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# Use of the Low-Potential Heat for Heating Helium in Rocket-Carrier Tank Pressurisation Systems

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**Abstract**. The energy efficiency of new technical developments is a critical issue. It should be noted that today the focus in this issue has seen a major shift to the maximum use of renewable energy sources. The purpose of this research is to reduce the weight of helium heat exchangers of the fuel tank pressurisation systems in modern rocket propulsion systems that use fuel components like liquid oxygen and kerosene-type fuel. This is the first time that the question has been raised about the possibility and advisability of increasing the temperature of helium at the heat exchanger inlet without the use of additional resources. The paper addresses the use of the waste ("low-potential") heat and "industrial wastes" present in propulsion systems. Basic laws of complex heat exchange and the retrospective review of applicable heat exchanger structures are applied as a research methodology. Two sources of low-potential heat are identified that have been previously used in the rocket engine building in an inconsistent and piecemeal manner to obtain and heat the pressurisation working fluid. These are the rammed-air pressurisation during the motion of the rocket carrier in the atmosphere, and the tank pressurisation as a result of boiling of the top layer of oxidiser which is on the saturation line. This is the first time that the advisability has been substantiated of increasing the temperature of the working fluid at the heat exchanger inlet, first of all due to the use of the low-potential heat. This is also the first time that unemployed sources of low-potential heat and "industrial wastes" are found in modern deep throttling propulsion systems. These are the high-boiling-point fuel in the tank, behind the high-pressure pump, at the exit of the combustion chamber cooling duct, and also the fuel tank structures, and the engine plume. A possibility is proved, and an advisability demonstrated of their implementation to increase the efficiency of pressurisation system heat exchangers. This is the first time that the methodology of combustion chamber cooling analysis has been proposed to be adopted for the heating of heat exchanger by the engine plume. This is the first time that a classification of waste heat sources has been developed which can be used to increase the pressurisation working fluid temperature. The identified reserves help to increase the efficiency of the helium heat exchangers of the tank pressurisation systems in the propulsion systems

**Keywords**: rocket engines, high-boiling-point fuel, heat exchanger inlet temperature, sources, low-potential heat



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## INTRODUCTION

Heat exchangers have been long and widely used in the technological processes in the mining, oil refining, automotive, aeronautical, petrochemical, chemical, nuclear, aerospace industries, in the agricultural sector, energy industry, public services. Suffice it to list their special names – steam generators, furnaces, cooling towers, water heater, evaporators, condensers, etc. As we can see, field of their application is very large. The rocket engine building is not an exclusion. The world's first ballistic rocket, the V-2, already had a heat exchanger for heating the pressurisation working fluid prior to feeding to the liquid oxygen tank.

In the context of the world economy globalisation, intensive fighting against climate change, greenhouse gas emission, the energy efficiency of new technical developments is a critical issue. It should be noted that today the focus in this issue has seen a major shift to the maximum use of renewable energy sources [1]. Therefore the urgency of the research aimed to reduce the energy consumption, expand the use of low-potential heat of the environment, is not in doubt.

Present-day rocket propulsion systems are widely using the liquid oxygen (LOX) and kerosene-type fuel (RP-1). Suffice it to list well known RC such as Zenith, Antares, Atlas-V, Falcon-9, Electron, Alfa, Angara, Cyclon-4M, Soyuz-5. The tank pressurisation systems with these components use hot helium as a pressurisation work fluid. Main reason why these systems are widely used, is that their design is simple. However, modern helium pneumatic systems are second most expensive parts of RC after liquid-propellant rocket engine (LPRE) [2]. That is why, it makes sense to foremost explore ways to improve the most expensive parts of rocket complex with most common fuel components.

Let us focus on the heat exchanger in the most common configuration of the hot helium system of oxygen tank pressurisation (Fig. 1). This will be useful for us in further researches.

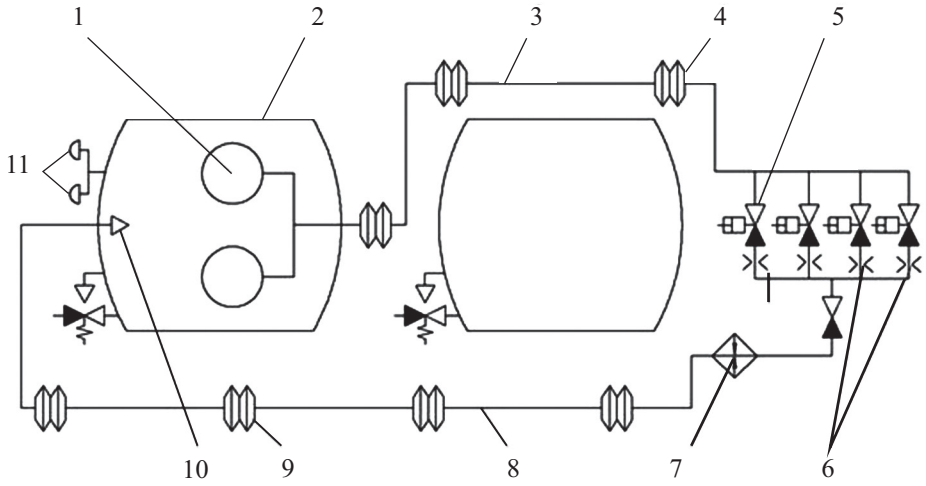


***Figure 1**. Schematic of hot gas bottle system of the oxidiser tank pressurisation:*

*1 – helium bottles; 2 – liquid oxygen tank; 3, 8 – pipelines; 4, 9 – temperature compensators; 5 – elements of automatic control; 6 – orifices; 7 – heat exchanger ; 10 – tank pressurisation gas supply device; 11 – tank gas pressure switch unit*

As we can see in the schematic above, the system contains helium high-pressure bottles 1 that are installed in LOX tank 2. This is a common configuration. By imparting cryogenic temperature to helium, the configuration allows to reduce almost two times the number of helium bottles. The bottles are connected through pipelines 3 with temperature compensators 4 by means of automatic control elements 5 to flow-metering orifices 6 and heat exchanger 7 of the engine that is placed in the tail compartment. The heat exchanger uses the coolant from the engine turbine, in this case, the oxidising generator gas. Hot helium is then fed, loosing the temperature, by pipeline 8 with temperature compensators 9 to the upper part of oxidiser tank 2. The gas passes into the free tank volume through a special gas supply device 10.

The rocket engine building may appear to be far from the use of renewable source of energy. However, under conditions of increased competition in the market of launch services [3], it is a time to deal with these possible sources. The purpose of the research is to:

– reduce the weight of heat exchangers of the fuel tank pressurisation systems in modern rocket propulsion systems in the ways that are unconventional for this technology;

– reduce the use of hydrocarbon fuel combustion products as a coolant in heat exchangers.

This is the first time that the issue has been addressed of finding and substantiating reasonable ways to employ the waste low-potential heat and the "industrial wastes" that are present in the rocket carrier (RC),

foremost for increasing the heat exchanger inlet temperature of helium.

The objectives of the research are to:

– identify drawbacks of applicable heat exchangers of the fuel tank pressurisation systems in modern rocket propulsion systems on the basis of critical retrospective review of their structures, configurations of modern rocket engines, and achievements of heat engineering;

– audit possible unemployed heat energy sources on board of RC that designers have previously missed;

– substantiate most promised and technologically simple ways to use low potential heat for the improvement of heat exchanger characteristics, using the example of rocket propulsion systems;

– classify the sources of low potential heat and "industrial wastes" identified on board of and near to RC.

## FEATURES OF ROCKET ENGINE HEAT EXCHANGERS

Rocket engine heat exchangers have a number of specific features that distinguish them significantly from their counterparts from other branches of technology. These features arise from peculiarities of their operation. The operation time of rocket heat exchangers is very short, just 120÷600 s. They are expendable, as a rule. The are manufactured 2-3 times a year, very rarely, 4-5 times. Liquid oxygen kerosene engines use oxidative or reductive generator gas from the turbine as a coolant. Such oxidative gas has a temperature of 620÷640 K, a pressure of 26÷28 MPa. The reductive generator gas from the turbine has a temperature of 820÷950 K, pressure is 1÷28 MPa, depending on the configuration of the engine.

Modern rocket engines are deeply and often throttled during the flight. This is a demand of time. During the throttling, the coolant consumption and temperature goes down significantly (for the configuration with afterburning of oxidative gas). A pronounced transient mode of operation of the heat exchanger is implemented. It should be understood that almost all officially accepted most accurate heat exchanger design methods are established for steady heat exchange conditions.

The first heat exchangers in the engines were of shell-and-tube type. They functioned with a low pressure of the coolant. A notable example is the heat exchanger [4] of the RD-107 engine of the Soyuz-2 rocket carrier stage 1 (Fig. 2).

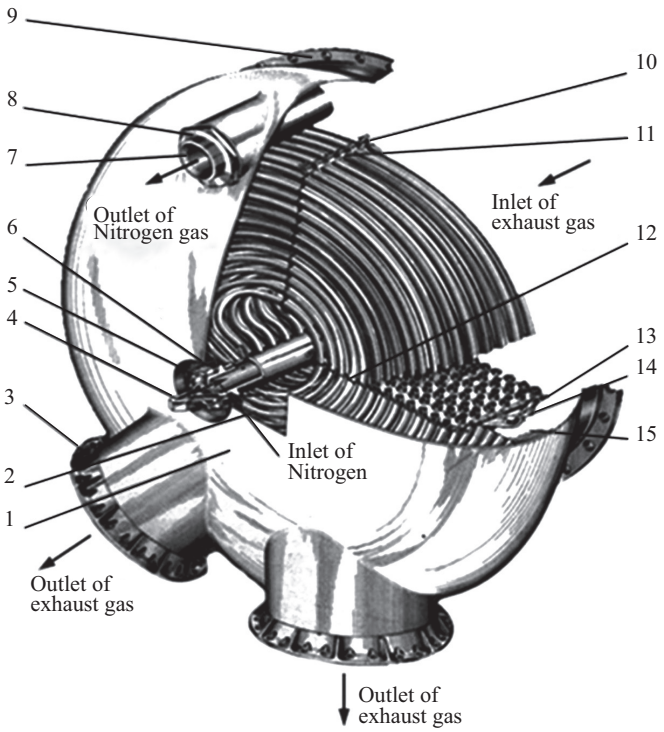


***Figure 2**. Section view of the RD-107 shell-and-tube heat exchanger:*
*1 – casing; 2 – coil manifold; 3, 9 – flanges of exhaust gas outlet and Nitrogen gas outlet respectively; 4 – liquid nitrogen inlet connection; 5, 8 – nuts; 6 – paronite gasket; 7 – Nitrogen gas outlet connection; 10 – wire; 11 – plate; 12 – locking wire; 13 – clip; 14 – screw; 15 – bracket*

The transition of engines to the configuration with afterburning of oxidative generator gas (high pressure) contributed to appearance of the contemporary cylinder heat exchanger. It was successfully used in the propulsion systems of two stages of all Zenith rocket carrier modifications, in four units of the first stage of the Energia rocket carrier. The coolant duct in the heat exchanger alternate with the duct of helium. The heat exchange surfaces of the helium duct walls are formed by the ribbing with direct channels. The finning in the generator

gas ducts helped to intensify the heat exchange process by implementing the vortex flow.

A modern plate-fin heat exchanger [4] is used in the RD-191 deep-throttling engine (the Angara rocket carrier) (Fig. 3). This is the first heat exchanger that uses oxidative generator gas from the gas generator as a coolant. The reason for that is to give meaning to the helium pressurisation system under deep throttling conditions of the propulsion system. In this case the whole range of problems relating to the combustion of materials in the high-pressure oxidative gas environment extend to the heat exchanger. The need of such decisions is far from clear-cut.

It is important to emphasise that this is the use limit of the engine generator gas heat. This is the hottest gas on-board the rocket carrier. It is also important to reflect the problems arising in the course of optimisation of this heat exchanger. There is nowhere except in the rocket engine that such a unique coolant with fast varying parameters can be obtained. Since the optimisation of the heat exchanger is carried out without the engine, as a matter of course, the optimisation is very rough. We have to include large spreads in its basic parameters.

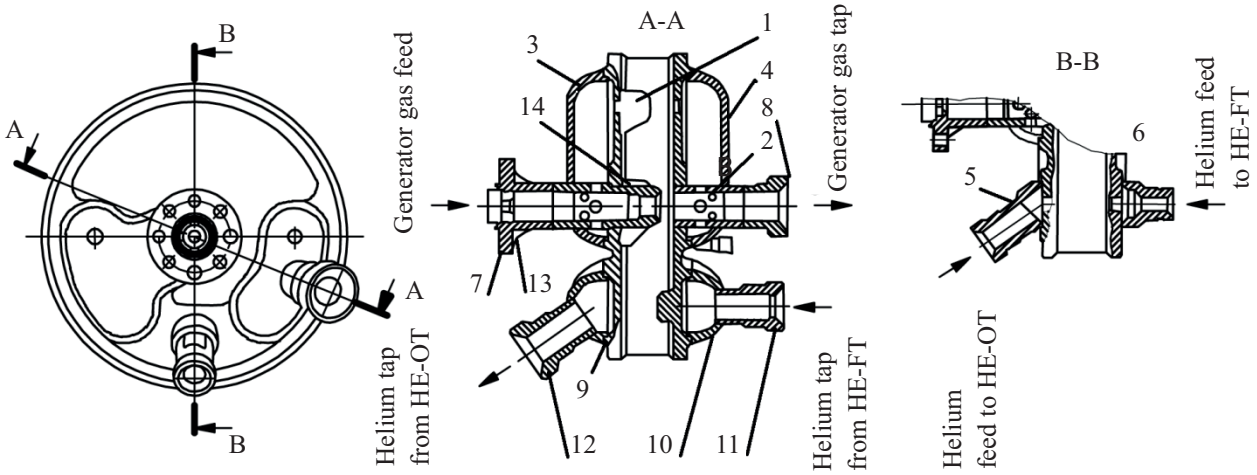


***Figure 3***. *The RD-191 plate-fine heat exchanger (first stage of the Angara rocket carrier): 1 – wall brazed package; 2 – central bushing; 3 – generator gas feeding manifold; 4 – generator gas tapping manifold; 5, 6 – helium feed; 7 – generator gas feeding flange; 8 – generator gas tapping connection; 9, 10 – helium tapping manifolds; 11, 12 – HELIUM tapping connections; 13 – washer; 14 – bypass hole*

It is important to emphasise that the final purpose of the tank pressurisation system of which the heat exchanger is a structural part, is not to form a record heat exchanger but provide required pressure in the ullage with less resources and with the required reliability. The gas pressure in the ullage depends on a number of factors. The temperature of helium at the tank inlet is just one of multiple affecting factors, more precisely, the temperature of the working fluid at the ullage inlet and not at the heat exchanger exhaust. Figure 4 illustrates these significantly varying temperatures.

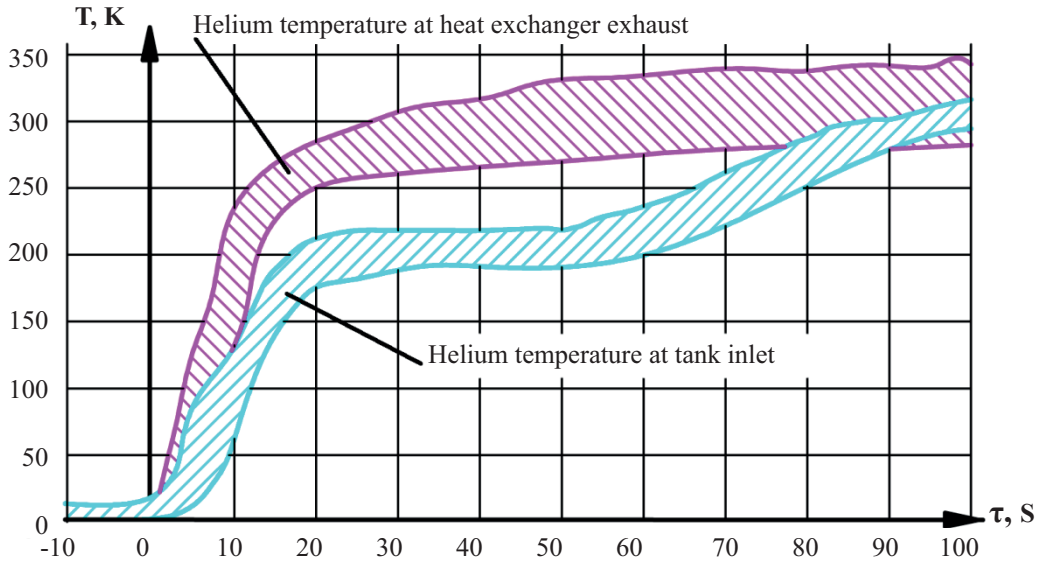


***Figure 4***. *Helium temperature at the heat exchanger exhaust and the oxidiser tank inlet (full-scale data)*

As an example, in the first stage of the medium class rocket carrier, the length of hot pressurisation lines (40x1 mm from stainless steel) from the heat exchanger to the tank inlet makes up about 40m. At approx.50$^{th}$ second of the flight, the difference between helium temperature at the heat exchanger exhaust and at the tank inlet makes up approx.100K (more than 20%). Actual contribution of means and time spent on improvement of the heat exchanger, to the pressurisation system parameters can only be assessed if taken together with other factors by applying complex method of mathematical modelling of innertank processes.

It is surprising that such enormous reserves, that effectively lie on the surface, remain out of sight of the researchers. They are not addressed in the technical literature. This situation is probably due to the fact that the heat exchanger is developed by engine designers following the Requirement specification, but the required gas pressure in the tank is a responsibility of another team of specialists. A tight schedule for the development of any new rocket complex prevents from finding the integrated solution of the problem, but the next new complex will be developed in the country in 20÷30 years at best, by other specialists. The situation repeats itself.

Because of existing breakdown of responsibilities, it would be meaningful to solve the problem within the framework of the Requirement specification for the development of the heat exchanger. The specification dictates the limit on the weight and space of the heat exchanger, the temperature of helium at the heat exchanger exhaust (with the spreads) with prescribed helium consumption, the helium pressure losses in the heat exchanger duct with prescribed consumption and temperature, minimum temperature of helium at the heat exchanger inlet. Therefore, we concretise the task of the research – to develop the recommendations for the design of the helium heat exchanger of the RC pressurisation systems, to substantiate the ways that could reduce the weight of heat exchangers and make their development significantly easier.

## THE TRADITIONAL WAYS TO IMPROVE THE EFFICIENCY OF HEAT EXCHANGERS

Let's try to analyse the assigned problem by the following areas of activity. The first area of activity represents the works aimed at the intensification of the heat exchange in the heat exchanger by means of various turbulators. The second area of activity represents the researches working to increase the efficiency of heat exchangers by means of circuit solutions.

The latest paper [5] addresses the architectures of recuperative heat exchangers of rocket propulsion systems. They are used in the fuel tank pressurisation systems of US rocket carriers. It is shown that the heat exchange efficiency in a pathway with inter-channel coolant transpiration through the porous mesh metal is higher than when compared to other heat exchange pathways. It has been established that the pathway efficiency is particularly high at low Reynolds numbers in the range of $1{\cdot}10^3 \div 5{\cdot}10^4$ the efficiency increases when the path of the coolant movement through the porous mesh metal decreases, and the porous mesh metal thermal conductivity increases. A conclusion is made that it makes sense to increase the heat exchange efficiency by developing the heat exchange surface rather than the by increasing the coolant movement speed.

In a number of works by A.A. Khalatov, e.g., [6], the efficiency of the dimpled surface of heat exchange is proved, which allows the turbulisation of the laminar sublayer of the flow boundary layer. It is the laminar sublayer that determines the rate of heat flow taken from the surface. Recommendations are developed for the distribution and geometry of the dimples. The parameters, at which the heat transfer grows faster than the pressure loss along the pathway, are shown.

For industrial shell-and-tube heat exchangers, the paper [7] addresses the effect of baffles on the increase in heat transfer efficiency. It is shown that the increase of the path of the coolant movement with simultaneous flow turbulisation gives a positive effect. However, this goes along with increasing the dimensions of the device, the pressure loss along the length of duct. As is known, the dimensionless heat-transfer coefficient *Nu* ($Nu_{sm}$ for a smooth wall) is proportional to the *Re* number to the power of 0.8, and the aerodynamic drag $\Delta p$ to a power close to:

$$Nu_{sm} = 0.021 \cdot Re^{0.8} \cdot Pr^{0.8} \quad (1)$$

$$\Delta p = \xi \cdot \frac{Re^2 \cdot \mu}{2 \cdot d^3 \cdot \rho} \cdot l \quad (2)$$

where $Pr$ – Prandtl number; $\xi$ – coefficient of friction; $\mu$, $\rho$ – coefficient of dynamic viscosity and coolant density respectively; $l$, $d$ – length and diameter of the duct respectively.

The paper [8] also addresses the efficiency improvement of industrial water-heating shell-and-tube heat exchangers. The problem is solved by means of coarse surface finishing (artificial roughness) and riffling. It is recommended to make ribbing on the outer surface. These solutions also lead to increasing pressure losses along the ducts of the coolant and the working fluid. It is known that the thermal hydraulic efficiency of ducts with artificial roughness:

$$E = \frac{Nu}{Nu_{sm} \cdot \left(\frac{\xi}{\xi_{sm}}\right)^{\frac{1}{3}}} \quad (3)$$

barely reaches 1, and only at small values of *Re* numbers tends to 1.2.

The paper [9] addresses, by means of mathematical modelling, the effects of the helical baffle size and tilt angle on the flow swirl and two ways of interrupting the

flow swirl in shell-and-tube heat exchangers. Recommendations for considered conditions are given.

The paper [10] brings light on the effects of circular fins in shell-and-tube heat exchangers on the increase in heat-transfer coefficients. It is shown that, under considered conditions, circular fins can lead to an improvement of the heat exchanger efficiency by ~ 8%.

A special case is the patent [11], which shows the way to significantly improving the efficiency of the helium propellant heat exchanger. This technology does not complicate the design of the latter, but greatly simplifies its experimental development. The exhaust products of the most common solid-fuel gas generators are proposed to be used as a heat carrier, e.g., based on sodium azide (used in automobile airbags). The use of a high temperature of the coolant helps to obtain a final high temperature of helium and minimise helium pressure losses in the heat exchanger ducts. At the same time, it is not linked to the engine, and it is logical to locate it in the intertank compartment of the rocket carrier. This significantly reduces the length of the pressurisation ducts, and, consequently, their total resistance. This solution allows the helium bottles to be more completely emptied.

A retrospective analysis of the studies on the improvement of the efficiency of the heat exchangers shows that almost all known studies are aimed at enhancing the heat transfer in the heat exchanger. The effect of various boundary layer turbulators such as dimples, artificial roughness, circular fins, helical baffles, porous mesh metal is discussed.

Surprisingly, the authors were not able to find any scientific paper on the possibility of increasing the working fluid temperature at the inlet of pressurisation system heat exchangers, though the results of such works could contribute to the reduction of the required heating value of the working fluid:

$$\Delta Q = mc_p \Delta T \quad (4)$$

where $\Delta T = T_{out} - T_{in}$; $m$ – weight of pressurisation working fluid fed through the heat exchanger, $c_p$ – average working fluid heat capacity at temperatures within the range of $T_{in}$ to $T_{out}$.

And this, giving other conditions being equal, will help to reduce the weight of the heat exchanger and the required consumption of the coolant. Moreover, the issues of searching and further using the low-potential heat have never been addressed in a targeted manner during the design of rocket heat exchangers.

It is also important to note that the transport of thermal energy, which is produced with such difficulty in the heat exchanger, to the consumer with minimal losses also remains beyond the attention of researchers. As Figure 4 shows, the helium temperature losses on the way from the heat exchanger to the oxidiser tank inlet of the medium-class RC. They make up at least 20%. So is it reasonable to spend resources, complicate the development and design of the heat exchanger in order to increase the heat exchange by 7%?

This gives grounds to affirm that the research, the first devoted to the ways of increasing the temperature of the working fluid at the rocket heat exchanger inlet, is useful. This will help to reduce the temperature difference by which the helium shall be heated. This solution, giving other conditions being equal, shall help to reduce the weight of the heat exchanger, what is extremely important for the rocket carrier. For example, a 10 kg weight reduction of heat exchanger at stage I of the Zenith rocket carrier makes it possible to increase the weight of the satellite by ~ 2.5 kg. The orbital insertion of 1 kg of the satellite costs the Customer today at least $20,000.

## SEARCH FOR ATTEMPTS TO USE HEAT WITHOUT BURNING FUEL

If you look closely, from the modern perspective at the generally accepted classification of heat sources [1], the following interesting facts can be stated. For the first time, waste heat (the authors will conventionally call it low potential in the future) was used in rocket technology already on the first V-2 rocket. In the pressurisation system of the fuel tank (it was the upper one on the stage) in the atmospheric phase of the flight, a high-speed air pressure was used. At supersonic flight speed, the deceleration temperature of the air entering the tank was significantly higher than fuel temperature and tank structure. In this case, the required gas pressure in the tank was provided reasonably enough. It can be assumed that outboard rammed air performs the functions of a heat exchanger here.

It is necessary to note one more peculiar pressurisation system, in which the low potential heat of the oxidiser is used unambiguously. We are talking about the so-called "self-pressurisation" boiling of the upper layer of fuel in the tank, due to which the required gas pressure in it was maintained. In the second phase of the flight of the American intercontinental ballistic missiles Atlas-D, Titan-I, Titan-II, this maximally simple pressurisation system was implemented. It does not require any additional elements. The heat for boiling the upper layer of oxidiser was not supplied from the outside, but was taken from the oxidiser itself. The oxidiser itself can be considered a heat exchanger. This is the standard of design simplicity and reliability. Unfortunately, this system was not used due to the complexity of measuring the level with discrete float-type systems in a boiling bed. At present, this problem has been solved by the Dnieper school of pressurisation systems.

In the mid-seventies, when designing the Zenith and Energia rocket carriers, the students of the Dnieper scientific school carried out work to abandon the "generally accepted" hot helium system for pressurising the fuel tanks of the listed rocket carriers. The newly patented

so-called "supercold" pressurisation was introduced. In the new system, helium from cylinders immersed in liquid oxygen is introduced into the fuel tank by the shortest way through the intertank bay. Its temperature at the tank inlet is in the range of 90÷60 K. As a result, the pressurisation system became ~ 30% lighter, the volume of experimental development decreased significantly, and its complexity and cost, due to the absence of a heat exchanger, also decreased significantly.

In this system, helium, with the help of a special input device, takes heat from the upper layers of the fuel, the weight of which is tens of tons, and from the tank structure, the weight of which is measured in tons. According to modern views, this can be considered the use of low potential heat. Except for the first seconds of operation of the pressurisation system, when the fuel level is at the outlet section of the input devices, the heat exchange of the pressurisation gas with the boundary surfaces proceeds according to the laws of natural convection, which is not particularly effective. The authors are not aware of any works aimed at heat transfer enhancement for these conditions. It is reasonable to carry them out.

By now, the supercold pressurisation system has been implemented in addition to Zenith rocket carrier, Energia rocket carrier, Atlas-III rocket carrier, and Atlas-V rocket carrier. An improved supercold system is used at stage I of the Antares rocket carrier [12], and is considered in the draft designs of Mayak, Cyclone-1M, and Cyclone-4M rocket carriers.

In work [13], it was proposed for the first time to use such a powerful heat source as a rocket engine plume for heating helium. It can be safely attributed to the typical "industrial wastes". Schematically, this is achieved by placing a simplified heat exchanger (some channels with helium) behind the bottom protection. In this case, a purely evaluative mathematical modelling of helium heating was carried out. As the total heat flux to the channels, the known value of the heat flux at the bottom protection for the F-1 engine of the Saturn-V rocket carrier first stage was used. This value is equal to 272 kJ / ($m^2$sec) [14]. It was obtained during ground tests of the engine. Apparently, this is the minimum value of the heat flux from the main engine plume. The fact is that the F-1 engine is the only one of its kind, in which the plume is shielded by reducing generator gas with soot, which is discharged tangentially at the turbine outlet into the engine nozzle (Fig. 5).

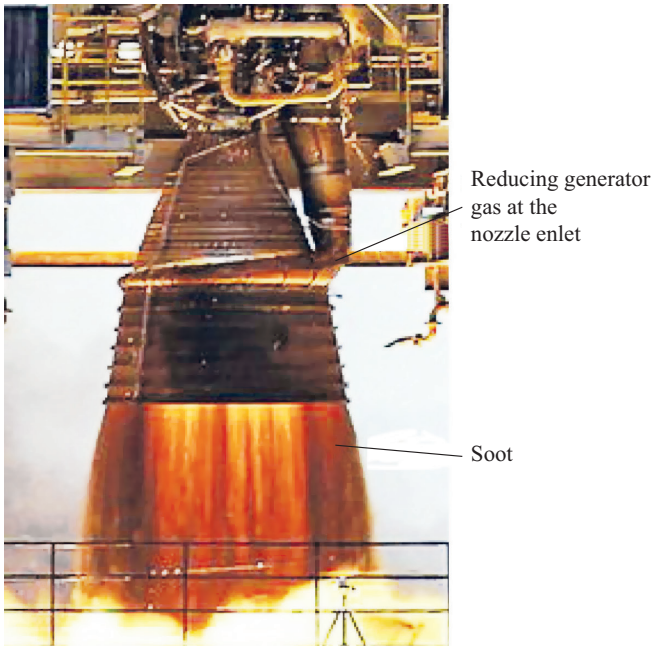


***Figure 5***. *Stage I of Saturn-V rocket carrier*

***Source***: *[15]*

The results of calculations on the dependences made by M. Mikheev [16] for complex heat transfer showed the following. Placing a heat exchanger made of chromium-nickel steels behind the bottom protection will bring it into a plastic condition already by 10÷12 s of engine operation, i.e. unserviceability. It is concluded that there is an excess heat flow behind the bottom shield and the need to take measures to reduce the specified heat flow. Modern shielding materials (marbled glass), which reduce heat fluxes, have been proposed.

In authors' opinion, more accurate modelling can be carried out with the following approach to the problem. One can notice an analogy in the physical processes occurring in the combustion chamber of a rocket engine and behind the bottom shield. In both cases, radiant heat fluxes and convective movement of combustion products act on the cooled walls. This makes it possible to take advantage of a well-developed methodology for calculating the cooling of the engine combustion chamber. It will be necessary to additionally take into account the

decreasing density of the medium with respect to the flight time behind the bottom shield and some uneven heat supply to the channels with helium.

Thus, the previously expressed emotional judgment that rocket engine technology is far from using low potential heat is untenable. The pioneers of rocket engine technology, not spoiled by their narrow specialisation and stereotypes, used widely the waste heat and industrial wastes. At the same time, small masterpieces were created in rocket propulsion systems.

As shown above, implemented methods of using waste low potential heat are known for fuel tank pressurisation. Let's try to find a solution to the problem in relation to a tank with liquid oxygen. The situation is more complicated here, because helium in cylinders and liquid oxygen in a tank have approximately the same temperature. And it is problematic to use a heat pump in flight conditions in such a situation.

Let's pay attention to the "cold" pressurisation line 3 (Fig. 1), which runs along the fuel tank (its nominal temperature is 258 K) from its outer side and enters the "warm" engine compartment. Figure 6 shows the change in helium temperature at RD-171 LPRE heat exchanger inlet over the time of its operation. As you can see from the diagram, helium temperature changes in a very interesting way. At the time the pressurisation system starts operation, the temperature is equal to 270 K, after fifteen seconds it gradually drops to 110 K, then steadily increases and by the end of the start it reaches 160 K. Thus, the authors are convinced that, without applying any special efforts, without spending additional energy, helium from cylinders with a temperature of 90÷60 K before entering the heat exchanger can heat up "spontaneously" by ~ 100 K. Such temperature change should induce active action.

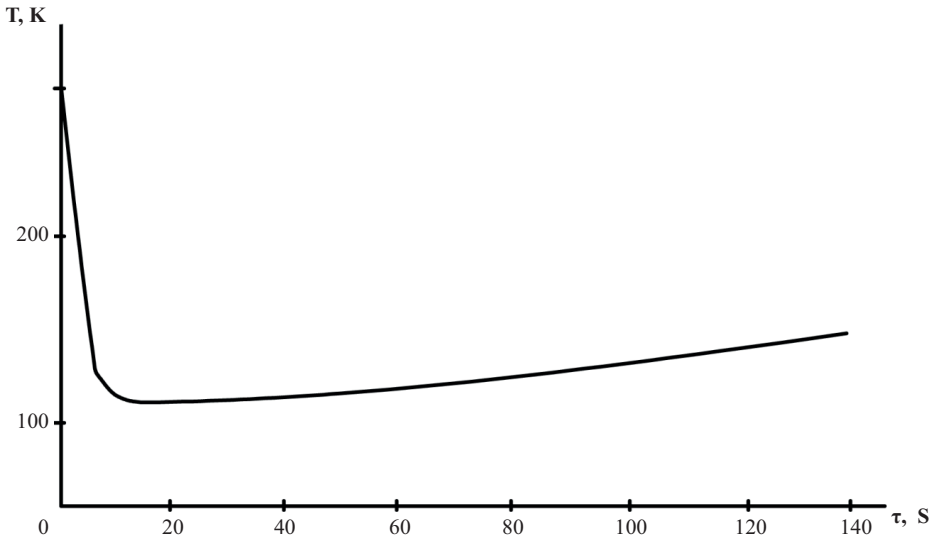


***Figure 6**. Helium temperature at heat exchanger inlet according to the operation time of the pressurisation system*

Naturally, a question arises: What if you make a purposeful effort? Let's try to find a solution and answer this question.

If the "cold" pressurisation line passed through the fuel, then it would take much more heat from it (different heat capacities) than from the ambient air, the density of which sharply decreases as the rocket carrier is flying. There is no doubt about it. Therefore, the authors will consider the following option for obtaining low potential heat, the "cold" pressurisation line 3 (Fig. 1) is laid inside the fuel tank [17]. Mathematical modelling of helium heating in the pipeline is carried out using dependencies (1) and (2). With regard to RD-171 fuel tank, helium will be heated for at least 130K. The helium temperature can be further increased by turbulisation of the fuel flow on the outer wall of the pipeline (artificial roughness, dimples). In this case, the length of the pressurisation line (resistance) does not change. It should be noted that, depending on the needs, it is possible to heat helium almost to the temperature of the fuel in the tank, additionally making several turns of the line in the region of its lower bottom.

Further, the low potential heat of the fuel can also be supplied to the helium at the pump outlet, in which it heats up by 6÷12 K in any case and has a higher speed than the lowering of the fuel level in the tank.

Another drawback of the old classical helium heating model is realised with throttling of the liquid propellant rocket engine. As already noted, in this case, the flow rate and temperature of the oxidising generator gas drop sharply. Turbine exhaust temperature also decreases. The heating of helium in the heat exchanger is reduced. To maintain the required gas pressure in the tank with colder helium, it is necessary to increase its flow rate and reserves on rocket carrier board. This, in turn, significantly reduces the mass properties of rocket carriers.

Can this phenomenon be countered? Consider the following design model. The cooling component of fuel (kerosene) from the nozzle head of combustion

chamber (the hottest cooling component) is used as a heat carrier. LPRE throttling in this case does not lead to such a sharp negative effect for the following reasons. So, when throttling, the ratio of the fuel components in the combustion chamber (temperature) practically does not change. Only the pressure in it decreases, and with it the heat flux into the wall of the combustion chamber decreases slightly. That is, the temperature of the proposed heat carrier will be more stable at different engine power ratings. It should also be noted that the heat capacity of kerosene is 2.9 times higher than that of the oxidising generator gas. All other things being equal, it can transfer more heat to helium. This is a vivid illustration of the use of industrial wastes in rocket engine technology.

Thus, the proposed simple model solutions significantly increase helium temperature at the heat exchanger inlet and stabilise the temperature of the heat carrier. Therefore, the design of the heat exchanger can ultimately be more compact. At the same time, the experimental development of it and pressurisation system is significantly simplified both for the nominal power rating and for the deep throttling.

For the fuel components: liquid oxygen and RP-1, the results obtained can be presented as follows (Fig. 7).

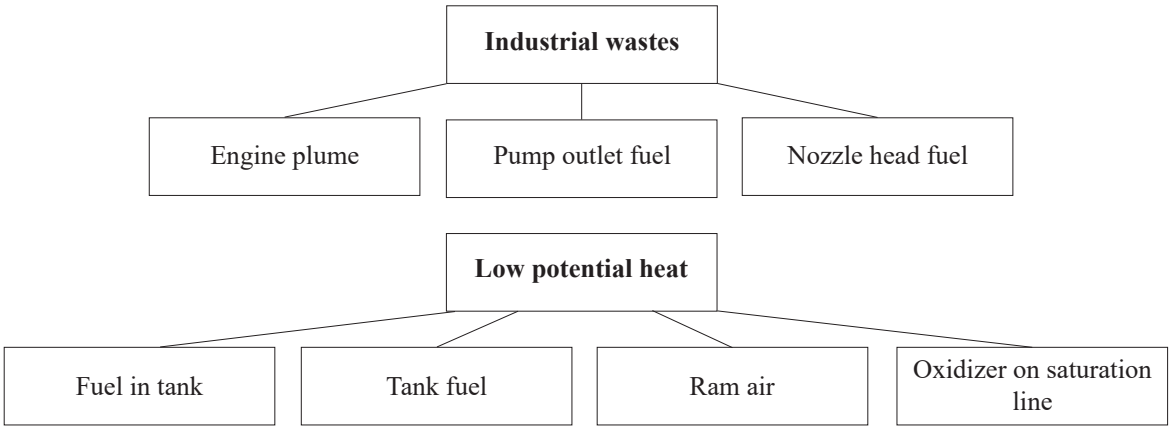


***Figure 7**. For the fuel components: liquid oxygen and RP-1, the results obtained can be presented as follows*

## CONCLUSIONS

The conducted studies made it possible to substantiate a new direction for increasing the efficiency of helium heat exchangers for pressurising the fuel tanks of the propulsion systems of launch vehicles. It consists in attracting low-potential heat and "industrial waste" available in the LV. The basic laws of complex heat transfer and a retrospective analysis of the designs of the applied heat exchangers of the working fluid for pressurising fuel tanks are used.

The main results of these researches are as follows. Turbine exhaust gas was used as a heat carrier in all known engine heat exchangers. Only one design is known in which an oxidising generator gas is used, which is bled immediately at the gas generator outlet. This is the thermal limit for the use of oxidising generator gas. As the authors assume, this experience is unlikely to be followed due to the complexity of its implementation, especially during experimental testing.

The increase in the efficiency of engine heat exchangers proceeded mainly by the traditional way of improving the cooling paths, their designs (coplanar channels, interchannel transpiration, plate-finned structures, hole relief in the paths). No works aimed at investigating the possibilities of increasing the inlet temperature of the pressurised working fluid to heat exchangers have been found. Also, no works were noticed on the efficient transportation of thermal energy from the heat exchanger located in the engine compartment to the upper points of the fuel tanks.

A search has been made for attempts to use low potential heat in fuel tank pressurisation systems. It was found that such attempts were mainly at the dawn of the development of rocket technology. This is the pressurisation of the tanks by ram air in the atmospheric phase (V-2, R-14), the maintenance of the required gas pressure in the tanks due to the boiling of the upper layer of oxidiser (oxygen, nitrogen tetroxide) located on the saturation line (Atlas-D, Titan- 1, Titan-II). These attempts were of a fragmentary, unsystematic nature, and did not develop further.

In modern developments (rocket carriers: Zenith, Energia, Antares, Atlas-V), the low potential heat is partially used in the so-called supercold pressurisation of helium tanks with a hydrocarbon fuel such as kerosene. Helium of cryogenic temperature is injected in a special way into the free volume of the fuel tank, the weight of which is measured in tens of tons, removes heat from it and from the tank structure, the weight of which is measured in tons, and creates the required pressure. In this case, the temperature of the gas in the tank, with

a competent input, by the time of engine shutdown, practically reaches the temperature of the fuel. This method of pressurisation is adopted in the preliminary designs of rocket carriers: Mayak, Cyclone-4M, Cyclone-1M.

From the standpoint of the achievements of thermal engineering, a search was carried out for previously unused low potential heat and industrial wastes in the propulsion systems of modern rocket carriers. Previously unused sources of low potential heat and industrial wastes were found and substantiated to improve the efficiency of heat exchangers for pressurisation systems of rocket carrier fuel tanks. They are the following: fuel in the tank, warmer fuel at the pump outlet, fuel from the nozzle head of the engine, engine plume. Realisation of the found possibilities of using waste heat makes it possible to significantly increase the efficiency of heat exchangers for pressurising tanks of propulsion systems, to reduce their weight and dimensions.

