. These are greenhouses with a multi-tiered arrangement of plants. They are “stuffed” with high technologies that control climate, water, and lighting. Such farms can be placed not only on the ground but also on the roof and in the basement. Their dimensions range from a meter-long cabinet or cargo container to a large greenhouse complex. The main advantages are efficient use of space and water, being independent of the weather, accelerated crop ripening, and the ability to harvest crops all year round. Plants do not grow in the soil, they are grown by hydroponics and aeroponics. Pesticides are not used, so the products are environmentally friendly. In international practice, vertical farms gained popularity in the last 20 years in various structural modifications, in particular [24]:

Vertical modules in basements, rooms or roofs are installed in private or apartment buildings in urban areas. Thus, Estonians expressed the aspiration to have healthier foods at home in 2009. The startup Click&Grow has developed “smart” baskets and cabinets for growing greens, herbs, tomatoes, which are in great demand [25].

Refrigerator cabinets. They are installed at home, in offices, restaurants, and even supermarkets. In such greenhouses mainly greens are grown, less often – other vegetables. The modules of the German manufacturer Infarm are popular around the world. Its cabinets-refrigerators are available in Canada, USA, Europe [24].

Sea Containers. This idea was brought to life by Kimball Musk’s company Square Roots. The first system was installed in New York. The entrepreneur wants to supply container farms for growing herbs, vegetables, and strawberries in all cities of the United States [24].

Large greenhouse farms consist of horizontal layers stacked vertically, equipped with IT technologies for climate control, dosed supply of water substrate, etc. They are built in many countries of the world mainly in cities or suburban areas to reduce the cost of logistics and improve the quality of products sold.

Thus, the vertical farm of the company CAN-Agri from South Africa is located in Pretoria and looks very different from a typical greenhouse. It consists of rows of vertical “plant walls”, which are placed in a structure with sufficient space between the rows – so that each wall fully receives plenty of sunlight. The irrigation system pre-processes the water, dispenses fertilisers, and then disinfects the water for irrigation and reuse [26].

French vegetable producer Lufa Farms has announced the construction of its fourth rooftop greenhouse in Montreal. The building will have an area of 163,800 square feet (about 3 football fields), making it the largest rooftop farm in the world and will feed 2% of Montrealers with fresh local vegetables [27].

The Dutch company Havecon is completing the construction of a high-tech greenhouse in New York, USA. This large-scale greenhouse project is called “Green Empire Farms” (GEF) and involves the construction of greenhouse complexes in 7 locations. They will grow berries, tomatoes, cucumbers, and peppers [28].

The main advantages of vertical farming are environmental friendliness, fast harvests and proximity to the buyer. Compared to traditional agriculture, vertical farming can grow 350 times more produce in the same space, using 95% less water and 95% less fertiliser [27].

Ukraine is already developing projects to replace bombed and damaged apartment buildings with modern residential complexes with bomb shelters, supermarkets, restaurants, etc. Vegetable vertical modules of various capacities should also feature prominently in these projects, thus accelerating the development of urban vegetable growing and the level of provision of citizens with vegetable and mushroom products. It is necessary to stimulate entrepreneurship development in this area both on the part of private entrepreneurs and condominiums. At the same time, it is desirable to implement programmes to support drip irrigation and greenhouse vegetable production projects of suburban households and family vegetable farms.

Post-industrial technologies for the production of grain and industrial crops. Enhancing the farming culture and development of industrial and intensive technologies for growing grain and industrial crops based on the use of new high-performance machinery, high-yielding zoned varieties, resource-saving and water-saving methods of soil cultivation, compliance with scientifically based crop rotations, seeding rates, fertilisers and pesticides, etc. allowed to increase yields from 2000 to 2020:

– grain and leguminous crops from 19.4 to 42.5 c/ha, or 2.2 times;

– sugar beet from 176.7 to 461.1 c/ha, or 2.6 times;

– sunflower seeds from 12.2 to 20.2 c/ha, or by 165.6%.

The production volumes of export-oriented cereals and legumes increased to 64.9 million tons or 2.7 times, sunflower to 13.1 million tons or 3.8 times, and sugar beet for sugar production mainly for domestic needs decreased to 9.1 million tons or 30%. Exports of cereals and legumes, including products of their processing in terms of grain, reached 52.2 million tons, and in terms of sunflower oil exports, Ukraine firmly ranks 1st in the world [2].

However, in 2022, according to the forecasts of the Ministry of Agrarian Policy [3], due to hostilities, the volume of grain exports may decrease to 21.0 million tons, sunflower oil – up to 40%, which may cause a global food crisis.

Therefore, the agro-industrial complex of Ukraine faces the challenge of raising the production of grain and industrial crops on the sown areas. This can be achieved through the widespread adoption of post-industrial IT technologies for precision farming.

Precision farming is a comprehensive high-tech agricultural management system that includes global positioning technologies (GPS), geographic information systems (GIS), yield monitoring technologies, variable rate technology, remote sensing technologies (RS) and Internet of Things solutions.

Precision farming technologies are based on the concept of managing crop yields in accordance with the conditions of each specific field, rather than solely on the scientifically based recommendations of agronomists for their cultivation, in particular, natural and climatic zone.

Each specific field, and even its individual parts, may have a different configuration, different qualitative composition of nutrients in the soil, different moisture content, contamination, etc., which, with an average approach to agricultural technology of growing a particular crop, leads to overspending of fuel, fertilisers, pesticides and herbicides, labour, etc., and shortage of crops due to suboptimal conditions for growing crops in this particular field. Therefore, the technology of precision farming is faced with the task of creating optimal conditions for growing a particular crop in each specific field.

This requires:

1. Collection of data on agrochemical and agrophysical properties of soil on the basis of space monitoring data, aerial photographs using agrodrones, special analytical sensors in certain areas of the field and their positioning in the GPS positioning system.

2. Research and accumulation of the collected data using special software of electronic field maps with the help of geographical information system (GIS), yield maps using Yield Monitor Technologies and determination of the exact number of resources needed using Variable Rate Technology, formation of an environmentally friendly plan for agricultural operations.

3. Automated performance of agricultural operations with reference to the specific features of each field. For this purpose, the following most popular elements of precision farming are used:

– autopilot and direction finder (agronavigator) – when installed on agricultural machinery (tractor, combine) allows to avoid skips or blocking of passes of machinery during pre-sowing tillage, sowing, crop care with the application of fertilizers and plant protection products, harvesting. A significant reduction in the consumption of fuel, seeds, fertilizers, plant protection products (up to 30%) is achieved, prevents crop losses during harvesting, makes it possible to cultivate fields in case of deteriorating visibility (at night, in fog, smoke, dust);

– system of automatic shutdown of sprayer sections – turning off sprayer sections when applying liquid fertilisers and plant protection products during overlaps and depending on the presence of nutrients in the soil, plant pests and weeds in certain areas of the field. It significantly saves the cost of fertilisers and plant protection products, prevents excessive processing of crops with herbicides and fungicides. Allows saving 4-6% of fertilizers and plant protection products on fields of regular shape and up to 20% – on fields with complex geometry [14];

– the system of automatic shutdown of seeder sections and its equipment with seeding monitoring sensors – implements the technology of precision sowing, depending on the seeding rates of plant varieties and agrotechnical and agrochemical characteristics of the soil in different parts of the field determined using the field map and yield. Significantly saves seed consumption, ensures optimal crop density;

– retrofitting the spreader for differentiated application of manure and granular fertilisers depending on the content of nutrients in the soil in certain areas of the field. It allows saving 10-15% of manure [14];

– drone, UAV – for alternative application of fertilisers, plant protection products by spraying from the air and monitoring the condition of the fields. Solves the issues of trampling, soil compaction and damage to the field drying out. Compared to the ground sprayer, investment and operating costs are 2-3 times lower [14].

The introduction of precision farming requires extensive investment. The practice of its implementation shows that these investments pay off when the size of the farm is 500 hectares and above. Therefore, most small agricultural enterprises and family farms introduce elements of precision agriculture gradually, making an investment calculation for the implementation of each element, or, if profitable, using the services of maintenance enterprises, which are becoming more and more numerous in Ukraine [14].