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# Використання низькопотенційного тепла для нагріву гелію систем наддування баків ракет-носіїв

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**Анотація**. В даний час максимально гостро постає питання енергоефективності будь-яких нових технічних розробок. Особливо слід зазначити, що сьогодні акцент у цій проблемі істотно змістився у бік максимального використання відновлюваних джерел енергії. Метою досліджень є зниження маси гелієвих теплообмінників систем наддування паливних баків сучасних рухових установок ракет-носіїв, що використовують компоненти палива рідкий кисень і пальне типу гас. Вперше поставлено питання про можливість і доцільність підвищення температури гелію на вході в теплообмінник, насамперед, без використання додаткових ресурсів. Розглянуто залучення непрямого («низькопотенційного») тепла і «промислових стоків», що є у складі рухових установок. В якості методики досліджень використані основні закономірності складного теплообміну і ретроспективний аналіз конструкцій теплообмінників, що застосовуються. Виявлено два джерела «низькопотенційного» тепла, які раніше безсистемно і фрагментарно використовувалися в ракетному двигунобудуванні для отримання і нагрівання робочого тіла наддуву. Це наддув баків швидкісним натиском повітря під час руху ракети-носія в атмосфері, створення тиску в баку за рахунок кипіння в ньому верхнього шару окислювача, що знаходиться на лінії насичення. У даній статті вперше обґрунтовано доцільність підвищення температури робочого тіла на вході в теплообмінники, і в першу чергу, за рахунок використання низькопотенційного тепла. Вперше знайдені джерела низькопотенційного тепла, що раніше не використовуються, і «промислових стоків» у складі сучасних рухових установок глибокого дроселювання. Це висококипляче пальне: у баку, за насосом високого тиску, на виході з тракту охолодження камери згоряння. Також це конструкції паливних баків, факел двигуна. Доведено можливість та показано раціональність їх реалізації для підвищення ефективності теплообмінників систем наддуву. Вперше запропоновано запозичити методологію розрахунку охолодження камери згоряння двигуна для нагрівання теплообмінника факелом. Вперше розроблено класифікацію непридатних джерел тепла, придатних підвищення температури робочого тіла наддува. Розкриті резерви дають змогу підняти ефективність гелієвих теплообмінників систем наддуву баків рухових установок

**Ключові слова**: ракетні двигуни, висококипляче пальне, температура на вході в теплообмінники, джерела, низькопотенційне тепло

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# Fauna and Ecology of Dipterous (Díptera, Muscidae) Livestock Biocenoses of Ukraine

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**Abstract**. The biology and ecology of parasitic insects are closely related to the life of people, and the leading role belongs to animal husbandry. It is difficult to overestimate the negative influence of parasitic dipterans on productive animals, especially during the season of their mass reproduction and distribution. The work aimed to study the species composition of Diptera in different livestock biocenoses in eastern and central Ukraine. Entomological nets and traps were used to capture zoophilic flies, the number of insects was determined using the fly index, and luminescent markers TAT 33 with a powder fraction of 30 microns. The collected insects were identified according to the existing modern identifiers. As a result of the studies, the presence of *Musca domestica* (Linnaeus, 1758) was determined in all livestock facilities for keeping animals and birds. The largest number of house flies was noted in the facilities for keeping sows with suckling pigs (312.0±35.3) and fattening animals (277.5±6.1). *M. domestica, M. autumnalis*, and *S. calcitrans* accounted for 75.57% of the entire complex of zoophilic flies. The species *M. vitripennis, M. tempestiva, L. irritans, H. atripalpis* also occupied an important place among the species that form the entomoparasitocenosis (18.91%). In pasture biotopes, two species of flies (*Ortellia caesarion* Meigen and *Ortellia cornicina* Fabr.) have been identified. They do not attack animals, but are mineralisers of cattle feces. Luminiferous marker L-1 basic green (TAT 33) fixes well on insects and lasts for 5 days. The density of the fly population in the pig houses is 36% higher than in the calf houses. The results obtained are the basis for the development of innovative, scientifically grounded schemes for control and the fight against parasitic insects at livestock enterprises

**Keywords**: zoophilic flies, species composition, *Musca domestica*, population size, agrobiocenosis, luminophore, marking



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## INTRODUCTION

Today, there are approximately 1.5 million, 5.5 million, and 7 million species of beetles, insects, and terrestrial arthropods in the world, respectively [1]. Among a large number of insects, some are herbivores and provide invaluable benefits to the ecosystem [2]. Some insects feed on organic substrates or are predators of other species [3; 4]. Insects, which lead a parasitic lifestyle, are of the greatest sanitary-epidemiological and epizootic importance [5].

True flies (Muscidae), one of the large families of the suborder Diptera (*Brachycera*), are distributed throughout the world, and about 5000 species from 100 genera have been described in the world fauna [6; 7]. The population of flies is characterised by their diversity, wide geographic and spatial distribution [8]. Flies can lay eggs on several types of substrates, which in turn allows them to colonise many regions [9]. There is competition between different species of flies in nature, which manifests itself in behavioral characteristics during feeding and reproduction [10].

On the territory of livestock biocenoses of the forest-steppe and steppe zones of Ukraine, 27 species of zoophilic flies have been identified, among which species of the Muscidae family dominate (74.1%). At the same time, the largest number of parasitic Diptera species was recorded in livestock buildings for keeping cattle, and a minimum of species was recorded in buildings for keeping poultry [4]. Due to significant climate changes, it is necessary to control the dominant species of zoophilous flies by studying their biology and ecology in the field on the territory of Ukraine.

Under the conditions of Colombia, the most abundant species are *B. normata* (24.31%), *Biopyrellia bipuncta* (20.60%) and *Pseudoptilolepis nigripoda* (15.82%), with the latter two species preferring uninhabited territories [11]. In Brazil, Colombia and Costa Rica, eight genera of Muscidae were collected, including 28 species: *Cyrtoneurina* (2 species), *Cyrtoneuropsis* (8 species), *Dolichophaonia* (1 species), *Neomuscina* (7 species), *Ophyra* (1 species), *Phaonia* (2 species), *Philornis* (5 species), and *Polietina* (2 species) [12]. To date, 153 species of blowflies (*Diptera, Sarcophagidae*) have been recorded in Turkey [13]. 3314 Stomoxyini flies belonging to the genera *Stomoxys, Haematobosca, Haematostoma* and *Haematobia* were collected from zoos, livestock farms, wildlife sanctuaries and the national park of Thailand, and eight species were identified: *S. calcitrans* (46.6%), *S. uruma* (26.8%), *S. pulla* (4.3%), *S. indicus* (0.7%), *S. sitiens* (0.1%), *H. sanguinolenta* (11.2%), *H. austeni* (0.5%) and *H. irritans exigua* (9.8%). At the same time, the diversity of Stomoxyini flies on livestock farms is higher than on other objects of study [14]. The wide distribution of flies of various species is established at an altitude of over 1200 meters above sea level [15].

*Stomoxyini* flies (Diptera: Muscidae) include parasitic fly species of medical and veterinary importance. Adult flies feed on mammalian blood and can transmit some parasites and pathogens. Adult *H. irritans* are constantly found in cattle in winter, and their numbers increase from late July to late August [16]. Seasonal fly activity shows one large peak in late summer and a second, smaller peak just before the end of the flying season [17]. The number of flies in a particular object also depends on the presence of their biological enemies: the genus Spalangia [18], *Hydrotea aenescens* [19].

Individual species of flies exhibit different behavior when parasitising on animals. It was found that *Haematobosca stimulans* (Mg.) And *Stomoxys calcitrans* (L.) feed from the back, side and legs of the animal. The fly *Haematobia irritans* (L.), as a rule, parasitises on the back, legs and udder nipples of animals, and *Musca autumnalis* Deg. was found mainly on the head of animals. The species *Hydrotaea irritans* (Fall.) has noticeable daily fluctuations in activity and was found on the head, abdomen, and udder nipples of animals [20]. From *Stomoxy*s spp. on cattle farms, *Stomoxys calcitrans* (91.5%), *Stomoxys indicus* (7.9%) and *Stomoxys sitiens* (0.6%) are the most widespread. Seasonal and daily activity of *S. calcitrans* was observed during a 1-year period, and the peak of daily flight activity in males fell on 10 a.m. and 4 p.m., while in females the activity increased throughout the day – up to 4 p.m. [21]. Other data indicate that the peak of daily activity of *Stomoxys spp*. was between 2 p.m. and 4 p.m. [22].

House flies play an important role in the mechanical transmission of various pathogens [23]. More than 130 pathogens, mainly bacteria (including some life-threatening species), have been identified from house flies. Antimicrobial resistant bacteria and fungi isolated from house flies have also been reported [24]. Thus, a study of 160 flies revealed on their surfaces the presence of *E. coli* (73.8%), and in their digestive tract – *P. aeruginosa* (100%). The most commonly isolated bacteria from flies are *P. aeruginosa, Salmonella* serogroup D, *S. dysenteriae*, *E. coli, C. freundii, S. aureus*, and *S. epidermidis* [25]. The fly *Hydrotaea irritans* (Fall.) is a vector of summer mastitis in cows [20]. Gene sequence analysis revealed that the most common classes of bacteria found in house flies on farms included Bacilli, Clostridia, Actinobacteria, Flavobacteria, and Proteobacteria, as well as Corynebacterium, Lactobacillus, Staphylococcus, Vagococcus, Weissella, Lactococcus, and Aerococcus [26]. At the same time, microorganisms isolated from flies exhibit increased resistance to antimicrobial drugs [27; 28]. *Musca domestica* L. plays a leading role in the transmission of exogenous forms of ascaridates and esophagostomas, and *Musca autumnalis De Gree* may be a source of environmental pollution with trichostrongylates [19]. In the conditions of the canine center, the fly *Musca domestica* L. is a source of pollution of livestock objects with exogenous forms of helminths *T. canis* and *T. vulpis*. The species *Muscina stabulans* F. and *Stomoxys calcitrans* L. can be the source of the distribution of *A. caninum* larvae and *T. vulpis* eggs, respectively [29].

A multidimensional approach that controls all life stages of the housefly while simultaneously preserving natural enemies of the flies can be an environmentally sustainable way to keep fly populations below maximum allowable limits [30; 31]. Despite the study of this issue, some species of flies are being redescribed today [32], new species are being discovered [33].

Due to the relevance of the problem of parasitic insects to agricultural science, the work was aimed to study the species composition of dipterans (Díptera, Muscidae) of different livestock ecosystems in the Eastern and Central Ukraine.

## MATERIALS AND METHODS

The capture of zoophilic flies was carried out in May-October in livestock facilities, pastures and summer camps for keeping animals. For this purpose, entomological nets and traps were used [34]. Field studies were carried out following current methods [35]. The number of flies was determined using the fly index (FI) (counting the number of flies per 10 animals and determining the average) [36].

To assess the insect population size, we used TAT 33 fluorescent markers with a powder fraction of 30 microns: basic green (L-1), basic violet (L-2), basic blue (L-3) (manufactured by Noxton Technologies, Ukraine). Labeled insects were indicated in a dark room using an OLD-1 illuminator for fluorescent diagnostics. Light compositions were applied by dry powder pollination [37]. The calculation of the average headcount indicators and confidence intervals was calculated by the method of R. Dajo (1975). The essence of this method is that part of the individuals is caught from the population, marked and then released into the same population, and after a day, part of the individuals is caught again and the population density is determined:

$$N = \frac{a \times b}{c} \quad (1)$$

where $a$ –marked and released flies; $b$ – recaptured flies in a day; $c$ – including marked flies; $N$ – absolute number of flies.

Under laboratory conditions, the collected insect larvae were cultivated in a thermostat at a temperature of 20-25°C in glass containers with a volume of 1000 $cm^3$. As a medium for larvae growing, bran moistened with water in a ratio of 3:1 and cattle feces were used. Insect puparia were kept on wet sand [38].

The adult flies were cultivated in the boxes of the insectarium, where the preset microclimate was automatically maintained: temperature 25-27ºC, relative humidity 55-65%, light period 16 hours. Adults of *Musca domestica* received glucose, whole milk, and water. A multicomponent nutrient medium consisting of milk powder, glucose, and stabilised bovine blood was used to feed the gray oviparous cowshed *Musca autumnalis*, and fresh cattle feces served as a medium for oviposition and development of larvae [39]. To feed the stable fly *Stomoxys calcitrans*, cattle blood stabilised with citric acid glucose solution was placed in the cages. For the development of larvae, we used a multicomponent medium consisting of alfalfa flour, wheat bran, dry yeast, cholesterol, dextrose, and nystatin [40]. To feed the glittering dung flies *Ortellia caesarion* Meigen, a mixture of milk powder with glucose in a ratio of 1:3, fresh milk, and water were used. Fresh cattle feces were placed daily for egg laying and larval development [41]. The flies were kept in cages measuring 25×25×25 cm.

The collected insects were identified according to the existing determinants [22; 42-44]. Collections of Diptera insects are kept in the collection of the National Scientific Center "Institute of Experimental and Clinical Veterinary Medicine" of the National Academy of Agrarian Sciences of Ukraine.

## RESULTS AND DISCUSSION

As a result of studying the diversity of the species composition of zoophilic flies in livestock biotopes in eight regions of Ukraine (Fig. 1), the presence of 27 mass species of zoophilic flies in livestock facilities for cattle, pigs, sheep and poultry was established.

It was found that the greatest diversity of dipterans, 25 species, was noted in livestock biocenoses for keeping and grazing of cattle, in farms for keeping and raising pigs 7 species of flies were noted, in livestock facilities for keeping small ruminants – 5 species, and in poultry premises – 4 species of flies. The species diversity of Diptera in livestock biocenoses for keeping and grazing of cattle is maintained due to the peculiarities of the biology (feeding and reproduction) of zoophilous flies. At the same time, *Musca domestica* (Linnaeus, 1758) was recorded in all livestock facilities for keeping animals and in poultry houses. The poultry houses had the smallest number of fly species. This is because flies do not attack birds, but they pose a problem in egg collection and grading facilities.

The species composition and the number of dipterans (Díptera, Muscidae) in different biotopes of livestock agroecosystems in the eastern and central Ukraine have been studied (Table 1).

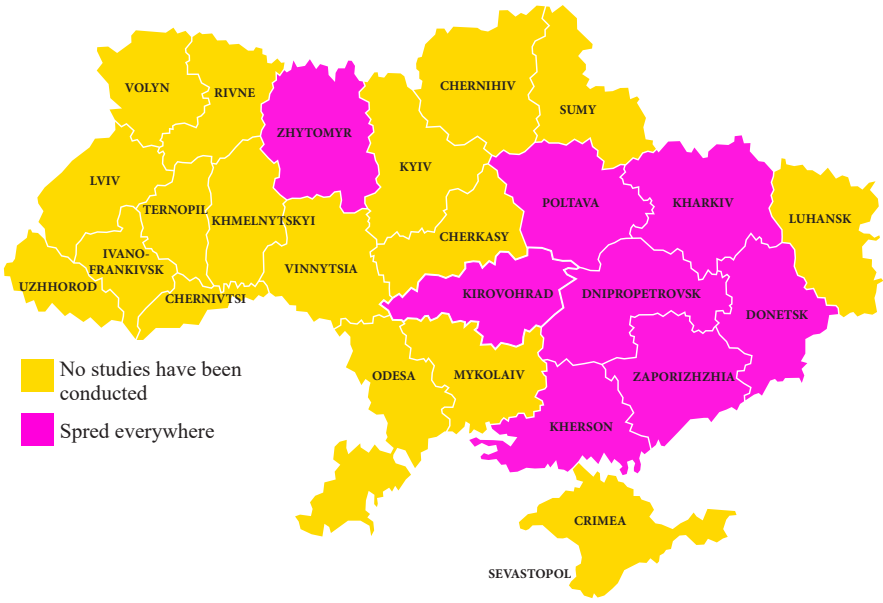


***Figure 1***. *Distribution of parasitic dipterous in different regions of Ukraine*

***Table 1***. *Species composition and the number of the main zoophilic flies in the biotopes of livestock agrobio-cenoses*

| Species of flies | Number of captured flies | Pasture | Summer camps | Premises | % from total number |
|---|---|---|---|---|---|
| *Musca domestica* (Linnaeus, 1758) | 3250 | 21 | 1604 | 1625 | 32.25 |
| *Musca autumnalis* (De Geer, 1776) | 1629 | 653 | 965 | 11 | 16.17 |
| *Musca larvipara* (Porchinskiy, 1910) | 232 | 137 | 93 | 2 | 2.30 |
| *Musca vitripennis* (Meigen, 1826) | 627 | 467 | 160 | 3 | 6.25 |
| *Musca tempestiva* (Fallén, 1817) | 582 | 317 | 263 | 2 | 5.78 |
| *Morellia simplex* (Loew, 1857) | 112 | 36 | 76 | – | 1.11 |
| *Morellia hortorum* (Fallén, 1817) | 95 | 40 | 54 | 1 | 0.94 |
| *Stomoxys calcitrans* (Linnaeus, 1758) | 2736 | 58 | 1857 | 821 | 27.15 |
| *Haematobia irritans* (Linnaeus, 1758) | 324 | 86 | 217 | 21 | 3.22 |
| *Haematobosca stimulans* (Meigen, 1824) | 121 | 94 | 19 | 8 | 1.20 |
| *Haematobosca atripalpis* (Bezzi, 1895) | 369 | 123 | 243 | 3 | 3.66 |

As you can see from the data in Table 1 livestock agrobiocenoses are represented by 11 species of zoophilic flies, of which the housefly *M. domestica* makes up 32.25% and it occupies the main biotopes – summer camps and livestock facilities. The gray oviparous cowshed *Musca autumnalis* makes up 16.17% and lives mainly in pastures and summer camps. Stable fly *S. calcitrans* – 27.15%, lives mainly in livestock facilities and summer camps. These three species account for 75.57% of the total complex of zoophilous flies. Of the remaining 9 species, *M. vitripennis, M. tempestiva, L. irritans*, and *H. atripalpis* should be noted, which also occupy an important place among the species that form entomoparasitocenoses (18.91%). The population of the remaining 4 species is small (5.55%) and does not play a significant role in the entomoparasitocenosis.

When studying pasture biotopes, we noted two species of flies that do not attack animals, but are utilisers of cattle feces – *Ortellia caesarion* Meigen (glittering dung fly) and *Ortellia cornicina* Fabr. (green dung fly). These two species *O. caesarion* and *O. cornicina* can compete for the habitat with the parasitic *M. autumnalis*. The larvae of zoophilic flies *M. larvipara, M. vitripennis, M. tempestiva, M. simplex, M. hortorum* develop in the feces of cattle, adult females attack animals in the area of the eyes, nostrils, and also feed on exudate from wounds and abrasions. The males of these species of flies feed on vegetation and do not attack animals. Zoophilic flies of the species *L. irritans, H. stimulans, H. atripalpis*, as well as the stable fly, feed on blood, both females and males. According to our observations, the adults of *H. stimulans* lead a trapping lifestyle.

The biology of the preimaginal stages of *O. caesarion* and *O. cornicina* is the same as in *M. autumnalis*, but the biology of the adults is different. Thus, *M. autumnalis* is an ectoparasite of cattle, while *O.caesarion* and *O. cornicina* do not attack animals. In the summer period (July), green dung fly and glittering dung fly can occupy the dominant among the complex of fly larvae that inhabit cattle feces. So, we found that the mass of excrement ranged from 10219 to 33542 g per 1000 m² (on average – 21880.5 per 1000 m²) of the pasture area. The main mass species of Diptera larvae inhabiting these biotopes were: *M. autumnalis, O. caesarion* – up to 85%, *M. hortorum* – 5%, *M. larvipara* – 3%, the remaining 7% were occupied by *Scatophaga stercoraria* (Robineau-Desvoidy, 1930) and other types.

A different number of the dominant species *M. domestica* was noted in premises for various economic purposes (Table 2).

***Table 2**. Population of the housefly M. domestica in livestock premises*

| Animals kept in different premises | Number of premises | Number of animals | Number of flies per one animal |
|---|---|---|---|
| ***Pigs*** | | | |
| Single and gestating sows | 5 | 469 | 145.0±19.7 |
| Sows with suckling piglets | 5 | 435 | 312.0±35.3 |
| Young animals 2-4 months of age | 5 | 2138 | 53.3±8.7 |
| Animals for fattening | 5 | 4732 | 277.5±6.1 |
| Boars | 5 | 27 | 351.8±11.2 |
| Total | 25 | 7801 | Average 227.9±39.5 |
| ***Cattle*** | | | |
| Calves | 5 | 534 | 258.3±83.4 |
| Cows | 5 | 858 | 36.9±8.3 |
| Total | 10 | 1392 | Average 147.6±45.9 |

As can be seen from Table 2, the largest number of house flies 312.0±35.3 and 277.5±6.1 was observed in the premises for keeping sows with suckling piglets and fattening animals, respectively. In cattle, a high number (258.3±83.4) was noted in the premises for keeping calves. Since the parasitism of house flies occurs in warm livestock buildings, their reproduction lasts all year round and can reach up to 10 generations, which can explain its high number. In order to study the density and migration of flies, the technique of marking insect individuals with recapture and determination of the proportion of marked insects was used. First, in laboratory conditions, the duration of luminophore fixation on the body of insects was determined (Table 3).

***Table 3**. Duration of luminophore fixation on the body of flies*

| Luminophore | The number of flies in the experiment | Glow color | Duration in days | | | | | Death of flies on day 5 |
|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | |
| ***Immersion marking*** | | | | | | | | |
| L-1 | 50 | Green | + | + | + | + | + | 1 |
| L-2 | 50 | Purple | + | + | + | ± | ± | – |
| L-3 | 50 | Blue | + | + | + | ± | ± | 1 |
| Control | 50 | – | – | – | – | – | – | – |
| ***Pollination marking*** | | | | | | | | |
| L-1 | 50 | Green | + | + | + | + | + | – |
| L-2 | 50 | Purple | + | + | + | ± | ± | 1 |
| L-3 | 50 | Blue | + | + | + | ± | ± | – |
| Control | 50 | – | – | – | – | – | – | – |

***Note***: *"–" – no glow; "+" – intense glow; "±" – weak glow*

It was found that both marking methods ensure reliable fixation of phosphors on the body of flies. The L-1 marker was clearly visible for five days. In flies treated with L-2 and L-3, on the 4th day, the luminescence gradually faded away, and on the 5th day it was almost not noticeable. Pollination marking turned out to be easier and more convenient, so it was later used on farms. To determine the density of insects in a production environment, 3 livestock facilities for keeping calves and sows with piglets were taken (Table 4).

***Table 4**. The absolute number of flies in livestock facilities by marking and recapturing*

| Animal groups | Square, $m^2$ | Flies caught and released | Flies caught after marking in 24 hours | | Absolute number | | Average density per $m^2$ |
|---|---|---|---|---|---|---|---|
| | | | Total | Marked | Average | At 95% confidence interval | |
| Pigs for fattening | 1000 | 3000 | 3000 | 24 | 375.0±91.3 | 266.6–631.9 | 375.5±91.3 |
| Sows with suckling piglets | 1000 | 5000 | 2500 | 38 | 328.9±59.1 | 248.8–485.1 | 328.9±59.1 |
| Sows with suckling piglets | 1000 | 3000 | 1000 | 19 | 157.9±45.2 | 108.6–289.4 | 157.9±45.2 |
| Calves | 550 | 2000 | 2000 | 43 | 93.0±14.9 | 73.5±133.2 | 93.0±14.9 |
| Calves | 550 | 3000 | 3000 | 72 | 125.0±15.3 | 101.4–162.9 | 227.3±27.8 |
| Calves | 550 | 1000 | 1000 | 46 | 43.5±6.9 | 33.7–61.3 | 79.1±12.5 |

As you can see from the Table 4, the highest density of the fly population was in the premises for keeping pigs and amounted to 328.9-375.5 individuals per 1 $m^2$, while in the calf houses this indicator was 227.3 individuals per 1 $m^2$.

The authors suggest that the method of marking and recapturing is quite accurate, but it also has a number of technical difficulties. This determination requires more than two days of time, you must have special equipment. Therefore, for those cases when the high accuracy of determining the number of flies is not of fundamental importance and where a large number of determinations are required (many premises of farms), a more accessible and quicker express method for determining the number of flies is needed.

In this regard, the authors drew attention to the possibility of determining the relative number of flies in the premises where animals are kept using the fly index. The time spent on determining the FI in one room does not exceed 30 minutes.

For catching flies, the authors used special traps, the use of which was recommended by a number of other researchers [14; 22]. It has also been found that traps are effective means of reducing the number of flies on cows during the grazing season [45].

Based on the results of our research, it was found that the housefly in livestock agrobiocenoses is the most adapted species and it perfectly adapted to the conditions of livestock facilities. The number of *M. domestica* is relatively high throughout the year, although fluctuations have been noted in winter. The housefly fly index does not fall below 30 individuals per animal (December, January). The authors believe that this is due to the fact that in livestock buildings, even with the observance of all sanitary standards for removing manure, there are still hidden breeding places. In the stall, the number of cows, air humidity and lighting conditions are the most likely factors to influence their distribution [17].

Despite the fact that the greatest problem for poultry farms is the parasitisation of mites [46], we also determined the presence of 5 species of Diptera in production facilities (*Musca domestica, Muscina stabulans, Fannia scalaris, Fannia canicularis, Drosophila funebris*). It is believed that poultry farms are highly associated with high density of flies and high infectious diseases in this area [47].

The breeding places of the stable fly (*S. calcitrans*) were practically not found in livestock facilities. However, some individuals of this species were found in December and January in animals and the FI was 1-3 individuals. Since this species prefers manure mixed with vegetation and food residues for laying eggs, it can be assumed that some individuals on animals in winter are individuals of the autumn generation.

Due to a decrease in the number of grazed animals on pastures and a high density of house flies in summer camps and in livestock facilities, which has become a competitor in the development of larval stages to the field fly (*M. autumnalis*), at present (2019-2020) this species has decreased. The fly index (FI) in summer camps was 3-5 individuals, and in the premises 2-4 individuals on animals. Dung flies *Scatophaga stercoraria* have recently become the standard test organism for evaluating the toxic effects of veterinary drugs in livestock manure [41].

Tracking the movement of insects in their natural habitat is an important link in understanding their basic biology, demography and ethology [48]. To study the ecology of flies, they are tagged with special markers [49; 50]. Using this research method, it was found that after 5 days, on average, 60% of the tagged flies released into

the poultry houses remained there, and 13% moved to dairy farms, and about 70% of the tagged flies released to dairy farms remained there after 5 days, while 10% moved to poultry houses [51]. In our studies, we also used luminiferous dyes of different colors, while the basic green dye (TAT 33) was more effective when treating flies for 5 days, compared to violet and blue dyes. Luminescences can be used in entomological studies to differentiate larval blowflies (or other dipterans) species or individuals [52].

As climate change progresses, the control program for parasitic dipterans must adapt [53]. A better understanding of the behavior of parasitic dipterans will help improve the effectiveness of fly control in the private and public sectors.

## CONCLUSIONS

The prospect for further research is the development of innovative, environmentally friendly means to control and combat parasitic dipterans in animal husbandry.

*Musca domestica* (Linnaeus, 1758) was found in all livestock facilities for keeping animals and in poultry houses in eight regions of Ukraine. In pasture biotopes, two species of flies have been identified that do not attack animals, but are mineralisers of cattle feces – *Ortellia caesarion* Meigen (glittering dung fly) and *Ortellia cornicina* Fabr. (green dung fly). The largest number of house flies was noted in the premises for keeping sows with suckling pigs (312.0±35.3) and fattening animals (277.5±6.1). In cattle, the largest number of flies (258.3±83.4) was recorded in the premises for keeping calves. *M. domestica, M. autumnalis*, and *S. calcitrans* account for 75.57% of the entire complex of zoophilic flies. The species *M. vitripennis, M. tempestiva, L. irritans, H. atripalpis* also occupy an important place among the species that form the entomoparasitocenosis (18.91%).

Luminiferous marker L-1 basic green (TAT 33) fixes well on insects and lasts for 5 days. The density of the fly population in the pig houses is 36% higher than in the calf houses. During the research, the species composition of zoophilic flies and their distribution over biotopes in different livestock agroecosystems have been studied.

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# Фауна і екологія двокрилих (Díptera, Muscidae) тваринницьких біоценозів України

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**Анотація**. Біологія та екологія паразитуючих комах тісно пов'язана з життєдіяльністю людей, і основне місце при цьому займає тваринництво. Негативний вплив паразитуючих двокрилих на продуктивних тварин важко переоцінити, особливо у сезон їх масового розмноження та поширення. Метою роботи було вивчити видовий склад двокрилих різних тваринницьких біоценозів східної та центральної України. Для вилову зоофільних мух використовували ентомологічні сачки та пастки, чисельність комах визначали за допомогою мушиного індексу, а також використовували люмінесцентні маркери ТАТ 33 з фракцією порошку 30 мікрон. Зібраних комах ідентифікували відповідно до існуючих сучасних визначників. В результаті проведених досліджень встановлено наявність *Musca domestica* (Linnaeus, 1758) у всіх тваринницьких приміщеннях з утриманням тварин та птиці. Найбільша чисельність кімнатної мухи відзначена у приміщеннях з утриманням свиноматок з підсосними поросятами (312,0±35,3) та тварин на відгодівлі (277,5±6,1). На частку *M. domestica*, *M. autumnalis* та *S. calcitrans* припадає 75,57 % від усього комплексу зоофільних мух. Види *M. vitripennis*, *M. tempestiva*, *L. irritans*, *H. atripalpis* також займають значне місце серед видів, що формують ентомопаразитоценоз (18,91 %). У пасовищних біотопах виявлено два види мух (*Ortellia caesarion* Meigen та *Ortellia cornicina* Fabr.), які не нападають на тварин, але є мінералізаторами фекалій великої рогатої худоби. Люміноформний маркер Л-1 базовий зелений (ТАТ 33) добре фіксується на комах та утримується протягом 5 днів. Щільність популяції мух у приміщеннях з утримання свиней вище на 36 % порівняно з приміщеннями, де утримуються телята. Отримані результати є підставою для розробки інноваційних, науково-обґрунтованих схем контролю та боротьби з паразитуючими комахами на тваринницьких підприємствах

**Ключові слова**: зоофільні мухи, видовий склад, *Musca domestica*, чисельність популяції, агробіоценоз, люмінофор, маркування

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# Ecomorphic Structure Transformation of Soil Macrofauna Amid Recreational Impact

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**Abstract**. The level of reacreation load on the components of urban green areas is increasing, so identifying the effective management tools in these ecosystems is becoming crucial for ensuring the maintenance of soil biota habitats. The purpose of this study is to reveal a pattern of structuring community of soil macrofauna under a recreational impact based on an ecomorphic approach. The article assesses the level of recreational transformation of the soil macrofauna of public green spaces in the city of Melitopol on the territory of Novooleksandrivskyi Park. For research purposes, a testing site was allocated in an area with a high level of recreational load, with samples taken within this site. To collect soil macrofauna and assess soil properties at each point of the testing site, soil and zoological tests were carried out and the following soil indicators were measured: temperature, electrical conductivity, humidity and soil penetration resistance, litter depth and grass stand height. The community ordination was performed using two approaches: OMI and RLQ analysis. The study found that the ecological niches of soil macrofauna in recreational conditions are spatially structured. The main factors for structuring the ecological niche of soil macrofauna within the study area are soil penetration resistance in the range of the entire measured layer, soil moisture, and distance to trees. As for the number of species, the basis of the coenomorphic structure of soil macrofauna are silvants (45.5%) and pratants (24.2%). As for the species abundance, the basis of the coenomorphic structure of macrofauna comprises pratants (64.5%), slightly less stepants (19.1%) and silvants (16.1%), and sporadic occurrence of paludants (0.2%). Such coenomorphic structure can be considered as ecologically labile. Zoophages, hemiaerophobes, and megatrophs are tolerant to a high level of recreational load. The area corresponding to the highest level of recreational load is vacant. This indicates factual absence of soil macrofauna species that could exist amid intense recreational exposure

**Keywords**: ecomorphes, soil, ecological niche, soil invertebrates, recreational pressure



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## INTRODUCTION

Public green spaces constitute a key component of urban ecosystems and provide important ecosystem services [1; 2]. Urban parkland provides the following ecosystem services: environmental regulation, resource supply, increased biological diversity, and aesthetic improvement [3-5]. The transformation of forest cover and the replacement of natural vegetation with buildings, roads, exotic vegetation, and other urban infrastructure is one of the greatest threats to global biodiversity [6; 7]. Biota in parks supports biodiversity, accumulates carbon, and improves microclimatic conditions [8; 9]. A vegetation cover and soil organisms in parklands provide the carbon sequestration, accumulating it as biomass [10]. As more and more land is allocated for urban development, identification of effective wildlife management tools in urban forests is becoming crucial for ensuring normal habitats for animal populations [11].

The forest parklands are subject to a complex impact, the sources of which are both anthropogenic pressure inherent in the urban environment in general, which is manifested in elevated air temperature, high concentrations of carbon dioxide, nitrogen compounds, and ozone in the atmosphere [12], as well as recreational load associated with visiting parks by the population for recreation [13]. Urban forests and parks, in addition to their recreational and aesthetic functions, provide carbon binding and oxygen production [14]. Another essential and rather elusive function of urban green spaces is to ensure biotic diversity. This is because considerable recreational pressure combined with the adverse impact of various anthropogenic factors negatively affects the possibility of forming habitats necessary to maintain biodiversity at a high level [15]. In this aspect, soil invertebrates are of particular importance. Since the protective ability of the soil allows preserving the conditions for the existence of groups of soil fauna, the latter consequently has a high level of abundance and diversity [16]. Notably, soil fauna is a vital component that performs many functions inherent in woodlands in an urban environment. In particular, soil animals are essential participants in the process of humification. It is the humification that is the basis of the mechanism of carbon binding to the state of persistent organic compounds that form a pool of organic matter in the soil [17]. In turn, the processes of mineralisation, which are activated by soil animals, create conditions for providing plants with nutrients, which is a factor of soil fertility [18]. As a result, soil animals regulate the intensity of primary production, which determines the performance of ecosystem services by public green spaces. Soil animals are a factor of pedogenesis, and therefore they affect the intensity of decomposition of toxic substances, deposition, and immobilisation of heavy metals and radionuclides within the urban environment [19]. In addition, the involvement of animals in the pedogenesis determines the hydrological properties of the soil, which affects the water regime of soils and the intensity of erosion [20; 21].

The diversity of soil macrofauna functions can be represented and quantified using an ecomorphic approach. Many scientists consider ecomorphes as basic components of the structural organisation of ecosystems [22-26]. The affiliation of an animal species with a particular ecomorph indicates a certain aspect of its adaptation to environmental conditions. O.L. Belgard identified trophotope, climatope, and hygrotope as the main limiting factors. Therefore, ecomorphes are divided into climamorphes (limiting factor – climatic conditions); heliomorphes (limiting factor – illumination), trophomorphes (most dependent on soil feeding modes); hygromorphes (least sensitive to the water regime of the ecosystem). Based on adaptations to the predominant phytocenosis, silvants (forest species), stepants (steppe species), pratants (meadow species), paludants (marsh species), and ruderants (weed species) are distinguished [27]. At the grouping level, a set of representatives of various ecomorphes forms an ecomorphic grouping structure, which indicates the adaptation of the grouping in general to the manifestation of a certain ecological regime (humidity or trophic conditions), or the intensity or location of a particular ecological process [28]. The ecomorphic approach has demonstrated its informational value both for diagnostics of natural soils [29] and technosol [30; 31]. This approach is effective for assessing the state of soil macrofauna groupings in conservation areas [32]. Therefore, an important scientific problem is the study of the possibility of applying an ecomorphic approach to assess the impact of recreation on soil biota.

*The purpose of this study* is to reveal a pattern of structuring communities of soil macrofauna under the recreational impact based on an ecomorphic approach.

## MATERIALS AND METHODS

### *Model testing sites of public green spaces in the city of Melitopol*

This study assesses the level of recreational transformation of the soil macrofauna of public green spaces in the city of Melitopol on the territory of Novooleksandrivskyi Park. A testing site was laid, within which samples were taken (Fig. 1). The level of recreational load was estimated using the average distance from recreational paths that are located within the testing site. Within the testing site, the average distance to the tracks is 3.1 m (standard deviation is 2.42 m). The testing site is classified as a high level of recreational load.

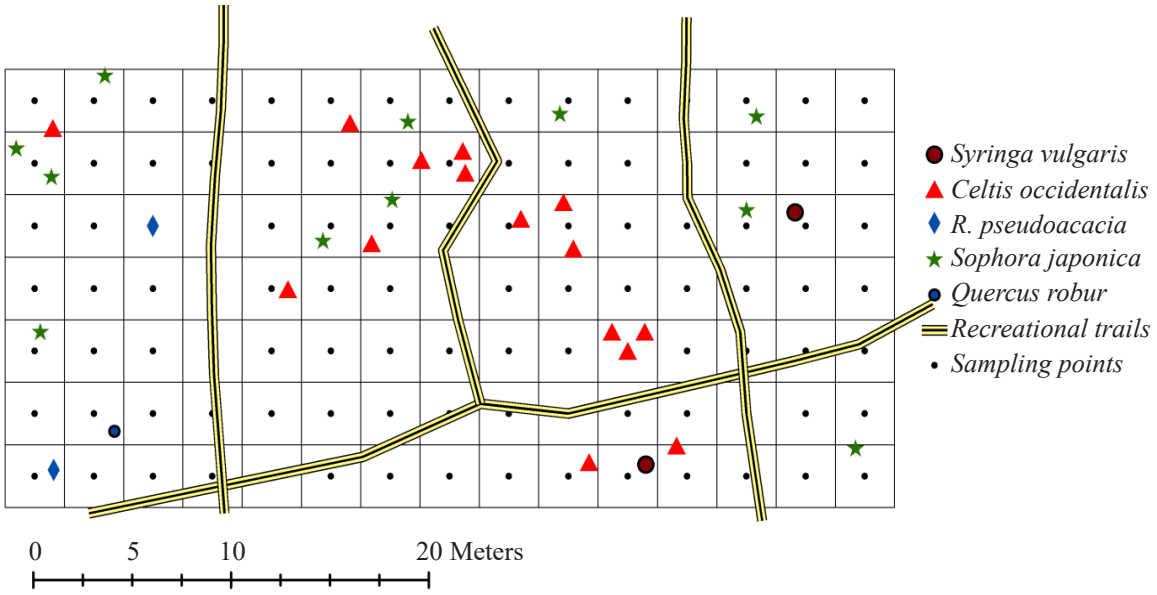


***Figure 1***. *Placement of sampling points in experimental testing sites. A – testing site 1, B – testing site 2*

The testing site was a collection of 105 test points that were gathered along 7 sections placed in parallel, with 15 test points in each section. The distance between the nearest sections was 3 metres, and the distance between the nearest sampling points in the section was 3 metres. Thus, the sampling points are a regular grid with a lag of 3 meters measuring 7×15 sampling points (24×45 meters) [28]. When selecting points, the location of a point within the limits was recorded and assigned local coordinates. To collect soil macrofauna and assess soil properties at each point of the testing site, soil and zoological tests were carried out (the results are presented in *L*-tables) and the following soil indicators were measured: temperature, electrical conductivity, humidity and soil penetration resistance, litter depth and grass stand height were made (*R*-table).

### *Sampling methods*

Soil and zoological samples had a size of 0.25×0.25 m to the depth of the greatest occurrence of soil animals. Admittedly, this depth was 0.20-0.25 m. Reduction of the size of the soil and zoological sample was made according to the recommendations of D. Pokarzhevskyi and co-authors [33; 34]. The transition from the conventional sample size in soil zoology from 0.50×0.50 m to 0.25×0.25 m allows considerably increasing the number of samples at the same working time expenditures. The soil macrofauna is selected by manual disassembly of the soil. The animals found were recorded in a 4% formalin solution and then identified in the laboratory. In the field, soil penetration resistance was measured at a depth of up to 1 m with an interval of 0.05 m using an Eijkelkamp hand-held penetrometer [31]. To measure the electrical conductivity of the soil *in situ,* a HI 76305 sensor (Hanna Instruments, Woodsocket, R. I.) was used. This sensor works together with the HI 993310 portable device.

### *Statistical analysis*

Group ordination was performed using two approaches: OMI analysis [36; 37] and RLQ analysis [38]. The idea of OMI ordination is to apply the concept of an ecological niche to explain the patterns of grouping organisation. In turn, the RLQ ordination allows testing the hypothesis that the ecological properties of species (in a broad understanding – the so-called *traits*) are capable of explaining the patterns that are formed in the grouping structure. The ecomorphes of plants were characterised by O.L. Belgarde [22] and V.V. Tarasov [39], the Q-table demonstrates the ecomorphes of soil animals [40]. Statistical procedures for RLQ and OMI analyses were performed using the ade4 package [41] for the R Shell [42]. The significance of RLQ is evaluated using the randtest.rlq procedure.

## RESULTS AND DISCUSSION

### *Ecomorphic structure of soil macrofauna*

Thirty-four species of soil animals were identified at the study site (Table 1). The population density of soil macrofauna is 376.53 ind./m$^2$. The most numerous and diverse group of saprophages of the testing site under study are earthworms, which are represented by 3 species. The share of the earthworm population from the total number of soil macrofauna is 66.78%. The largest number among earthworms has a medium-tiered soil species *Aporrectodea trapezoides*, the population density of which is 209.91 ind./m$^2$.

***Table 1***. *Species structure, ecological Indicators, and abundance of soil macrofauna*

| Species | Coenomorph | Trophomorph | Topomorph | Hygromorph | Trophocoenomorph | Phoromorph | Aeromorph | Carbonatomorph | Phase | Density±st. error, ind./m² |
|---|---|---|---|---|---|---|---|---|---|---|
| *Aporrectodea trapezoides* | Pr | SF | End | Ms | OlgTr | B4 | APhil | HCarPhil | Imago | 208.91±15.93 |
| *Aporrectodea rosea* | St | SF | End | Ms | MsTr | B4 | SAPhil | CarPhil | Imago | 31.39±2.75 |
| *Dendrobaena nassonovi* | St | SF | Anec | Ks | UMgTr | B4 | SAPhil | CarPhil | Imago | 11.89±1.65 |
| *Lumbricidae sp.* | Sil | SF | End | Ms | UMgTr | B4 | APhil | CarPhil | Cocoon | 20.57±2.52 |
| *Enchytraeus sp. 1* | Pr | SF | End | Hg | MgTr | A1 | SAPhil | CarPhil | Imago | 9.60±1.14 |
| *Pardosa lugubris* | Sil | ZF | Ep | Ms | MsTr | A2 | SAPhil | ACarPhil | Imago | 0.15±0.15 |
| *Geophilus proximus* | Pr | ZF | End | Ms | MgTr | A2 | SAPhil | HCarPhil | Imago | 0.76±0.33 |
| *Lithobius curtipes* | Sil | ZF | Ep | Hg | OlgTr | A1 | SAPhil | ACarPhil | Imago | 0.15±0.15 |
| *Megaphyllum rossicum* | Sil | SF | Ep | Ms | MsTr | A2 | APhil | ACarPhil | Imago | 29.71±2.86 |
| *Malthodes marginatus* | Sil | ZF | Ep | Hg | MsTr | A2 | SAPhil | ACarPhil | Larvae | 0.15±0.15 |
| *Brachinus crepitans* | Sil | ZF | Ep | Ms | MgTr | A1 | APhil | HCarPhil | Imago | 0.46±0.33 |
| *Calathus fuscipes* | St | ZF | Ep | Ms | UMgTr | A2 | APhil | HCarPhil | Imago | 0.15±0.15 |
| *Harpalus affinis* | Pr | ZF | Ep | Ms | UMgTr | A2 | APhil | HCarPhil | Imago | 4.88±1.33 |
| *Harpalus affinis* | Pr | ZF | Ep | Ms | UMgTr | A2 | APhil | HCarPhil | Larvae | 1.68±0.53 |
| *Harpalus distinguendus* | St | ZF | Ep | Ms | UMgTr | A3 | APhil | HCarPhil | Imago | 0.30±0.30 |
| *Ophonus azureus* | Pr | ZF | Ep | Ms | MgTr | A2 | APhil | CarPhil | Imago | 0.15±0.15 |
| *Poecilus versicolor* | Pr | ZF | Ep | Ms | MgTr | A1 | SAPhil | CarPhil | Imago | 0.15±0.15 |
| *Cetonia aurata* | Sil | SF | End | Ms | UMgTr | B7 | SAPhil | CarPhil | Larvae | 0.15±0.16 |
| *Otiorhynchus raucus* | Sil | FF | End | Ks | MgTr | B7 | HAPhob | CarPhil | Larvae | 1.98±0.64 |
| *Silpha carinata* | Pal | SF | Ep | Hg | MgTr | A3 | HAPhob | ACarPhil | Imago | 0.30±0.22 |
| *Silpha carinata* | Pal | SF | Ep | Hg | MgTr | A3 | HAPhob | ACarPhil | Larvae | 0.30±0.21 |
| *Philonthus decorus* | Sil | ZF | Ep | Ms | OlgTr | A1 | APhil | ACarPhil | Imago | 0.30±0.22 |
| *Staphylinus erythropterus* | Sil | ZF | Ep | Hg | MsTr | A1 | SAPhil | ACarPhil | Imago | 0.15±0.15 |
| *Rhizotrogus aestivus* | St | FF | End | Ms | UMgTr | B7 | SAPhil | CarPhil | Larvae | 1.83±0.59 |
| *Chloromyia formosa* | Sil | SF | Ep | Hg | MgTr | A2 | SAPhob | HCarPhil | Larvae | 0.15±0.15 |
| *Tabanus bromius* | Pr | ZF | End | Ms | MsTr | B5 | SAPhil | CarPhil | Larvae | 0.30±0.21 |
| *Agrotis segetum* | Sil | FF | End | Ks | MsTr | B4 | SAPhil | CarPhil | Larvae | 1.52±0.63 |
| *Armadillidium vulgare* | Sil | SF | Ep | Ms | MgTr | A3 | APhil | CarPhil | Imago | 0.15±0.15 |
| *Trachelipus rathkii* | Pal | SF | Ep | Hg | MgTr | A3 | HAPhob | CarPhil | Imago | 0.15±0.15 |
| *Chondrula tridens* | St | FF | Ep | Ks | MgTr | A3 | APhil | CarPhil | Imago | 5.33±1.20 |
| *Helix albescens* | St | FF | Ep | Ks | MgTr | A3 | APhil | HCarPhil | Imago | 15.24±2.12 |
| *Monacha cartusiana* | Sil | FF | Ep | Ks | MgTr | A2 | APhil | CarPhil | Imago | 0.15±0.15 |
| *Limacus maculatus* | Sil | FF | End | Ms | MgTr | B4 | SAPhob | ACarPhil | Imago | 0.15±0.16 |

***Notes***: *Coenomorphes: St – stepants, Pr – pratants, Pal – paludants, Sil – silvants; Trophomorphes: SF – saprophages, FF – phytophages, ZF – zoophages; Topomorphes: End – endogeic, Ep – epigeic, Anec – burrowers; Hygromorphes: Ks – xerophiles, Ms – mesophiles, Hg – hygrophiles, Uhg – ultrahigrophiles; Trophocoenomorphes: OlgTr – oligotorophocoenomorphes, MsTr – mesotrophocoenomorphes, MgTr – megatrophocoenomorphes, UMgTr – ulramegatrophocoenomorphes; Phoromorphes: A – movement through existing soil fracturing; B – active tunnelling; 1 – body sizes smaller than soil fracturing, 2 – body sizes comparable to fracturing, 3 – body sizes larger than cavities in the subsoil or comparable to large crevices or cracks in the soil, 4 – moving with a change in body thickness, 5 – moving without a change in body thickness, 6 – digging holes with limbs, 7 – C-shaped body; Aeromorphes: APhil – aerophiles, SAPhil – subaerophiles, HAPhob – hemiaerophobes, SAPhob – subaerophobes, APhob – aerophobes; Carbonatomorphes: CarPhob – carbonatophobes, ACarPhil – acarbonatophiles, HCarPhil – hemicarbonatophiles, CarPhil – carbonatophiles, HpCarPhil – hypercarbonatophiles*

The other two representatives of earthworms are *Aporrectodea rosea* and *Dendrobaena nassonovi*. The distribution density of earthworm cocoons is 20.57 ind./m$^2$. The structure of earthworm hygromorphes is dominated by xerophiles and mesophiles. Among the representatives of earthworms, there are pratants and stepants. Consequently, the structure of the earthworm grouping in the study area is numerous and diverse both in terms of taxonomy and ecology. The trophic group of saprophages also includes endogeic enchitreids (9.60 ind./m$^2$), epigeal millipedes *Megaphyllum rossicum* (29.71 ind./m$^2$), larvae and imagos *Silpha carinata* (0.30 ind./m$^2$), larvae Chloromyia formosa (0.15 ind./m$^2$) and woodlice *Trachelipus rathkii* (0.15 ind./m$^2$) and Armadillidium vulgare (0.15 ind./m$^2$).

Representatives of predatory lip legged millipedes are in themselves the soil centipede *Geophilus proximus* (0.76 ind./m$^2$ for its movement, it uses a system of soil burrows and cracks and an epigeal stone centipede *Lithobius curtipes* (0.15 ind./m$^2$). Representatives of predators are imagos of ground beetles (*Brachinus crepitans, Calathus fuscipes, Harpalus distinguendus, Harpalus affinis, Ophonus azureus, Poecilus versicolor*), an adult of short-winged beetles (*Staphylinus erythropterus* and *Philonthus decorus*), larvae *Harpalus affinis, Malthodes marginatus, Tabanus bromius* and spiders. The group of phytophages is diverse and is represented by larvae turnip moth (*Agrotis segetum*), lamellar beetles (*Rhizotrogus aestivus*), broad-nosed weevil (*Otiorhynchus raucus*) and shellfish (*Limacus maculatus, Chondrula tridens, Helix albescens, Monacha cartusiana*).

The basis of the coenomorphic structure of soil macrofauna in terms of the number of species is silvants (45.5%) and pratants (24.2%) (Fig. 2). The number of stepants (21.2%) and paludants (9.1%) is slightly less. As for the species abundance, the situation is somewhat different – the basis of the coenomorphic structure of macrofauna comprises pratants (64.5%), slightly less stepants (19.1%) and silvants (16.1%), and sporadic occurrence of paludants (0.2%).

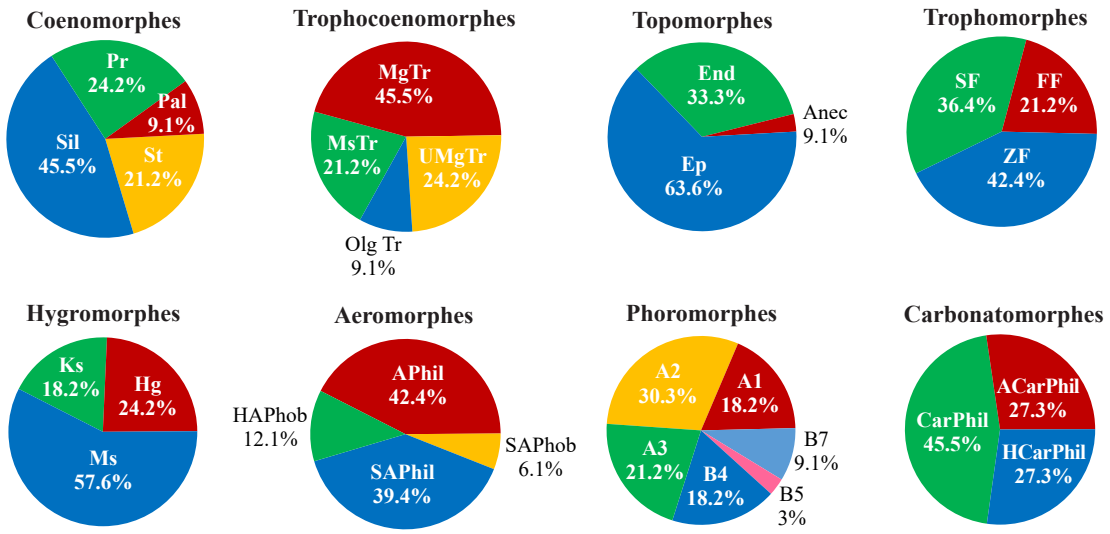


***Figure 2***. *Ecological structure of soil macrofauna (% by number of species)*

***Notes***: *Coenomorphes: St – stepants, Pr – pratants, Pal – paludants, Sil – silvants; Hygromorphes: Ks – xerophiles, Ms – mesophiles, Hg – hygrophiles, Uhg – ultrahigrophiles; Trophocoenomorphes: MsTr – mesotrophocoenomorphes; MgTr – megatrophocoenomorphes; UMgTr – Ultramegatrophocoenomorphes; Aeromorphes: APhil – aerophiles; SAPhil – Subaerophiles; HAPhob – hemiaerophobes; Carbonatomorphes: CarPhob – Carbonatophobes; ACarPhil – acarbonatophiles; HemiCarPhil – hemicarbonatophiles; CarPhil – carbonatophiles, HiperCarPhil – Hypercarbarbonatophiles; Topomorphes: End – endogeic. Ep – epigeic, Anec – burrowers; Phoromorphes: a –movement through existing soil fracturing; B – active laying of passages; 1 – body sizes smaller than soil fracturing, 2 – body sizes comparable to fracturing, 3 – body sizes larger than cavities in the subsoil or comparable to large crevices or cracks in the soil, 4 – moving with a change in body thickness, 5 – moving without a change in body thickness, 6 – digging holes with limbs, 7 – C-shaped body; Trophomorphes: SF – saprophages; F – phytophages; ZF – zoophages*

The environmental conditions determine the potential for settlement of a biotope, which is reflected in the features of the ecomorphic structure of populations, which, in turn, determines the ecological groups that will prevail in a particular ecosystem. Consequently, this ecosystem is developed in a predominantly meadow-forest environment, and the conditions in the middle of this ecosystem are steppe-meadow. The forest coenomorphes, represented by a considerable variety of species, is inferior in number compared to other coenomorphes. Marsh species are represented by a certain number, but in terms of abundance, these coenomorphes practically disappear from the grouping. Among hygromorphes, mesophiles predominate in terms of the number of

species (57.6%), slightly less so – hygrophiles (24.2%) and xerophiles (18.2%). As for the species abundance, the hygromorphic structure is considerably dominated by mesophiles (86.4%), slightly less by xerophiles (10.4%) and hygrophiles (3.22%). Thus, the general conditions in which the population of the studied biotope is developed are mesophilic. The specific features of particular conditions lie in a shift towards greater mesophytisation due to a decrease in the proportion of both xerophilic and hygrophilic species. Thus, this grouping is stenotopically mesophilic. The structure of Trophocoenomorphes is dominated by megatrophocoenomorphes (45.5%) and ultramegatrophocoenomorphes (24.2%) in terms of the number of species. The proportion of megatrophocoenomorphes (21.2%) and oligotrophocoenomorphes (9.1%) is slightly lower. As for the species abundance, the positions of these ecomorphes change places: representatives of oligotrophocoenomorphes become the leader (59.6%), they are considerably superior to mesotrophocoenomorphes (18.3%). The proportion of other Trophocoenomorphes is much smaller. This suggests that the ecosystem is formed in an ultramega-megatrophic edaphotope in terms of trophic level, but certain factors of the ecosystem cause a change in its trophic level to an oligotrophic one.

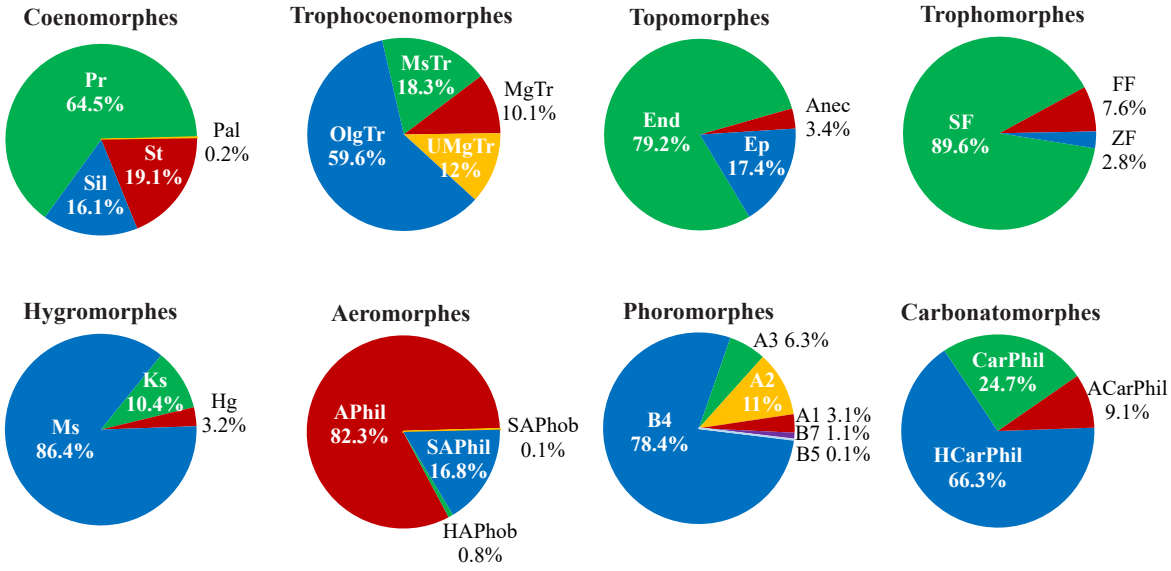


***Figure 3***. *Ecological structure of soil macrofauna (% by species abundance)*

***Notes***: *Coenomorphes: St – stepants, Pr – pratants, Pal – paludants, Sil – silvants; Hygromorphes: Ks – xerophiles, Ms – mesophiles, Hg – hygrophiles, Uhg – ultrahigrophiles; Trophocoenomorphes: MsTr – mesotrophocoenomorphes; MgTr – megatrophocoenomorphes; UMgTr – Ultramegatrophocoenomorphes; Aeromorphes: APhil – aerophiles; SAPhil – Subaerophiles; HAPhob – hemiaerophobes; Carbonatomorphes: CarPhob – Carbonatophobes; ACarPhil – acarbonatophiles; HemiCarPhil – hemicarbonatophiles; CarPhil – carbonatophiles, HiperCarPhil – Hypercarbarbonatophiles; Topomorphes: End – endogeic. Ep – epigeic, Anec – burrowers; Phoromorphes: a – movement through existing soil fracturing; B – active laying of passages; 1 – body sizes smaller than soil fracturing, 2 – body sizes comparable to fracturing, 3 – body sizes larger than cavities in the subsoil or comparable to large crevices or cracks in the soil, 4 – moving with a change in body thickness, 5 – moving without a change in body thickness, 6 – digging holes with limbs, 7 – C-shaped body; Trophomorphes: SF – saprophages; F – phytophages; ZF – zoophages*

The predominant number of Aeromorphes in terms of the number of species are aerophiles (42.4%) and subaerophiles (39.4%). As for species abundance, the share of aerophiles is considerably increasing (82.3%). Thus, the animal population of the soil of the ecosystem under study is described by a high need for a sufficient level of soil aeration. Among Topomorphes, epigeal forms predominate (63.3%). The share of endogeic species is almost twice as low (33.3%). Burrowers make up 3%. As for abundance, endogeic species significantly predominate (79.2%). This indicates favourable conditions for the existence of pedobionts in the soil, and on the other hand – considerable pressure on the subsoil block in recreational conditions in public green spaces. In terms of the number, Phoromorphes are represented by a wide range of species, which are generally represented equally. In terms of abundance, Phoromorphes are considerably dominated by species capable of laying soil passages with changes in body shape (78.4%).

The representation of Trophomorphes concerning the number of species is quite equalised. Zoophages make up 42.4% of the number of species, saprophages – 36.4%, phytophages – 21.2%. Saprophages significantly predominate in abundance (89.6%). Zoophages account

for 7.6% and phytophages – for 2.8%. Among Carbonatomorphes, carbonatophiles predominate in terms of the number of species (45.5%). Acarbonatophiles and hemicarbonatophiles are presented in equal proportions (27.3%). The abundance of species is dominated by hemicarbonatophiles (66.3%). Acarbonatophiles make up 9.1% and carbonatophiles make up 24.7%.

***Soil determinants of the spatial structure of ecomorphes of soil macrofauna***

The soil indicators are used as determinants of the ecological space of macrofauna communities (Table 2). The soil penetration resistance within the test site under study increases along with depth. Thus, the upper layer of soil has an average hardness of 1.41±0.049 MPa, and the lower layer has an average hardness of 3.75±0.059 MPa.

***Table 2***. *Soil indicators that determine the ecological space of macrofauna and their correlations with axes obtained during OMI and RLQ analyses (statistically significant for p<0.05)*

| Environment variable | Average ± st. deviation | Percentile | | CV, % | OMI-Axis 1 | OMI-Axis 2 | RLQ-Axis 1 | RLQ-Axis 2 |
|---|---|---|---|---|---|---|---|---|
| | | 2.5% | 97.5% | | | | | |
| *Soil penetration resistance at depth, MPa* | | | | | | | | |
| 0-5 cm | 1.41±0.049 | 0.60 | 2.50 | 35.87 | −0.15 | −0.11 | −0.12 | 0.14 |
| 5-10 cm | 1.86±0.052 | 0.90 | 2.90 | 28.52 | −0.23 | −0.11 | −0.26 | 0.05 |
| 10-15 cm | 2.23±0.064 | 1.00 | 3.50 | 29.51 | −0.24 | −0.05 | −0.16 | −0.01 |
| 15-20 cm | 2.55±0.079 | 1.20 | 4.30 | 31.69 | −0.21 | −0.04 | −0.09 | −0.06 |
| 20-25 cm | 2.56±0.052 | 1.70 | 3.67 | 20.90 | −0.21 | −0.03 | −0.27 | 0.04 |
| 25-30 cm | 2.59±0.060 | 1.65 | 4.30 | 23.70 | −0.27 | 0.01 | −0.27 | −0.18 |
| 30-35 cm | 2.70±0.059 | 1.60 | 4.00 | 22.36 | −0.26 | −0.02 | −0.32 | −0.16 |
| 35-40 cm | 2.80±0.059 | 1.70 | 4.00 | 21.57 | −0.27 | 0.00 | −0.35 | −0.05 |
| 40-45 cm | 2.91±0.058 | 1.90 | 4.10 | 20.48 | −0.26 | −0.02 | −0.23 | −0.14 |
| 45-50 cm | 3.05±0.061 | 2.00 | 4.40 | 20.55 | −0.26 | −0.01 | −0.25 | 0.13 |
| 50-55 cm | 3.28±0.067 | 2.25 | 4.53 | 21.01 | −0.28 | 0.01 | −0.21 | 0.12 |
| 55-60 cm | 3.39±0.069 | 2.20 | 4.50 | 20.71 | −0.29 | −0.01 | −0.18 | 0.21 |
| 60-65 cm | 3.50±0.065 | 2.30 | 4.80 | 19.05 | −0.27 | 0.00 | −0.19 | 0.05 |
| 65-70 cm | 3.54±0.067 | 2.30 | 5.00 | 19.40 | −0.27 | 0.02 | −0.21 | 0.07 |
| 70-75 cm | 3.54±0.067 | 2.30 | 4.80 | 19.33 | −0.22 | 0.02 | −0.11 | −0.02 |
| 75-80 cm | 3.62±0.065 | 2.30 | 5.00 | 18.45 | −0.26 | 0.04 | −0.13 | −0.12 |
| 80-85 cm | 3.70±0.072 | 2.00 | 5.15 | 19.96 | −0.26 | 0.03 | −0.15 | −0.13 |
| 85-90 cm | 3.69±0.082 | 2.30 | 5.30 | 22.85 | −0.26 | 0.04 | −0.11 | −0.13 |
| 90-95 cm | 3.75±0.058 | 2.60 | 5.00 | 15.95 | −0.24 | 0.01 | −0.23 | −0.30 |
| 95-100 cm | 3.75±0.059 | 2.60 | 5.00 | 16.12 | −0.24 | 0.01 | −0.23 | −0.30 |
| *Physical properties of the soil* | | | | | | | | |
| Electrical conductivity, dS/m | 0.11±0.004 | 0.04 | 0.19 | 38.10 | 0.02 | −0.13 | 0.14 | 0.41 |
| Humidity, % | 22.8±0.33 | 16.00 | 29.01 | 14.67 | 0.08 | −0.09 | 0.15 | 0.48 |
| *Distances to walking paths and trees* | | | | | | | | |
| Distance to recreation tracks, m | 3.08±0.236 | 0.00 | 9.07 | 78.58 | 0.01 | 0.12 | 0.13 | −0.14 |
| Distance to trees, m | 3.16±0.190 | 0.68 | 8.19 | 61.66 | 0.16 | −0.16 | −0.10 | 0.41 |

The upper layer of soil is described by a rapid increase in the soil penetration resistance, which stops at a depth of 20-25 cm. Within the test site under study, the average soil penetration resistance values starting from soil layers of 10-15 cm are, with varying probability, higher than those critical for the growth of plant root systems (3-3.5 MPa) [43]. This confirms the fact that spatial variability in soil penetration resistance has a considerable structuring effect on the formation of grass cover and the organisation of soil animal populations. The coefficient of variation in soil penetration resistance tends to decrease with increasing depth, but local highs

interrupt this monotonous trend. The coefficient of hardness variation has a local maximum in the soil layers of 20-25 cm and 90-95 cm and is 31.69% and 22.84%, respectively. The minimum variability of soil penetration resistance, which is 15.95-16.12%, falls at a depth of 90-100 cm.

The average electrical conductivity of the soil is 0.11±0.004 dS/m and has a variation coefficient of 38.10%. The maximum value of this indicator is approximately 0.19 dS/m, which does not exceed the lower threshold of electrolyte concentrations (1.5-2.0 dS/m), which negatively affect vegetation [44]. The low level of electrical conductivity of the soil suggests a low trophic level of the soil of the ecosystem under study. Electrical conductivity is statistically significantly correlated with soil penetration resistance at different depths. The correlation is positive with soil penetration resistance at a depth of 0-5 cm ($r$=0.25, $p$<0.01). The correlation is negative with hardness at depths from 55-60 cm to 90-95 cm (statistically significant correlation coefficients are within -0.20 – -0.31). Soil moisture is 22.8±0.33%, and in 95% of cases is with 16.00%-29.01%. Humidity and electrical conductivity are positively correlated with each other ($r$=0.52, $p$<0.01). In turn, the correlation between soil moisture and soil penetration resistance is negative (statistically significant correlation coefficients are within -0.21--0.36). The distance to recreational paths averages 3.08±0.236 and in 95% of cases varies between 0.00-9.07 m. The distance to tree trunks, regardless of the species, averages 3.16±0.19 and in 95% of cases varies between 0.68-8.19 m.

***Spatial ordination of soil macrofauna groups***

The simultaneous measurement of soil indicators and features of the structure of groups of organisms allowed assessing the distribution of the ecological space of the ecosystem between the ecological niches of soil macrofauna (Table 3). The analysis determined the total inertia at the level of 1.47. As a result of OMI analysis, two axes were obtained, the one of which describes 86.72%, and the other – 7.03% of inertia. Thus, 93.75% of inertia is described by the first two axes, which proves that the space created by these axes is sufficient to describe the differentiation of ecological niches of macrofauna in the test site under study. The average value of the grouping marginality is *OMI*=25.07 with the significance level *R*=0.01, which reflects the essential role of the investigated variables in structuring soil macrofauna groups.

Of the 33 species for which OMI analysis was performed, for 18 species, marginality differs statistically significantly from the random alternative (Table 3). Thus, the typical edaphic conditions of the test site do not coincide with the centroid of the ecological niche of a considerable part of macrofauna species. The marginality of a niche determines the degree of difference between the optimum conditions for the existence of a species and the factual conditions of a particular place of existence. Niche tolerance is the opposite of specialisation: the higher the tolerance, the lower the specialisation. Residual tolerance is an indicator of the role of random and neutral factors, as well as measurement errors.

***Table 3***. *Assessment of the marginality of soil macrofauna species*

| Macrofauna species | Inertia | OMI | Tol | Rtol | *p-level* |
|---|---|---|---|---|---|
| *Aporrectodea rosea* | 24.25 | 1.90 | 44.50 | 53.50 | 0.05 |
| *Aporrectodea trapezoides* | 26.26 | 3.30 | 54.00 | 42.70 | 0.01 |
| *Dendrobaena nassonovi* | 20.51 | 1.60 | 19.90 | 78.60 | 0.53 |
| *Lumbricidae (cocoon)* | 22.66 | 2.80 | 41.50 | 55.70 | 0.15 |
| *Enchytraeus sp.* | 28.36 | 4.80 | 52.10 | 43.10 | 0.03 |
| *Pardosa lugubris* | 9.20 | 100.00 | 0.00 | 0.00 | 0.94 |
| *Geophilus proximus* | 20.55 | 15.70 | 26.40 | 57.90 | 0.15 |
| *Lithobius curtipes* | 32.04 | 13.20 | 56.10 | 30.70 | 0.10 |
| *Megaphyllum rossicum* | 24.49 | 1.10 | 34.40 | 64.50 | 0.31 |
| *Malthodes marginatus* | 23.27 | 5.80 | 5.50 | 88.70 | 0.99 |
| *Brachinus sclopeta* | 12.37 | 38.10 | 13.00 | 48.80 | 0.91 |
| *Calathus fuscipes* | 25.62 | 12.60 | 22.70 | 64.70 | 0.66 |
| *Harpalus affinis* | 40.26 | 22.20 | 37.70 | 40.10 | 0.01 |
| *Harpalus affinis (larvae)* | 22.04 | 4.40 | 29.40 | 66.20 | 0.69 |
| *Harpalus distinguendus* | 24.05 | 21.50 | 29.50 | 49.00 | 0.31 |
| *Ophonus azureus* | 24.74 | 100.00 | 0.00 | 0.00 | 0.38 |
| *Poecilus versicolor* | 16.85 | 7.90 | 12.70 | 79.40 | 0.95 |
| *Cetonia aurata* | 16.43 | 37.00 | 15.50 | 47.50 | 0.86 |
| *Otiorhynchus raucus* | 26.09 | 4.10 | 12.10 | 83.80 | 0.33 |

*Table 3, Continued*

| Macrofauna species | Inertia | OMI | Tol | Rtol | *p-level* |
|---|---|---|---|---|---|
| *Silpha carinata* | 34.77 | 28.30 | 42.20 | 29.50 | 0.05 |
| *Silpha carinata (larvae)* | 27.50 | 25.20 | 35.50 | 39.30 | 0.05 |
| *Philonthus decorus* | 22.01 | 29.90 | 18.00 | 52.10 | 0.69 |
| *Staphylinus erythrocephalus* | 8.56 | 100.00 | 0.00 | 0.00 | 0.98 |
| *Rhizotrogus aestivus* | 25.28 | 5.60 | 43.70 | 50.70 | 0.63 |
| *Chloromyia formosa* | 35.43 | 14.50 | 53.90 | 31.60 | 0.09 |
| *Tabanus bromius* | 20.12 | 58.30 | 3.70 | 38.00 | 0.05 |
| *Agrotis segetum* | 25.80 | 15.70 | 42.10 | 42.20 | 0.01 |
| *Armadillidium vulgare* | 29.84 | 6.30 | 4.20 | 89.50 | 0.68 |
| *Trachelipus rathkii* | 40.98 | 48.60 | 25.00 | 26.40 | 0.01 |
| *Chondrula tridens* | 23.40 | 9.20 | 35.50 | 55.20 | 0.02 |
| *Helix albescens* | 27.51 | 10.80 | 47.50 | 41.70 | 0.01 |
| *Monacha cartusiana* | 18.60 | 27.20 | 17.10 | 55.70 | 0.05 |
| *Limacus maculatus* | 47.41 | 77.50 | 1.40 | 21.00 | 0.01 |
| *OMI* | 25.07 | – | – | – | 0.01 |

***Notes**: OMI-index of the average distance (marginality) for each species; Tol – tolerance, Rtol – residual tolerance; index data are presented in % of the total variability; R – Monte Carlo level after 999 iterations*

Species such as *Staphylinus erythrocephalus* and *Pardosa lugubris* have a high marginality. This means that the typical ecological conditions of the test site are considerably different from the optimum for these species. These types are subsoil. A significant transformation of the subsoil block under the influence of recreation drastically transforms the ecological environment of these species.

The most tolerant species are as follows: *Aporrectodea rosea, Helix albescens, Enchytraeus sp., Chloromyia formosa, Aporrectodea trapezoides, Lithobius curtipes*. In fact, this list indicates a complex of species that is typical of a given ecosystem and occupies the corresponding territory in general as one that best meets the ecological standard of the species. On the contrary, highly specialised species, the existence of which is possible only in limited areas within the territory, are *Malthodes marginatus* and *Poecilus versicolor*.

The residual tolerance is high for a number of species (for *Armadillidium vulgare* – 89.5%, for *Malthodes marginatus* – 88.7%, for *Otiorhynchus raucus* – 83.8%), which indicates that the structuring of the grouping of soil macrofauna factors is greatly influenced by factors of a neutral nature, including those that are not considered in this study. Correlation analysis of soil properties and OMI axes demonstrated that the main factors for structuring the ecological niche of soil macrofauna within the study area are soil penetration resistance in the range of the entire measured layer, soil moisture, and distance to trees (Axis 1) (Table 2). Soil penetration resistance in the surface layers (0-5 and 5-10 cm), electrical conductivity, humidity, and distance from recreational paths (Axis 2) also play an essential role. Axis 1 can be interpreted as a natural variation in the environment properties, which leads to structuring of the grouping. Axis 2 can be interpreted as variability in the grouping structure, which is caused by the influence of recreation. OMI axes define gradients of the medium along which the views are ordered (Fig. 4). On one side, the extreme positions along the OMI-Axis 1 are occupied by *Monacha cartusiana, Pardosa lugubris, Tabanus bromius, Limacus maculatus,* and on the other – by *Trachelipus rathkii, Ophonus azureus, Silpha carinata, Harpalus affinis*. Along the OMI-Axis 2, the extreme positions are occupied by *Rhizotrogus aestivus, Malthodes marginatus, Pardosa lugubris, Ophonus azureus,* on one side, and *Harpalus affinis, Tabanus bromius, Armadillidium vulgare, Chondrula tridens* – on the other. Notably, the vast majority of species are subsoil, but at this stage of analysis it is extremely difficult to put forward a hypothesis that would explain the observed ordination of species in the grouping.

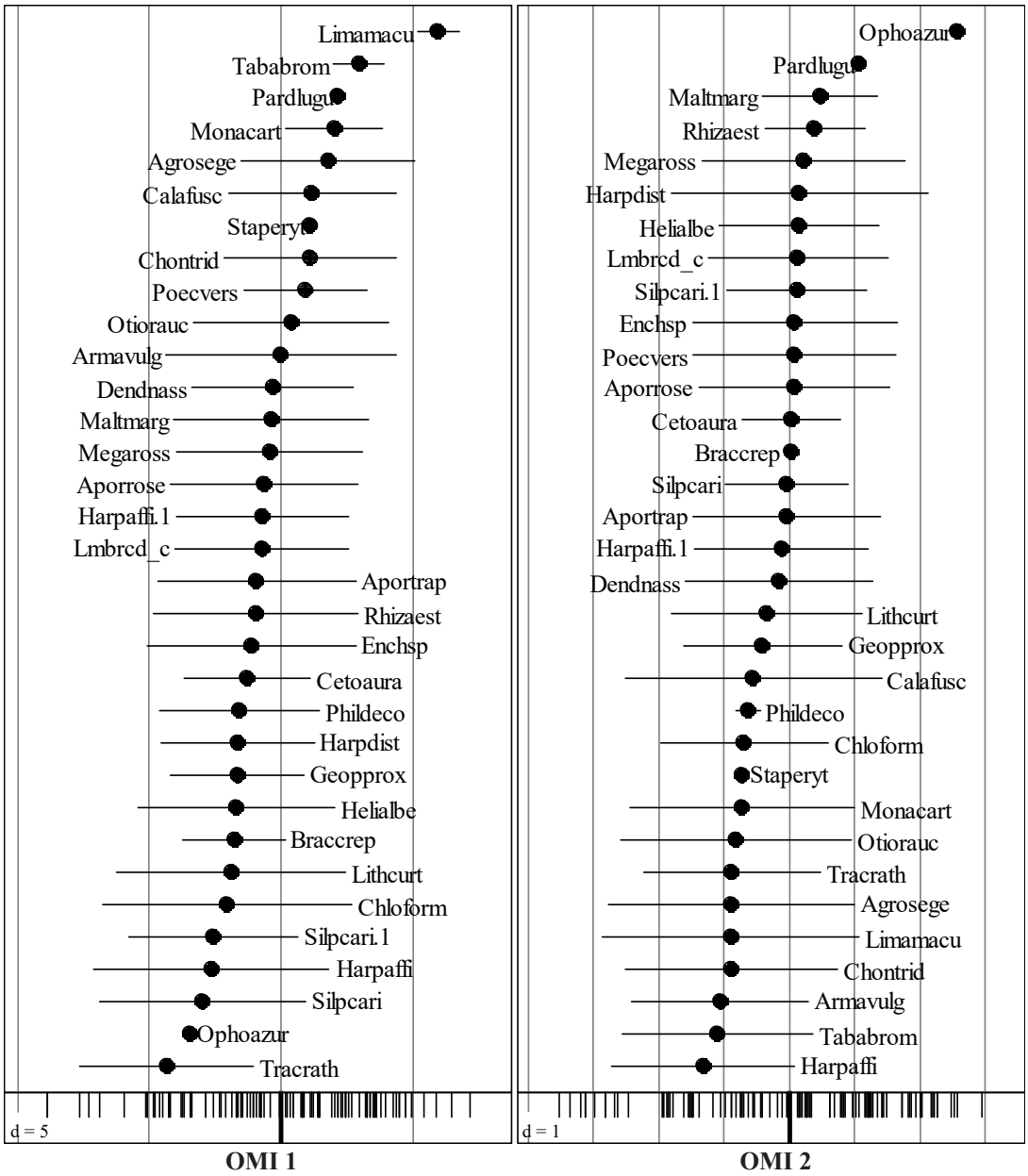


***Figure 4***. *Projections of ecological niches of soil macrofauna species on the OMI 1 and OMI 2 axes: the lower half – negative values of the axes, the upper half – positive values of the axes*

***Notes***: *Aporrose – Aporrectodea rosea; Aportrap – Aporrectodea trapezoides; Dendnass – Dendrobaena nassonovi; Lmbrcd_c – Lumbricidae (cocoon); Enchsp – Enchytraeus sp.; Pardlugu – Pardosa lugubris; Geopprox – Geophilus proximus; Lithcurt – Lithobius curtipes; Megaross – Megaphyllum rossicum; Maltmarg – Malthodes marginatus; Bracsclo – Brachinus sclopeta; Calafusc – Calathus fuscipes; Harpaffi – Harpalus affinis; Harpaffi.1 – Harpalus affinis (larvae); Harpdist – Harpalus distinguendus; Ophoazur – Ophonus azureus; Poecvers – Poecilus versicolor; Cetoaura – Cetonia aurata; Otiorauc – Otiorhynchus raucus; Silpcari – Silpha carinata; Silpcari.1 – Silpha carinata (larvae); Phildeco – Philonthus decorus; Staperyt – Staphylinus erythrocephalus; Rhizaest – Rhizotrogus aestivus; Chloform – Chloromyia formosa; Tababrom – Tabanus bromius; Agrosege – Agrotis segetum; Armavulg – Armadillidium vulgare; Tracrath – Trachelipus rathkii; Chontrid – Chondrula tridens; Helialbe – Helix albescens; Monacart – Monacha cartusiana; Limamacu – Limacus maculatus*

RLQ analysis found that 92.91% of the total variation (total inertia) describes the first two RLQ axes (84.44 and 8.47%, respectively). The randtest procedure confirmed the significance of the results of the RLQ analysis on *p*-level 0.018. The presence of a statistically significant correlation between ecomorphes of macrofauna and environmental predictors was confirmed by a multiple test of global significance of correlations based on site permutation ($p$=0.003) and based on the permutation of species ($p$=0.024). RLQ axes constitute integral indicators for assessing the correlation between environmental factors and the ecomorphic community structure. One metric space reflects the location of macrofauna species, the influence of environmental factors on them, and the value of ecomorphic indicators affecting the structuring of soil macrofauna grouping (Fig. 5). As a result of RLQ analysis, Axis 1 was identified, which explains the effect of soil penetration resistance on the structuring of macrofauna grouping at all measured depths (Table 2, Fig. 5). Axis 1 correlates negatively with soil penetration resistance, but positively with electrical conductivity and soil moisture. Axis 1 correlates positively with the distance from paths and negatively with the distance to trees. Markers of positive values of Axis 1 are xerophiles, phytophages, and carbonatophiles. Markers of negative values of Axis 1 are pratants or paludants, hypercarbonatophiles, and saprophages. This axis can be interpreted as the result of the structural influence of tree vegetation.

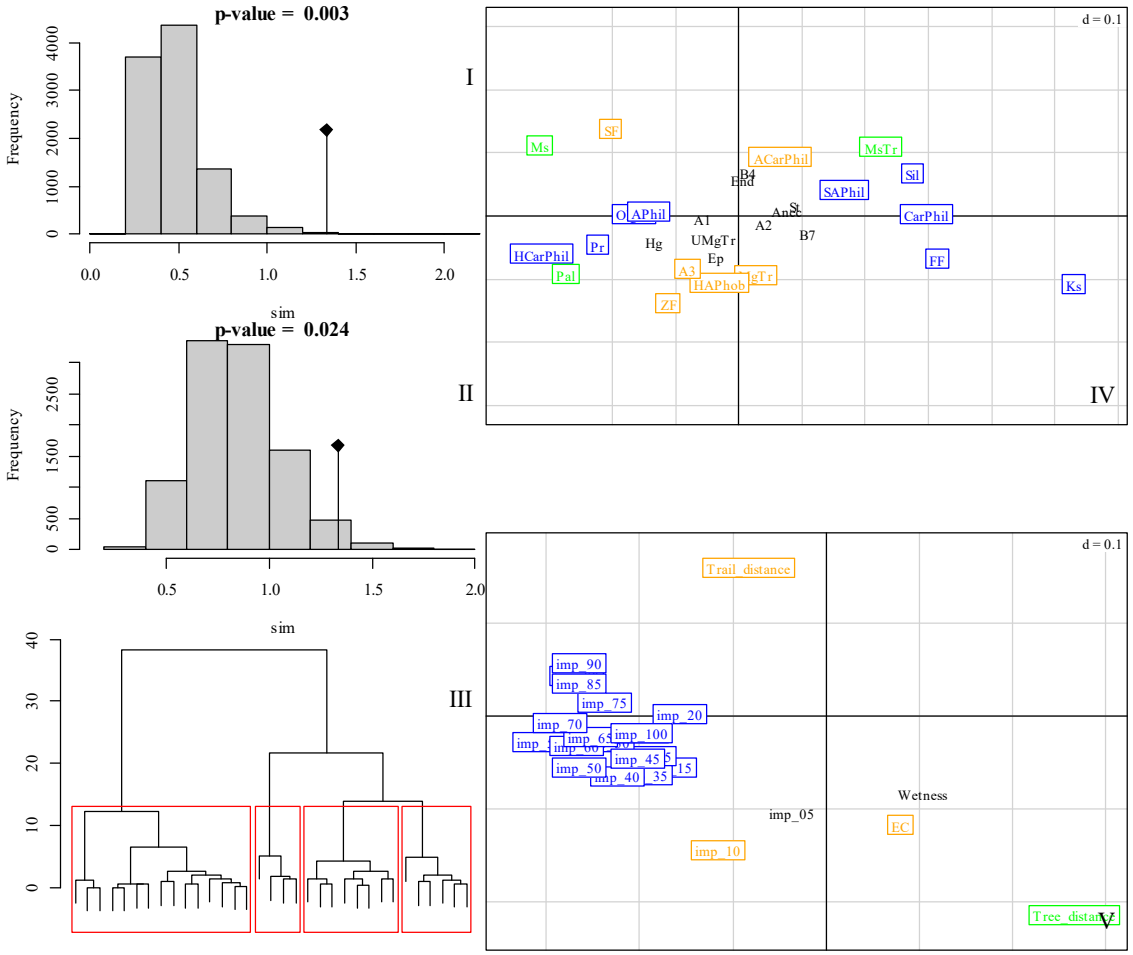


***Figure 5***. *Results of RLQ analysis: I – multiple test of global significance of correlations between ecomorphes of soil macrofauna and ecological predictors based on site permutation, II – multiple test of global significance of correlations between ecomorphes of macrofauna and ecological predictors based on species permutation, III – cluster analysis of species based on values of RLQ axes, IV – placement of ecomorphes in the environment of RLQ axes (blue – statistically probable correlation with Axis 1; yellow – with Axis 2; green – with both axes), V – placement of environmental predictors in the environment of RLQ axes (blue – statistically probably correlation with Axis 1; yellow – with Axis 2; green – with both axes)*

Axis 2 is sensitive to trends of opposite changes in soil penetration resistance at different depths. This refers to a tendency to increase hardness at depths of 0-5 and 55-60 cm on the one hand, which is accompanied by a decrease in hardness at depths of 25-35 and 90-100 cm, on the other hand. This axis considerably correlates with electrical conductivity and humidity, as well as distances to trees and paths. Axis 2 can be interpreted as a structuring

effect of recreational load on soil macrofauna. Positive values of Axis 2, which correspond to a lower level of recreational load, are marked with saprophages and acarbonatophiles. Negative values of Axis 2, which correspond to a high level of recreational load, are marked with zoophages, hemiaerophobes, and megatrophes.

The RLQ analysis allowed classifying living organisms according to the specific features of their ecological structure and relationships with environmental factors. Cluster analysis identified four populations of species that form functional groups A, B, C, and D (Fig. 6). Functional group A has a centroid, which is close to the territories characterised by the lowest level of recreational load. This cluster includes all earthworm species, earthworm cocoons, and larvae *Cetonia aurata,* which prefer rotting wood. The opposite position within the axes is factually vacant and corresponds to the conditions of the greatest recreational load. This indicates factual absence of soil macrofauna species that could exist amid intense recreational exposure. Cluster B combines species that are moderately tolerant to recreational load. Cluster C is a group of hygrophilous species that prefer shaded parkland areas. Cluster D is a group of species that prefer more open areas where moisture deficiency is more common.