Since 2010, with the development of robotics, various modifications of autonomous (unmanned) tractors – robot tractors – have appeared on the market. Thus, built on the basis of the John Deere 8R harvester, the drone is equipped with a GPS module and six stereoscopic cameras for panoramic viewing and detection of possible obstacles. Images captured by the cameras are transmitted to a neural network that analyses each pixel and determines with an inch accuracy where the tractor is located and what it is doing. The farmer only needs to deliver the car to the field and set it up for autonomous operation. While the machine is working, the farmer can go about their daily business, monitoring the status of the machine from their mobile device [29].

Such equipment can work around the clock and almost without interruption, so it will be in demand both among large agricultural companies and smaller farmers.

The above shows that precision farming systems and robot tractors can be effectively used not only for the production of cereals and industrial crops but also for other open-ground crops, such as orchards and berry gardens.

Post- and neo-industrial technologies in animal husbandry. Despite the measures taken by the Government of Ukraine to stimulate the development of livestock industries, compared to crop production, the rates of their progress are significantly behind. Thus, the authors' analysis of data [2] for the period from 2000 to 2020 showed that the number of cattle decreased from 9423,7 to 2874,0 thousand heads, or 3.3 times, including cows, from 4958,3 to 1673 thousand heads, or 3.0 times. Moreover, this decrease is observed both in agricultural enterprises and in family farms. The number of pigs in 2020 was 76.8%, among them in farms 42.9% since 2000, and the number of sheep and goats is 61.1% and 67.7%, respectively. During this period, only the number of poultry of all species increased by 162.2% due to the development of poultry farming in agricultural enterprises. Livestock and pig breeding industries in Ukraine are gradually declining. In 2020, the level of self-sufficiency of the population of Ukraine (production to domestic consumption) was: for meat and meat products – 110.1% due to an increase in the production of poultry meat, milk 99.1%, eggs 125%. Ukraine faces the threat of becoming an importer of cattle and pig products.

The roots of the decline in the number of cattle lie primarily in the high labour intensity of livestock maintenance. According to the author's calculations [29], with the existing low-mechanised maintenance of cows in households, the labour intensity of keeping one cow (including labour costs for feed preparation) is about 2/3 of an 8-hour working day. But maintaining a farm also requires the allocation of labour time to perform other household and social tasks. The working hours of the farmer start at dawn and end late in the evening. Therefore, most rural households refuse to keep livestock, and this trend will persist in the future.

Another significant factor in the reduction of livestock is the low investment attractiveness – the high cost of investment combined with a long payback period hinders investment in the development of the industry. This makes the expansion of livestock breeding in agricultural enterprises and farms unattractive.

A similar, though less prominent, picture of relatively high labor intensity is observed in the pig farming. The investment attractiveness of this industry is also declining due to the constantly occurring outbreaks of the African plague. In 2022, another threat was added to this – the military aggression of the Russian Federation, which unleashed a full-scale war against Ukraine. The invaders slaughter and export livestock and pigs from the occupied parts of Ukraine, destroying the production base.

Thus, to preserve and develop the livestock industry, especially cattle and pig breeding, it is necessary to dramatically increase labour productivity in livestock through the development and implementation of new innovative technologies.

The grouping of enterprises by the number of livestock kept at the end of 2020, carried out by the authors on the basis of statistical data, shows that milk and beef production is mainly concentrated in a small number of agricultural enterprises with a livestock population of 500 heads and above: out of 1911 farms engaged in cattle breeding, 642 farms or 33.6% keep 80.3 livestock. In the pig farming industry, 244 farms out of 1,491 contain more than half of the pig population (51.8%) [2].

Thus, the scale effect is manifested, in which the increase in the level of mechanisation and automation of operations allows improving the investment attractiveness of livestock industries.

Milking parlours of the "carousel" or "parallel" type, free-stall cattle keeping, mechanised and automated preparation and distribution of feed and manure cleaning, computer tracking of the health status of each animal allowed to increase the productivity of cows and the quality of milk in specialised enterprises.

However, for a sharp increase in labour productivity and milk quality, it is necessary to switch to more efficient post-industrial technologies for milk and meat production, in particular to develop robotic farms.

Robotic farms in the standard configuration are equipped with robots – milkers and/or robots-pushers.

Milking robot as a rule, consists of a manipulator for spatial movement of udder teat cleaning systems with brushes and cleaning solution, a device for putting on and taking off milking cups, control and sensor devices, scales for automatic weighing of cows, milk and concentrates, a system for controlling the volume and speed of milk production not only for a single cow, but even for each teat, a system for monitoring milk quality by colour, conductivity, temperature, acidity, etc. The system rejects products of undesirable quality by separating them into a different container and monitors the health of each cow using a sensor attached to the ear or neck of the animal. The computer programme combines these elements into a single robotic milking system with placement in a separate box or even with several boxes. The most popular single-box systems are capable of supporting 50-70 cows.

Most milking robots operate on a voluntary milking system – the cow itself goes to the milking station. The operator only watches the herd.

The main advantage of the milking robot is the reduction of labour costs of farm workers by about 2/3 compared to the "herringbone" system, and each milking robot replaces 2.5 workers [30]. In addition, the milk yield increases up to 15% due to the increase in the number of teats during free-stall milking. Another important advantage is the improvement of milk quality due to the rejection of low-quality milk and compliance with EU standards for bacterial contamination.

Robot pusher is an automatic system for performing the laborious process of turning and hilling the feed when feeding animals, which do not just eat the feed on the feed table, but choose the tastier parts and, as a result, scatter. Therefore, during the day one has to turn and huddle the feed several times. The robot not only pushes the food onto the feed table, but also simultaneously refreshes and mixes it and adds concentrates, which makes the food more attractive. As a result, livestock consume more feed, which contributes to higher productivity [31].

The system can automatically transport various types of feed, including any mono-mixtures, straw, hay, and fresh grass to move independently not only in the cowshed but also between yards. The system eliminates deviations from the route, has an auger, which is completely safe for people and animals. Security sensors are installed around the perimeter of the machine. If there is an obstacle in its way (for example, a cow), the sensor will be triggered and the robot will stop, and then continue to move along a given trajectory.

The first robotic farm in the world was put into operation in 1992 in the Netherlands [32]. Today, there are more than 60 thousand farms with robotic farms in the world [33].

Interest in the introduction of robotic farms in Ukrainian farms is growing rapidly. However, their widespread implementation is hindered by high costs for the purchase and maintenance of equipment. Therefore, it is advisable to make long-term loans for the purchase of equipment more accessible and attract foreign investment. In the near future, the industrial production of plant-based meat and dairy products (vegetable milk, vegetable meat), and cultivated (artificial) meat looks especially promising for solving the meat and dairy industry crisis.

Plant-based meat. The functional purpose of the development of livestock industries is the production of meat, milk, eggs, etc. to meet the consumer needs of the population. From this point of view, a cow or pig can be considered as a living apparatus for converting crop products into meat. With the development of info-, bio- and nanotechnologies it becomes possible to transform crop production into meat in an industrial way, by creating a sort of robo-cows, robo-pigs and robo-chickens.

The first product, "plant-based chicken", was sold by Beyond Meat, a startup from California, in 2013. There was no chicken as such in it. The product consisted entirely of vegetable components: pea and soy proteins, flour, oils, and seasonings. Already in 2014, Beyond Meat developed a beef imitation product. By 2016, the startup has announced the sale of 25 million plant-based burgers. Today, the startup's products can be bought in more than 53 thousand points in the United States, and since 2018, sales have been launched in Europe. The company claims that it uses 90% less water, 93% less land, 46% less energy and emits 90% less CO^2 compared to companies that grow animal meat [17].

In Ukraine, plant-based meat from the American startup Beyond Meat became available in 2019. It tastes no different from real beef in texture, smell, taste, and colour, although it consists of pea protein, rice, beetroot, water and oil and is 100% vegan. The only ingredient in meat that cannot be synthesised from plants is cholesterol, so it is not found in a vegetable burger. Burger patties are sold in a wholesale package – 42 patties at a price of UAH 90 per piece. For comparison, the average wholesale price of an animal cutlet is UAH 13-15. Such a high price is explained by the fact that large investments were made in the experimental development of plant-based meat [17]. With the establishment of industrial production of plant-based meat, the price will fall to the level of animal meat prices.