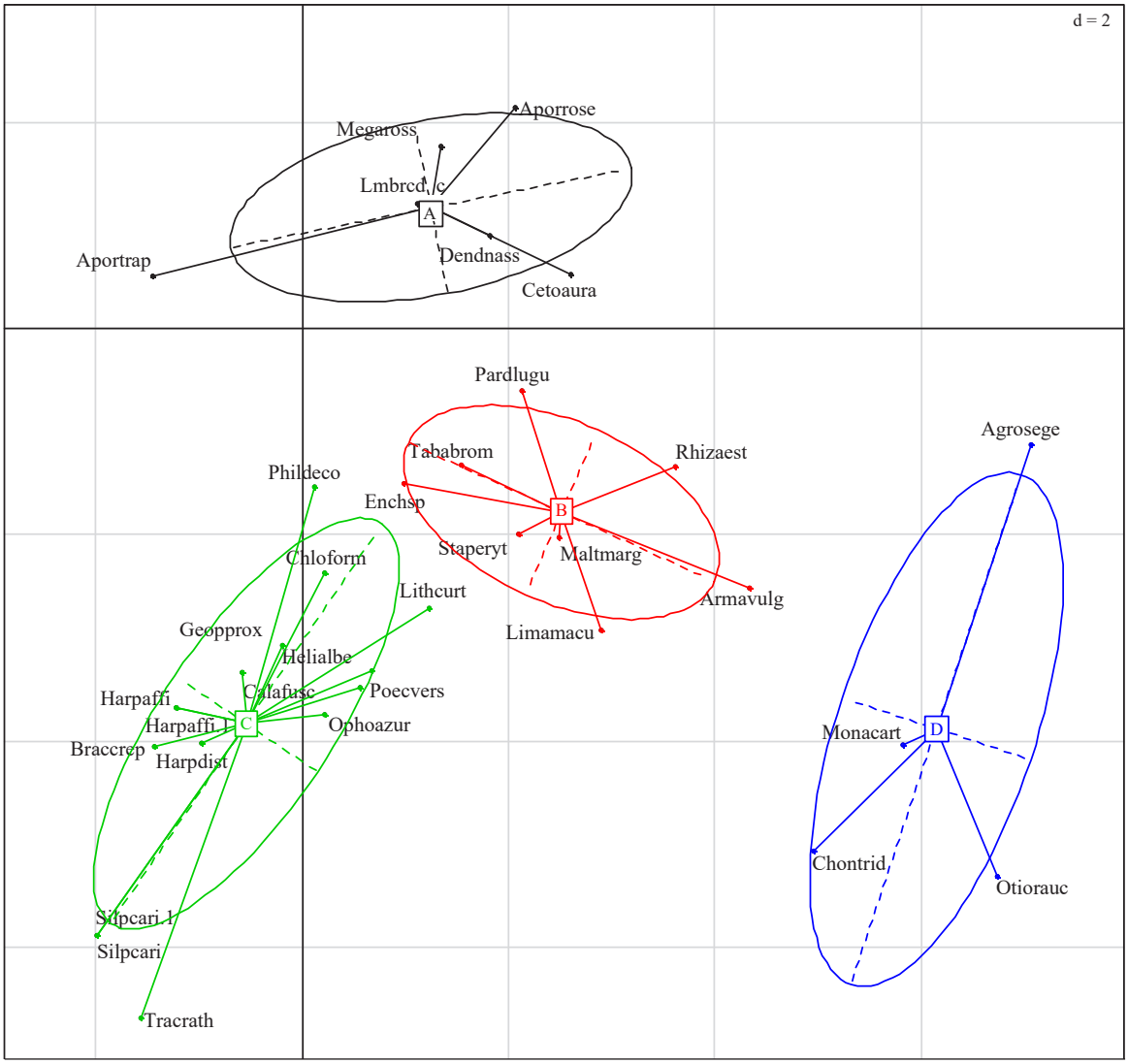


***Figure 6***. *Placement of functional groups (clusters) within RLQ axes: Aporrose – Aporrectodea rosea; Aportrap – Aporrectodea trapezoides; Dendnass – Dendrobaena nassonovi; Lmbrcd_c – Lumbricidae (cocoon); Enchsp – Enchytraeus sp.; Pardlugu – Pardosa lugubris; Geopprox – Geophilus proximus; Lithcurt – Lithobius curtipes; Megaross – Megaphyllum rossicum; Maltmarg – Malthodes marginatus; Bracsclo – Brachinus sclopeta; Calafusc – Calathus fuscipes; Harpaffi – Harpalus affinis; Harpaffi.1 – Harpalus affinis (larvae); Harpdist – Harpalus distinguendus; Ophoazur – Ophonus azureus; Poecvers – Poecilus versicolor; Cetoaura – Cetonia aurata; Otiorauc – Otiorhynchus raucus; Silpcari – Silpha carinata; Silpcari.1 – Silpha carinata (larvae); Phildeco – Philonthus decorus; Staperyt – Staphylinus erythrocephalus; Rhizaest – Rhizotrogus aestivus; Chloform – Chloromyia formosa; Tababrom – Tabanus bromius; Agrosege – Agrotis segetum; Armavulg – Armadillidium vulgare; Tracrath – Trachelipus rathkii; Chontrid – Chondrula tridens; Helialbe – Helix albescens; Monacart – Monacha cartusiana; Limamacu – Limacus maculatus*

The RLQ Axis 1 statistically significantly correlates with both OMI Axis 1 and RLQ Axis 2 ($r$=0.99, $p$<0.001 and $r$=0.32, $p$=0.02). The RLQ Axis 2 also statistically significantly correlates with the OMI Axis 1 ($r$=0.42, $p$<0.001) and OMI Axis 2 ($r$=0.87, $p$<0.001). Accordingly, the spatial patterns of the RLQ and OMI axes are very similar to each other (Fig. 7).

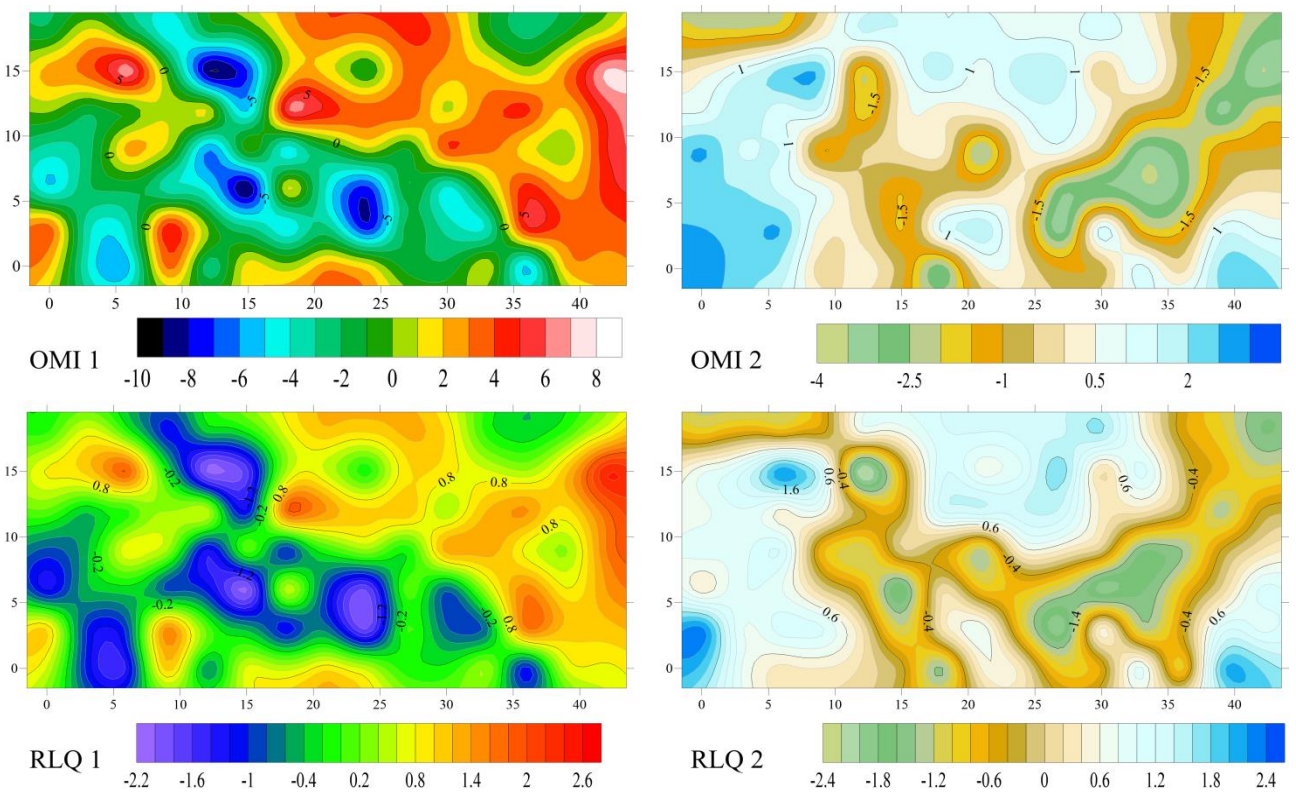


***Figure 7***. *Spatial variation of the OMI and RLQ axes. The abscissa and ordinate axes are local coordinates of the testing site under study*

Thus, ecomorphes reflect the adaptations of the animal population not to the ecological parameters of the environment, but to the typological indicators of the ecosystem in general. Soil is a special bioinert body, which, according to many researchers, constitutes an intermediate element between living and inanimate nature. Therefore, a topical scientific issue is the identification of the forms and degree of similarity of the characteristics of soil and living matter [45]. Genetic soil science allows considering the dynamics, structure, and functions of the soil [46; 47]. However, the manifestation of obvious changes in the composition of the soil or its functioning takes long periods of time — tens, and sometimes hundreds of years. Clearly, the soil is a full-fledged component of the ecosystem, which interacts with all its other components throughout the entire period of its existence. Plants and animals are active participants in the soil-forming process, since they are involved in the formation of humus by producing detritus [48; 49]. Thus, the metamorphism of the soil material is carried out. Being a bioinert system, the soil adapts to changes in environmental conditions in the system of soil-forming factors, which manifests itself in temporal and spatial heterogenisation, uneven structure in both horizontal and vertical profiles [50]. Since these transformations are ecological in nature, prerequisites are developing for applying an ecomorphic approach to investigating the features of soil structuring.

The obtained data indicate that the grouping of soil macrofauna of public green spaces has the features of amphicoenosis, where the steppe and meadow components are considerably represented against the background of the predominance of the forest component. Tree stands in urban parks form a common forest environment, although they do not form a stable forest monocoenosis. Recreation and other forms of anthropogenic impact do not allow a forest monocenosis or pseudomonocenosis to develop. The trophic aspect can allow deciphering the meaning in the grouping of coenotic components. The trophic structure of silvants repeats the trophic structure of the general grouping. The advantage of silvants in general grouping allows considering them as the functional basis of the complex of soil fauna of public green spaces. Phytophages predominate among steppes, which fully corresponds to the typical trophic structure of steppe zonal groups. This feature, considering the proportional representation of zoophages and saprophages, allows enables the assessment of functional stability of the structure of the group of stepants.

## CONCLUSIONS

1. The ecological space of ecosystems in recreational conditions is structured between ecological niches of soil macrofauna. Marginality, tolerance, and residual tolerance quantify the position of ecological niches in the ecological space. Variability of soil properties caused by natural factors or recreation is a driver of structuring the ecological space of soil macrofauna. Soil animals are most sensitive to changes in soil penetration resistance, humidity, and electrical conductivity.

2.There is a correlation between environmental factors in public green spaces, the grouping structure of soil macrofauna, and its ecomorphic organisation. The ecomorphic aspect of the soil macrofauna grouping structure is more sensitive to recreational load than the distribution of ecological niches between species in the ecological space, which suggests that rearrangements of the ecomorphic grouping structure are a condition for the stability of its organisation.

3.The natural variability of soil conditions within the ecosystem manifests itself in changes in the ratio of xerophiles, phytophages, carbonatophiles on the one hand and pratants, paludants and hypercarbonatophiles on the other hand. Zoophages, hemiaerophobes, and megatrophs are tolerant to a high level of recreational load. The area corresponding to the highest level of recreational load is vacant. This indicates that the most transformed areas are randomly populated by representatives of different ecological groups.

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## Трансформація екоморфічної структури ґрунтової макрофауни в умовах рекреаційного впливу

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**Анотація**. Рівень реакраційого навантаження на компоненти міських зелених зон зростає, тому визначення ефективних інструментів управління в цих екосистемах набуває вирішального значення для забезпечення підтримки місць існування популяцій тварин, зокрема ґрунтової біоти. Метою роботи є встановлення закономірності структурування угруповань ґрунтової макрофауни в умовах рекреаційного впливу на основі екоморфічного підходу. У роботі виконано оцінку рівня рекреаційної трансформації ґрунтової макрофауни зелених насаджень загального користування м. Мелітополь на території парку Новоолександрівський. У зоні з високим рівнем рекреаційного навантаження для досліджень було закладено полігон, у межах якого зроблено відбір проб. З метою збору ґрунтової макрофауни та оцінки властивостей ґрунту у кожній точці дослідженого полігону були проведені ґрунтово-зоологічні проби та здійснені вимірювання таких грунтових показників, як: температура, електропровідність, вологість та твердість ґрунту, потужність підстилки та висота травостою. Ординація угруповань проведена за допомогою двох підходів: OMI-та RLQ-аналізів. Виявлено, що екологічні ніші ґрунтової макрофауни в умовах рекреації є просторово структурованими. Основними факторами структурування екологічної ніші ґрунтової макрофауни у межах досліджуваної території є твердість ґрунту в діапазоні усього вимірюваного шару, вологість ґрунту та дистанція до дерев. Основу ценоморфічної структури ґрунтової макрофауни за кількістю видів становлять сильванти (45,5 %) та пратанти (24,2 %). За чисельністю видів основу ценоморфічної структури макрофауни становлять пратанти (64,5 %), трохи менше степантів (19,1 %) та сильвантів (16,1 %) та одинично зустрічаються палюданти (0,2 %). Таку ценоморфічну структуру можна розглядати як екологічно лабільну. До високого рівня рекреаційного навантаження толерантними є зоофаги, геміаерофоби та мегатрофи. Область, яка відповідає найбільшому рівню рекреаційного навантаження, є вакантною. Це вказує на те, що фактично не існує видів ґрунтової макрофауни, які могли б існувати за умов інтенсивного рекреаційного впливу

**Ключові слова**: екоморфи, ґрунт, екологічна ніша, ґрунтові безхребетні, рекреаційний тиск

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# The Effect of the Timing of Manure Application in Combination with Mineral Fertilizers and Planting Density on the Weediness of Potato Plantings

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**Abstract**. Potatoes are one of the most responsive crops for grooming techniques since in the period from seedlings before closing rows are easily suppressed by weeds that take away nutrients, water, light from it. The factor that causes high harm to potatoes is weed. By absorbing a large number of nutrients and moisture from the soil, weeds inhibit the growth and development of plants, reducing their potential productivity. The purpose of the study was to establish the effect of the timing of the introduction of bedding manure in conjunction with mineral fertilizers and planting density on the weediness of potato plantings. Studies were provided to identify the impact of the timing of bedding manure together with mineral fertilizers and planting density for weed planting potatoes. Experiments were laid by the systematic method with a tiered arrangement of variants in the experiment with a 3-fold repetition. We used cattle manure on straw bedding for autumn-winter harvesting. The following types of fertilizers were used: ammonium nitrate, double superphosphate, potassium chloride. Determination of the amount and biomass of weeds in potato plantings was carried out in the flowering phase and before harvesting. The application of manure was accompanied by an increase in the number and weight of weeds. Annual weeds predominated in potato plantings: *Amaranthus retroflexus* L., 1753 and *Amaranthus blitoides* S. Watson, 1877, *Chenopodium album* L. Chenopodium album L., 1753, *Setaria* P. Beauv, 1812 and *Setaria viridis* (L.) P. Beauv, 1812, *Echinochloa crus-galli* (L.) BEAUV., 1812 and others, perennials included *Cirsium arvense* (L.) SCOP. 1772 and *Sonchus arvensis* L., 1753, (*Elytrigia repens* (L.) DESV. ex NEVSKI, 1933 and others. Planting density also has a definite effect on the development of weeds. When manure was applied in autumn under the plow, the number of weeds increased in comparison with other options, where only mineral fertilizers were applied. The application of manure over frozen plow and in winter over snow leads to a slight decrease (2.3-2.5 pcs/m$^2$) of weeds. The greatest number of weeds is observed during the spring application of manure for plowing the fall plow. Nevertheless, studies aimed at clarifying the composition and structure of weediness, the number and weight of weeds in potato plantings are of great practical importance for local agricultural producers. These data should contribute to the development of an effective weed control system and high yields of potatoes in the region

**Keywords**: quantity and weight of weeds, annual and perennial weeds, weed planting of potatoes, manure and mineral fertilizers



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## INTRODUCTION

Preservation and improvement of soil fertility is the main part of the general problem of rational use of land resources, increasing productivity, and improving the soil ecology of agricultural landscapes [1; 2]. One of the most effective factors affecting plant growth and productivity, is mineral nutrition. By regulating the intensity of nutrient supply to plants by applying fertilizers, it means changing the activity, and even the direction of biochemical reactions, which, ultimately, will significantly increase the efficiency of the fertilizers used and use the potential of the crop or varieties [3].

Some authors [4] found the use of mineral fertilizers, especially nitrogen, in moderate doses in combination with phosphorus, significantly improved the nutrient regime of the studied crops during their vegetation.

Potatoes are one of the most responsive crops for grooming techniques since in the period from seedlings before closing rows are easily suppressed by weeds that take away nutrients, water, light from it. The factor that causes high harm to potatoes is weed. The presence of weeds on the field leads to a dramatic decrease in the productivity of land and the marketability of tubers. By absorbing a large number of nutrients and moisture from the soil, weeds inhibit the growth and development of plants, reducing their potential productivity. Caring for potato plantings and harvesting tubers infested with weeds is difficult, therefore total costs also increase. After planting, tubers germinate slowly while weeds grow fast. In addition, the non-simultaneous germination of weeds complicates their elimination in the field. Weeds generally absorb moisture and nutrients by growing in potato plantings. Thereby they reduce the moisture and nutrient content of the soil.

Strong weeds *Amaranthus*, *Sonchus arvensis* L., *Echinochloa crus-galli* (L.) Beauv, various species of *Polygonum* (L.) have a negative effect not only on the potato yield, but also on the size tubers which reduces them marketability complicate mechanized harvesting, increases storage losses [5]. Weed control is a necessary condition for increasing the yield of potatoes, improving their quality, and reducing labor costs [6]. B.A. Pisarev [7], and N.M. Nenakhova [8] argue that it is difficult to get rid of weeds sprouting in the second half of the summer, after closing the tops on heavily weedy potato plantings, even with frequent mechanical treatments, especially with frequent rains or irrigation.

According to A.M. Shpanev and others [9], the results of the research have revealed general positive effect of the mineral fertilizer application and protective measures on weed infestation and potato yield. This effect was developed on the second half of the vegetation and expressed in stronger inhibition of plant development (from 36.6 to 20.4 and 11.1 g/m$^2$ on low, medium, and high levels of mineral nutrition, respectively), in the reduction of species diversity (from 12 to 10 and 10 species/m$^2$) and number (from 69 to 42 and 32 species/m$^2$) of weeds. The highest biological (biomass reduction – 95.3%, the number of weeds – 79%) and economic (yield increase – 228 c/ha or 107%) effect was achieved by a high rates of mineral fertilizer application with combined protective measures of potato crops from weeds. In addition, this option was characterized by the greatest profitability (125.3%), whereas chemical protection, providing double treatment of potato plantings with herbicides, even at the middle and high level of mineral nutrition was less effective (102.6 and 109%) in economic terms.

J.V. Aspidova, M.S. Galiev [10] note that a high degree of weed infestation in the field reduces the productivity of harvesting machines by 50%, increases potato damage by 70%, and reduces the yield by 25%.

Some researchers [11] proved that the qualitative characteristics of potato weediness also changed significantly, whereas mechanical treatment of the control variant contributed to the preservation of the number of species of the weed component of the agrocenosis at a high level – 10 species/m$^2$ before hilling. In the studies of a number of authors [12], the use of the albite complex drugs in a tank mixture with the herbicide lapis lazuli, SP, in comparison with the treatment of plantings with herbicide only, increased the yield of potato tubers to 4.5 t/ha (by 19%) and tops to 0.6 t/ha (by 8%).

It is certain that in the presence of 10 weeds/m$^2$ before flowering, the productivity of plants decreases by 75.2 g, that is, each weed reduces the average yield of tubers by 4.5 g/m$^2$ [13]. For the Non-Black Earth Zone of Russia, the presence of 5 *Chenopodium album* L. plants per 1 m$^2$ reduces the yield by 43%. 40 plants – up to 74% [14]. Therefore, an analysis of research data carried out in a wide variety of soil and climatic zones shows that fertilizers and planting density have a certain effect on the weediness of the planting, which ultimately affects the yield and quality of potato tubers.

*The purpose of the study* was to establish the effect of the timing of the introduction of bedding manure in conjunction with mineral fertilizers and planting density on the weediness of potato plantings.

## MATERIALS AND METHODS

The experiment scheme:

1. $N_{60}P_{120}K_{60}$
2. $N_{90}P_{120}K_{60}$
3. 40 t of manure for wintering + $N_{60}P_{120}K_{60}$
4. 40 t of manure for wintering + $N_{90}P_{120}K_{60}$
5. 40 t of manure on frozen plow + $N_{60}P_{120}K_{60}$
6. 40 t of manure on frozen plow + $N_{90}P_{120}K_{60}$
7. 40 t of manure in winter on snow + $N_{60}P_{120}K_{60}$
8. 40 t of manure in winter on snow + $N_{90}P_{120}K_{60}$
9. 40 t of manure for plowing + $N_{60}P_{120}K_{60}$
10. 40 t of manure for plowing + $N_{90}P_{120}K_{60}$

Landing scheme: 70x25 cm and 70x25 cm. The research was carried out peasant farm "Tuatay" Chingirlau

district of West Kazakhstan region of the Republic of Kazakhstan in 2017-2019.

Soil dark chestnut, medium loamy [15]. The humus content in the arable horizon is from 2.6 to 3.4%, the thickness of the humus horizons is 45-55 cm, effervescence from 45-50 cm. In terms of the content of total nitrogen, phosphorus and potassium, as well as in terms of soil pH, experimental crop rotation fields were relatively homogeneous: total nitrogen content – 0.292-0.356%; $P_2O_5$ – 2,6-3,5 and $K_2O$ – 45,8-52,0% mg per 100 g of soil; pH – 7.2-7.3 aqueous extract.

The experiments were laid by the systematic method with a tiered arrangement of variants in the experiment. The total area of the plot is 84 $m^2$, the counting area is 56 $m^2$, the replication is 3 times. The experimental plot was divided into plots in the fall. The experiments were carried out in an irrigated area. The moisture content of the soil was maintained by irrigation in the range of 75-85% of the lowest moisture capacity of the soil.

The potatoes were placed in the vegetable crop rotation after the cucumbers. Winter plowing was carried out at the beginning of September to a depth of 27-30 cm. The selection of medium sized tubers (50-80 g) for the establishment of experiments was carried out in early spring. In the experiments, we used the zoned medium-early variety Nevsky. Planting was carried out with tubers germinated in the light.

Cattle manure on straw bedding was used for establishing the trial for the autumn-winter harvesting. Manure was obtained by bedding 5 kg of straw per 1 head of cattle with daily harvesting and storage in a pile on a concrete area. The characteristics of manure were as follows: humidity: 58-62%, pH: 7.5-8.0, total nitrogen: 0.50-0.55, phosphorus: 0.22-0.25, potassium: 0.58-0.62, ash: 12-14%. The composition of the manure differed little over the years. The following types of mineral fertilizers were used: ammonium nitrate, double superphosphate, potassium chloride.

Before the potatoes were planted in spring the soil was prepared in early-spring by plowing with fertilizer and harrowing.

Determination of the number and weight of weeds in potato plantings was carried out in the flowering phase and before harvesting.

## RESULTS AND DISCUSSION

The application of bedding manure was accompanied by an increase in the number and biomass of weeds (Table 1). The data show that the number and weight of weeds varied both by year and by variant. Irrigated lands West Kazakhstan region are littered with *Amaranthus retroflexus* L., 1753 and *Amaranthus blitoides* S. Watson, 1877, *Chenopodium album* L., 1753, *Xanthium strumarium* L., 1753, *Solanum nigrum* L., 1777, *Setaria* P.Beauv, 1812 and *Setaria viridis* (L.) P.Beauv, 1812, *Convolvulus arvensis* L., 1753, *Barbarea vulgaris* W.T.Aiton. 1812, *Echinochloa crus-galli* (L.) Beauv, 1812 and others.

In field experiments Z.P. Okazova [16], it was found that the main weeds of potato seeding are: *Galinsoga parviflora* (Cav.), 1795, *Artemisia vulgaris* L., 1753, *Ambrosia* L., 1753, *Panicum capillare* L., 1753, *Centaurea cyanus* L., 1753, *Papaver* L., 1753, *Atriplex* L., 1753, *Convolvulus arvensis* L., 1753, *Girsium arvense* L., 1753, *Melandrium album* L., 1789, *Erigeron canadensis* L., 1753, *Digitaria sanguinatis* L., 1753, *Cirsium arvense* (L.) SCOP., 1772 *Capsella bursa-pastoris* L., 1792, *Helianthus tuberosus* L., 1753.

***Table 1**. Influence of the timing of the introduction of manure on the weediness of potato plantings*

| Landing scheme | Terms of application of manure | The number and weight of weeds | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2017 | | | | 2018 | | | | 2019 | | | | Average over 3 years | | | |
| | | Flowering phase | | Before cleaning | | Flowering phase | | Before cleaning | | Flowering phase | | Before cleaning | | Flowering phase | | Before cleaning | |
| | | pcs/$m^2$ | g/$m^2$ | pcs/$m^2$ | g/$m^2$ | pcs/$m^2$ | g/$m^2$ | pcs/$m^2$ | g/$m^2$ | pcs/$m^2$ | g/$m^2$ | pcs/$m^2$ | g/$m^2$ | pcs/$m^2$ | g/$m^2$ | pcs/$m^2$ | g/$m^2$ |
| 70x25 cm | $N_{60}P_{120}K_{60}$ | 7.9 | 35.5 | 11.7 | 104.9 | 9.8 | 125.1 | 12.2 | 150.9 | 10.3 | 51.5 | 13.3 | 226.1 | 9.3 | 70.7 | 12.4 | 160.6 |
| | $N_{90}P_{120}K_{60}$ | 9.0 | 41.7 | 12.8 | 106.7 | 10.1 | 127.4 | 12.6 | 157.6 | 11.3 | 61.2 | 13.4 | 231.4 | 10.1 | 76.7 | 12.9 | 165.2 |
| | 40 t of manure for wintering + $N_{60}P_{120}K_{60}$ | 15.9 | 65.8 | 18.2 | 174.6 | 14.2 | 140.2 | 15.2 | 184.3 | 12.0 | 142.2 | 14.4 | 237.4 | 14.0 | 116.0 | 15.9 | 198.7 |
| | 40 t of manure for wintering + $N_{90}P_{120}K_{60}$ | 15.9 | 65.6 | 18.2 | 184.6 | 14.6 | 147.3 | 15.6 | 187.1 | 12.3 | 144.4 | 14.4 | 238.6 | 14.2 | 119.1 | 16.0 | 203.4 |
| | 40 t of manure on frozen plow + $N_{60}P_{120}K_{60}$ | 18.2 | 72.8 | 24.5 | 305.2 | 14.9 | 151.2 | 16.2 | 191.2 | 13.2 | 145.4 | 14.6 | 282.2 | 15.4 | 123.1 | 18.4 | 259.5 |
| | 40 t of manure on frozen plow + $N_{90}P_{120}K_{60}$ | 18.8 | 86.9 | 25.5 | 322.2 | 15.0 | 152.6 | 16.4 | 191.9 | 13.4 | 145.5 | 15.5 | 246.3 | 15.7 | 128.3 | 19.1 | 253.4 |

*Table 1, Continued*

| Landing scheme | Terms of application of manure | The number and weight of weeds | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2017 | | | | 2018 | | | | 2019 | | | | Average over 3 years | | | |
| | | Flowering phase | | Before cleaning | | Flowering phase | | Before cleaning | | Flowering phase | | Before cleaning | | Flowering phase | | Before cleaning | |
| | | pcs/m$^2$ | g/m$^2$ | pcs/m$^2$ | g/m$^2$ | pcs/m$^2$ | g/m$^2$ | pcs/m$^2$ | g/m$^2$ | pcs/m$^2$ | g/m$^2$ | pcs/m$^2$ | g/m$^2$ | pcs/m$^2$ | g/m$^2$ | pcs/m$^2$ | g/m$^2$ |
| 70x25 cm | 40 t of manure in winter on snow + $N_{60}P_{120}K_{60}$ | 19.2 | 94.6 | 24.6 | 300.6 | 14.5 | 150.2 | 16.4 | 192.5 | 13.2 | 144.9 | 14.5 | 240.7 | 15.6 | 129.9 | 18.5 | 244.6 |
| | 40 t of manure in winter on snow + $N_{90}P_{120}K_{60}$ | 20.5 | 101.4 | 25.0 | 308.2 | 14.9 | 151.7 | 16.5 | 192.7 | 13.2 | 145.0 | 14.8 | 243.2 | 16.2 | 132.7 | 18.7 | 248.0 |
| | 40 t of manure for plowing + $N_{60}P_{120}K_{60}$ | 24.5 | 128.5 | 27.4 | 328.2 | 15.4 | 157.2 | 17.8 | 195.2 | 13.9 | 148.4 | 15.3 | 248.2 | 17.9 | 144.7 | 20.1 | 257.2 |
| | 40 t of manure for plowing + $N_{90}P_{120}K_{60}$ | 25.6 | 134.6 | 28.1 | 333.6 | 15.7 | 161.4 | 18.1 | 198.2 | 14.0 | 148.8 | 15.4 | 252.3 | 18.4 | 148.2 | 20.5 | 261.3 |
| 70x35 cm | $N_{60}P_{120}K_{60}$ | 10.8 | 42.4 | 13.4 | 216.4 | 10.4 | 122.4 | 12.6 | 152.4 | 10.9 | 58.3 | 13.7 | 244.1 | 10.7 | 74.3 | 13.2 | 204.3 |
| | $N_{90}P_{120}K_{60}$ | 12.4 | 44.6 | 14.1 | 218.6 | 11.3 | 129.1 | 13.4 | 158.1 | 11.6 | 67.1 | 15.1 | 249.7 | 11.7 | 80.2 | 14.2 | 208.9 |
| | 40 t of manure for wintering + $N_{60}P_{120}K_{60}$ | 16.6 | 78.4 | 22.2 | 372.8 | 15.2 | 134.2 | 19.1 | 224.2 | 13.3 | 150.7 | 16.7 | 252.6 | 15.0 | 121.1 | 19.3 | 283.2 |
| | 40 t of manure for wintering + $N_{90}P_{120}K_{60}$ | 19.8 | 82.8 | 23.2 | 384.5 | 15.4 | 134.9 | 19.2 | 225.2 | 13.6 | 159.4 | 17.5 | 257.9 | 16.2 | 125,7 | 19.9 | 289.2 |
| | 40 t of manure on frozen plow + $N_{60}P_{120}K_{60}$ | 22.4 | 98.4 | 22.0 | 364.6 | 15.7 | 139.3 | 19.4 | 225.6 | 13.7 | 161.3 | 17.6 | 263.2 | 17.2 | 133.0 | 19.6 | 284.4 |
| | 40 t of manure on frozen plow + $N_{90}P_{120}K_{60}$ | 23.1 | 104.5 | 22.8 | 369.1 | 15.9 | 141.1 | 19.5 | 226.3 | 13.9 | 162.2 | 17.8 | 264.1 | 17.6 | 136.0 | 20.0 | 286.5 |
| | 40 t of manure in winter on snow + $N_{60}P_{120}K_{60}$ | 22.8 | 136.6 | 21.8 | 351.4 | 15.3 | 154.1 | 19.0 | 225.2 | 13.4 | 153.3 | 17.1 | 248.2 | 17.1 | 148.0 | 19.3 | 274.9 |
| | 40 t of manure in winter on snow + $N_{90}P_{120}K_{60}$ | 23.4 | 137.4 | 22.2 | 371.2 | 15.6 | 157.2 | 19.1 | 224.9 | 13.5 | 157.2 | 17.3 | 249.1 | 17.5 | 150.6 | 19.5 | 281.7 |
| | 40 t of manure for plowing + $N_{60}P_{120}K_{60}$ | 28.4 | 211.6 | 29.5 | 394.6 | 17.2 | 167.6 | 20.2 | 251.2 | 14.4 | 171.8 | 19.1 | 283.2 | 20.0 | 183.4 | 22.9 | 309.6 |
| | 40 t of manure for plowing + $N_{90}P_{120}K_{60}$ | 29.6 | 244.4 | 30.4 | 401.4 | 18.2 | 172.1 | 21.1 | 256.3 | 14.7 | 178.3 | 19.7 | 286.3 | 21.1 | 198.2 | 23.7 | 314.6 |

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

The development and predominance of certain weed plants determined their different number and weight. The experimental plot was dominated by annual weeds: *Amaranthus retroflexus* L., 1753 and *Amaranthus blitoides* S. Watson, 1877, *Chenopodium album* L. Chenopodium album L., 1753, *Setaria* P.Beauv, 1812 and *Setaria viridis* (L.) P. Beauv, 1812, *Echinochloa crus-galli* (L.) BEAUV., 1812 and others, perennials included *Cirsium arvense* (L.) SCOP., 1772 and *Sonchus arvensis* L., 1753, (*Elytrigia repens* (L.) DESV. ex NEVSKI, 1933 and others.

In the field experiments A.A. Samarkin [17], by the time of harvesting, perennial weeds that were remained are: *Cirsiuem arocusa* (L.) Scop, 1772, *Soulus arocusis* L., 1753, of juvenile spring weeds met *Raphanus aphanisfmen* L., 1753, as well *Chenopodium alhem* L., 1753, among wintering ones - *Cenfaupea cuames* L., 1753, and *Capselle bursa - pasfonis* L., 1792.

The largest number of weeds was recorded in 2017. It was also noted that an increase in nitrogen in mineral fertilizer from $N_{60}$ to $N_{90}$ promotes an increase

in weeds in different variants from 0.6 to 3.2 weeds per square meter. This trend was observed in all years of research (Table 1).

Such data were also shown by A.A. Skryabin [18], where the highest percentage of weeds was observed during the use of nitrogen fertilizers at a dose of 90 kg (35 kg dry matter), the smallest 201 kg dry matter – at the introduction of 120 kg of a.s. of nitrogen.

With the introduction of bedding manure in the fall under the fall, the number of weeds increased in comparison with other options where only mineral fertilizers were applied, in 2017 by 6.9-8.0 pieces, in 2018 – by 4.4-4.5, in 2019 – by 1.0-1.1 pcs, and the weight, respectively, by 23.9-30.3; 15.1-19.9 and 83.2-90.7 grams in the flowering phase and 69.7-77.9; 29.5-33.4 and 7.2-11.3 g before harvesting.

In the studies of A.V. Ivenin [19], weed control reduces the level of weed infestation at the beginning of the growing season (after germination) to 7.1-8.2 weeds/m², including 0.7-1.6 weeds/m² of perennials. In the option of the field experiment with autumn tillage use, the amount of weeds is lower than in the option without it. By the end of the growing season of potatoes, the infestation of annual weeds increases and reaches 8.0-8.9 pcs/m².

The application of manure over frozen plow and in winter over snow leads to a slight decrease (2.3-2.5 pcs/m²) of weeds. The greatest number of weeds is observed during the spring application of manure for plowing the plow (Fig. 1). Such data were also shown in the experiments of A.A. Vasiliev [20], that in the South Urals the infestation of potato plantings with wheatgrass is low (0.2 pcs/m²). Steaming with the use of spring rape resulted in a 4-fold decrease in this indicator, and a 2-fold decrease in the vetch-oat mixture, compared with black fallow.

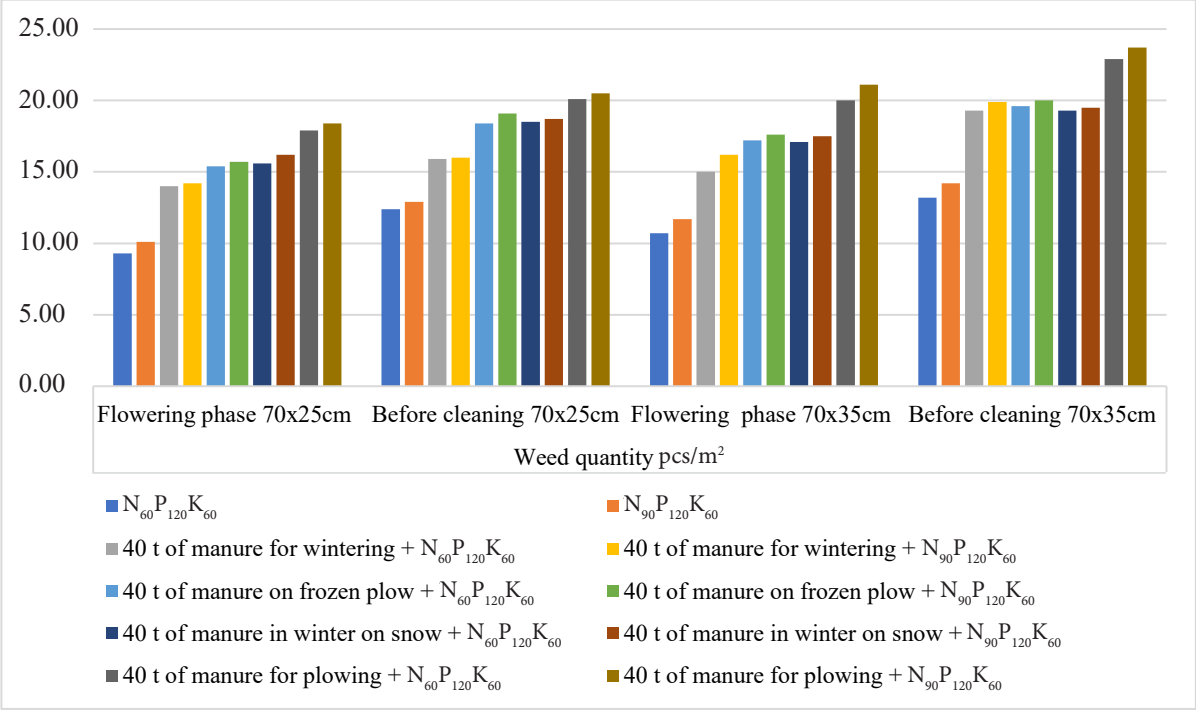


***Figure 1***. *Influence of the timing of the introduction of manure on the weediness of potato plantings, pcs/m²*
***Source***: *compiled by the authors*

In the flowering phase, on average for 3 years in this variant, there were 20 weeds against the background of $N_{60}P_{120}K_{60}$ and 21.1 weeds against the background of $N_{90}P_{120}K_{60}$ with a planting of 70x35 cm and 17.9 and 18.4, respectively. when planting 70x25 cm, before harvesting – respectively 22.9; 23.7; 20.1 and 20.5, which is 7.6-7.7 tons more than on the variants without manure application 9.5-9.7 weeds before harvesting, and in comparison with the flowering phase – by 8.3-8, 6 when planting 70x25 cm and by 9.3-9.4 (when planting 70x35 cm), and their mass increased, respectively, in the flowering phase by 2.47; 1.93-2.05 times, before harvesting – 1.50-1.51 and 1.58-1.60 times (Fig. 2).

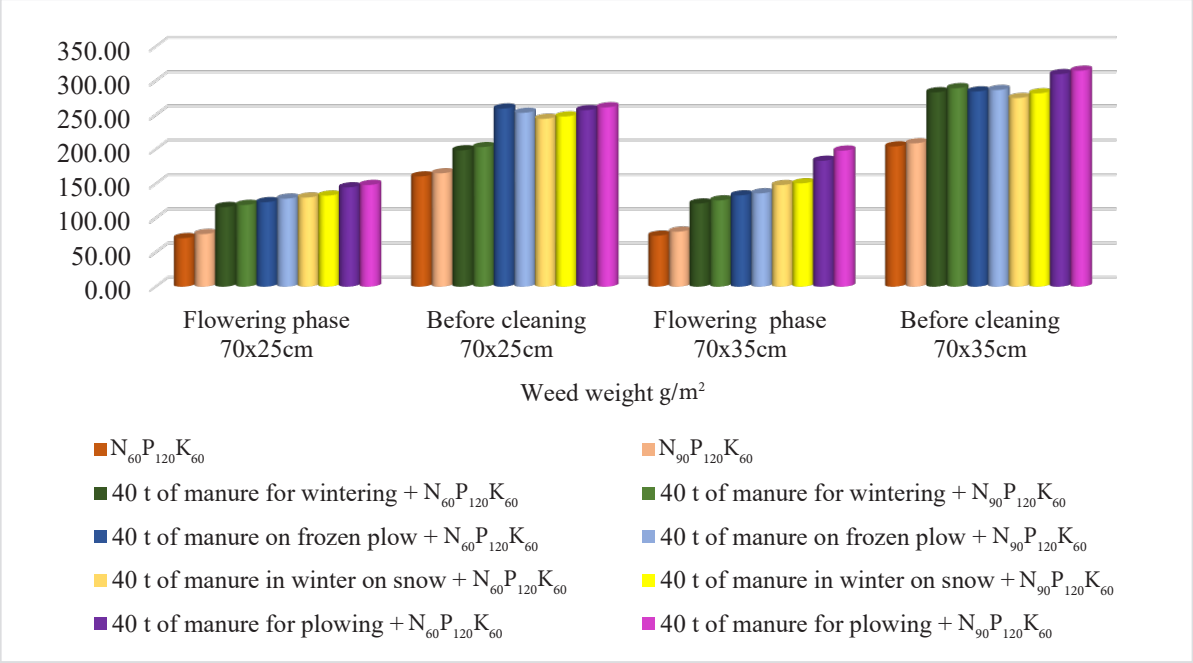


***Figure 2**. Influence of the timing of manure application on the weight of weeds, g/m²*
***Source**: compiled by the authors*

The planting density of potatoes also has a definite effect on the development of weeds. So, when applying only mineral fertilizers in doses of $N_{60}P_{120}K_{60}$ and $N_{90}P_{120}K_{60}$and when planting 70x25 cm, the number of weeds on average for 3 years was, respectively, in the flowering phase 12.4 and 12.9 per 1 m², when planting 70x35 cm – 13.2 and 14.2 pcs/m², and their weight increased by 38.1-96.6 g/m², before harvesting – by 70.6-105.7 g/m².

## CONCLUSIONS

Thus, the introduction of bedding cattle manure increases the number of weeds on plantings and their weight:

– an increase in nitrogen in mineral fertilizers from $N_{60}$ to $N_{90}$ promotes an increase in weeds;

– a certain influence on the development of weeds is also exerted by the planting density of potatoes;

– with the introduction of bedding manure in autumn under the winter plow, the number of weeds increased in comparison with other options;

– application of manure over frozen plow and in winter over snow leads to a slight decrease in weeds.

– the greatest number of weeds is observed during the spring application of manure for plowing the fall plow.