Cultivated (artificial) meat. In 2021, meat grown in vitro appeared on the shelves of US stores. This goal was set by the San Francisco-based food tech startup Memphis Meats [34]. Along with Californians, several other laboratories in different parts of the world are developing technologies for the production of lab-grown meat. In particular, Aleph Farms, Beyond Meat, Mosa Meat, MorningStar Farms, Tyson Foods, etc.

Food tech startups have taken the achievements of fabric engineering as a basis. Stem cell samples are taken from the animal whose meat is to be obtained.

They are placed in a bioreactor – a tank with "broth", which contains growth factors, vitamins, minerals, and other nutrients. In this environment, oxygen-supplied stem cells actively multiply. The process takes about three weeks. When a critical mass of cells is gained, they merge to form muscle fibers. Thus, lab-grown meat, also known as clean or cultured meat is a product of animal origin. This is natural meat obtained in a non-standard way. It was not part of the carcass of a slaughtered animal, it was literally grown in a laboratory. In early 2016, the Americans showed a meatball made from artificial beef, and in the spring of this year they cultivated chicken and duck meat [34].

Lab-cultured meat is considered safe and potentially even healthier than natural meat. In the process of cultivation, it is possible to regulate the nutritional value of the product – for example, to reduce the content of cholesterol and "harmful" fats and increase the proportion of useful ones. Another advantage of in-vitro meat is its "purity". The product is created in a sterile environment, without the involvement of animals, which means that pesticides and antibiotics, which are widely used in animal husbandry, will not be ingested by humans. It is hoped that the new production method will limit the spread of bacterial resistance to antibiotics.

The development of technologies for the production of plant-based and cultivated meat can forever change the market of the meat industry. After all, it will be possible to produce meat products industrially in cities, similar to the way bread is baked today: from bread factories to bakeries and home baking.

Plant-based milk. Vegetable milk is an extract from seeds, cereals, or nuts. They are soaked, crushed together with water, and then pressed [35]. The result is a drink that looks and even tastes like cow's milk. However, it has other properties. The most popular types of vegetable milk are coconut, soy, almond, oatmeal, and buckwheat [35; 36]. There are also options such as rice, walnuts, cashews, flax, sesame, and other products. It can either be bought in a store or made at home. It requires only the main ingredient, water, and a blender.

Unlike cow's milk, vegetable milk does not contain such substances as:

– cholesterol (contrariwise, helps to remove it from the body)

– Lactose – some people are intolerant to milk sugar (lactose) as they lack the enzyme to digest it.

– casein – is poorly broken down in the stomach and can cause inflammatory processes in the body.

However, plant-based milk is also associated with some disadvantages [37]. Therefore, before choosing to consume this product, it is essential to be conscious of these aspects.

1. Plant-based milk cannot completely replace dairy milk. After all, protein and calcium from traditional milk are absorbed by the body more easily and efficiently.

2. Plant-based drinks are not always dietary. Some varieties have even more calories than traditional milk.

3. To improve the taste and increase the shelf life, sugar, preservatives, stabilisers, and vegetable oil are sometimes added to the drink. Plant-based milk is recommended for the following categories of people:

– vegans and raw foodists who have consciously chosen not to consume animal products;

– fasting people;

– persons for whom milk is contraindicated for medical reasons (lactose intolerance, etc.);

– gourmets who want to diversify their diet with new flavours.

Widespread introduction of new post- and neo-industrial technologies of agro-industrial production will not only increase the volume of agricultural products for the inhabitants of our country in the post-war period, but will also have other equally important effects: creation of conditions for the restoration of the agricultural sector, increasing employment in agriculture, transition of the agricultural sector to the sixth-seventh technological system, formation of a positive image of a modern innovative and developed state, acceleration of the transition to the information society, etc.

▸ Conclusions

In the war and post-war periods, the agro-industrial complex faced the task of not only restoring production capacities, ensuring food security and competitiveness of Ukrainian agricultural products on world markets in such difficult conditions, but also identifying solutions and implementing measures for further innovative development of agro-industrial production. One of such possibilities is the widespread introduction of new post- and neo-industrial technologies of agricultural production.

In vegetable, berry, and mushroom growing – it is a large-scale application of drip irrigation and development of greenhouse farming, including the construction of vertical farms as a part of the reconstruction of bombed residential and commercial infrastructure of cities with the transfer of part of the production infrastructure of indoor crops to suburban and urban areas.

In the production of open ground crops – introduction of elements of precision farming and agricultural robotics. In the production of meat, dairy and other livestock products, in addition to the development of robotic farms, it is advisable to develop the production of plant-based and cultured and artificial milk with the placement of industrial capacities in places of mass consumption, that is, in places of residence of urban residents.

The introduction of post- and neo-industrial technologies of agricultural production will solve the challenge of growing vegetable and meat and dairy production and ensure further innovative development of the agro-industrial complex. The agricultural order of Ukraine will also change significantly, as the production of some agricultural products will be expanded to urban areas.

Given the prospects and significance of industrial production of indoor vegetables, plant-based and cultivated meat and dairy products, it is advisable for scientific institutions of NAAS to develop and implement special scientific and technical research programmes related to this issue to develop effective technologies for their industrial production at enterprises, family farms and households in both rural and urban areas.

The widespread adoption of post- and neo-industrial technologies requires large amounts of investment. Therefore, it is necessary to redirect the allocation of state support funds in favour of the implementation of innovative projects for the introduction of new innovative technologies in the agro-industrial complex, to boost foreign investment for these objectives.

It is also expedient to create a state network of specialised advisory services for free advisory assistance to rural farms and households in the development and implementation of their investment projects on the introduction of post- and neo-industrial technologies for agricultural production.

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Пост- та неоіндустріальні технології в повоєнній розбудові аграрного устрою в Україні

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▶ **Анотація.** Стаття присвячена ідентифікації шляхів інноваційного розвитку аграрного устрою України у воєнний та післявоєнний періоди. Актуальність вирішення цієї фундаментальної науково-практичної проблеми полягає в тому, що аграрний устрій нашої держави в сучасних соціоекономічних умовах потребує впровадження новітніх і принципово відмінних від довоєнних шляхів розвитку, які б найбільш повно використовували сучасні науково-обґрунтовані методи розвитку організаційно-правових суб'єктів господарювання. Метою роботи є висвітлення викликів, які стоять перед сільським господарством України в повоєнній розбудові аграрного устрою та шляхів їх вирішення з використанням пост- та неоіндустріальних технологій. У процесі дослідження використано системно-структурний аналіз і синтез, монографічний, історичний методи, методи абстракції й економічних порівнянь. Теоретико-методологічна основа: концепції, положення, висновки, що розглядаються в наукових працях українських і зарубіжних вчених, теорії інновацій, комунікацій, інформаційних технологій. Розглянуто сутність технологічних устроїв та їх вплив на розвиток економіки в історичному аспекті, а також сучасних моделей індустріалізації та рівня інноваційного розвитку в країнах світу і в Україні. Проаналізовано результати і виклики інноваційного розвитку АПК України за 2000–2020 роки, виокремлено галузі, низькі темпи розвитку яких загрожують продовольчій безпеці країни та подальшому розвитку АПК, зокрема виклики і загрози в результаті розв'язання РФ повномасштабної війни та окупації частини території України. Виявлено та виокремлено сучасні інноваційні пост- та неоіндустріальні технології (зокрема технології крапельного зрошення, виробництва овочів закритого грунту, точного землеробства, виробництва рослинного м'яса тощо), широке впровадження яких в повоєнний період дозволить не тільки відновити довоєнний потенціал АПК, а і забезпечити його подальший конкурентоспроможний розвиток. Отримані висновки та результати можуть бути використані в практичній діяльності: підприємств, сільських і міських домогосподарств – виробників сільськогосподарської продукції та продуктів харчування щодо широкого впровадження технологій крапельного зрошення, тепличного господарства, точного землеробства та робототехніки, нетваринного виробництва м'ясо-молочної продукції з високою ефективністю; спеціалізованих наукових установ та стартапів щодо розгортання широких досліджень в напрямі створення нових інноваційних пост- та неоіндустріальних технологій виробництва продукції сільського господарства та продуктів харчування; органів державної виконавчої влади щодо стимулювання широкого запровадження цих технологій для забезпечення повоєнного відновлення і подальшого конкурентоспроможного інноваційного розвитку АПК

▶ **Ключові слова:** АПК, повоєнний розвиток, інноваційні технології, ефективність, аграрна політика