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## Вплив термінів внесення гною у поєднанні з мінеральними добривами та густоти посадки на засміченість посадок картоплі

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**Анотація**. Картопля є одним з найбільш чуйних культур на прийоми догляду, оскільки в період від сходів до змикання рядів легко пригнічується бур'янами, які відбирають у неї живильні речовини, воду, світло. Велику шкоду картоплі завдають бур'яни. Наявність на полі бур'янів сприяє сильному зниженню врожайності та товарних якостей бульб. Поглинаючи з ґрунту велику кількість поживних речовин та вологи, бур'яни пригнічують ріст і розвиток рослин, знижуючи їхню потенційну продуктивність. Дослідження проводилися для виявлення впливу термінів внесення підстилкового гною разом із мінеральними добривами і густоти посадки на засміченість посадок картоплі. Досліди закладалися системним методом з ярусним розташуванням варіантів в досліді, повторність 3-кратна. Використовували гній великої рогатої худоби на солом'яній підстилці осінньо-зимової заготівлі. Застосовували такі види добрив: аміачну селітру, подвійний суперфосфат, хлористий калій. Визначення кількості та біомасу бур'янів у посадках картоплі проводили у фазі цвітіння та перед збиранням урожаю. Внесення гною супроводжувалося збільшенням кількості та маси бур'янів. У посадках картоплі переважали однорічні бур'яни: *Amaranthus retroflexus* L., 1753 і *Amaranthus blitoides* S. Watson, 1877, *Chenopodium album* L., 1753, *Setaria* P. Beauv, 1812 і *Setaria viridis* (L.) P. Beauv, 1812, *Echinochloa crus-galli* (L.) BEAUV., 1812 та ін., з багаторічних зустрічалися *Cirsium arvense* (L.) SCOP., 1772 і *Sonchus arvensis* L., 1753, (*Elytrigia repens* (L.) DESV. ex NEVSKI, 1933 та ін. Певний вплив на розвиток бур'янів і густота посадки. При внесенні гною восени під зяб кількість бур'янів зростала порівняно з іншими варіантами, де вносилися тільки мінеральні добрива. Внесення гною по замерзлому зябу і взимку по снігу призводить до незначного зниження (2,3–2,5 шт./м$^2$) бур'янів. Найбільша кількість бур'янів відзначається при весняному внесенні гною під переорювання зябу. Тим не менш, для місцевих сільгоспвиробників велику практичну значущість мають дослідження, націлені на уточнення складу та структури засміченості, кількості та маси бур'янів у посадках картоплі. Ці дані мають сприяти виробленню ефективної системи боротьби з бур'яном і отриманню високих урожаїв картоплі в регіоні

**Ключові слова**: кількість та маса бур›янів, однорічні та багаторічні бур›яни, засміченість посадок, гній та мінеральні добрива

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# Quality of Pea Seeds and Agroecological Condition of Soil When Using Structured Water

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**Abstract**. The widespread use of water in crop production and agriculture is due to a significant increase in yields during the watering of agricultural crops, as well as the transfer of pesticides and mineral fertilizers to plants and soil by water. One of the ways to improve the quality of water used in crop production is to structure it. An urgent task is to study the effect of structured water delivered to agricultural crops by watering or spraying on the yield, quality of the resulting products and agroecological condition of the soil. Field studies on pea crops were conducted at experimental sites of the Vinnytsia National Agrarian University, laboratory studies were conducted in accredited laboratories for monitoring the quality, safety of feed and raw materials of the Institute of Feed Research and Agriculture of Podillya of the National Academy of Agrarian Sciences of Ukraine and the testing centre of the Vinnytsia branch of the state institution "Institute of Soil Protection of Ukraine". When watering peas with structured water, its yield increases by 42.3% compared to the version without water application and by 22.3% compared to the version with watering with plain water. Pea seeds when watered with structured water have a lower content of crude protein by 0.43 %, crude fat – by 0.09%, crude ash – by 0.63%, but a higher content of crude fibre by 0.11% and nitrogen-free extractives – by 0.99% compared to the version without water. The content of humus in the soil, when watered with structured water, was lower than in the version without water by 0.04%, lightly hydrolysed nitrogen – by 8.0%, mobile phosphorus – by 20.0%, exchangeable potassium – by 7.9%, the reaction of the soil solution – by 0.2 pH, hydrolytic acidity – by 21.7%, the concentration of mobile lead – by 18.4%. However, the concentration of mobile cadmium increased by 43.8% and soil moisture – by 4.3%. When comparing the indicators of the agroecological state of the soil, which was watered with structured and plain water, it was found that watering with structured water reduces the content of humus by 0.03%, lightly hydrolysed nitrogen – by 2.3%, mobile phosphorus – by 20%, exchange potassium – by 9.7%, hydrolytic acidity – by 7.7%, the reaction of the soil solution – by 0.3 pH, but increases the content of mobile lead by 10.9%, mobile cadmium – by 25.0% and increases the moisture content in the soil – by 2.7%

**Keywords**: grain, chemical composition, fertility, acidity, heavy metals, humidity



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## INTRODUCTION

Water is widely used in crop production and agriculture, in particular, most pesticides and some fertilisers are applied through transportation by the aquatic environment. In the conditions of climate aridisation, the role of water in the watering and irrigation of crops is growing. It is a well-known fact that crop yields increase considerably when crops are watered. At the same time, it is not rational to fully use irrigation of agricultural crops by sprinkling due to the high material costs of restoring or creating an irrigation system and water needs. Therefore, a more promising method of irrigation is drip irrigation with economical use of water by bringing irrigation tapes to each row. This method of watering the crops is mainly used in vegetable growing and in limited areas [1].

Due to global warming, water shortages in crop production will become more and more acute every year, so the question of delivering water to plants in some form or other in the most sustainable way with special preparation and saturation with nutrients, growth regulators or pesticides will be extremely relevant. Among the methods of water treatment for use, structuring has recently become widespread, which implies the acquisition of a natural molecular structure by water. Among a significant number of methods of water structuring: freezing, cavitation, the use of ultrasound, magnetic radiation – a new method is information structuring by activating water. Unlike prolonged freezing, water structuring through activation occurs almost instantly. This is confirmed by studies of the laboratory of the company "Soyana" and experiments to assess the average motor ability of spirost (infusoria type). The method of structuring water by activation is based on the transmission of bioelectric information, or energy. Structuring occurs in the form of changes in the geometric structures of water crystal molecules. Changing the structure of water can change its physical and chemical characteristics and affect the growth and development of plants and the state of the soil in a completely different way [2].

Structured water is largely close to natural water in its characteristics. It is characterised by an ordered liquid crystal structure with the preservation of biological information. Structured water is more fluid with altered dielectric properties. These changes accelerate the processes of crystallisation, dissolution, adsorption and energy transfer. It is these characteristics that accelerate the course of biological processes in the cell [3].

Structured water is marked by an ordered cluster structure. Such water corresponds in structure to the water contained in the cells of organisms, so the processes of its assimilation proceed much faster. When this water enters plants, the protective functions of the cell increase, and a number of biochemical processes accelerate. Components of structured water – mineral salts, trace elements, gases, as well as temperature have a positive effect on living organisms [4].

In structured water, the rate of chemical reactions and crystallisation of solutes increases, adsorption processes intensify, coagulation of impurities and their precipitation improves. The structuring of water affects the behaviour of impurities contained in it, although the essence of these phenomena has not yet been precisely clarified. It is quite possible that the biological effect of structured water on the body is since the channels (pumps) of tissue cell membranes pass structured water molecules at an increased rate, because the regular structure of water resembles the regular structure of the cell membrane itself – highly structured organelles [5].

Clusters of water molecules are generally made up of many well-attracted molecules. This form of attraction allows toxins and pollutants to enter a cluster of water molecules. When these clusters of water pass through the cell membrane, many of them linger because they are too large or because of toxins that the plant is programmed to reject. Smaller of these chaotic clusters will enter the cell, and some carry toxins with them [6].

Structuring changes water molecules into very small clusters, each consisting of six symmetrically organised molecules. This cluster is called "biologically pure" because of its hexagonal structure and because toxins cannot move inside the cluster and easily enter the passages of plant and animal membranes. The result provides maximum, healthy hydration with less water. Structured water breaks down clusters of individual molecules, providing better hydration for humans, animals, and plants.

Water structurizers further break down minerals into small particles, making them more bioavailable to plant cells. This contributes to maximum hydration of healthy water with greater absorption of nutrients and leads to increased yields, better quality, earlier maturation, long-term storage and higher resistance of plants to harmful organisms. It also reduces the amount of water, fertilisers, and pesticides applied [7]. As structured water breaks down all minerals into smaller particles, the salt in the soil is broken down by the structured water, causing it to sink deeper into the soil away from the plant roots and be washed away. Decontamination occurs quickly throughout the season, creating much healthier plants, higher yields, and a better end product.

Today, there are no problems in obtaining structured water. There are compact and widely available water structurizers of both industrial and domestic nature. It is a nozzle that must be connected to the water supply pipes, which ensures the structuring of water. The only problem is calculating the required amount of liquid and the pressure supplied to the nozzle [8].

*Purpose of the article* is to determine the effectiveness of using structured water on pea crops and determine the most economical way to deliver such water to plants.

## THEORETICAL OVERVIEW

According to H. Xu, R. Yang, J. Song agricultural water use is one of the largest in terms of water intake, so improving the efficiency of water use and quality by agricultural enterprises is an important way to reduce water scarcity. However, the expected saving of water by improving the efficiency of use and improving its quality may have the opposite result – insufficient increase in crop yields, deterioration of product quality and soil degradation [9].

According to S. Hou, H. Guo, K. Pan, J. Liu, and L. Zhang [10] studying the structure of water use in crop cultivation can become the basis for agricultural water management and a way to improve the efficiency of agricultural water use. The use of the necessary water resources for agricultural production, including chemical fertilisers, pesticides and the capacity of agricultural machinery, will inevitably provide indirect water for agricultural production.

N. Lu, K.M. Villa studied the influence of the use of contaminated water for agricultural needs on the health status of the population that ate products obtained by watering with such water [11]. J. Xie and X. Su investigated ways of rational water use in agriculture and crop production based on determining the costs of water delivery, preparation and application [12].

Since agriculture is a water-intensive industry, smart planning of agricultural water use is very important to ensure food security, therefore C. Li, T.T. Jiang, X.B. Luan, Y.L. Yin, P.T. Wu, Y.B. Wang, S.K. Sun analyse the contribution of four factors (water efficiency, productivity, crop structure, and scale of production) that affect the need for water for agriculture. Among these, water use efficiency and adjustments to the plantation structure have played a decisive role in helping to reduce water demand. Increasing productivity will increase water efficiency, thereby reducing the need for water for agriculture. However, large-scale expansion of production compensates for the role of increasing productivity and leads to an increase in the need for water for agriculture. To reduce the demand for water for agriculture, it would be important to improve water efficiency, improve irrigation technology, and not introduce more water resources to expand production [13].

The increased solubility of minerals enhanced microbiological properties and a long storage period after water treatment with structurizers can ensure not only an increase in the productivity of agricultural crops, but also change the chemical composition of products and the agroecological state of the soil, taking into account the significant saturation of crop rotations with mineral fertilisers and pesticides. The use of such water when spraying or watering crops by installing structurizers in the path of water movement can affect the overall state of the agroecosystem. However, very few such studies have been conducted, so there is little reliable data on the increase of agricultural crop productivity, changes in the chemical composition of products and the agroecological state of the soil when using structured water [14].

Therefore, an important direction for studying the effectiveness of using structured water in crop production is the method of treating agricultural crops with such water in different phases of their growth and development; the study of the optimal method of transporting structured water to plants by watering the soil or spraying crops.

## MATERIALS AND METHODS

The research was conducted during 2019-2021 at the experimental sites of the Vinnytsia National Agrarian University within an open stationary greenhouse without covering with free precipitation and with centralised water supply. A small-plot experiment with an estimated plot area of 4 $m^2$ in 5 replications was established. The research programme was supposed to study the effect of using structured water on the yield of pea grain, its chemical composition and agroecological state of the soil. For this purpose, 5 variants were laid: 1 – without processing the pea crop with water (control); 2 – spraying the crop with structured water; 3 – watering the crop with structured water; 4 – water-ing the crop with plain water.

Processing of pea crops was carried out three times during the growing season: 1 – in the phase of three pea leaves; 2 – in the branching phase; 3 – in the budding phase. Spraying was carried out with a satchel sprayer with a water consumption of 200 l/ha. Watering was carried out by sprinkling with a sprinkler with an irrigation dose of 300 l/ha at a time. Water structuring was carried out by installing a structuring device on a centralised water supply pipe, followed by filling it with a sprayer or sprinkler. Spraying and watering was carried out in the evening in dry weather. The water structurizer "Ojas" was used [15].

The pea variety Album was sown. The yield of the variety is 2.96-3.78 t/ha. The duration of the growing season is about 82-84 days. Plant height – 63.6-72.5 cm. Resistance to lodging – 6.6-7.4 points. Resistance to shedding – 8.2-8.5 points. Drought resistance – 8.7-8.8 points. The suitability of the variety for mechanised harvesting – 7.8-8.8 points. Resistance to peronosporosis – 8.5-8.7 points. Resistance to root rot – 8.6-8.8 points. Resistance to ascochytosis – 7.8-8.5 points. Resistance to anthracnose – 8.3-8.4 points. The protein content – 24.4-24.8%. The height of attachment of the lower bean – 40-45 cm. Adapts to a variety of soil and climatic growing conditions. A highly suitable variety for mechanised harvesting [16].

Peas were sown manually in mid-April. Special measures to protect pea crops from pests and diseases were not carried out. One-time manual weeding was

performed. The crop was harvested manually with grain weighing.

The following records and observations were carried out: grain yield was determined by weighing grain from the entire accounting area with conversion to 1 ha and to the standard humidity of seeds [10]; the chemical composition of grain in absolutely dry matter was determined in certified to confirm technical competence when conducting measurements in accordance with the requirements of DSTU ISO 10012:2005 "Measurement management system. Requirements for measurement processes and measuring equipment" of Laboratory for Monitoring the Quality, Safety of Feed and Raw Materials of the Institute of Feed Research and Agriculture of Podillya of NAAS: crude protein – by the Kjeldahl method, crude fat – by the Rushkovsky method for the amount of fat – free residue, crude fibre – by the Henneberg and Stoman method in the CSRIASA modification according to DSTU ISO 21415-2:2009, crude ash – by the dry ozylation method, nitrogen-free extractives – by the calculation method [17].

Agroecological analysis of the soil was carried out in the certified test centre of the Vinnytsia branch of the state institution "Institute of Soil Protection of Ukraine" in accordance with the requirements of DSTU ISO/IEC 17025:2017 according to the following indicators: humus – according to GOST 26213-91; lightly hydrolyzed nitrogen – by the Kornfield method according to DSTU 7863:2015; mobile phosphorus and exchangeable potassium – by the Chirikov method according to DSTU 4115:2002; the reaction of the soil solution PH – according to DSTU ISO 10390-2007; hydrolytic acidity – according to DSTU 7537-2014; mobile lead – according to DSTU 4770.9-0007; mobile cadmium – according to DSTU 4770.3-0007; moisture – by thermostatic-weight method [18; 19].

The soil on the experimental site of a stationary greenhouse is bulk, chernozem. Weather conditions during the years of research were typical for the forest-steppe zone of right-bank Ukraine with an uneven distribution of precipitation during the growing season of peas: prolonged droughts were replaced by intense precipitation, which limited the introduction of water to pea crops, especially in the late phases of its growth and development.

## RESULTS AND DISCUSSION

The humus content in the soil of the control variant without water use was the highest and amounted to 4.44%. This was 0.01% more than in the variant of watering of pea crops with plain water, 0.02% more than in the variant of spraying pea crops with structured water, and 0.04% less than in the vari-ant of irrigation of pea crops with structured water (Table 1).

***Table 1**. Indicators of the agroecological state of the soil when processing pea crops using structured water (2019-2021), m±m*

| Indicator name | Experiment options | | | |
|---|---|---|---|---|
| | Without water use (control) | Spraying with structured water | Watering with structured water | Watering with plain water |
| Humus, % | 4.44±0.02 | 4.42±0.01 | 4.40±0.02 | 4.43±0.02 |
| Lightly hydrolyzed nitrogen, mg/kg | 137±3 | 120±2 | 126±3 | 129±3 |
| Mobile phosphorus, mg/kg | 600±8 | 480±12 | 480±12 | 600±8 |
| Exchangeable potassium, mg/kg | 252±2 | 222±3 | 232±2 | 257±3 |
| Soil solution reaction, pH | 6.9±0.1 | 7.0±0.1 | 6.7±0.2 | 7.0±0.1 |
| Hydrolytic acidity, mg-equiv./100 g | 0.46±0.03 | 0.37±0.02 | 0.36±0.02 | 0.39±0.02 |
| Mobile lead, mg/kg | 1.58±0.03 | 0.95±0.02 | 1.29±0.02 | 1.15±0.03 |
| Mobile cadmium, mg/kg | 0.09±0.01 | 0.13±0.01 | 0.16±0.01 | 0.12±0.01 |
| Moisture, % | 12.5±1.2 | 18.1±0.8 | 16.8±0.6 | 14.1±0.9 |

***Source**: authors' research*

The content of lightly hydrolysed nitrogen in the control soil without water application was 137 mg/kg and was the highest among all experimental variants. When watering pea crops with plain water, the content of lightly hydrolysed nitrogen in the soil decreased by 5.8%, when watering pea crops with structured water – by 8.0%, when spraying pea crops with structured water – by 12.4%.

The content of mobile phosphorus in the soil of the control variant without using water and the variant of watering of pea crops with plain water was the highest and amounted to 600 mg/kg. When using structured water on pea crops, the content of mobile phosphorus in the soil decreased by 20%.

The concentration of exchangeable potassium in the soil of the control variant without the use of water

was 252 mg/kg. This was 1.9% less than when watering peas with plain water, but 7.9% more than when watering peas with structured water and 11.9% more than when spraying peas with structured water.

The reaction of the soil solution in the control without water application was 6.9 pH, which was 0.1 pH less than in the variants of spraying peas with structured water and watering peas with plain water, but 0.2 pH more than in watering peas with structured water.

The hydrolytic acidity of the soil in the control variant without water application was the highest and amounted to 0.46 mg-equiv./100 g. In the variant of watering peas with plain water, it was 15.2% less, on the option of spraying peas with structured water – by 19.6%, and on the option of watering peas with structured water – by 21.7% less.

The concentration of mobile forms of lead in the soil in the control variant without water use was the highest and amounted to 1.58 mg/kg. In the variant of watering pea crops with structured water, the concentration of mobile forms of lead decreased by 18.4%, in the variant of watering of pea crops with plain water – by 27.2%, and on the option of spraying pea crops with structured wa-ter – by 39.9% less.

The concentration of mobile cadmium forms in the control without water use was 0.09 mg/kg. This was 25% less than the variant of watering peas with plain water, 30.8% less than the option of spraying peas with structured water, and 43.8% less than the option of watering peas with structured water.

The soil moisture content of the control variant without water use was 12.5%, which was the lowest indicator among all the studied variants. When watering peas with plain water, soil moisture increased by 1.6%, when watering peas with structured water – by 4.3%, and when spraying peas with structured water – by 5.6%.

The analysis of the agroecological state of the soil when using structured water on pea crops showed that on the variants for using structured water, the lowest content of humus, lightly hydrolyzed nitrogen, mobile phosphorus, exchangeable potassium in the soil is observed, the lowest reaction of the soil solution pH, hydrolytic acidity and concentration of mobile forms of lead. This indicates that structured water in the soil translates nutrients and toxic substances into easily accessible forms for plants, they consume more of it, which affects the higher productivity of plants from variants for processing pea crops with structured water. Reducing the hydrolytic acidity of the soil on the use of structured water has a positive role, since more favourable conditions for plant growth and development are created. At the same time, options for treating pea crops with structured water had the highest content of mobile forms of cadmium and moisture in the soil. The increased moisture content in the soil determines the formation of favourable conditions for the moisture supply of the next crop in the crop rotation due to more economical use of structured water by the crop that was watered.

Comparison of agroecological indicators of the soil in variants for watering of pea crops with structured and plain water showed that the content of humus in the soil where pea crops were watered with structured water was 0.03% less, lightly hydrolysed nitrogen – by 2.3%, mobile phosphorus – by 20%, exchangeable potassium – by 9.7%, the reaction of the soil solution – by 0.3 pH less than when watering pea crops with plain water. However, the hydrolytic acidity of the soil decreases when using structured water on pea crops by 7.7% and the moisture content increases by 2.7%, which is a positive manifestation. The concentration of mobile forms of heavy metals in the soil also increases when watering peas with structured water, compared to watering peas with plain water: lead – by 10.9%, cadmium – by 25.0%.

Comparison of the effect on the soil of spraying and watering with structured water of pea crops revealed a tendency to reduce the humus content by 0.02%, increase the concentration of mobile forms of lead by 26.4%, cadmium – by 18.8%, decrease soil moisture by 7.2% and the reaction of soil solution – by 0.3 ph when watering pea crops with structured water. A negative manifestation of structured water spraying of pea crops, compared with their watering, was observed in relation to a decrease in the content of lightly hydrolysed nitrogen by 4.8%, exchangeable potassium – by 4.3%, but a positive change in the hydrolytic acidity of the soil, which decreased by 2.7%.

The obtained indicators confirm the thesis that structured water breaks down minerals contained in the soil into smaller particles, which facilitates their use by plants, including such toxic substances in the soil as heavy metals. This leads to a decrease in the concentration of minerals in the soil when watering crops with structured water.

The highest yield of pea grain was found in the variant of watering its crops with structured water – 5.79 t/ha, which was 42.3% more than in the control without water and 22.3% more than in the variant of watering peas with plain water. Spraying pea crops with structured water provides a seed yield of 4.65 t/ha, which was 28.2% more than in the control without water, but 19.7% less than when watering pea crops with structured water (Table 2).

***Table 2**. Pea grain yield depending on its processing with structured water (2019-2021), m±m*

| Variants for processing pea crops | Seed yield, t/ha | ± Before control, % |
|---|---|---|
| Without using water (control) | 3.34±0.08 | – |
| Spraying with structured water | 4.65±0.05 | +28.2 |
| Watering with structured water | 5.79±0.03 | +42.3 |
| Watering with plain water | 4.50±0.05 | +25.8 |

***Source**: authors' research*

Thus, it was found that at the site of watering pea crops with structured water, the yield of its seeds increases due to more intensive absorption of nutrients from the soil and, accordingly, impoverishment of the soil on them.

Analysis of the chemical composition of pea seeds in absolutely dry matter during the processing of its crops with structured water showed that the crude protein content was the highest in the control without the use of water – 26.41%. When spraying pea crops with structured water, the content of crude protein in its seeds, compared with the control without water application, decreased by 0.13%, when watering pea crops with plain water – by 0.43%, and when watering pea crops with structured water – by 1.2% (Table 3).

***Table 3**. Chemical composition of pea grain depending on its processing with structured water, % for absolutely dry matter (2019-2021), m±m*

| Variants for processing pea crops | Crude protein | Crude fat | Crude fibre | Crude ash | Nitrogen-free extractives |
|---|---|---|---|---|---|
| Without using water (control) | 26.41±0.34 | 3.42±0.04 | 11.13±0.09 | 4.76±0.13 | 54.27±1.56 |
| Spraying with structured water | 26.28±0.27 | 3.39±0.03 | 13.11±0.07 | 4.38±0.11 | 52.84±1.61 |
| Watering with structured water | 25.21±0.22 | 3.33±0.03 | 11.24±0.07 | 4.13±0.08 | 56.09±1.70 |
| Watering with plain water | 25.98±0.24 | 3.28±0.02 | 11.55±0.06 | 3.93±0.08 | 55.26±1.62 |

***Source**: authors' research*

The crude fat content of pea seeds in the control variant without water was 3.42%. In the variant of spraying peas with structured water, the fat content in their seeds decreased by 0.03% compared to the control without water, when watering peas with structured water – by 0.09% and in the variant of watering peas with plain water – by 0.14%.

The crude fibre content of pea seeds from the control variant without water was 11.13%. In the variant of watering peas with structured water, it increased by 0.11%, in the variant of watering peas with plain water – by 0.42% and in the variant of spraying peas with structured water – by 1.98%.

The crude ash content of pea seeds in the variant without water use was 4.76% and was the highest among all experimental variants. When spraying pea crops with structured water, the content of raw ash in its seeds, compared with the control without the use of water, decreased by 0.38%, when watering pea crops with structured water – by 0.63%, when watering pea crops with plain water – by 0.83%.

Nitrogen-free extractives in pea seeds from the control variant without the use of water contained 54.27%. This was 1.43% more than in the variant of spraying pea crops with structured water, but 0.99% less than in the variant of watering pea crops with plain water and 1.82% less than in the variant of watering pea crops with structured water.

The results of the research showed that watering pea crops with structured water, compared with watering its crops with plain water, reduces the content of crude protein in pea seeds by 0.77%, crude fibre – by 0.31%, but increases the content of crude fat by 0.05%, crude ash – by 0.2% and nitrogen-free extractives – by 0.83%.

Spraying pea crops with structured water, compared with watering its crops with structured water, increases the content of crude protein in pea seeds by 1.07%, crude fat – by 0.06%, crude fi-bre – by 1.87%, crude ash – by 0.25%, but reduces the content of nitrogen-free extractives by 3.25%.

Thus, watering pea crops with structured water contributes to obtaining the highest yield of its seeds, the highest content of nitrogen-free extractives in the seeds, but the lowest content of crude protein.

Irrigation with structured water of pea crops leads to an increase in its yield by 42.3% compared to the control variant without using water. This is due to more intensive use of nutrients from the soil, which causes a decrease in the humus content in the variant of watering pea crops with structured water by 0.04%, lightly hydrolysed nitrogen – by 8.0%, mobile phosphorus – by 20.0%, exchangeable potassium – by 7.9%, acidification of the reaction of the soil solution by 0.2 pH, compared with the control variant without water use. The increase in the yield of pea seeds from the variant of watering peas with structured water occurs against the background of a decrease in its seeds, compared with the control without water, the content of crude protein – by 1.2%, crude fat – by 0.09%, crude ash – by 0.63%, but an increase in the content of crude fibre by 0.11% and nitrogen-free extractives – by 1.82%.

The efficiency of using structured water irrigation of pea crops in comparison with conventional water is manifested in an increase in the yield of its seeds by 16.5%. This indicator was achieved by reducing the content of humus in the soil by 0.03%, lightly hydrolysed nitrogen – by 2.3%, mo-bile phosphorus – by 20.0%, exchangeable potassium – by 9.7%, and acidification of the soil solution reaction by 0.3 pH. However, with an increase in the yield of pea seeds, when watering its crops with structured water, the content of crude protein decreases by 0.77%, crude fat – by 0.05%, and crude fibre – by 0.31%.

## CONCLUSIONS

Watering pea crops with structured water increases the yield of its seeds by 42.3% compared to the variant without using water and by 22.3% compared to watering with plain water. However, pea seeds reduce the content of crude protein by 0.43%, crude fat – by 0.09%, crude ash – by 0.63%, but increase the content of crude fibre by 0.11% and nitrogen-free extractives – by 0.99% compared to the option without water use. When watering peas with plain water, the content of crude protein in seeds from the structured water variant decreased by 0.77%, crude fibre – by 0.31%, but the content of crude fat increased by 0.05%, crude ash – by 0.2% and nitrogen-free extractives – by 0.83%.

When watering pea crops with structured water, changes in the agroecological state of the soil were observed compared to the variant without water use. In particular, the content of humus decreased by 0.04%, lightly hydrolysed nitrogen – by 8.0%, mobile phosphorus – by 20.0%, exchangeable potassium – by 7.9%, the reaction of soil solution – by 0.2 pH, hydrolytic acidity – by 21.7%, the concentration of mobile forms of lead – by 18.4% but increased the concentration of mobile forms of cadmium – by 43.8% and soil moisture – by 4.3%. Compared with the variant of watering pea crops with plain water, in the soil watered with structured water humus content was reduced by 0.03%, lightly hydrolysed nitrogen – by 2.3%, mobile phosphorus – by 20%, potassium exchange – by 9.7%, hydrolytic acidity – by 7.7%, the reaction of the soil solution – by 0.3 pH, but the concentration of mobile forms of lead increased by 10.9%, cadmium – by 25.0%, soil moisture content – by 2.7%.

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# Якість насіння гороху та агроекологічний стан ґрунту при використанні структурованої води

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**Анотація**. Широке використання води у рослинництві та землеробстві зумовлене значним приростом урожаю під час поливу сільськогосподарських посівів, а також донесення до рослин і ґрунту пестицидів і мінеральних добрив водою. Одним із способів покращення якості води, що використовується у рослинництві є її структуризація. Актуальним завданням є вивчення впливу структуризованої води, що доноситься до посівів сільськогосподарських культур поливом або обприскуванням на урожайність, якість одержаної продукції та агроекологічний стан ґрунту. Польові дослідження на посівах гороху проводили на дослідних ділянках Вінницького національного аграрного університету, лабораторні – у акредитованих лабораторії моніторингу якості, безпеки кормів і сировини Інституту кормів та сільського господарства Поділля НААН та Випробувальному центрі Вінницької філії Державної установи «Інститут охорони грунтів України». При поливі гороху структурованою водою відбувається підвищення його урожайності на 42,3 % відносно варіанту без внесення води та на 22,3 % відносно варіанту з поливом звичайною водою. Насіння гороху при поливі структурованою водою має нижчий вміст сирого протеїну на 0,43 %, сирого жиру – на 0,09 %, сирої золи – на 0,63 %, проте вищий вміст сирої клітковини на 0,11 % і безазотових екстрактивних речовин – на 0,99 % відносно варіанту без внесення води. Вміст гумусу у ґрунті при поливі структурованою водою був нижчим, ніж на варіанті без внесення води на 0,04 %, азоту легкогідролізованого – на 8,0 %, фосфору рухомого – на 20,0 %, калію обмінного – на 7,9 %, реакція ґрунтового розчину – на 0,2 pH, гідролітична кислотність – на 21,7 %, концентрація рухомого свинцю – на 18,4 %. Проте зростала концентрація рухомого кадмію на 43,8 % і вологість ґрунту – на 4,3%. При порівнянні показників агроекологічного стану ґрунту, який поливали структурованою та звичайною водою, встановлено, що полив структурованою водою зменшує вміст гумусу на 0,03 %, легкогідролізованого азоту – на 2,3 %, рухомого фосфору – на 20 %, обмінного калію – на 9,7 %, гідролітичної кислотності – на 7,7 %, реакції ґрунтового розчину – на 0,3 pH, проте підвищується вміст рухомого свинцю на 10,9 %, рухомого кадмію – на 25,0 % та зростає вміст вологи у ґрунті – на 2,7 %

**Ключові слова**: зерно, хімічний склад, родючість, кислотність, важкі метали, вологість

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# Features of Growth Processes of Sweet Cherry Trees of Various Ripening Terms in the Conditions of the Right-Bank Forest-Steppe of Ukraine

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**Abstract**. One of the main requirements of the new stone fruit varieties recommended for commercial cultivation is a compact crown shape that allows for greater plant density and easier crown maintenance. The aim of the research was to establish the growth processes of the above-ground parts of cherry trees in varieties of different ripening periods. The article presents the results of studies of the features of apical and lateral growth of sweet cherry trees. Biological and varietal features of tree growth strength, growth and total length of annual shoots are determined. The dependence of tree trunk growth on apical growth force is established. According to the results of research, sweet cherry varieties are grouped according to the strength of growth: the vigorous varieties are Amazonka, Dar Mliyeva, Zoryana, Mliyivska zhovta; the semi dwarf are Aboryhenka, Alyonushka, Drohana zhovta, Mirazh; the dwarfing are Biryuza, Donetskyy uholyok, Melitopolska krapchasta, Meotida. The smallest increase in trunk diameter was found for the dwarfing variety Biryuza, and the largest – for the variety Drohana zhovta. The highest yield load per unit cross-sectional area of the trunk was recorded for the variety Donetskyy uholyok, the lowest – for Drohana zhovta. The amount of growth in the trunk diameter was inversely dependent on a load of trees with the crop and the strength of apical growth of sweet cherry trees. The features of shoot-forming ability allow characterising the shape of the crown of cherry trees: round – Donetskyy uholyok, Amazonka; high-round – varieties of Aborigenka, Dar Mliyeva, Zoryana; wide-pyramidal – Alyonushka, Drohana zhovta, Melitopolska krap-chasta; pyramidal – Mliyivska zhovta, Mirazh; low – Meotida, Biryuza. Dar Mliyeva, Zoryana, Mirazh, Melitopolska krapchasta and Drohana zhovta varieties have high shootability; the Mliyivska zhovta, Aboryhenka, Meotida, Amazonka varieties have medium shootability; Alyonushka, Biryuza, Donetskyy uholyok varieties have low shootability

**Keywords**: sweet cherry varieties, tree growth strength, trunk diameter, trunk girth, growth of annual shoots



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## INTRODUCTION

The basis of intensive gardening is the introduction of new dwarfing varieties into production in order to increase the planting density to 2000 trees per hectare, which reduces the cost of manual labour for harvesting and pruning trees, chemical protection, etc. The size of the tree is taken into account when planning the organisation of plantings, selecting planting schemes and other elements of agricultural technology, although the height of the tree is to a certain extent limited by the design of plantings. The introduction of the latest technologies for growing stone crops is mainly hindered by the lack of low growing clonal rootstocks [1; 2]. Reducing the size of cherry trees is also of great importance when harvesting. Since rootstock combinations of stone breeds are mainly vigorous, therefore harvesting manually is the most time-consuming process, which accounts for 50-80% of all cultivation costs [2].

Young cherry trees show strong growth of the trunk and skeletal branches of the first order and weak – semi-skeletal (semi-basic) branches and overgrown wood. O.A. Kishchak [3] identified a group of varieties in which, without special pruning, many shoots with a length of more than 20 cm are formed during fruiting and growth. They make up more than 50% of the whole crop.

On annual growth shoots, generative buds are placed in the lower part. The ratio of the number of growth and fruit buds on an annual growth depends on its length. On short growth shoots (up to 10 cm), mainly generative buds are formed and only one growth bud is formed at the top. Growths 25-30 cm long have growth buds, from which bouquet twigs are formed. On growths with a length of more than 30 cm, bouquet twigs and lateral growths of the growth type are formed [4]. The growth force of a fruit tree is best regulated by a rootstock [5]. However, currently, there are few vegetatively propagated rootstocks for sweet cherries, although in recent years dwarf rootstocks of Gisela 5 of German and VSL-2 of Russian selection have become widespread [6; 7].

A high effect was obtained from the use of MV+25105 (propyl-3-butyl-phenoxy acetate) on sweet cherry trees [8]. In the plants treated with it, apical dominance decreased due to the synthesis and movement of auxins and changes in hydrocarbon metabolism in the tissues of the central conductor. This contributed to the formation of dwarfing trees with a large number of side shoots, while the yield for the 4$^{th}$ year increased by an average of 1.5 times.

The most effective are gardens with dense planting of dwarfing trees. They enter marketable fruiting early (3-4 years), provide an average yield of 8-10 t/ha and save 5-6 times labour costs for the crown formation and pruning compared to vigorous varieties. Dwarfing trees are more convenient for caring for and harvesting fruits, both manually and mechanically [9-11].

It is established that the environmental conditions, agricultural techniques of growing crops (type of planting, rootstock, crown shape) in which biochemical characteristics were formed and fixed, leave a significant imprint on the taste and chemical composition of fruits [12; 13]. Therefore, one of the main requirements that are set for new varieties of stone crops recommended for industrial cultivation is the compact shape of the crown and convenient placement of the main branches, simultaneous ripening of fruits with a dry separation from the peduncle.

*Research purpose* – to establish the features and activity of apical and lateral growth of trees of different varieties of sweet cherries. To study the growth processes in the crown of a tree characteristic of each variety. Based on the obtained data, to determine the shape of the crown and the shoot-forming ability of the variety.

## MATERIALS AND METHODS

The territory of experimental plantings is located in the central part of the region of the central subzone of the Right-Bank Forest-Steppe, which is characterised by a significant variety of soil cover, which is caused by relatively similar natural conditions.

The soils of the experimental site are gray podzolic. These soils are similar in characteristics and qualities to sod-podzolic and chernozem soils. They have well-defined processes of podzolization, as a result of which the profile is clearly differentiated according to the eluvial-iluvial type and at the same time, there is an accumulation of humus. Its content in various subtypes of gray forest soils varies significantly, but vegetation features cause a significant annual intake of organic residues in the soil and a relatively high content of humus in the soil profile.

The objects of research were 12 varieties of sweet cherries of different ripening periods: Aboryhenka, Biryuza, Dar Mliyeva, Zoryana, Mliyivska zhovta, Mirazh, Melitopolska krapchasta, Meotida, Donetskyy uholyok, Alyonushka, Amazonka, Drohana zhovta. Trees grafted on the rootstock of wild cherries, planted according to the scheme 6x4 m (416 trees/ha) and formed by a sparse-tiered crown.

Records and observations were carried out for three years according to the "Methodology for conducting field studies with fruit crops" by P. V. Kondratenko and M.O. Bublyk [14]. The circumference of the trunk was determined by measuring tape at a height of 10 cm from the soil surface. The increase in the trunk diameter during the growing season was determined by the difference in autumn measurements in the current and past years. The total growth of annual shoots with a length of 5 cm or more was measured with a measuring tape at the end of the growing season. At the same time, the average length of shoots was determined by dividing their total length by the number. Tree habitat was determined by calculating the area of crown projection and tree volume.

For statistical processing of data expressed in points, data conversion was performed according to the method of B.A. Dospekhov [15].

## RESULTS AND DISCUSSION

According to the results of the conducted studies, it was found that by the age of 6-7 years, sweet cherry trees reached their maximum size. The maximum tree height was characterised by the varieties Zoryana, Amazonka and Dar Mliyeva (5.1-4.9 m) (Fig. 1). Given the fact that the studied trees are 6-7-8 years old, when the period of growth stops and the plantations begin to bear fruit (according to P.G. Shit), according to the technology of cultivation, the growth of trees was limited to five meters by pruning.

It was found that trees of early-ripening varieties of cherries were characterised by a significant growth force, which on average for three years of research was close to 4.8 m. The trees of the control variety Zoryana reached the optimal size the fastest, but the highest height was observed in the trees of the Dar Mliyeva variety. Mliyivska zhovta trees were characterised by more gradual growth of the conductor. However, by the age of 8, they reached the same level as trees of other early-ripening varieties. So, the studied early ripening varieties of sweet cherries have a tendency to strong apical growth of trees.

Compared to early-ripening varieties, medium-ripening varieties up to 8 years of age were characterised by a lower tree growth force (on average, 3.9 m). The strongest growing varieties were Mirazh and Aboryhenka (4.5 m), lower growth was observed for the variety Melitopolska krapchasta (3.2 m), and especially for the control variety Meotida (3.0 m). The height of trees of these varieties was maintained at the same level by pruning. So, cherry varieties of medium ripening were characterised by moderate growth of trees in height.

The height of trees of late-ripening varieties of sweet cherries averaged 3.4 m, which is 1.4 m lower than the average of early-ripening varieties and 0.5 m lower than the medium-ripening varieties (Fig. 1). The best in this respect was the late-ripening variety Biryuza, in which the height of trees during the study did not exceed 2.6 m and did not require agrotechnical intervention by pruning.

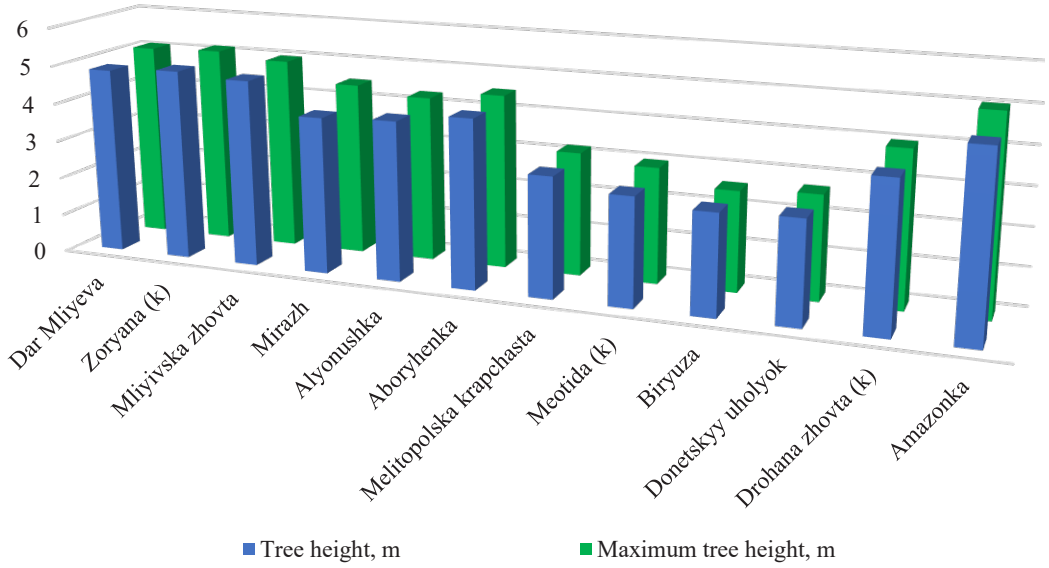


***Figure 1**. Average and maximum height of sweet cherry trees, m*

Late-ripening trees of the late-ripening Donetskyy uholyok variety proved to be weak, but they were slightly higher than the variety Biryuza. Significant heights at the age of 8 reached the Amazonka variety trees and according to this indicator they should be classified as vigorous. Thus, according to the strength of tree growth, the studied sweet cherry varieties can be arranged in the following order (according to the ripening period): vigorous – Dar Mliyeva, Zoryana, Mliyivska zhovta, Amazonka; semi dwarf Mirazh, Alyonushka, Aboryhenka, Drohana zhovta; dwarfing – Melitopolska krapchasta, Meotida, Biryuza, Donetskyy uholyok.

The obtained indicators of tree habit make it possible to characterize the shape of the crown of cherry varieties: round – Donetskyy uholyok, Amazonka; high-round – varieties of Aborigenka, Dar Mliyeva, Zoryana; wide-pyramidal – Alyonushka, Drohana zhovta, Melitopolska krapchasta; pyramidal – Mliyivska zhovta, Mirazh; low – Meotida, Biryuza.

One of the main indicators of tree growth processes is an increase in the trunk diameter, which clearly reflects the activity of lateral growth [16; 17]. As a result of three years of observations on the growth of sweet cherry trees in thickness, it can be observed that the increase in trunk diameter was directly dependent on the strength of apical growth of the tree and inverse – on the level of crop load.

In 2019, the largest increase in the diameter of

the trunk of early-ripening varieties was observed for the variety Mliyivska zhovta, and the smallest – for the variety Dar Mliyeva, although the growth of trees of the variety Dar Mlieva in height was stronger (Table 1). The cross-sectional index of the trunk of trees of early-ripening varieties, respectively, was the highest in the vigorous variety Dar Mliyeva, which prevailed over other vigorous varieties of early ripening.

***Table 1**. Apical and lateral growth of sweet cherry trees of different ripening periods*

| Pomological variety | Number of shoots, pcs. / trees. | Average length of annual shoots, cm | Total length of annual increments, m | Tree trunk circumference, cm | Increase in tree trunk diameter, cm |
|---|---|---|---|---|---|
| *Early-ripening varieties* | | | | | |
| Dar Mliyeva | 49 | 18.4 | 10.09 | 70.6 | 0.37 |
| Zoryana (k) | 46 | 15.1 | 6.24 | 53.9 | 0.38 |
| Mliyivska zhovta | 35 | 23.4 | 8.71 | 42.9 | 0.84 |
| *Medium-ripening varieties* | | | | | |
| Mirazh | 61 | 21.8 | 13.57 | 32.7 | 0.49 |
| Alyonushka | 12 | 24.7 | 2.67 | 38.7 | 1.03 |
| Aboryhenka | 39 | 25.7 | 10.07 | 47.0 | 0.14 |
| Melitopolska krapchasta | 72 | 24.5 | 18.56 | 35.5 | 0.59 |
| Meotida (k) | 44 | 22.6 | 9.55 | 33.4 | 0.36 |
| *Late-ripening varieties* | | | | | |
| Biryuza | 34 | 22.2 | 7.21 | 34.8 | 0.1 |
| Donetskyy uholyok | 20 | 18.2 | 3.82 | 32.5 | 0.13 |
| Drohana zhovta (k) | 49 | 20.2 | 9.26 | 40.3 | 0.85 |
| Amazonka | 12 | 22.5 | 8.94 | 54.96 | 0.35 |
| $LSD_{05}$ | *0.5* | *1.4* | *1.0* | *0.6* | *0.2* |

***Note**: – *$LSD_{05}$ – least significant difference at 0.05 significance level*

Fruit plantations in the 2021 season were characterised by a high load of fruits, which in turn affected the decrease in lateral growth of sweet cherry trees. High yields were observed in the varieties Dar Mliyeva and Zoryana (k), in which the increase in trunk diameter was insignificant (0.25 cm). The yield of the Mliyivska zhovta variety was significantly lower, which was accompanied by a more active thickening of the trunk – by 0.76 cm.

In general, on average for three years, the strongest thickening of tree trunks of early-ripening sweet cherry varieties was observed for the Mliyivska zhovta variety, while in other varieties it was much weaker. The largest increase was observed in the trees of the semi dwarf variety Alyonushka, which also had a low level of load on the crop.

Among the varieties of medium ripening, trees of the semi dwarf variety Aboryhenka were characterised by a low stem diameter gain, 0.89 cm less than the highest in this group. As a result of research, the strongest growth of the trunk of trees of medium-ripening sweet cherry varieties in thickness was noted for the Alyonushka variety, and the smallest – for the Aboryhenka variety. In the group of late-ripening varieties, the thickening of the trunk was observed in the vigorous Amazonka variety is more active, and this is natural since the trees of other late-ripening varieties studied are dwarfing. In general, over the years of research, the smallest increase in the trunk diameter was observed in the dwarfing variety Biryuza, and the largest – in the variety Drohana zhovta. The highest yield load per unit cross-sectional area of the trunk was recorded for the variety Donetskyy uholyok, the lowest – for Drohana zhovta. Consequently, the value of the increase in the trunk diameter was inversely related to tree crop loading and the strength of sweet cherry tree apical growth ($r = -0.77 \pm 0.07$).

The total increase in the length of annual shoots in some way affects the formation of the crop [18]. According to the results of research, the difference between the total growth of annual shoots in different years is quite significant. In the seventh year of tree vegetation, growth processes were quite intense, possibly due to the low level of load on the trees. In terms of the total length of annual shoots of the studied varieties, the highest level of the indicator was achieved

in trees of the variety Melitopolska krapchasta, and the lowest in the variety Alyonushka.

Analysing the obtained data separately for the growing seasons, it was found that the largest total length of growth was observed in 2020, when the productivity of plantations was the lowest. It is likely that the nutrients absorbed from the soil were used by the trees for wood growth. However, this statement is not correct in all cases: in the varieties Mliyivska zhovta, Melitopolska krapchasta, Biryuza, Drohana zhovta and Amazonka, the largest total length of annual shoots was observed in the previous year 2019 simultaneously with the maximum yield of trees of these varieties. High yields in 2021 negatively affected the total length of annual shoots, causing it to decrease. Despite this, the growth trend for varieties continued over the years. Thus, the indicator of the total length of annual increments is determined by the biological characteristics of the studied sweet cherry varieties.

This is confirmed by the fact that among the group of early-ripening varieties, the Dar Mlieva variety, which also has the largest crown volume, had the greatest total length of one-year shoots on average over the three years of the study. Also, in stands of medium-ripening varieties, according to the results of three-year observations, the dwarfing variety Melitopolska krapchasta, although the crown volume of the trees was the smallest compared to other medium-ripening varieties, had a high total length of annual growth. A significant total length of annual growths in trees of late-ripening sweet cherry varieties was obtained in semi dwarf, with a fairly small crown volume of the Drohana zhovta variety. It is believed that the structure of the crown of trees with a mixed type of fruiting should be dominated by shoots up to 10 ... 20 cm long [18; 19], this contributes to the formation of fruit-bearing formations and generative buds.

Having considered the length of annual shoots of sweet cherry trees by years of research, it can be assumed that the change in this indicator was most influenced by the level of tree productivity and weather conditions during the growing season. It is possible that the high air temperature in 2019 during the first wave of shoot growth slowed down apical growth and caused premature formation of apical buds.

The total growth of annual shoots also depends on the number of shoots on the tree, that is, the shoot-forming ability of sweet cherry trees. As is known from literature sources, sweet cherry trees by their biological characteristics are mainly vigorous and have a weak shoot-forming ability [19; 20]. Analysing the data obtained, it should be noted that the number of shoots on the tree changed significantly in some years.

If the rate of early-ripening varieties in 2019 ranged from 39-73, in the following years, respectively – 32-67 and 30-41. A sharp decrease in the shoot-forming ability of sweet cherry trees in 2020 can be explained by a significant load on their yield, while in 2021 its practical absence contributed to the activation of vegetative growth. A significant number of shoots on trees of the varieties Zoryana (k) and Mliyivska zhovta in 2019 may be due to less favourable overwintering conditions for the trees and damage to the generative buds, which resulted in increased growth processes. A similar situation was observed in sweet cherry trees of medium-ripening periods, in 2020, when there was an increase in the number of shoots with a high level of yield of plantings. High shoot-forming ability in this group was observed for the variety Melitopolska krapchasta, which formed about 72 shoots per tree. Low shoot-forming ability is characteristic of the variety Alyonushka – from 9 to 16 shoots per tree.

In the group of late varieties, an average of 12-49 shoots per tree were formed during the research period. The highest rate was recorded in 2020 for the Drohana zhovta variety, which can also be attributed to the group with high bud excitability. The lowest number of shoots was observed for the variety Donetskyy uholyok – no more than 24 shoots per tree.

Thus, according to the obtained data, it is advisable to divide cherry varieties into groups according to their ability to shoot: with a high degree – Dar Mliyeva, Zoryana, Mirazh, Melitopolska krapchasta and Drohana zhovta; medium – Mliyivska zhovta, Aboryhenka, Meotida, Amazonka and low degree of shoot formation – varieties Alyonushka, Biryuza, Donetskyy uholyok.

## CONCLUSIONS

Analysis of the data obtained showed that the growth vigour of the cherry trees depended on the biological characteristics of the variety, while no effect on fruit ripening time was detected. According to the strength of tree growth, cherry varieties were vigorous – Amazonka, Dar Mliyeva, Zoryana, Mliyivska zhovta; semidwarf – Aboryhenka, Alyonushka, Drohana zhovta, Mirazh; dwarf – Biryuza, Donetskyy uholyok, Melitopolska krapchasta, Meotida. The maximum height (within 5 m) was observed in trees of the varieties Zoryana, Dar Mliyeva, Amazonka.

As a result of observations, the largest increase in the diameter of the trunk was found in trees of the varieties Alyonushka, Mliyivska zhovta and Drohana zhovta. The ripening period of the variety did not affect the lateral growth of trees. The increase in trunk diameter was in direct correlation with the strength of the tree's apical growth and inversely with the level of crop loading.

The shape of the crown, and therefore the formation of the future crop, was significantly influenced by the indicators of shoot-forming ability: the number of shoots, the average and total length of annual shoots. High ability to shoot was noted in the varieties Melitopolska krapchasta, Mirazh, Dar Mliyeva, Zoryana. The smallest number of shoots and their annual growth was obtained in the varieties Alyonushka, Biryuza, Donetskyy uholyok.

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# Особливості ростових процесів дерев черешні різних строків достигання в умовах Правобережного Лісостепу України

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**Анотація**. Однією з основних вимог, які ставлять до нових сортів кісточкових культур, рекомендованих для промислового вирощування є компактна форма крони, яка дозволяє збільшити щільність насаджень та спростити догляд за кроною. Метою досліджень було встановити ростові процеси надземної частини дерев черешні сортів різних строків достигання. В статті наведено результати досліджень особливостей апікального і латерального росту дерев черешні. Визначено біологічні та сортові особливості сили росту дерев, приріст і загальну довжину однорічних пагонів. Встановлено залежність приросту штамбу дерев від сили апікального росту. За результатами досліджень сорти черешні згруповано за силою росту: сильнорослими були сорти черешні – Амазонка, Дар Млієва, Зоряна, Мліївська жовта, середньорослими – Аборигенка, Альонушка, Дрогана жовта, Міраж; слаборослими – Бірюза, Донецький угольок, Мелітопольська крапчаста, Меотіда. Найменший приріст діаметра штамбу встановлений для слаборослого сорту Бірюза, а найбільший – для сорту Дрогана жовта. Найбільше навантаження врожаєм на одиницю площі поперечного перерізу штамбу зафіксовано для сорту Донецький угольок, найменше – для сорту Дрогана жовта. Величина приросту діаметра штамбу знаходилася в оберненій залежності від навантаження дерев урожаєм і сили апікального росту дерев черешні. Особливості пагоноутворювальної здатності дають змогу охарактеризувати форму крони дерев черешні: округла – Донецький угольок, Амазонка; високо-округла – сорти Аборигенка, Дар Млієва, Зоряна; широко-пірамідальна – Альонушка, Дрогана жовта, Мелітопольська крапчаста; пірамідальна – Мліївська жовта, Міраж; поникла – Меотіда, Бірюза. Високою пагоноутворювальною здатністю володіють сорти – Дар Млієва, Зоряна, Міраж, Мелітопольська крапчаста і Дрогана жовта; середньою – Мліївська жовта, Аборигенка, Меотіда, Амазонка; низькою – Альонушка, Бірюза, Донецький угольок

**Ключові слова**: сорти черешні, сила росту дерев, діаметр штамбу, обхват штамбу, приріст однорічних пагонів

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# Assessment of the Impact of the Armed Conflict in Ukraine on the Development of the Agricultural Sector and Price Setting

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**Abstract**. This paper analyses the impact of the armed conflict in Ukraine on the development of the agricultural sector and changes in average prices of agricultural products, and also identifies a possible relationship between changes in prices for agricultural products and financial expenditures for defence needs. The paper also investigates the possible relationship between changes in military spending, gross harvest of cereals and legumes, harvested and threshed area, their yield levels. The study considers how the presence and duration of armed conflict in the country affects: macroeconomic indicators, intensity of hostilities and their localisation in areas of economic activity, gross domestic product (GDP), government expenditures, export-import indicators; household expenditures and domestic investment, consumer and household expenditures. All this, indirectly, has an impact on fluctuations in average prices of products of different sectors of agriculture sold by enterprises. The study takes into account the importance of the agricultural sector of Ukraine, which is a significant part of the country GDP. The dependence of military spending on the size of GDP is the reason for analysing the relationship between the impact of the existing armed conflict on changes in the state of agriculture in Ukraine. One of the results of such actions was also the spending of more money on the purchase of agricultural products to support the defence needs of the state, etc. Therefore, to understand the magnitude of the impact of gross harvest factors, crop yields, and agricultural land volumes on the pricing of agricultural output using the method of statistical equation dependencies, the findings of the relevant analysis can be used as a basis for developing approaches, methods, and techniques to improve crop yields, or – initiate economic development of the country by increasing agricultural crop yields

**Keywords**: financial costs, macroeconomic indicators, gross domestic product, domestic investment, agricultural sector



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## INTRODUCTION

Analysis of the current geopolitical situation in recent decades indicates a dynamic transformation of the system of international relations, which, in turn, is caused by increasing struggle for resources and markets, and attempts by some countries to strengthen their influence on world politics by force. Some countries consider using the armed forces not only to ensure their own security and protect national interests, but also to influence other countries to assert their political status and warn other countries about the possibility of using force against any country. The global spread of armed conflicts encourages countries to allocate significant human and financial resources to ensure and maintain the necessary level of their own security in the military-political political situation in the world. Nowadays, in every state, in any society, agriculture is a vital sector of the national economy, as it affects the interests not only of each person but also the nation as a whole, because food production is the first prerequisite for quality life. It is also a raw material base for other industries, including light and food industry. Agricultural economics is an integral part of the system of economic sciences, which consider various aspects of social relations of people in the field of production and distribution of material goods. One of the important areas of economics is military-economic theory, or military economics, which can decisively affect the development of both state industry and the agricultural part of the national economy. Economic theory studies the laws of social production and consumption of products, goods and services at different stages of human society, including an integral part of it is the study and research of the agro-industrial complex of the state.

Nowadays, the agro-industrial complex (AIC) is a set of branches of the national economy for Ukraine, which are interconnected by economic relations regarding the production, distribution, exchange, and consumption of agricultural products. It includes industries that ensure the production of agricultural products, their processing, storage and sale, manufacturing of means of production in the agro-industrial complex and its maintenance. About 80 branches of the national economy take part in the agro-industrial complex at different stages of production and circulation. AIC is one of the main components of the national economy. It accounts for about 1/3 of GDP, fixed assets and the number of employees. Today, the development of agriculture in the country is aimed at increasing the efficiency of agricultural labour, i.e., to produce more agricultural products with less work [1]. The agro-industrial complex has its own peculiarities of development: dependence on natural conditions; seasonal nature of production and cash receipts; slowed down in comparison with industry cycle and turnover of fixed and working capital; use as means of production – land, productive animals, and cultivated plants; combinatorial variety of combinations of forms of production, management, and ownership; features of production technologies associated with living organisms – plants, animals, microorganisms; territorial dispersion of production and remoteness of structural units from the centre, the differences of social nature between urban and rural areas; survivability of economic traditions and customs of the rural population; the impact of personal households on the economic situation of workers, etc.

The level of development of the agro-industrial complex largely determines the level of economic and food security of the country, as the specificity of its role is conditioned by food production as the basis of human life and reproduction of labour, production of raw materials for many non-productive consumer goods and industrial products. The level of economic and food security is one of the main characteristics of the level of military and economic security and national security of Ukraine as a whole. Today, it is not possible to find a country with a low rate of agricultural development among the world's leading countries, because the most important task of agriculture is to provide the population with food and industry with the necessary raw materials. In the conditions of development of market economy this problem can be solved only by increase of economic efficiency of agricultural production. It is the level of agricultural efficiency that determines the degree to which the population is provided with foodstuffs. Therefore, one of the primary tasks of science is to develop economic bases for the development of the industry in market conditions and effective management methods, but considering the factors influencing the development of the agricultural sector and the national economy as a whole.

In the context of Ukraine, one of the most influential factors in the development of agriculture is the state of armed conflict. A study of the development of certain countries (USSR, Germany, Japan, Yugoslavia, Iraq, Israel, Georgia) that have had or have an armed conflict in their territory shows that any armed conflict affects the country's economic growth, as a result of hostilities its resources and infrastructure are destroyed, and the outflow of human resources is observed [2-4]. That is, the state suffers losses caused by damage incurred during armed conflicts, and these losses are reflected in the economic growth of the country, and in the development of its agricultural sector in the first place. The speed of recovery of the national economy after the armed conflict will also directly depend on the damage inflicted. The annexation of Crimea and hostilities in eastern Ukraine in some regions of Donetska and Luhanska oblasts have a negative impact on the economic development of the entire country. Sharp reduction in GDP of Ukraine is conditioned by closure, relocation or suspension of enterprises, loss of territory and significant amounts of agricultural land, infrastructure losses, job losses, significant decline in income and forced migration [5].

In this regard, *the purpose of the study* is to investigate the impact of the state of armed conflict in Ukraine on the development of agriculture and the national economy as a whole. But the definition of such impact is expected to be made by analysing the dynamics of prices for agricultural products during the armed conflict in Ukraine with the subsequent establishment of functional dependencies of projected price growth by regression and correlation analysis, and extrapolation of price dynamics based on available statistics.

## THE ROLE OF AGRICULTURE IN THE DEVELOPMENT OF THE NATIONAL ECONOMY

Agriculture plays an extremely important role for Ukraine as a catalyst for the development of the national economy, as it is an industry that ranks 3-5$^{th}$ annually in terms of contribution to GDP. This is facilitated by the significant scale of agricultural land use and fertile land. Thus, it can be argued that the development of agriculture plays a significant role in the development of the national economy, and thus it can be concluded that the development of agriculture also plays a significant role in shaping the military and economic potential of Ukraine. Nowadays, agricultural development of Ukraine is a platform for job creation and poverty reduction. This is a branch of material production, which is important in providing the population with food and industry with raw materials. The development of agriculture is a vital factor in the development of all sectors of the national economy. Today, most of the expenditures of the Ministry of Defence (MoD) are aimed at providing social guarantees for servicemen, both in cash and in kind. At the same time, the current structure of state budget expenditures does not allow fully meeting the needs of the Ministry of Defence of Ukraine and providing servicemen with their social guarantees. The war has a negative impact on economic development and key indicators of agriculture in the country. In particular, one of the criteria for the negative impact was a sharp decline in GDP, in particular, in the first year of the war, Ukraine's GDP per capita fell by 47.5% from USD 3,014.6 in 2014 to the value of USD 2,115 in 2015, which corresponds to the global trend of the consequences of military events.

Ukraine's GDP is affected by the consequences of the armed conflict: destruction of production facilities, infrastructure, transport, loss of land use capacity due to shelling, mining, outflow of human resources from the country, loss of civilian population, and more. All these consequences have a negative impact on GDP, which in turn has a negative impact on social protection, the state of the national economy and its components, the main of which is the agricultural sector. Therefore, a very important and urgent task of research today, when Ukraine is in its hybrid war for six years, is to investigate the problems of assessing the real impact of armed conflict in Ukraine on the agricultural sector and the national economy. One of the possible ways of such a study is to analyse the dynamics of pricing of agricultural products before and during the armed conflict. Based on the results of the analysis, it is necessary to investigate the correlations between the effects of armed conflict on agricultural development and the national economy as a whole. The results of the analysis should determine the regression relationships between the level of agricultural development (the share of agriculture in GDP) and the volume of defence spending to assess the density of the relationship between the dynamics of defence spending and agricultural development in Ukraine.

A number of research papers are devoted to the study of the interdependence of the size of military expenditures of countries and individual sectors of the economy. Thus, T. Rahman and A. Siddiqui [1] considered this issue, touching upon the aspect of trade in goods of the military-industrial complex. N. Eftychia [2] approached the study from an extraordinary standpoint: the researcher considered the role of military expenditures in the debt crisis in Greece. R.F. Pustoviyt [3] analysed the factors influencing military spending on the country's economy. The impact of military spending on the economy is rather underinvestigated. The question of assessing the damage caused by the annexation of Crimea by Russia is reflected by Ukrainian researchers, in particular V.V. Anisimov [4], B.A. Karpinsky [5], O.P. Korniychuk [6], K.M. Kornienko [7], papers by analysts of consulting agencies [8]; studies by S.F. Garkavy [9], E.M. Libanova [10], O.V. Sobkevich [11], O.Yu. Snigova and T.Yu. Zagorelska [12] and investigation by non-governmental organisations [13; 14]. However, this issue needs further study for the following reasons: firstly, the insufficient study of the peculiarities of Ukraine's economy before the start of hostilities, in particular in terms of its structure, trade cooperation with other countries; secondly, the fragmentary nature of the study of military aggression in Donetska and Luhanska oblasts and the Crimea, in connection with which there was a need to summarise the results of research in this area; thirdly, the issues of assessing the consequences of annexation of parts of the territory and hostilities from the standpoint of already incurred losses (value of real estate, inventories, infrastructure) and lost opportunities, based on the share of affected regions in the economy, were incompletely covered. In addition, researchers do not have a consensus on approaches to assessing the relationship between defence spending and the development of both agriculture and industry, or other sectors of the national economy.

Therefore, one of the approaches to assessing the impact of the presence of armed conflict in Ukraine on the development of the agricultural sector is to assess the dynamics of agricultural prices in the country during and before the conflict. The price setting for agricultural products, the impact of the price mechanism on the development of the agricultural sector of Ukraine is the subject of research by many Ukrainian researchers [15-18].

They worked out the theoretical aspects of the price setting for agricultural products in the context of value theory, considered the principles and features of the mechanism of pricing in the agricultural sector [19; 20]. Most scholars analyse the impact of the economy as a whole and the defence sector separately, so there is a need to expand research in this area, namely: to determine the possible impact of the agricultural sector on meeting the financial needs of defence, which is one aspect of timely prevention of possible threats.

## GENERAL INDICATORS OF GROWTH OF AGRICULTURAL PRODUCTION

A special place in any economic model is occupied by the price setting mechanism, which should balance the diverse interests of sellers (producers) and buyers (consumers) of goods, allocate resources, stimulate rational allocation of production, innovation, etc. The state and trends of development of both individual sectors of the economy and the national economy as a whole depend on the effectiveness of the implementation of the functions assigned to it by this mechanism. Price dynamics is an important indicator of the state of individual sectors of the economy, and the impact on price setting is one of the tools for optimising economic processes. This fully applies to pricing in the Ukrainian agricultural sector. Prices for agricultural products are the most dynamic characteristics of the agricultural market. They are sensitive to the influence of numerous economic, technological, weather, socio-political factors and in turn determine the vectors and rates of development of individual agricultural sectors, the level of food security of the country. Significant differentiation and fluctuations in the dynamics of prices for agricultural products indicate poor controllability of processes in the agri-food market, including the presence of influences not taken into account by specialists factors that decisively affect price setting. This creates the preconditions for the emergence of instability, which reduces the investment attractiveness of the agricultural sector, exacerbates the imbalances in the development of some of its components.

Ukraine ranks third in the list of largest suppliers of agricultural products to EU member states (EU), exporting more than EUR 7.3 billion [21]. More than 83% of the commodity structure of supplies to the EU is accounted for by exports of cereals and oil. Since October 1, 2017, the EU has introduced additional duty-free tariff quotas (autonomous trade preferences) for agricultural and food products temporary additional EU trade preferences for Ukraine (Regulation (EU) 2017/1566). In particular, the following duty-free quotas were increased: honey, barley, barley flour and granules, processed grain and flour, processed tomatoes, grape juice, oats, corn, corn flour and granules, soft wheat, wheat flour and granules. Most additional duty-free quotas apply from October 1, 2017, except for quotas for wheat, corn, and barley, which are available from January 1, 2018, crops, fats, and oils, residues of the processing industry. However, the occupation of the Crimean Peninsula has led to the decision for the closure of the North Crimean Chanel in 2014, which met 85% of the Autonomous Republic of Crimea's (ARC) water needs (850 million $m^3$ per year).

At the same time, 72% of this water was used for the needs of the agricultural sector of the economy [22]. Russia's occupation of Crimea has collapsed due to forced closure of the channel between mainland Ukraine and the peninsula to create water shortages in the occupied territories, but this in turn has led to violations of agricultural irrigation technology in the ARC, where 18% of sown areas require this agro-technological measure. In the period 2015-2019, due to the lack of irrigation water, the area of irrigated land decreased by 10-12 times. If Crimea is returned to Ukraine, it will have multi-billion negative consequences, namely in the northern part of the peninsula 14 thousand hectares of orchards and vineyards will suffer irreversible losses, and this will lead to irreversible loss of soil fertility in the ARC. The rice farm on the peninsula will be practically destroyed (the capacity of the industry was 19 thousand hectares of agricultural land). Due to the lack of water in 2015-2018, 350-400 thousand tonnes of rice were lost annually (about 50% of the harvest) [23]. The occupation of the Autonomous Republic of Crimea has led to the fact that Ukraine meets the needs of the domestic market for rice with only 30% of its own production capacity, which affected its price on the domestic market of Ukraine. The main rice-growing regions were Khersonska (Skadovsk, Kalanchak, Holoprystan and Tsyurupynsky raions) and Odeska (Kiliya and Izmail raions) oblasts. 50% (30 thousand hectares) of irrigation systems remained on the territory of the occupied ARC [24], the loss of which in 2015 had a significant impact on the development of Ukraine's agricultural sector and its national economy as a whole.

The armed conflict in Donetska and Luhanska oblasts leads to an imbalance of inter-economic relations in the agro-industrial complex (AIC) and reduces the level of its investment attractiveness. The hostilities in the Donbass naturally caused the main producers of mineral fertilisers to stop their production activities. Thus, in the area of the anti-terrorist operation (ATO) the production facilities of the PAT Severodonetske Obyednannya Azot and PAT Koncern Styrol are located. At the same time, the production and economic activity of PAT Azot in Cherkasy and PAT Rivneazot is unstable. This has exacerbated the shortage of mineral fertilisers in the national market. About 35% of the territory of Donbass is occupied and not under the control of the Ukrainian authorities [24]. As a result of the armed conflict, Ukraine is sowing only 50% of the projected areas of spring crops in Donetska and Luhanska oblasts. In the Donetska oblast, 22.3 thousand hectares of agricultural land need demining and elimination of the consequences

of hostilities. In turn, there are 10.6 thousand such areas in the Luhanska oblast. Of these, 7 and 9.1 thousand hectares were demined, respectively. The total area of mined and contaminated areas is 34 thousand hectares. At the same time, fortifications are being built on agricultural lands in the occupied territories.

In general, the volume of agricultural lands in Donetska and Luhanska oblasts is 26.5 million hectares, which is 8.8% of the structure of sown areas of Ukraine, including 485 and 198 thousand hectares in the ATO zone or 1.8 and 0.7%, respectively. All agricultural products produced along the line of demarcation cannot physically enter the domestic food market of Ukraine. In the occupied territories of Donbass, farming was destroyed as a class of socio-economic relations. According to available information, more than 30,000 hectares of arable land from Novoazovsk to Artemivsk raions of Donetska oblast have been mined or are in the combat zone. Only about 6,000 hectares were demined [19]. Ukraine has huge potential for the development of the agricultural sector of the national economy. This is evidenced by a number of important macroeconomic parameters. The most important among them is the share of agriculture in GDP, which was 10% in 2013, in 2016 – 14%, in 2019 – 11%, and in 2020 – 13% [25]. In highly developed countries, in particular in Germany and France, agriculture accounts for only 1-2% of GDP. Today, the armed conflict on the territory of Ukraine has a negative impact on its economic development and the main indicators of economic activity in the country, but it is unforeseen that the Ukrainian national economy still manages to adapt quickly to existing challenges. Tables 1 and 2 provide statistics on GDP dynamics, defence budgets of Ukraine, and key indicators of agricultural development in Ukraine to assess the density of the relationship between these indicators using regression and correlation analysis methods.

The analysis of the above statistical data shows that one of the criteria for the negative impact was a sharp decline in GDP, in particular, in the first year of the war, Ukraine's GDP per capita fell by 47.5% from USD 3,014.6 in 2014 to the value of USD 2,115 in 2015, which corresponds to the global experience of the consequences of military events. For the first time since 2014, Ukrainian scholars have faced problems with the interdependence of increasing military spending caused by the armed conflict with Russia on its own territory and the development of key sectors of the national economy. The need to increase defence spending and reshape some of the national economy in the interests of the military organisation of the state created the preconditions for studying the impact of armed conflict in Ukraine on major sectors of the national economy to determine a rational relationship between defence spending and economic development spending. One of the criteria that characterises the desire of the state to provide the necessary conditions for effective development of its armed forces to maintain their combat capability in accordance with existing threats is the amount of defence spending and their distribution in generally accepted areas, such as personnel maintenance, training and combat training, development armaments and military equipment, infrastructure [26].

***Table 1**. Statistics on the main indicators of the dynamics of agricultural development and spending on the Ministry of Defence (MoD) in Ukraine in the period before and during the armed conflict (2010-2020)*

| Indicators | Years | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
| GDP[1] (in actual prices) UAH billion | 1,079.346 | 1,299.991 | 1,404.669 | 1,465.198 | 1,586.915 | 1,988.544 | 2,385.367 | 2,981.227 | 3,560.302 | 3,977.198 | 4,191.9 |
| GDP[1] (in actual prices) USD billion | 136.013 | 163.160 | 175.781 | 183.310 | 133.503 | 91.031 | 93.356 | 112.091 | 130.891 | 153.883 | 155.486 |
| Expenditures of the MoD, UAH billion | 10.5 | 12.7 | 14.81 | 15.32 | 26.5 | 49.1 | 58.1 | 68.9 | 94.3 | 103.3 | 116.6 |
| Expenditures of the MoD, USD billion | 1.323 | 1.594 | 1.853 | 1.917 | 2.229 | 2.248 | 2.274 | 2.591 | 3.467 | 3.997 | 4.325 |
| Official exchange rate of UAH against 100 USD | 793.56 | 796.76 | 799.1 | 799.3 | 1,188.67 | 2,184.47 | 2,555.13 | 2,659.66 | 2,720.05 | 2,584.56 | 2,696 |
| Population (estimated on January 1) | | | | | | | | | | | |
| Current population, million | 43.6 | 43.4 | 43.3 | 43.2 | 43.1 | 42.9 | 42.8 | 42.6 | 42.4 | 41.9 | 41.6 |

*Table 1, Continued*

| Indicators | Years | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** |
| Population (estimated on January 1) | | | | | | | | | | | |
| Rural population, million | 13.7 | 13.6 | 13.5 | 13.4 | 13.3 | 13.2 | 13.2 | 13.1 | 13 | 12.9 | 12.8 |
| % of rural population to the total population | 31.4 | 31.3 | 31.2 | 13.1 | 31 | 30.9 | 30.8 | 30.8 | 30.7 | 30.8 | 30.8 |
| Export of cereals | | | | | | | | | | | |
| USD billion | | | | 6.4 | 6.5 | 6.1 | 6.1 | 6.5 | 7.24 | 9.63 | 9.4 |
| Physical volumes, million tonnes | | | | 27 | 32.6 | 37.4 | 40.2 | 41.8 | 39.4 | 50.4 | 57.2 |
| Sown areas of agricultural crops (thousand hectares) | 26.085 | 26.846 | 27.022 | 27.573 | 27.239 | 26.902 | 27.026 | 27.585 | 27.699 | 28.001 | |
| Crop production (thousand tonnes) | | | | | | | | | | | |
| Cereals and legumes | 37.867 | 54.816 | 45.308 | 62.285 | 63.859 | 60.126 | 66.088 | 61.917 | 70.057 | 75.143 | 64.933 |
| Sugar beet | 13.749 | 18.740 | 18.439 | 10.789 | 15.734 | 10.331 | 14.011 | 14.882 | 13.968 | 10.204 | 9.150 |
| Sunflower | 6.735 | 8.614 | 8.313 | 10.789 | 10.134 | 11.181 | 13.627 | 12.236 | 14.165 | 15.254 | 13.110 |
| Potato | 18.338 | 23.781 | 22.906 | 21.852 | 23.693 | 20.839 | 21.750 | 22.208 | 22.504 | 20.269 | 20.838 |
| Number of farm animals (at the end of the year; thousand units) | | | | | | | | | | | |
| Cattle | 4.351 | 4.290 | 4.506 | 4.398 | 3.884 | 3.750 | 3.682 | 3.531 | 3.333 | 3.092 | 2.874 |
| Pigs | 7.775 | 7.204 | 7.418 | 7.765 | 7.351 | 7.079 | 6.669 | 6.110 | 6.025 | 5.727 | 5.876 |
| Bird of all species (million units) | 191.5 | 189 | 206.9 | 220.6 | 213.3 | 204 | 201.7 | 204.8 | 211.7 | 220.5 | 200.6 |
| Production of animal goods | | | | | | | | | | | |
| Meat in slaughter weight (thousand tonnes) | 1.914 | 1.996 | 2.063 | 2.260 | 2.360 | 2.323 | 2.324 | 2.318 | 2.355 | 2.492 | 2.478 |
| Milk, million tonnes | 10.9 | 10.7 | 11.1 | 11.2 | 11.1 | 10.6 | 10.4 | 10.3 | 10.1 | 9.7 | 9.3 |
| Eggs, million pcs | 16.242 | 17.897 | 18.364 | 19.094 | 19.587 | 16.783 | 15.100 | 15.506 | 16.132 | 16.678 | 16.167 |
| Price indices of agricultural products sold by agricultural enterprises (up to 2020; %) | | | | | | | | | | | |
| Agricultural products | 127 | 113.7 | 107.2 | 97.3 | 124.3 | 154.5 | 109 | 111.5 | 108.2 | 101.4 | 89.9 |
| Crop products | 139.5 | 118.2 | 106.9 | 91.7 | 129.2 | 167.2 | 116.3 | 107.3 | 110.2 | 101.8 | 87.9 |
| Livestock products | 114.4 | 109.2 | 107.6 | 102.8 | 119.1 | 141.3 | 101.7 | 130.7 | 101.2 | 100.2 | 97.5 |

***Note**: [1] – is gross domestic product*

Table 2 provides statistics for the establishment of relationships between prices for agricultural products and defence spending to assess the impact of armed conflict in Ukraine on the pricing process for the main types of agricultural products, namely cereals and legumes. The analysis of the obtained statistical data in Table 1 reveals the growth of the main indicators that characterise the impact of the factor of armed conflict in Ukraine, both on GDP and on the growth rates of agricultural production (Fig. 1).

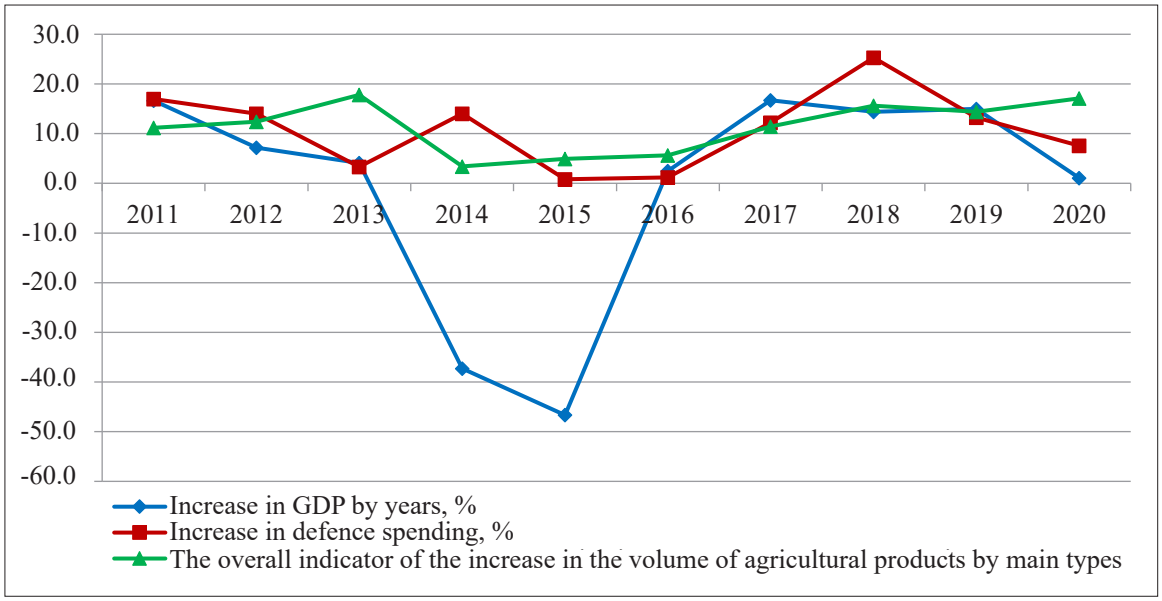


***Figure 1**. Dynamics of GDP growth, defence spending, and agricultural output for the period 2011-2020*

***Table 2**. Dynamics of gross harvest of cereals and legumes, harvested and threshed area, levels of their yield, and expenditures on defence needs of Ukraine for 2010-2020*

| Years | Expenditures for the needs of the MoD (UAH million / %) | | Gross harvest of cereals and legumes (including corn) (thousand centners / %) | | Harvested and threshed area of cereals and legumes (including corn) (thousand hectares / year) | | Average prices of agricultural products sold by enterprises (UAH per tonne / %) | | Crop yield (centners from 1 hectare / %) | |
|---|---|---|---|---|---|---|---|---|---|---|
| 2010 | 10,553.2 | – | 389,077.5 | – | 14,217.3 | – | 1,120.9 | – | 27.4 | – |
| 2011 | 12,295.1 | 16.51 | 505,433.5 | 29.91 | 14,156 | -0.43 | 1,374.2 | 22.60 | 35.7 | 30.29 |
| 2012 | 14,814.3 | 20.49 | 408,806.1 | -19.12 | 13,581.6 | -4.06 | 1,547.1 | 12.58 | 30.1 | -15.69 |
| 2013 | 15,174.0 | 2.43 | 510,706.3 | 24.93 | 13,717.7 | 1.00 | 1,299.8 | -15.98 | 37.2 | 23.59 |
| 2014 | 27,346.0 | 80.22 | 572,347.8 | 12.07 | 13,583.9 | -0.98 | 1,801.4 | 38.59 | 42.1 | 13.17 |
| 2015 | 27,346.0 | 0.00 | 560,592.5 | -2.05 | 13,254.1 | -2.43 | 2,912.1 | 61.66 | 40.6 | -3.56 |
| 2016 | 58,099.1 | 112.46 | 561,067.2 | 0.08 | 12,802.1 | -3.41 | 3,414.0 | 17.23 | 43.8 | 7.88 |
| 2017 | 68,537.4 | 17.97 | 527,574.3 | -5.97 | 12,977.4 | 1.37 | 3,771.6 | 10.47 | 44.2 | 0.91 |
| 2018 | 94,959.4 | 38.55 | 604,121.3 | 14.51 | 13,578 | 4.63 | 4,315.0 | 14.41 | 44.5 | 0.68 |
| 2019 | 105,542.8 | 11.15 | 691,361.9 | 14.44 | 14,340.4 | 5.61 | 3,867.5 | -10.37 | 48.2 | 8.31 |
| 2020 | 121,681.2 | 15.29 | 633,445.4 | -8.38 | 14,759.1 | 2.92 | 4,794.1 | 23.96 | 42.9 | -11.00 |

***Source**: [26]*

Calculations of the total growth rate of agricultural production were performed on the main indicators, which are shown in Table 1 as the arithmetic mean of the growth of all major types of such products. The obtained data allowed forming a graphical dynamics of changes in these indicators over the years to study their correlation with each other. Notably, during the study period the arithmetic mean GDP growth rate was -0.6%, and the average growth rate of defence spending (+10.9) and agricultural output (+11.4) were positive and correlated in some way (Fig. 2). This can be explained by the anomaly of the country's economic development, i.e., the general economic policy of Ukraine stubbornly does not notice something very significant. Ukraine's national economy has experienced shocks at least twice: in 2008 due to the global financial crisis and in 2014 due to internal disorganisation and external aggression, but managed to disregard the first shock caused by the collapse of Soviet economic ties and adapt to development economy even in conditions of protracted armed conflict.

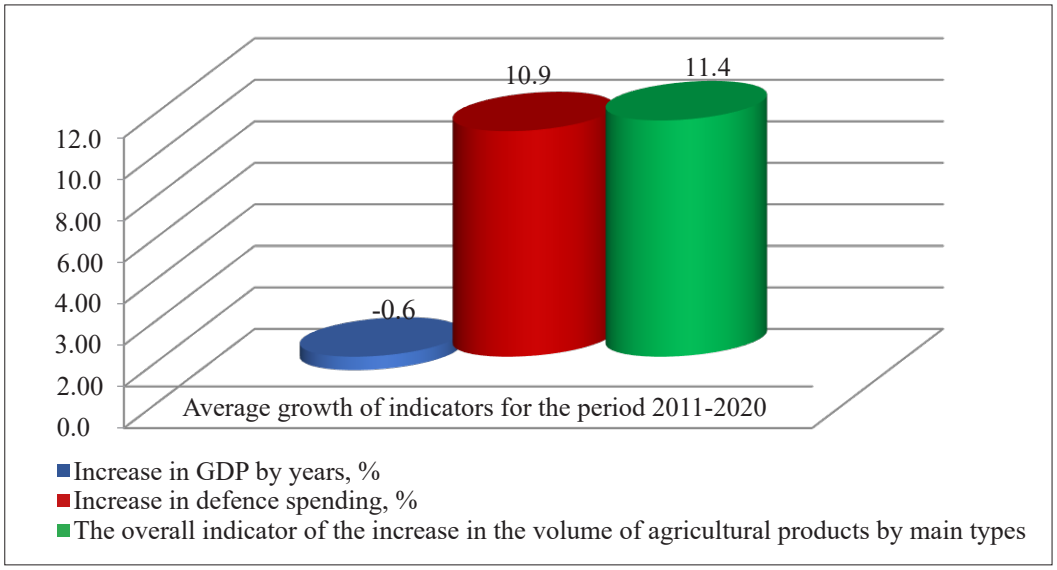


***Figure 2**. Dynamics of GDP growth, defence spending and agricultural output for the period 2011-2020*

For example, in 2008 the decline of Ukraine's economy was very deep, over 15.1%, i.e., the largest in the world, and in 2014-2015 over 15.8% in two years. However, the development of Ukraine's economy continues and this is clear evidence of growth in agricultural production (Figs. 1 and 2), i.e., agriculture was able to adapt to the influence of the factor of armed conflict on the territory of Ukraine. Most world economists believe that the structural degradation of Ukraine's economy has led to the loss of its recovery properties and identified a general downward trend, but studies show that in 2019-2021 Ukraine has regained its position on economic growth, and agricultural development even in 2015-2018. In 2018 and 2019, the growth trend in the main areas of agricultural development was over 25-40%, which characterises the full adaptation of this industry to the operation in conditions of the ongoing armed conflict. If the statistical data in Tables 1 and 2 are used to form a correlation field between indicators of growth of defence expenditures and growth (rate) of development of the agricultural sector by main types of products, at the initial stage it becomes clear that these indicators have a low level of correlation, since the coefficient of determination by the best regression equation is only $R^2 = 0.1652$, that is 16.5% coherence (Fig. 3). But with a slight (2-3 years (points)) smoothing of the regression model on the same equation, it turns out quite a significant dependence of these indicators, the coefficient of determination of the same regression equation will be $R^2 = 0.8997$, i.e., almost a correlated relationship of indicators, which is considered quite strong at about 90%.

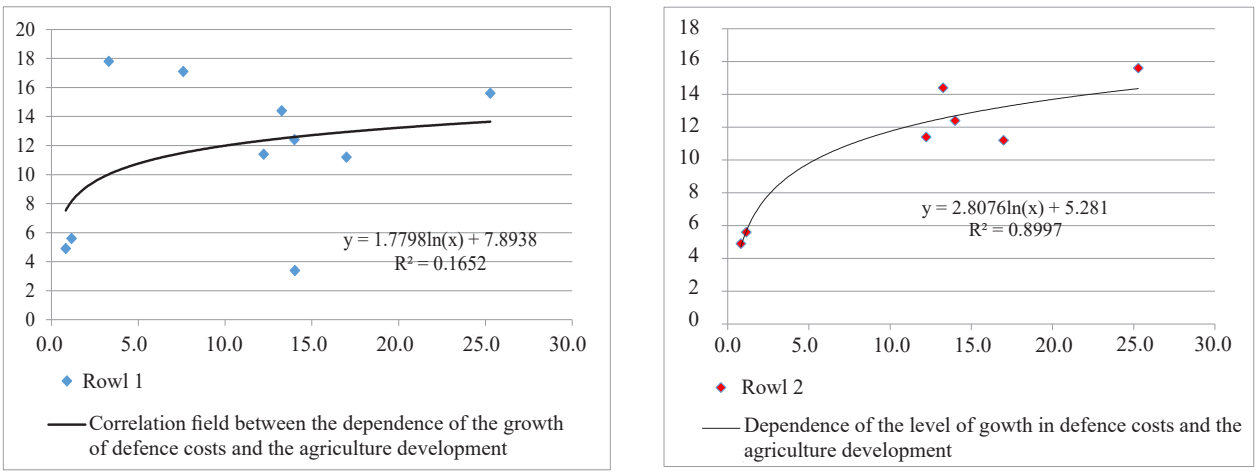


***Figure 3**. Correlation fields and regression relationships between indicators of growth of defence expenditures and growth (rate) of development of agriculture of Ukraine in the period 2010-2020*

This indicates that when formulating development programmes for both the armed forces of Ukraine and the agricultural sector in the medium and long term, it is necessary to take into account the impact of these

factors when forecasting the expected end results of their implementation. Figure 4 shows the dynamics of Ukraine's GDP by share of its main components to compare existing indicators of their development during the period of armed conflict and indicators before it (as of 2010). The structural degradation of Ukraine's economy conditioned by the existing armed conflict is primarily characterised by a decline in the share of manufacturing, professional and scientific-technical areas, but surprises by the growing share of agriculture in the country's GDP.


***Figure 4**. Dynamics of Ukraine's GDP distribution by shares of its main components for the period 2015-2020 and as of 2010*

## THE IMPACT OF ARMED CONFLICT ON PRICES FOR AGRICULTURAL PRODUCTS

One of the results of the impact of the military conflict is that in 2014-2020 there was a significant correlation between the growth rates of the studied indicators. The results of changes in the dynamics of average prices of agricultural products sold by enterprises and the volume of military expenditures are shown in Figure 5. Their relationship (2015) after the start of the anti-terrorist operation (ATO) in eastern Ukraine, then, during 2016-2020, is quite clear correlation trend.

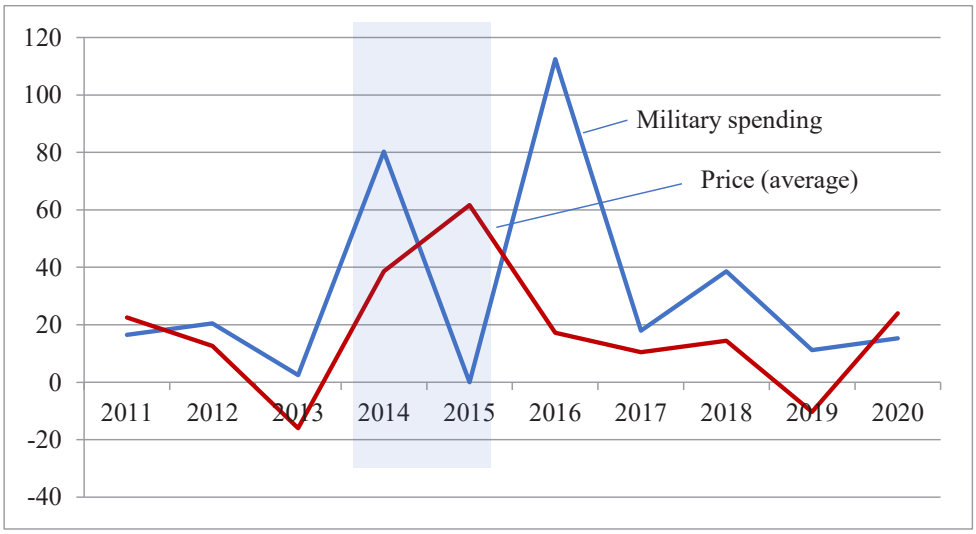


***Figure 5**. Dynamics of changes in defence spending and average prices of agricultural products sold by enterprises (compared to the previous year)*

The method of statistical equations of dependences was used to highlight the consequences of the armed conflict on the state of some agricultural sectors, namely to determine the possible relationship between changes in prices for agricultural products sold by enterprises, volumes of cereals and legumes, their yields, and financial spending for defence needs [27]. Which has gained wide international recognition because of a significant advantage – it solves the inverse economic and statistical problem and is used along with mathematical methods of correlation and regression analysis to study the relationships in large and small sets, including correlation or functional dependence.

The main equations of the method are linear, parabolic, hyperbolic, and logical functions, among which the researcher chooses the best to study according to the available parameters and criteria. The basis of the method of statistical equations of dependences is the calculation of comparison coefficients. Properly selected statistical methods provides an objective quantitative assessment of the relationship between economic phenomena. The principle of choosing the right methods and ways to assess the impact of factors on the results of socio-economic development requires significant efforts to prepare conclusions and proposals, to clarify how broad they are and the goals to achieve them. Here it is necessary to avoid choosing the wrong purpose of the applied use of the obtained calculations, because obtaining, according to all criteria, an accurate answer to the wrong function will be less useful than an incomplete answer due to the correct choice of regression or dependence equation. Therefore, more and more scientists from all over the world are dealing with the problem of choosing the best method for such a study of statistical analysis of the relationship between social and technical phenomena and processes. The results of using the method of statistical equations of dependences are shown in Tables 3 and 4.

***Table 3**. The results of determining the possible relationship between changes in financial expenditures for defence needs and possible factors of influence*

| Factors | Parameters of one-factor dependence equations | Connection stability coefficient | Connection characteristic |
|---|---|---|---|
| Gross harvest of cereals and legumes (including corn) | $Y_{x1}=121,681.2(1-2.70899*d_{1-x/xmin})$ | 0.672 | Direct connection (reduction of factor and result characteristic) |
| Harvested and threshed area of cereals and legumes (including corn) | $Y_{x2}=121,681.2(1-8.33462*d_{1-x/xmin})$ | 0.447 | Direct connection (reduction of factor and result characteristic) |
| Average prices of agricultural products sold by enterprises | $Y_{x3}=121,681.2(1-1.36852*d_{1-x/xmin})$ | 0.815 | Direct connection (reduction of factor and result characteristic) |
| Yields of cereals and legumes (including corn) | $Y_{x4} = 121,681.2(1 - 3.31359*d_{1-x/xmin})$ | 0.601 | Direct connection (reduction of factor and result characteristic) |

***Table 4**. The results of determining the possible relationship between changes in average prices of agricultural products sold by enterprises and possible factors of influence*

| Factors | Parameters of one-factor dependence equations | Connection stability coefficient | Connection characteristic |
|---|---|---|---|
| Gross harvest of cereals and legumes (including corn) | $Y_{x1} = 4,794.1(1 - 1.97949*d_{1-x/xmin})$ | 0.672 | Direct connection (reduction of factor and result characteristic) |
| Harvested and threshed area of cereals and legumes (including corn) | $Y_{x2} = 4,794.1(1 - 6.09023*d_{1-x/xmin})$ | 0.294 | Direct connection (reduction of factor and result characteristic) |
| Yields of cereals and legumes (including corn) | $Y_{x3} = 4,794.1(1 - 2.42129*d_{1-x/xmin})$ | 0.833 | Direct connection (reduction of factor and result characteristic) |

When comparing the dynamics of financial expenditures for defence needs and possible factors of influence, the most stable and direct relationship (reduction of factor and performance) is identified between "changes in average prices of agricultural products sold by enterprises and changes in military expenditures" – "0.815". According to the results obtained using the method of statistical equations of the relationship

between changes in average prices of agricultural products sold by enterprises and possible factors of influence, the most stable and direct relationship was observed with cereals and legume yields (Table 4). Thus, the comparison of three possible ways of influence of cereals and legumes on the pricing of agricultural enterprises (gross harvest, area and yield) shows the importance of crop yields.

An important component of the state should be a targeted policy on food production, the most important conditions for the establishment of which should be the development of mathematical models that can adequately assess the real and potential development of the agro-industrial complex as a whole and within its regions, analysis of dynamics, identification of positive and negative aspects in this area. For the current level of research on the food complex of agriculture and in particular agriculture, a significant approach is one in which the dynamics of milk production [28] is analysed using mathematical methods and models that allow for deeper analysis and obtain the most structured and mathematically sound results at the moment of consideration of the process and its perspective. This approach can also be applied to the agricultural sector. Extrapolation of the dynamics of average prices for agricultural products sold by enterprises in 2022-2024 indicates its future increase by an average of 8% (Fig. 6).

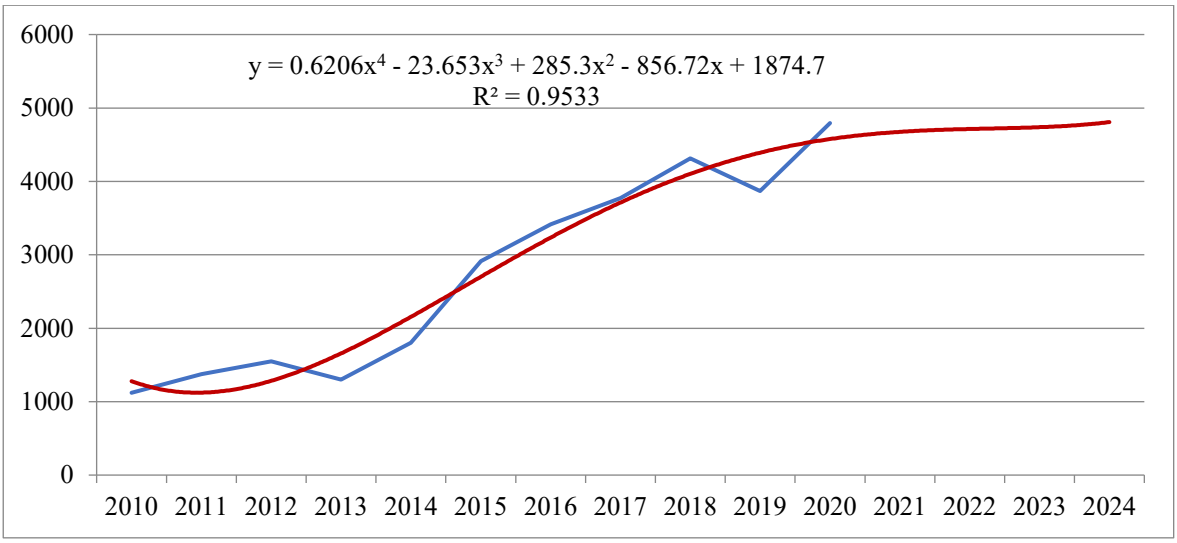


***Figure 6***. *Extrapolation values of average prices of agricultural products sold by enterprises for 2022-2024*

Military spending is important for the national security of the country, so its full and timely provision is part of the priority areas of public policy at present. There are conflicting views on the interdependence of military spending and economic development of sectors of the national economy. In general, due to the loss of government control over part of the territory and ongoing hostilities in society, transformation processes have begun, aimed at mobilising resources as quickly as possible to prevent further escalation of the conflict. Ukraine's economy, which was not ready for military aggression, was forced to take the first steps to move to a new state – the wartime economy. The final assessment of the consequences of this is possible only after the end of hostilities, and current calculations only make it possible to predict with some probability the further development of the situation. A thorough examination of the economy's losses from the conflict should be the starting point for its post-war recovery. The results of relevant analyses can be used in the development of approaches, methods, techniques for "increasing crop yields to reduce average prices for products", or – "initiating military and economic development of the country by increasing crop yields", etc.

## CONCLUSIONS

The example of Ukraine shows that with the increase in military spending there is a decline in GDP per capita, slow economic development, significant changes in the development of some industries in the national economy, etc. But this dependence is largely conditioned upon the military conflict, so the conclusions cannot be unequivocal. For example, Ukraine's agricultural sector suffered some upheavals at the beginning of the 2015-2016 armed conflict, but as of today it has practically adapted to operating in such conditions, as evidenced by growth rates in most key positions. There are losses of agricultural land, significant losses of the rice sector and several other positions, but innovative changes have had a positive impact on the development of the industry as a whole, even in the face of another state and partial loss of eastern export markets (Russia, Belarus). New areas of export of products have been formed, which are more demanding to quality but more profitable.

When comparing the dynamics of financial expenditures on defence needs and possible factors of influence, the most stable and direct relationship "change in average prices of agricultural products sold by enterprises and changes in military expenditures", the factor

that has the greatest impact on pricing was "crop yield". Proper public administration of the agricultural sector in an agricultural country such as Ukraine is part of increasing the country's GDP, which in turn can be used to increase funding for defence needs. This aspect can serve as a basis for further research in this area, namely the impact of armed conflict on the state of all agricultural sectors, taking into account the relationship between changes in prices for agricultural products and financial expenditures for defence needs. The basis of further research in the direction defined in the paper is the establishment of a general mathematical model for forecasting the results of development programmes of the defence industry of Ukraine, taking into account trends in the agro-industrial complex of Ukraine in the medium and long term.

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## Оцінювання впливу збройного конфлікту на території України на розвиток сільськогосподарської галузі та ціноутворення її продукції

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**Анотація**. У статті проведено аналіз впливу збройного конфлікту на території України на розвиток сільськогосподарської галузі та зміну середніх цін продукції, реалізованої підприємствами сільського господарства, а також визначено можливий взаємозв'язок між зміною ціни на продукцію сільського господарства, реалізовану підприємствами, та фінансових витрат на оборонні потреби. У статті також розглянуто можливий зв'язок між зміною обсягів воєнних витрат, валового збору зернових і зернобобових культур, зібраної та обмолоченої площі, рівнями їх урожайності. Авторами взято до уваги, що наявність і тривалість збройного конфлікту на території країни впливає на: макроекономічні показники, інтенсивність бойових дій і їхню локалізацію в районах економічної активності, ВВП, видатки уряду, експортно-імпортні показники; видатки домогосподарств та внутрішні інвестиції, на споживчі видатки та видатки домогосподарств. Усе це, опосередковано, має вплив на коливання середніх цін продукції різних секторів сільського господарства, реалізованої підприємствами. Під час проведення досліджень авторами врахована важливість аграрного сектору України, що є вагомою частиною ВВП держави. Залежність воєнних витрат від величини ВВП слугує причиною до аналізу взаємозв'язків між впливом наявного збройного конфлікту на зміну стану сільського господарства України. Одним із результатів таких дій також стало витрачання більшої грошової маси на закупку продукції сільськогосподарського спрямування для підтримання оборонних потреб держави тощо. Тому для розуміння величини впливу факторів валового збору, урожайності та обсягів сільськогосподарських угідь на ціноутворення продукції сільського господарства за допомогою методу статистичних рівнянь залежностей авторами отримані результати відповідного аналізу, що можна використовувати як базу для розроблення підходів, методів і методик щодо підвищення рівня врожайності сільськогосподарських культур, або – ініціювання економічного розвитку країни за рахунок підвищення урожайності сільськогосподарських культур

**Ключові слова**: фінансові витрати, макроекономічні показники, валовий внутрішній продукт, внутрішні інвестиції, аграрний сектор

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# Coherence of Marketing Imperatives for Managing the Development of Socio-Economic Systems

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**Abstract**. At present, there is a reorientation of the current model of the market economy towards the principles of sustainable development. The process is accompanied by the implication of the marketing concept of managing socio-economic systems, the technology of which provides reasoning of the determined guidelines that must be adhered to. In this context, the coherence of marketing imperatives is a determinant of ensuring the development of socio-economic systems, whereas the marketing-imperative approach should be considered one of the levers of sustainable economic development. Therefore, the purpose of the study is a complex substantiation of the theoretical and methodological content of marketing imperatives, the interpretation of their coherent influence on the management of socio-economic systems. The methodological basis of the study is an integrated combination of general scientific methods of systematic cognition and possibilities of application of specific methodological approaches to solving problems and verification of the formulated study hypothesis; the methods include monographic, hypothetical prediction, abstract-logical, induction and deduction, historical and economic, structural-functional analysis, abstraction and content analysis, construction of concepts and categories, graphical and tabular. The study provides insights into the special features of the evolution of the etymological essence of the imperative in the context of transformations of socio-economic systems; the essence of marketing imperatives in view of marketing ideology is substantiated; the mechanism of transformation of objectives into imperatives in achieving the goal of socio-economic system is developed; the necessity of the implication of the marketing-imperative approach in sustainable economic development is proved. The practical value of the study consists in the scientific substantiation of the theoretical and methodological content of marketing imperatives, the specification of their coherent impact on the management of socio-economic systems. Further studies are aimed at developing criteria for measurement, assessment, and interpretation of the effect after the implementation of marketing imperatives with subsequent testing of results

**Keywords**: marketing imperative, marketing concept, marketing objectives, socio-economic system, development management, transformation



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## INTRODUCTION

Modern stage of the development of the national economic system, along with quantitative changes in its key parameters, is characterised by: firstly, considerable qualitative transformations associated with the growth of market uncertainty, the aggravation of competition, including in the international arena; secondly, the increased orientation of production on the needs of consumers, maximum consideration and satisfaction of their needs and interests (meeting consumer demand is a priority for business); thirdly, the acceleration of the pace of scientific and technological progress, innovatisation as a predictive idea of the development of socio-economic phenomena and processes, which causes the emergence of new branches, technologies, industries, reduction of the life cycle of goods (services); fourth, digitalisation of business processes and emphasis on new logistics approaches to the organisation of basic models for product (service) promotion; fifth, strengthening of the requirements for the quality and prestige of the product, trademark, reputation and image of the producer, etc. Under such circumstances, the need is exacerbated and the paramount importance of marketing tools and technologies for the development and implementation of innovative models of economic development in general and in terms of its individual segments is emphasised.

The focus of modern researchers on the priority of marketing approaches to managing socio-economic systems is caused by the growing need to raise the role of market levers and mechanisms in the context of a globally oriented mainstream of social development. The current emphasis on the use of conventional management concepts is shifting towards the privileged principles of sustainable development management. Confirmation of this is that the mission of the National Economic Strategy until 2030 is defined as "creating opportunities for the fulfilment of the existing geographical, resource, and human potential to ensure the well-being, self-fulfilment, security, and freedoms of every citizen of Ukraine through innovative economic growth" [1]. In the implementation of this vision, a prominent place is given to the use of a marketing and imperative platform for forming concepts for managing this process with a focus on challenges of the global economic space and sustainable development goals.

Currently, the imperative principle is increasingly appearing in the discourse of researchers of various interest spheres of scientific schools and trends. The essence of the imperative is explained by philosophers, linguists, lawyers, managers, economists, marketers, environmentalists, technologists, sociologists, historians, and other specialists, with an emphasis on individual professional provisions. That is, the "imperative" principle is increasingly used in relation to the basics of human life in almost all spheres of its existence. The outlined facts stimulate development and are simultaneously determined by the transformations of social phenomena and processes, that is, their binary content is emphasised – compliance with Imperative norms ensures development. In turn, in economic theory, development is considered mainly as a process that results in a change in the quality of the developing object, a transition from one qualitative state to another – the highest. It is well known that development as an economic category has such characteristic features as movement, process, change, and time. In addition, the development of any system takes on a systemic character due to such properties as irreversibility, orientation, and regularity. According to the opinions and approaches of modern researchers, development is "evolution with a directed trajectory and a linear causal relationship" [2, p. 19]. Therefore, there is reason to assert that imperatives are an indispensable component of mechanisms for managing socio-economic systems and the prerogative of their development.

*The purpose of this study* is a substantiation of the theoretical and methodological content of marketing imperatives, a definition of the level of their coherent impact on the management of the development of socio-economic systems. The key *tasks* are as follows:

1) to highlight the features of the evolution of the etymological essence of the imperative in the conditions of market transformations;

2) to characterise the content of marketing imperatives in view of marketing ideology from the standpoint of transformation of goals into imperatives in achieving the goal of development of the socio-economic system;

3) to prove the need to apply the marketing-imperative approach in the sustainable economic development.

## LITERATURE REVIEW

The principle of the imperative is considered to be applied mainly in the field of practical philosophy. The fundamental analysis of its etymological essence is conducted in the studies of the well-known researcher I. Kant, "Groundwork of the Metaphysics of Morals" (1785) and "Critique of Practical Reason", (1788), which highlight "…cognitive capabilities of the mind, in isolation from knowledge obtained empirically, that is, through experience" [3]. The imperative, according to the researcher, is "a rule containing objective compulsion to act of a certain kind; it is the relation of human freedom to the laws of morality" [3]. That is, the studies of I. Kant are based on the examination of imperatives in the philosophical cognition of man. I. Kant divides all imperatives into two groups: a) categorical (undeniable, unprecedented moral precepts "on the proper behaviour of a person as an intelligent being with free will; the execution of this order is absolutely necessary, regardless of whether a person receives benefits for oneself as a result)" [3] and b) hypothetical (relatively variable imperatives, which largely depend on various factors; certain requirements that must be observed as necessary conditions for achieving

the goals set; it is not an end in itself and it only acts as a means achieving the goal) [3].

In the new dictionary of foreign words, imperative (lat. *imperativus* – mandatory) is considered as 1) urgent demand, behaviour; 2) imperative mood [4, p. 257]. In the online dictionary of the Ukrainian language, this definition is presented as an unconditional, categorical demand, command, order [5, p. 20]. In a well-known American dictionary *Merriam-Webster*, the imperative a) "expresses the will and influences the behaviour of another"; b) "expresses pleas, persuasions, necessity"; c) "has the ability to restrain, control" [6]. That is, the majority of modern dictionaries emphasise the persistence or requirement to comply with the imperative, the mandatory method of compliance.

Modern researchers use the principle of imperative mainly as a completely understandable phenomenon without detailing its deep essence and features of the application in the relevant fields or industries. In identifying existing developments on the essence of the "imperative" in the economic sphere, it should be noted that quite often Ukrainian researchers consider the imperatives of economic development: firstly, as *individual phenomena* (sustainable economic growth, social and environmental stability, innovative transformations, creative management decisions, digitalisation of business, etc.) [7-9]; secondly, the imperatives of individual *areas or branches of activity* (strategic, economic, institutional, geo-economic, financial, environmental, social, European integration, convergent, humanistic, creative, cultural, tourist, technological, informational, cultural, social) [10-12]; thirdly, as absolutely diverse, often unrelated aspects with *synonymous substantiation*, in particular, the identification of imperatives with: a) determinants (focuses on components, causes, conditions of influence) [13-15]; b) factors, drivers (emphasise the sources of influence) [16; 17]; c) opportunities, areas, features, trends, manifestations (options for solving problems are outlined) [15; 18].

## METHODOLOGY

The theoretical and methodological platform for conducting this research was an organic combination of generally accepted provisions and principles of economic research, fundamental postulates of economic theory, the concepts of the theory of managing the development of socio-economic phenomena and processes with the appropriate study of the possibilities of applying specific methodological approaches to in-depth argumentation and solving tasks and verifying the formulated research hypothesis, the content of which is that the introduction of marketing imperatives of managing socio-economic systems will ensure their sustainable development. In addition, the research methodology is supplemented by an in-depth study of the scientific heritage of Ukrainian and foreign researchers, whose research interests are the problems of forming imperatives of economic development and highlighting the place and role of the marketing concept in this process.

The methodological tools of the research portfolio are formed from general scientific and special scientific methods. Upon using *methodological constructions of the system approach*, the components of the "spiral model" of society development (immanent effect of the imperative → identification of advantages, disadvantages, threats, opportunities, risks → actualisation of the need for transformation → development of a qualitatively new imperative) in the plane of proliferation and their system interaction with the focus on the features of the life cycle of the imperative and the time interval of its action are characterised. A *hypothetical prediction* allowed characterising the potential opportunities and advantages of orienting the development of socio-economic systems in the area of activating mechanisms and technologies for managing economic phenomena using marketing tools, its implementation in all spheres of the economy.

The study of the problem of development of marketing imperatives for managing the development of socio-economic systems is conducted in an organic combination of historical aspects of this phenomenon with the logic of transformation of this process and abstract configuration of expected results. The *abstract-logical* method is applied to generalise scientific results, formulate relevant conclusions through in-depth cognition of managing the development of socio-economic systems on a marketing basis. This approach was based on the fact that if the implementation of marketing imperatives in the practical plane of managing the development of socio-economic systems can be learned empirically, the meaning of this phenomenon – only through logical thinking. The *historical and economic method* was used to highlight the features of the evolution of the etymological essence of the imperative in the context of transformations of market-oriented economic systems. The results of the study on the etymological essence of marketing imperatives are compared based on the method of *comparative analysis*. The *induction and deduction* are used for in-depth study and systematisation of the basic provisions of the theory of marketing management through their extrapolation into the plane of managing the development of socio-economic systems at various hierarchical levels (micro-, macro-, meso-), their systematisation with subsequent differentiation of scientific approaches to understanding the essence of imperatives, their classification in the context of various scientific schools and trends. The *monographic* method is used for in-depth research of the problems posed and substantiation of the possibilities of involving individual marketing tools and technologies in the management process. The *structural and functional* analysis identifies the components and processes of creating an institutional environment for the implementation of marketing imperatives in managing the development of socio-economic systems.

During the study, the following methods were also used: *abstraction and content analysis to deepen* the content of marketing imperatives in view of marketing ideology and prove the need to implement the principle of a marketing-imperative approach to the study of socio-economic units in the establishment and development of a market economy. The method of *constructing concepts and categories* is applied for the purpose of critical analysis of existing ones and formulation of the author's vision regarding the definition of the principle of "marketing imperative". The mechanism of transformation of goals into imperatives in achieving the goal of the socio-economic system with the appropriate formulation of the vision, concept, and strategy is substantiated using the *transformational analysis*. Upon using *tabular and graphical* methods, a visual interpretation of the obtained research results is conducted for a better perception of the presented research results.

## RESULTS AND DISCUSSION

***The implication of the imperative in the establishment and development of socio-economic systems***

The methodological perspective of the study of the development is associated with positive changes in the object under study, the processes of improvement, acquisition of new qualities and properties, the transition from one qualitative state to another – higher, characterised by the opposite of the invariance of being [2]. That is, there is a transformation of quantitative signs of development into qualitative ones with corresponding changes in individual elements of the system, directly in the production system and, as a result, in structural and functional relations. Coherence of marketing imperatives in this regard should be considered a necessary condition for ensuring development. Modern mechanisms for ensuring socio-economic well-being and growth are accompanied by the establishment of self-regulatory relationships and their development through the "spiral" character of this phenomenon [18, p. 23]. This phenomenon occurs due to the fact that after achieving maximum efficiency, under certain circumstances, the next stage is when the imbalance between the existing imperative norm and the environment transformed in the process of development increases over a certain period. As a result, there is a need for a qualitative update of the previous content of the imperative, considering the new initial provisions, to ensure effective interaction in a society designed to ensure socio-economic development. This process takes on the character of proliferation – a continuous increase of new rules and norms of socio-economic interaction of individuals based on those that have already completed their development [4, p. 499; 20]. Thus, considering the above provisions, Figure 1 generalises the model of the establishment of imperatives of socio-economic system development.

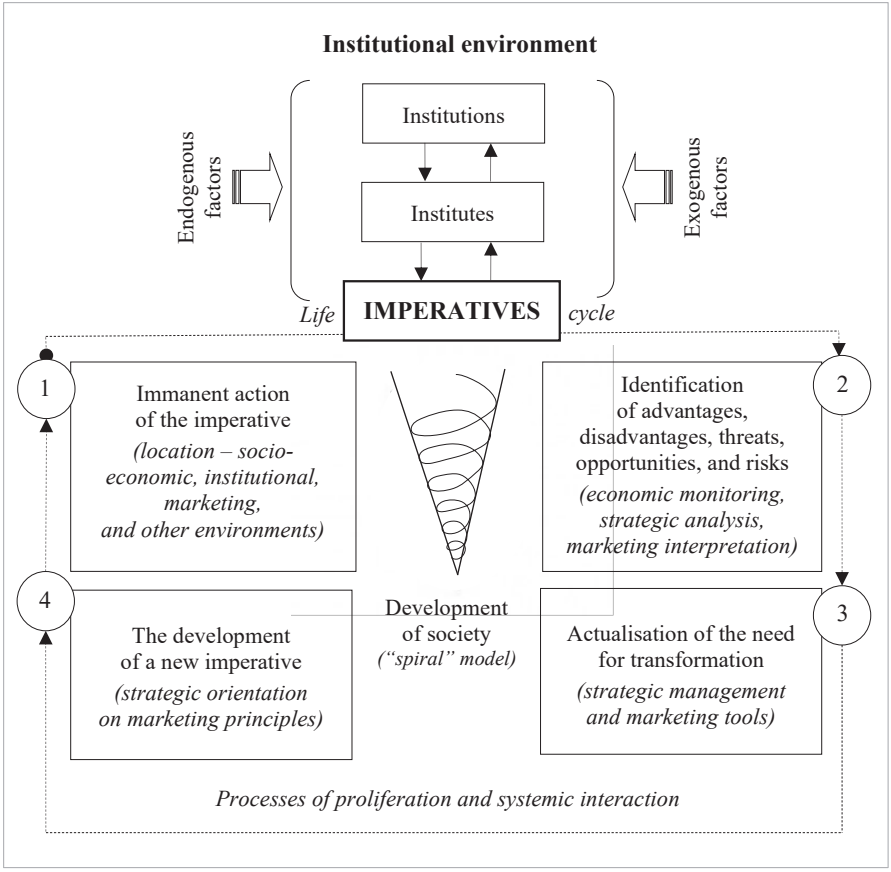


***Figure 1***. *Establishment of imperatives for the development of socio-economic systems*
***Source***: *developed by the authors based on the studies [17; 19, p. 225]*

***Explication of marketing imperatives: Convergence and divergence of scientific approaches***

In one of the modern dictionaries, the imperative is interpreted as "a principle that has the character of an unconditional duty and is based on deep moral and ethical beliefs of a person, which as a result makes a formalised moral or ethical social norm as effective as possible" [21]. This aspect, according to M. Ilina, and Y. Shpyliova, is a key for identifying the differences between formal and informal social rules and, in fact, imperatives [10, p. 222]. Researchers claim that with this approach the relationship between the definitions of "institution", "institute", and "imperative" is established, which occurs mainly in the case of identifying mandatory and formal norms while simultaneously delineating their boundaries and criteria. Admittedly, these concepts are not identical, despite their functional and evolutionary similarity. This approach lies in the fact that the institution as a certain form of organisation, regulation of public life, activities and behaviour of people gives an impetus to the establishment and further development of the institution as a characteristic organisational and structured form of interaction of individuals in society [19, p. 22]. As a result, the institution based on generally accepted customs and considering the probability of its perception by society forms an imperative that should ensure the necessary regulation and coordination of relations in a certain institutional environment [10, p. 222; 11]. For their part, national researchers define institutional environment as "a clear ordered set of institutions that determine the framework conditions for the functioning and development of economic entities" [10, p. 223], or "infrastructure that is designed to contribute to efficient production activities, rapid commodity exchange, the development of a positive image of the enterprise, and the use of innovative developments in economic activities" [22, p. 284], etc.

As for the classification of imperatives, they are most often divided into a) imperatives of direct influence (direct action); b) intermediate imperatives (adaptive action); c) hidden imperatives (indirect action). It is important to focus on the imperatives of direct action, which, primarily, should include economic, political, environmental, and social. Economic imperatives are often considered to be the statement that the national economic system should be "efficient, competitive, and, at the same time, socially oriented, resource- and energy-efficient, environmentally stable, etc." [10, p. 224]. That is, such imperatives are based on mandatory requirements because otherwise there will be irreversible processes of social importance that are not desirable in the creation of a certain course of development of the economic system.

It is well known that "the laws and regularities of economic management are objective and do not depend on the will and consciousness of people. Their effect is manifested only in human activity, depending on how fully the requirements of objective laws are considered" [23]. In this sense, the term "*marketing imperative*" is becoming increasingly important, because, as already noted, under market conditions, the role of marketing institutions in the management of socio-economic phenomena and processes increases. In view of this, it can be argued that its content, in relation to the fundamental nature of the requirement to perform specific actions, is expanded due to marketing specific features or the field of research. In this regard, it becomes clear that when referring to marketing imperatives, it is necessary to apply the tools of marketing – a branch of economics that studies the theory and methodology of marketing [4, p. 367].

In the studies of foreign researchers, most often attention is focused, firstly, on the substantiation of marketing imperatives as tools for responding to the consequences of the globalisation of marketing, that is, expanding its framework boundaries and promotion in the international environment [24; 26]; secondly, on highlighting the principles of strategic marketing as target indicators for defining the imperatives of the development of socio-economic phenomena and processes [25]; thirdly, on the exposure of marketing technologies for the establishment and development of business [27].

R. Griffin and M. Pastey in the famous study named *International Business* consider three key marketing imperatives in the context of business globalisation, namely: 1) the use of key competence of the enterprise (that is, the possibility of wider application of those competencies (strengths, competitive advantages) that were most developed in the national market); 2) penetration of the company into new markets (in the conditions of a fully formed national market, in which the opportunities for further development and profit generation narrow); 3) the need to compete in own industry (to maintain existing competitive advantages and identify new ones) [24].

American researchers M. Czinkota, I. Ronkainen, J. Tarrant, etc., in their study *The Global Marketing Imperative*, 1995, thoroughly cover the mission of marketing imperatives as a determinant of competition management at the international level, emphasising the role of strategic marketing tools in promoting business to the global environment [26]. Researchers have detailed marketing steps to ensure the success of business structures in the international arena.

C. Churchwell, based on the scientific statements of K. Bartlett and S. Goshal, suggests reflecting the following marketing imperatives in the activities of a modern enterprise: "1) it is necessary to remain effective on a global scale and maintain competitiveness, integrating different types of activities and coordinating the work of labour resources in different countries of the world; 2) it is necessary to respond sensitively to the tastes of customers and the requirements of governments; 3) a modern manager should see the world not only as a set of national markets but as a source of information, knowledge, and skills, which, in turn, are key resources for ensuring the development of innovations and their implementation all over the world" [25].

Research has established that in Ukrainian studies, the coverage of the essence of marketing imperatives is not given due attention. Therewith, adherents of modern marketing emphasise the need to strengthen the marketing orientation of technologies for managing socio-economic phenomena and processes [27-29]. A review of papers on this subject suggests that most researchers associate this principle mainly with the features of marketing activities of business entities, stating that its structuring is based on *MarTech*, and technologisation of marketing activity is considered as an objective requirement of the present and a tool for improving the organisation and clarity of the work performed, a clear substantiation for the stages of its implementation, techniques and actions aimed at achieving marketing goals [9, p. 45].

Marketing technologies, in the conditions of effective support of the development and implementation of marketing solutions for the coordination of interests of business entities, consumers, and society in general, contribute to solving problems not only in the production but also in the management of a specific sphere of socio-economic relations. The most common modern marketing technologies, the effectiveness of which is proven in practice, are the following: merchandising; direct, network, viral, guerrilla marketing; cross-marketing; product placement; Internet marketing; SEO; SMM and SMO; branding; social marketing technology, etc. The expediency of using a particular technology, or a combination of them, is determined by the tasks set within the framework of achieving specific goals.

If the mission defines the business philosophy, imperatives are positioned as real goals, the effect of achieving which can be quantified. The above refers to, for example, such goals as business expansion, improving the quality of products (services), high level of service, image growth, brand promotion, etc. Evidently, the established goals are not imperatives in their content, but they are transformed into imperatives when the management decision states the need to achieve these goals in a mandatory manner (Fig. 2).

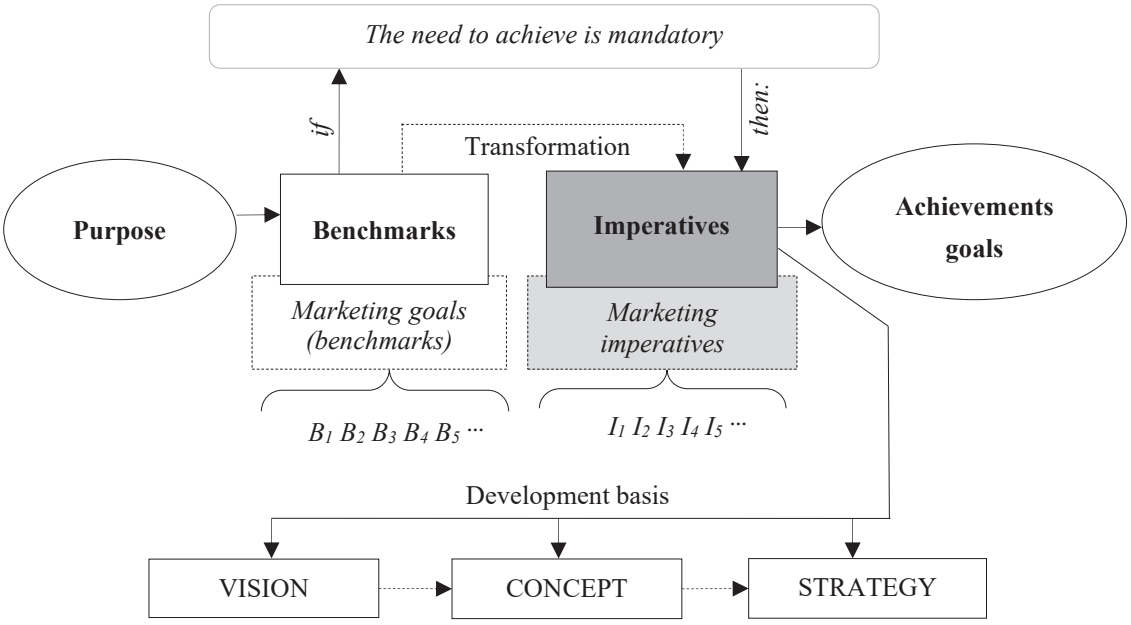


***Figure 2**. Mechanism of transformation of "benchmarks" into "imperatives" in achieving the goal of the socio-economic system*

***Source**: authors' own research*

Summarising the above, it is proposed to consider marketing imperatives as benchmarks (marketing goals) that must be followed in managing the economy to ensure its development on a marketing basis.

***Marketing imperatives – vectors of modern business development***

It is worth noting the importance of the research results of N. Capon (USA), V. Kolchanov (Russia), and J.McHulbert (USA), which distinguish six generalised marketing imperatives, which, in fact, allow modelling the vector of scientific search on the studied problems: 1) identify and recommend markets to work with; 2) identify market segments and focus on them; 3) choose a strategic area and positioning; 4) develop marketing proposals (marketing complex); 5) ensure consistency with other functions (support of project development and implementation processes); 6) monitor implementation and control results [31]. Details of these imperatives in terms of their practical implementation are presented in the book by N. Capon *The Virgin Marketer*, which outlines the key marketing principles: selectivity and concentration; values for the consumer; competitive advantage; integration [30].

Indisputable scientific value from a theoretical, methodological, and practical standpoint is represented by annual thorough research conducted by the world's leading marketing companies. The importance of the results of sociometric observations conducted by the agency *Merkle* should be emphasised [32]. The company positions marketing imperatives from the perspective of strategic vectors of modern business development at various levels of object-subject relations. The credibility of the results presented in social networks is characterised by uniqueness, constructiveness, relevance, and accessibility of perception of the information resource presented on the platform based on the involvement of various marketing technologies (Table 1).

***Table 1**. Content of marketing imperatives of modern business (according to research by Merkle marketing agency)*

| Year | Key orientation |
|---|---|
| 2017 | Building a digital marketing strategy to predict the prospects of retail |
| | *Imperative 1*. Using digital marketing to improve customer interaction.<br>*Imperative 2*. Using multi-channel features.<br>*Imperative 3*. Using data to form a digital strategy |
| 2018 | Strengthening of email-marketing |
| | *Imperative 1*. Centralised customer data to improve access and promote growth.<br>*Imperative 2*. Construction of a map in real time before the implementation of the solution.<br>*Imperative 3*. Involving IT in vendor evaluation |
| 2019 | Integrated marketing strategy focused on people |
| | *Imperative 1*. Integration of the client's strategy.<br>*Imperative 2*. Integration of one's own technology stack.<br>*Imperative 3*. Integration of one's own execution |
| 2020 | Hyper-personalisation and customer interaction |
| | *Imperative 1*. Ensuring complete customer experience.<br>*Imperative 2*. Personal ownership (personal brand) as a key business advantage.<br>*Imperative 3*. Ensuring agility through strategic search |
| 2021 | Customer experience |
| | *Imperative 1*. Data transformation.<br>*Imperative 2*. Digital transformation.<br>*Imperative 3*. Adaptive organisation |

***Source**: developed by the authors based on the studies [32-34]*

The results of summarising the information published on the website [32] indicate a systematic innovation-oriented update of targeted marketing imperatives for business process development, which allows stakeholders to gain personalised opportunities and skills to improve the effectiveness of management processes in rapidly changing external conditions. Notably, considering the proposed imperative substantiation for managing the development of socio-economic systems is an indisputable tool for activating the management system at various levels of hierarchical influence.

## CONCLUSIONS

1. In modern research on management, economics, and marketing, imperatives are laid down as the basis for setting the mission and goal of developing socio-economic systems and are considered at different levels (micro-, meso-, macro-), which, accordingly, causes differences in their content, orientation, manifestation, evaluation parameters, interpretation of effects, etc. The potential effect, if the corresponding marketing imperative is met, is achieved in immanent conditions of the socio-economic system, the level of influence of factors of its marketing endo- and exogenous habitats, and proliferation of the imperative.

2. The essence of marketing imperatives in view of marketing ideology is covered through their consideration as benchmarks (marketing goals), which must be adhered to when managing the socio-economic system to ensure its permanent development. Certain goals are not imperatives in their content, but they are transformed into imperatives when a management decision states that they are mandatory. The transformation of goals into imperatives is conducted based on an appropriate mechanism, which is characterised by internal organisational system connections. At each hierarchical level of the management system, the overall goal turns into specific imperatives (categorical or hypothetical), which are based on various functionals, including marketing ones. Marketing imperatives, based on the dynamism of economic progress and goal-oriented principles of constancy, are tools for achieving the goal of the socio-economic system.

3. The need to imply the principle of marketing-imperative approach in the process of sustainable economic development is explained by the fact that, on

the one hand, marketing imperatives form a "road map" for building and implementing a marketing strategy for individual businesses as local units of compliance and promotion of sustainable development using appropriate marketing technologies, on the other hand, they should be attributed to the fundamental principles of creating a general strategy for sustainable development of the national economy. The prospects for further research in this scientific area are the development of criteria for measuring, evaluating, and interpreting the effect of implementing marketing imperatives, followed by verification of the results obtained.

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## Когерентність маркетингових імперативів управління розвитком соціально-економічних систем

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**Анотація**. Актуальний насьогодні процес переорієнтації існуючої моделі ринкової економіки на засади сталого розвитку супроводжується імплікацією маркетингової концепції управління соціально-економічними системами, технологія якої передбачає аргументацію визначених орієнтирів, яких необхідно дотримуватися. У контексті зазначеного когерентність маркетингових імперативів є детермінантою забезпечення розвитку соціально-економічних систем, а маркетингово-імперативний підхід варто вважати одним із важелів формування концепції сталого розвитку економіки. Метою наукового дослідження є комплексне обґрунтування теоретико-методологічного змісту маркетингових імперативів, інтерпретації контурів їх когерентного впливу на процес управління розвитком соціально-економічних систем. Методологічною основою дослідження є органічне поєднання загальнонаукових методів наукового пізнання на засадах системності із опрацюванням можливостей застосування специфічних методичних підходів до вирішення поставлених завдань та верифікації сформульованої гіпотези дослідження, зокрема монографічного, гіпотетичного передбачення, абстрактно-логічного, індукції та дедукції, історико-економічного, порівняльного, трансформаційного, структурно-функціонального аналізу, абстрагування і контент-аналізу, конструювання понять і категорій, графічного і табличного прийомів. У статті розкрито особливості еволюції етимологічної сутності імперативу за умов трансформацій соціально-економічних систем, обґрунтовано сутність маркетингових імперативів у світлі маркетингової ідеології, розроблено механізм трансформації цілей в імперативи у процесі досягнення мети соціально-економічної системи, доведено необхідність імплікації концепції маркетингово-імперативного підходу в процесі сталого розвитку економіки. Практична цінність проведеного дослідження полягає у науковому обґрунтуванні теоретико-методологічного змісту маркетингових імперативів, характеристиці їх когерентного впливу на управління розвитком соціально-економічних систем. Подальші дослідження націлені на розроблення критеріїв виміру, оцінки та інтерпретації ефекту імплементації маркетингових імперативів з подальшою апробацією отриманих результатів

**Ключові слова**: маркетинговий імператив, маркетингова концепція, маркетингова ціль, соціально-економічна система, управління розвитком, трансформація

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# Digitisation of Ukraine in Terms of Public Electronic Services' Distribution

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**Abstract**. Modern scientific and technological progress makes the use of information, communication, and digital technologies an attribute of any business's functioning and people's lives. COVID-19 pandemic, which has led to widespread quarantine restrictions, has necessitated an accelerated transition to digital remote access services. In this regard, the authors have investigated the development and spread of digital technologies in Ukraine to implement e-government policy. To assess the realities and determine the prospects of becoming a "state in a smartphone", the authors have conducted a SWOT analysis of electronic public services. The analysis allowed to identify the advantages and threats of e-government at the present stage and outline the strategies for developing Ukrainian digitalisation. In the state as a service, digital changes are taking place in many industries and spheres, so the authors have identified key components of the digital state, including cybersecurity, e-government, smart cities, digital skills, e-court, e-health care, e-transport, and the Internet. These components are closely linked to e-democracy, e-business, and e-education. In Ukraine, there is a unique state web portal of electronic services, "Diia", which provides access to dozens of electronic state services. Therefore, the authors have studied the purpose, features of use, opportunities, and difficulties of the portal and mobile application "Diia". In the usage part, the authors have considered the specifics of authorisation on the portal through the file media of the digital signature and built the appropriate algorithm of actions. Along with the potential risks, modern information technologies provide many opportunities for their users. Finally, the study allowed to outline the prospects for the digitalisation of the Ukrainian state in modern realities

**Keywords**: "Diia", digital transformation, digital state, e-government



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## INTRODUCTION

Digital technologies are a modern key trend, mediating all spheres of social life and economy. As a result, a digital economy is being developed, characterised by the active use of informational technologies and the turnover of specific electronic goods and services. Digitalisation goes beyond economic processes, and digital technologies are widely used in government structures and organisations.

Although Ukrainian e-government has just started to develop, there are examples of modern research on this topic. Among them, I. Fyshchuk and O. Evsyukova have explored effective communication in the digital transformation of service state during change management processes in Ukraine [1]. The authors' work, published in a Lithuanian journal, underlines the introduction of many reorganisation forms like civil society, unions, or associations. It makes a need to provide an efficient way for them to communicate with authorities altogether and due to personal requests. Furthermore, V. Psota et al. have investigated the "Competition in public procurement in the fight against corruption: analysis of an example of Ukraine" [2]. This paper gives evidence of the beneficial impact of e-reforms which help save budget money and reduce the possibility for corruption, increase transparency, and help to arrange the monitoring and control systems.

World COVID-19 pandemic has put new tasks to improve every country health system. Digital technologies, like e-health, give the change to react faster, keep and analyse big data, get information remotely. S. Kutia et al. have evaluated the socio-technological factors affecting users' adoption of e-Health functionalities [3].

Modern e-government can help arrange regular communication and surveys to find out the residents' point of view in a small community [4]. Moreover, it is essential to note the involvement of the public in the reforms as a critical guarantee of their success in the long run [5].

Thus, modern information technology has become part of the developed economies' daily lives, the work of their governments and local authorities, and rapidly spreads in growing economies. After all, such communication is an opportunity to be in touch with the whole world, process large amounts of information rapidly, provide many services remotely, and maintain a decent quality of life in the conditions of quarantine restrictions. The broader use of gadgets by all segments of the population, including the elderly and children necessitates public services via mobile devices. The growing coverage of access to the global Internet allows making various online purchases in different parts of the world, process statistical information by a wide range of specialists, make an appointment to the specific doctor at a convenient time, receive and provide advice, work as a freelancer, and even travel virtually.

All the above mentioned gives confidence that public electronic services have a certain future, needs to be explored, improved, and widely discussed. Moreover, this discussion can help finding new answers to the old questions, modern problems, visions, and ideas to fix bugs or eliminate the barriers. That helps to formulate the aim of the study: to investigate the current state of electronic public services in Ukraine and determine its strengths and weaknesses to substantiate the key trends and prospects of becoming a "state in a smartphone".

## LITERATURE REVIEW

The informatisation has reached government systems and public services. In this context J.D. Twizeyimana and A. Andersson have made a literature review on the public value of E-Government [6]; I.K. Mensah – the impact of E-government performance on the process of adoption of E-Government services [7]; D. Valle-Cruz has evaluated the public value of e-government services through emerging technologies [8]; S. Defitri et al. have discussed determinant factors of e-government implementation and public accountability [9]; N.G. Elbahnasawy has answered the question if E-government can limit the scope of the informal economy [10]; D. Geneiatakis et al. have made a blockchain performance analysis for supporting cross-border E-Government services [11]; L. Sundberg has searched for an answer if the democracy is at risk in electronic government [12]; M. Danyliuk et al. have formulated the factors of direct and indirect influence of informatisation on the society, economy, and the state [13], and finally; V. Roblek et al. have evaluated the best practices of the social innovations in the framework of the e-government evolution [14].

Ukraine and other developing countries have just started to use e-services in a wide range of spheres. For instance, I. Palaco et al. have investigated the public-private partnerships for e-government in developing countries [15]; C. Knox and S. Janenova have examined the e-government paradox in post-Soviet countries [16]; L. Glyptis et al. have explored the project manager's perspective of e-Government implementation challenges in small countries [17]; M. Barna and S. Moroz have studied the digital development of the economies of Ukraine and the European Union [18].

Simultaneously many scientists have investigated a lot of different features in e-government services all over the world. Among them are Y.C. Chen et al., exploring the determinants of performance of the cross-boundary e-government systems [19]; R. Pérez-Morote et al. – the EU effects of e-government evaluation, trust, and the digital divide [20]; M.D. Lytras and A.C. Şerban – e-government insights to EU smart cities research [21]; I.O. Adam – E-Government development effects on corruption in

Africa [22]; Y. Li and H. Shang – the service quality, perceived value, and citizens' continuous-use intention regarding e-government in China [23]; T. Bournaris – e-government web portals in Greece [24]; S. Kukovič and G. Justinek – modernisation trends in public administration in Slovenia [25]; A. Sandor – web-based information management [26].

In Ukraine, digitalisation is entering a qualitatively new stage of its development, characterised by the development of digital technologies, the spread of Internet networks, and mobile communications. This allows to unite the state with a single communication system and create a holistic financial and information space. To optimise the central executive bodies, the Cabinet of Ministers of Ukraine in 2019 established the Ministry of Digital Transformation of Ukraine to implement digital development and e-government [27].

The main principles of the Ministry's work are based on the Concept of e-government development in Ukraine [28]. The purpose of the Concept is to coordinate cooperation between public authorities and local governments to achieve a high level of e-government efficiency, implementation of the decentralisation reform based on the widespread use of modern digital technologies throughout the country following the European requirements.

In Ukraine, public authorities and local governments provide more than 2,000 services, but 91.5% of the population of Ukraine do not use public services online [29]. At the same time, the public services' provision is accompanied by significant inconveniences, time, and financial costs. Instead, the public services digitisation will make them accessible, transparent, convenient, and understandable.

Moreover, electronic public services have not yet become familiar to all Ukrainians, and their implementation, in addition to the benefits, is accompanied by risks and caveats.

## MATERIALS AND METHODS

To achieve the research aim, the authors have studied the scientific works of leading national and foreign researchers in this field, as well as current trends in the digital transformation of Ukraine. This made it possible to identify the key components of the digital state, to assess their role, relationship, and interaction. This research step used historical and logical scientific research methods, induction and deduction, scientific abstraction, and systems analysis.

At the stage of studying the "Diia" portal and application, the authors considered the technical side of its work from the user's point of view, built an algorithm for using the electronic signature file media, explored the possibilities of "Diia" at the present stage. To do this, the authors downloaded from the App Store (digital distribution platform for selling mobile applications to iPhone smartphone owners) the application "Diia" on the smartphone and chose the most convenient way to authorise through BankId, using Privat24. By permitting to the Ministry of Digital Transformation of Ukraine to process personal data, the authors gained access to digital documents and electronic government services. Then the authors have also registered on the "Diia" web portal to get additional information.

For the study, the authors used the problem-finding method and the comparison method. Based on the analysis and synthesis, the authors have found that the number of services available in the "Diia" is somewhat limited compared to the web portal. Also, by comparison, the authors were able to determine the regional nature of e-government services and identify the most popular services.

The own empirical user's experience also influenced the presentation of this part of the study material. This, in turn, has increased the efficiency of identifying shortcomings and "bottlenecks" in the system's functioning.

Based on the statistical observation method, the authors were able to determine the dynamics of the users' number in the web portal and the application "Diia", the number of vaccination applications, and identify the regions where the most significant percentage of families used the service "eMaliatko."

Using the method of generalisation, it was concluded that despite some limitations and ambiguous attitudes in society, the project "Diia" is a significant achievement in the rapid development of digitalisation.

To assess the realities and prospects of the digital state in Ukraine, the authors have chosen the SWOT analysis method [30], which significantly helped identifying the strengths and weaknesses of the electronic public services system and the opportunities and threats of their implementation in everyday practice. After this, the strategic tasks and goals were determined.

## RESULTS AND DISCUSSION

### *Digital state*

Digitalisation of public services is designed to change the mechanisms and principles of public services radically. However, as the authors are considering the scale of the whole country, this process is not simple and is accompanied by complex technical, technological, social, and cultural changes.

Modern electronic public services have not yet completely replaced their previous paper counterparts. This means that many services coexist in both forms, which leads to an increase in funding for providing them during the transition to complete digitalisation. However, while the population is not technically ready for complete digitalisation, it has not yet become accustomed to the convenience of electronic services; public authorities and local governments have not yet worked out an effective mechanism for the digital state – this situation is forced but logical and understandable.

In Ukraine, there is an active development of the

most prominent digital project, "Digital State", which considers the state service in global informatisation and digitalisation. The changes in Ukraine concern both administrative services and the areas of health care, business, education, transport, courts, democracy issues, etc. Figure 1 shows the digital state components, which ensure its proper and efficient functioning.

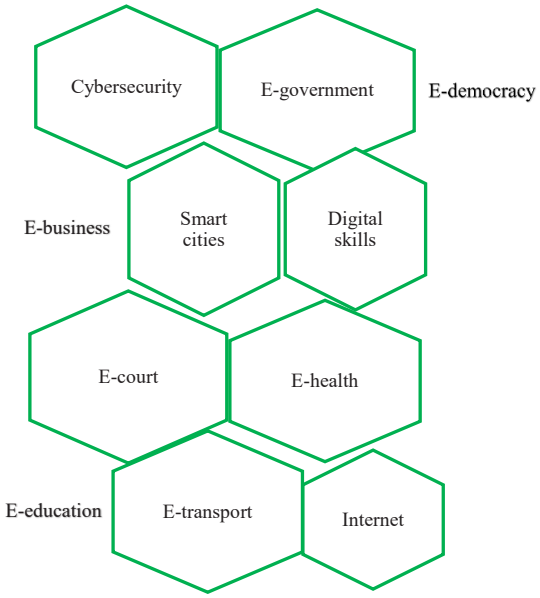


***Figure 1***. *Components of the digital state*

As shown in Figure 1, digital technologies play a significant role in building a digital state. Therefore, it is necessary to ensure proper Internet access to electronic services, especially in rural areas.

The provision of the Internet in the context of the spread of COVID-19 has become one of the most pressing problems, the solution of which will help to overcome the digital divide, create new jobs in cities and villages. Simultaneously, it is crucial to develop digital literacy, which is one of the main drivers of the unrestricted use of electronic services. Moreover, modern realities demonstrate the urgent need to govern the state with the help of information technology, the so-called "state in a smartphone".

One of the long-term goals in building a "state in a smartphone" is online democracy. For example, the introduction of digital voting in Ukraine will significantly reduce the scale of election fraud and help consolidate young Ukrainians' participation in the country's democratisation [31].

### *"Diia": Purpose and use*

At the beginning of 2020, the Ministry of Digital Transformation of Ukraine has introduced the state web portal of electronic services the "Diia", which provides access to 50 electronic services. In addition, the mobile application "Diia ", which provides access to digital documents and public services, has also become widely available. The mobile application allows access to 9 digital documents: passport of a citizen of Ukraine in the form of an ID-card; biometric passport; taxpayer cards; driver's license; vehicle registration certificates; student card, certificate of internally displaced person; birth certificate of the child [32].

The "Diia" project is a flagman for Ukraine in the digitalisation process. According to the Ministry of Digital Transformation of Ukraine, by 2024, all public services in Ukraine will be provided online [32]. Regarding the financing of this project: public funds were not spent. The "Diia" portal was created in cooperation with the Ministry of Digital Transformation of Ukraine with the support of the USAID / UK aid project "Transparency and Accountability in Public Administration and Services / TAPAS", the EGAP Program funded by the Swiss Agency for Development and Cooperation and implemented by the Eastern Europe Foundation and Innovabridge, USAID project the "VzaemoDiia" (SACCI) and the EGOV4UKRAINE project.

Registering a user on the "Diia" portal involves several steps. First, authorisation takes place from ID.GOV.UA using BankID, MobileID, personal file key, or hardware key. The private key (electronic signature) can be stored on file, cloud, or other secure media. It can also be written to an ID-card or token. The latter can take the form of a USB device or smart card.

The most common authorisation method on the "Diia" portal is signature electronic file media. This file is usually called Key-6 with the extension *.dat (there are also extensions *.pfx, *.pk8, *.zs2, *.jks). The algorithm for using file media is shown in Figure 2.

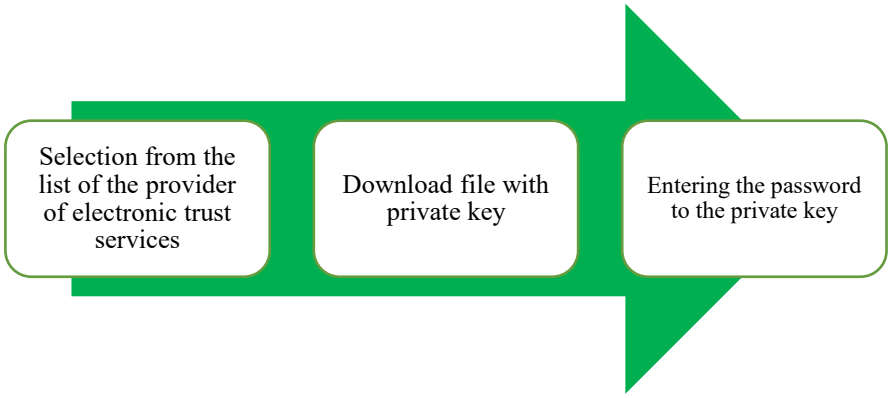


***Figure 2**. Algorithm for using the electronic signature file media*

For the first step, the user must choose the e-trust provider from the 22 entities available on the portal. Therefore, the experience of using the "Diia" portal is sometimes accompanied by a failure and termination of user access. Yet, the situation can be easily corrected by clearing the cache or using another browser for electronic digital signature authorisation.

At the same time, citizens of Ukraine have the opportunity to download the "Diia" application on their smartphone from the App Store or Play Market. After downloading the application, the user must log in using BankID, which is possible for the clients of 31 banks, and consent to the transfer of information to the "Diia" application. Here the authors can declare one of the disadvantages of this application because if a person is not a client of any of the listed banks, he/she will not be able to use the "Diia". Therefore, improving the authorisation process with a new modern identification using Near Field Communication (NFC) technology would probably be appropriate.

However, the number of banks that have joined BankID is constantly growing. At the authorisation stage, the user has a logical question about the leakage of personal data because authorisation with BankID gives the application access to bank cards, accounts, and, ultimately, personal data. The government portal notes that information about the leak of citizens' data from the digital public service the "Diia", which assertedly took place in May 2020, during some operational and investigative actions, was not confirmed, and the Cyberpolice Department did not reveal the facts of cyber incidents [33].

However, the official portal states that the "Diia" is a well-protected platform located in a reliable data center and meets global standards for protection against cyber threats [34].

***"Diia": Scope***

During the authorisation in the "Diia" application with the help of, for instance, Privat24, the user gives consent to the Ministry of Digital Transformation of Ukraine to process personal data. The Ministry of Digital Transformation of Ukraine gets access to personal data:

- full name;
- registration number of the taxpayers' account card;
- passport series and number;
- e-mail address;
- phone number;
- address of residence;
- place of birth.

According to the Ministry of Digital Transformation of Ukraine, the "Diia" keeps a minimum of information about its users through encryption and the use of blockchain distributed storage technologies. It is also defined that the application does not access the user's financial data in Privat24, which is quite logical from cybersecurity.

Currently, digital documents and many services are available in the "Diia" application, but their number, compared to the official portal, is somewhat limited. The user has the opportunity to receive the following services:

- to pay a fine for violating traffic rules;
- to pay debts on enforcement proceedings;
- to share copies of digital documents;
- to verify the authenticity of another person's digital documents.

With the help of a digital document, Ukrainians can:

- use administrative and other public services;
- travel the country by rail and air;
- receive medical care;
- conduct banking operations;
- confirm the person upon request.

The application's purpose is to reduce all bureaucratic procedures and processes to a smartphone. As a result, any user does not need to worry about documents that could be forgotten at home. As for user statistics, their number has been actively growing since the beginning of the "Diia" application. On the day of application release on February 6, 2020, 310,031 users had already registered in it. In April 2020, the application was used by 2 million citizens, as of May 5, 2020 – 3 million citizens, and the portal – 107,708". According to the Minister of Digital Transformation Mykhailo Fedorov this number has not decreased and amounted to 3 million 512 thousand as of June 2020. As of February 2021, the number of users exceeded 10 million people [35].

***"eMaliatko"***

Today, of the 43 services available on the official "Diia" portal, the most popular are the entry to the COVID-19 vaccination waiting list, the opening of a natural person – entrepreneur, there is a baby registration of the child's place of residence, unemployment benefits and signing documents. However, each of the services mentioned above has its regional characteristics. Thus, if the entry in the vaccination waiting list allows the vaccine to be adequately distributed among the regions, the registration of the child's place of residence is available in Kharkiv, Lutsk, Rivne, Vinnytsia, Mariupol, Kryvyi Rih, Khmelnytskyi, Lviv.

Services such as traffic fines, enforcement proceedings, and registration in the COVID-19 vaccination waiting list are available in the "Diia" application. Currently under development are the following services: driver's license replacement, technical passport sharing, taxes, and smart-Diia.

Despite all the positive characteristics, the "Digital State" project needs to be improved. So, for example, using the "eMaliatko" service, one can register the birth of a child, get a certificate of birth, as well as order 9 other government services required for a newborn child. However, to order the service, one must have a medical report number from eHealth by phone text message to the number specified in the declaration signed with the family doctor. In case of loss of the sim card or change of the phone number, the procedure of changing the patient's contact phone number is quite tricky and can take an unreasonably long time. Therefore, being registered on the "Diia" portal, a young mother does not have the opportunity to use electronic services without queues, bureaucracy, unnecessary travel, and effort. Nevertheless, she is forced to apply to the Department of Social Policy, to spend her time in long queues to get to the appropriate specialist. Thereby, there is the need to significantly simplify the procedure for changing the doctor's phone number specified in the declaration.

Since June 2021, the comprehensive service "eMaliatko" has become available to parents of children born in the temporarily occupied Autonomous Republic of Crimea or areas in Donetsk or Luhansk regions. In July, 86% of parents used the "eMaliatko" service. According to statistics, the most popular service is in Rivne and Cherkasy regions (98%), Lviv region (97%), Volyn, Ternopil and Chernivtsi regions (95%). More than 125,000 families in 780 settlements have already used the "eMaliatko" service [36].

In August 2021, Ukraine joined the Digital COVID Certificate initiative, and the EU officially recognised the Ukrainian COVID certificates available in the "Diia" application. In a broad context, such a European Commission's decision, in our opinion, testifies to the recognition of the work efficiency and trust in Ukrainian state institutions and the appropriate personal data protection. The COVID certificate, generated in the "Diia" application in a few clicks, confirms the vaccination status. The introduction of COVID-certificates will guarantee the citizens' safety in pandemics and restore regular communication between countries.

In 2021, Ukraine equated digital passports with paper ones, indicating the rapid pace of digitalisation as a world leader. This positively distinguishes our country from others that have not yet introduced such an innovation [37].

Creating the "Diia" and the transformation to the service state aims to destroy the old bureaucratic system. Today Ukraine's entry into "paperless" mode can be witnessed, which is the basis of the digital state. However, some public authorities are slow to respond to these innovations, thus slowing down the whole transition process.

The essential components for the "paperless" implementation are digital documents the "Diia", the availability of all public services online and the electronic document management introduction, as well as the adoption of appropriate laws to implement the "paperless" regime. Furthermore, the electronic document management introduction will create a new state-of-the-art state system, services will become more transparent and accessible to citizens, and the human factor will be excluded from the decision-making process. The latest technologies are one of the main methods to combating bureaucracy, corruption, and injustice.

***Difficulties***

It is worth noting that the rapid digitalisation, which has gripped society and economy, has met the people' resistance. Some do not want or do not have the opportunity to use the modern system and continue to work manually. Therefore, the authors consider it necessary to make changes in the legislation and functionality of the application to make the use of digital passports convenient for citizens and accessible to businesses. After all, the absence of data readers significantly slows down the process of building a "state in a smartphone". Thus, the process of digitalisation is quite long in time, and the construction of a digital state is not a one-time act.

Ambiguous attitudes have been developed among Ukrainian society regarding the electronic service "Diia at Home", which, according to the Chairman of the Ukrainian Helsinki Human Rights Union, Director of the Kharkiv Human Rights Group Yevhen Zakharov, actually violates human rights to personal data protection and privacy of communications convention. Installing the "Diia at Home" application involves monitoring the observation. Then, the user enters the address at which they undertake the isolation for two weeks. However, the essential condition for successful self-isolation is the availability of the Internet. Therefore, its absence entails administrative and criminal liability; if a person does not get in touch, the verification is considered unsuccessful, and an automatic notification is sent to the

National Police. This state of affairs caused mass dissatisfaction among Ukrainians.

From March 1, 2021, helpful service in a problematic epidemiological situation has become available in the "Diia": an entry to the vaccination from the COVID-19 waiting list. It saves much time, avoids queues, and the process of drawing up unnecessary documents. The implementation of this service is possible thanks to the EGAP Program, implemented by the Eastern Europe Foundation and funded by Switzerland.

Thus, as of March 2, 2021, out of 45.5 thousand applications for vaccination, 40.065 thousand were made in the "Diia" application, 5435 – on the "Diia" portal. Of the first 100 thousand applications as of March 3, 2021, 87.3 thousand (87.3%) were submitted in the "Diia" application, 9.9 thousand (9.9%) – on the "Diia" portal, 2.8 thousand (2.8%) – with the help of the contact center of the Ministry of Health of Ukraine. On July 21, 2021, the 5th stage of the national vaccination plan began. Now everyone, regardless of age and other factors, can sign up directly for vaccination. Therefore, the entry in the queue for vaccination through the site or mobile the "Diia" application is canceled. However, 698 thousand Ukrainians signed up for vaccination during the whole time, and more than 40% have already been vaccinated [35].

Another limitation for users of the "Diia" should also be noted – the lack of the account deleting function, which, in our opinion, is quite debatable. For instance, it is needed to take the following steps to delete the account on the portal:

- the user writes to the "Diia" Support Service, stating the reasons for deleting the account;
- the manager processes the application and sends it to a specialist;
- the specialist studies the situation and decides on the possibility or impossibility of removal.

Therefore, deleting an account is a long process, and the reasons for deletion must be valid.

In addition, along with the unconditional advantages of digital services, it cannot be ruled out that some people do not want or will not be able to go online due to religion, age, and other characteristics. However, they cannot be deprived of the opportunity to receive the necessary services. Thus, it is vital to simultaneously promote digital literacy, education, and instruction of citizens on the use of information and communication systems to establish an alternative way of providing such services. Of course, in the rapid development of digitalisation, the state will be irrational and simply unprofitable to provide paper and digital services in parallel, so, in the authors' opinion, based on the administrative service centers in the united territorial communities should remain a specialist who can help to use the required service on appropriate equipment.

Recently European Union have announced European Digital Identity Wallet which is accepted in all member states which will allow citizens to digitally identify themselves, store and manage identity data and official documents in electronic format [38].

Thereby, the "Diia" application is a new impulse in the field of electronic public services. The application allows receiving the maximum of public services online, establishes and accelerates any interaction of citizens with the state, and encourages to expand one's horizons and acquire digital literacy. Furthermore, it destroys bureaucracy and constant queues to obtain the necessary state-standard document.

### *SWOT analysis*

In the authors' opinion, SWOT analysis allows users to take a more reasonable approach to their adoption of electronic services. Areas for improving e-public services should be developed based on a thorough analysis of their strengths and opportunities to correct weaknesses based on identifying external and internal factors (Table 1).

***Table 1**. SWOT analysis of the digital state in Ukraine*

| S-Strengths | W-Weaknesses |
|---|---|
| Single data system | Low digital literacy |
| Public services' quality and speed increasing | Distrust of public authorities |
| Services availability in the outlying area | Service provision mechanism failure |
| Innovation in the public sphere | Incomplete Internet access coverage |
| Environmental and energy efficiency | Rejection of the population that does not accept change |
| Effective feedback | Limited state financial and technical resources |
| Stable work in pandemic conditions | |
| **O-Opportunities** | **T-Threats** |
| Expanding the list of e-documents and e-services | Low cyber security |
| Public authorities' efficiency improving | Possibility of uncontrolled access to the data |
| Budget savings | User errors risk |
| Transparency increasing | System failures |
| State bureaucracy's level reducing | Development underfunding |
| World-wide services use | The low popularity of e-products |
| Information availability increasing | Political transformations and change of strategic priorities |

The analysis of the advantages of e-public services allowed identifying the strengths and opportunities for their improvement, which are to displace paperwork and routine administrative procedures, speed up processing and exchange of information, provide timely information, improve the quality and effectiveness of feedback and communication transparency with public authorities and achieve a higher level of service to users of public services.

Identifying the problems associated with the development of electronic public services helped the authors finding their weaknesses and threats to its implementation and dissemination. In the authors' opinion, the analysis of barriers and problems facing the spread of electronic public services is fundamental in choosing the most acceptable option for their adaptation into practice.

The main reasons that hinder the introduction of electronic public services are satisfied with the current practice of providing public services, the uncertainty of users and misunderstanding of the benefits of electronic public services, and the lack of resources to implement shared services (financial and technical). Last but not least is the issue of cyber security, as hacker attacks can lead to the leakage of personal data and paralyse the work of public authorities. When joining together:

• Opportunities and Strengths – one can get O-S Strategy;

• Opportunities and Weaknesses – one can get O-W Strategy;

• Treats and Strengths – one can get T-S Strategy;

• Treats and Weakness – one can get T-W Strategy (Table 2).

***Table 2**. Digital state strategies*

| **O-S Strategy** | **O-W Strategy** |
|---|---|
| All data in one place collecting | Digital friendly users rising |
| High-efficiency and high-speed e-government | State-People closer connection |
| Sustainable development | Transparency policy |
| **T-S Strategy** | **T-W Strategy** |
| E-services popularisation | Life-long learning |
| Quality management | Internet access spread |
| Money redistribution | Political stability |

The SWOT analysis allowed the authors to identify critical areas of digital state development, which is primarily represented by e-government. Gathering all crucial information on one platform will significantly increase data processing speed, the efficiency of electronic services in general, and sustainable development.

It would be logical to implement measures to expand the number of confident Internet users, including lifelong learning to overcome the threats in this context. In the authors' opinion, the digital literacy achievement, in turn, will raise the government trust level as a whole. However, for the e-government system to work effectively, it is also necessary to pay attention to quality management and boost the productivity of civil servants.

Thus, the current priorities necessitate the redistribution of financial resources from often bureaucratised and inefficient paper transactions to informatisation.

## CONCLUSIONS

Today, the world is increasingly moving to the Internet, digital codes, and mobile applications. To stay in the world change trend and use modern information progress advantages, every citizen and the state must be open to innovation. In the research, the authors studied the current state of digitalisation of Ukraine and identified the following key characteristics and trends of this process:

• necessary conditions for the successful completion of the digitalisation process are the population's readiness for qualitative changes and purely technical aspects related to increasing the Internet coverage area.

• An essential step forward in digitalisation was the launch of the flagship project "Diia", which should provide access to digital documents and e-government services and minimise the human factor in the decision-making process.

• Building a "state in a smartphone" is a long and challenging process on the road to universal digitalisation, which will destroy the old bureaucratic system, move to a "paperless" business and make services more transparent and accessible with free Internet access.

• A crucial element of the transition to a digital state is the promotion of digital literacy through educational activities.

• Based on SWOT analysis, in addition to strengths and opportunities, barriers and threats that hinder the digitalisation process were identified, including the lack of public understanding of the benefits of e-government and cybersecurity. Timely identified threats can be minimised or eliminated through effective and timely strategic and tactical planning.

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## Цифровізація України в частині поширення публічних електронних послуг

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**Анотація**. Сучасний науково-технічний прогрес робить застосування інформаційно-комунікаційних технологій атрибутом функціонування будь-якого господарюючого суб'єкта та життя кожної людини. Пандемія коронавірусу, що призвела до масових карантинних обмежень, зумовила необхідність пришвидшення переходу до надання цифрових послуг в умовах віддаленого доступу. У зв'язку з цим метою роботи було дослідження розвитку і поширення цифрових технологій в Україні в частині реалізації політики електронного урядування. Для того, щоб оцінити реалії та визначити перспективи становлення «держави у смартфоні», було проведено SWOT-аналіз електронних публічних послуг. Відтак було визначено переваги та загрози електронного урядування на сучасному етапі, а також намічено подальші стратегії розвитку цифровізації в Україні. У процесі розвитку ідеї держави як сервісу відбуваються цифрові зміни у багатьох галузях та сферах, тому було виокремлено ключові складові цифрової держави, зокрема кібербезпеку, електронне урядування, розумні міста, цифрові навички, електронний суд та систему охорони здоров'я, електронну транспортну систему та Інтернет. Визначено, що ці складові тісно стосуються таких компонентів як електронна демократія, електронний бізнес та електронна освіта. Варто відзначити, що в Україні функціонує унікальний державний веб-портал електронних послуг «Дія», що забезпечує доступ до десятків електронних послуг держави. Тому було детально досліджено призначення, можливості та труднощі користування порталом і мобільним додатком «Дія». У частині системи користування «Дією» було розглянуто специфіку авторизації на порталі через файловий носій цифрового підпису та побудовано відповідний алгоритм дій. Підтверджено, що поряд із потенційними ризиками сучасні інформаційні технології дають безліч можливостей для їхніх користувачів. Загалом дослідження дало змогу окреслити перспективи цифровізації української держави в умовах сучасних реалій

**Ключові слова**: «Дія», цифрова трансформація, цифрова держава, електронне урядування

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# Brand Promotion Strategy in the Internet Services Market

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**Abstract**. Digital technologies have become an integral part of modern life, the Internet services market is rapidly developing all over the world, which requires business companies to enter cyberspace. Staying on the Internet has long been an obligatory part of the business not only for large multinational companies but also for small regional and local business structures. It is not just the presence of a website or a group in social networks that is important, a brand communication strategy is necessary. The relevance of the studied subject is due to the need to increase the competitiveness of Ukrainian companies in the field of Internet marketing. The purpose of the article is to develop standard recommendations for strategic brand promotion in the Internet services market, to study the most effective promotion tools and communication channels with the audience in cyberspace. The leading methods for studying the problem were sociological and statistical methods. The technologies of system analysis and modeling are applied. The article analyses the best international and industry branding practices in cyberspace, examines the e-commerce market in Ukraine, and structures the main trends in its development. The material of the article formulates the mechanism for developing and introducing a brand positioning strategy in the e-commerce market, the main characteristics of successful branding, structures recommendations for the use of marketing technologies on the Internet. An important component of the research is the analysis of digital marketing tools and communication channels in the Internet services market. The materials of the article are of practical importance for the business community, specialists in the field of public relations, marketing, advertising, sales departments, and other specialists in the field of management. Effective brand management of Internet services allows increasing the commercial results of one's business, provides additional competitive advantages

**Keywords**: brand promotion, branding strategy, brand management, Internet services market, e-commerce



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## INTRODUCTION

In recent decades, there has been explosive growth in the volume of services in cyberspace. The COVID-19 pandemic has reinforced this trend. The formulation of a verified strategy of marketing activities on the Internet remains an urgent task for the business community, for local and federal companies since, without a comprehensive strategy for brand promotion, it is impossible to achieve the company's goals and profit indicators that ensure systematic growth and stable development [1]. The e-commerce development intensively affects all spheres of the world economy and the economy of Ukraine, in particular, financial and trading instruments, forms of transactions and logistics concepts. New types of market interaction and impersonal sales allow reducing the costs of enterprises and individualising the offer for the consumer, anonymously studying consumer's interests and offering the most relevant services and goods in the format of a public offer, even without personal interaction [2]. In this regard, automated analytical systems that collect data about users based on their behaviour in cyberspace (Big Data) come to the fore. Information technologies are becoming the reason for the development of new methods of brand promotion and the emergence of new types of business in cyberspace [3].

In recent years, a considerable number of studies have been devoted to the strategy of brand promotion in the Internet services market, but the study of understanding the principles of formulating an accurate strategy for long-term brand development remains one of the key tasks [4]. Modern research shows that the creation of a recognisable company, with a reputation and associations among customers, becomes a prerequisite for the effective functioning of the business, that is, the branding strategy comes to the fore [5]. Trends in the development of digital markets indicate the need for a comprehensive study of the relationship between brand awareness and an effective marketing strategy [6]. The COVID-19 pandemic, the global lockdown, and the forced decline in offline communication of brands increased the importance of brand fixation in the digital environment using strategic tools [7]. The role of influencers in social networks has grown along with confidence in the so-called microbloggers (from 2000 to 5000 subscribers) and nanobloggers (up to 2000 subscribers), thus, the role of native advertising increases [8].

Modern tools for promoting services differ from conventional ones. Therewith, the development of IT technologies contributes to their further transformation, which is facilitated by the globalisation of modern commercial markets [9]. Modern marketing strategies: gamification, advertising, viral marketing, social media marketing (social media marketing) come to the fore in the implementation of the marketing strategy. The requirements for modern marketing concepts are growing in direct proportion to the increase in the number of users of services on the Internet, which is relevant for all sectors of the Ukrainian economy [10]. Social media marketing in Ukraine is adaptive and rapidly developing. To date, 60 per cent of Ukrainian residents are registered in social networks; the widespread "smartphoneisation" of the population, that is, a growth in the number of smartphone users increases the number of users of social networks [11].

*The purpose of the study* is to identify the most effective tools for the development and promotion of the company's brand in the Internet services market of Ukraine.

The relevance and originality of the article are due to the analysis of the most modern channels of digital communication with customers (Tik Tok, Reels), the study of current trends in the impact of the pandemic on the market for the provision of services and the sale of goods in the electronic space. The authors have developed and presented in the article a model for implementing brand management in the Internet services market. The practical importance of the study lies in the possibility of using the methodology and algorithms of strategic branding described in the article in the activities of companies and enterprises operating in the field of Internet services in the territory of Ukraine.

## MATERIALS AND METHODS

The material of the study is the analysis of strategic communications of major international and regional trends in cyberspace, which allows identifying the patterns and principles of an effective brand strategy, developing a methodological approach and a practical algorithm for Internet marketing in the field of e-commerce in the Ukrainian market, considering leading practices and benchmarking. In the course of the research, theoretical methods were used, such as synthesis and analysis, concretisation and generalisation; the method of analogies; modelling). Empirical methods were applied, including the study of normative and educational-methodical documentation; experimental methods (ascertaining, forming, control experiments); mathematical statistics, sociological and statistical. The method of analysis was used to examine component parts of the scientific problem for a detailed study. Synthesis – for the development of a system of different elements for a large-scale study of processes. Methods of generalisation – the identification of a set of similar properties and features of the subject.

The method of induction is a consideration from particular views to general conclusions; the method of deduction is a theoretical study or reasoning from a general thesis to particular conclusions. Statistical and economic method – to study statistical data on the development of the e-commerce market in Ukraine. The main methodological approach is a group of general scientific and philosophical approaches (including systemic and synergetic) and a set of different methods (historical, comparative, scientific abstraction method). The method of graphical visualisation was also used to

reflect the results. For the analysis of publications and research in the mass media, the method of content analysis using search engines and information and analytical systems, other cabinet methods were applied. Meta-analysis was used for systematic integration of the available data. In the course of the research, the following methods were applied: theoretical; mathematical statistics and graphical representation of the results.

The theoretical basis consists of practical research, scientific and methodological, and educational studies of leading Ukrainian, Russian, and foreign specialists in the field of marketing and management [12-14]. The research examines articles and studies that address the problems of developing and implementing a marketing strategy, branding, brand management, and digital marketing [15-17]. The studies on the problems of marketing promotion of brands in the offline retail market and in the Internet services market are examined [18-20]. The methodological approaches of Western researchers, such as B. Schmitt [21], D. Aaker [22], T. Ambler [23], P. Doyle [24], L. Chernatony, M. McDonald [25], J. Lambin [26], are studied. The authors included a scientific and methodological base of digital economy research for a period of up to 10 years to identify trends in brand management and the evolution of approaches to the definition of the term "brand" [27; 28]. The information in the mass media of Ukraine devoted to e-commerce, online sales and the development of social networks in Ukraine are analysed. The trends of the last few years, which were developed during the COVID-19 pandemic, are studied [29; 30].

The information base of the research includes legal regulations; monographs and didactic studies of leading economists and marketers; Western, Russian and Ukrainian specialists in the field of management; materials of periodicals and conferences; collections of articles, abstracts of reports, electronic sources, and databases, relevant statistical materials.

1. At the first stage, the analysis of existing theories and methodological approaches to the definition of a brand, the formulation of a branding strategy and brand management in the Internet services market are carried out; the problem, purpose, and research methods are highlighted.

2. At the second stage, the main stages of brand strategy development are formulated and reflected in the integrative model, the key tools of digital promotion are classified.

3. At the third stage, the theoretical and practical conclusions are clarified, the results obtained are systematised.

## RESULTS AND DISCUSSION

The brand value is a combination of the unique properties of the product and is defined as the ratio of benefits from the acquisition of the brand and all required costs in connection with the ownership and operation of the product [17]. Most studies devoted to the essence and content of brand values include functional benefits based on the properties of the product and psychological benefits reflecting the intangible properties of the product as the main benefits. Intangible benefits include emotional and symbolic benefits. Some specialists in the field of marketing include in this list the so-called conceptual benefits, that is, the satisfaction of curiosity [26]. The American specialist D. Aaker [22] describes his approach to determining the brand value by adding to the number of functional and emotional benefits of satisfying the need for self-expression. Recently, the consumer's need for social approval has been growing, which may be an additional type of added brand value. Thus, to develop an appropriate brand management strategy in the Internet services market, it is important to include the set of all possible benefits for the consumer in the planned brand image.

The main benefits that increase the attractiveness of the brand for the client:

*Functional benefits*. Product properties that provide functional utility. For example, for video conferencing systems (such as Skype or Zoom), the functional properties are the number of conference participants and the ability to record.

*Emotional benefits*. The focus of the study should be shifted to feelings when the purchase of a particular brand causes certain emotions in the buyer.

*Symbolic benefits*. Some products (perfume, clothing) in the minds of customers are symbols that allow them to demonstrate their status or position in society.

The brand image in its complex sense is shaped by the following attributes: visual range, corporate identity, logo, fonts; key brand values; the form and channels of communication with the consumer; consumer reviews; competition policy, that is, the type of interaction with other brands; participation in charity programmes, events held with the participation of the brand; marketing activity, including loyalty programmes; consumer emotions and impressions of the brand from actual and potential consumers.

The sales process and brand awareness are closely linked, without the image component, it is impossible to fulfil the long-term commercial goals of the company. The promotion strategy is a comprehensive action plan aimed at achieving the company's business goals [13]. E-commerce began its development in the field of electronics, it is still the largest category on the national market. In recent years, there has been a considerable increase in such categories as clothing, furniture, household goods, cosmetics, and entertainment. A great share of the market is the industry of video games, movies, e-books, and music. Nevertheless, the Ukrainian production and sale of such goods are inconsiderable. According to a study by GlobalLogic, presented by Interfax Ukraine, the number of social network users in Ukraine increased by 7 million people in 2020 (Fig. 1).

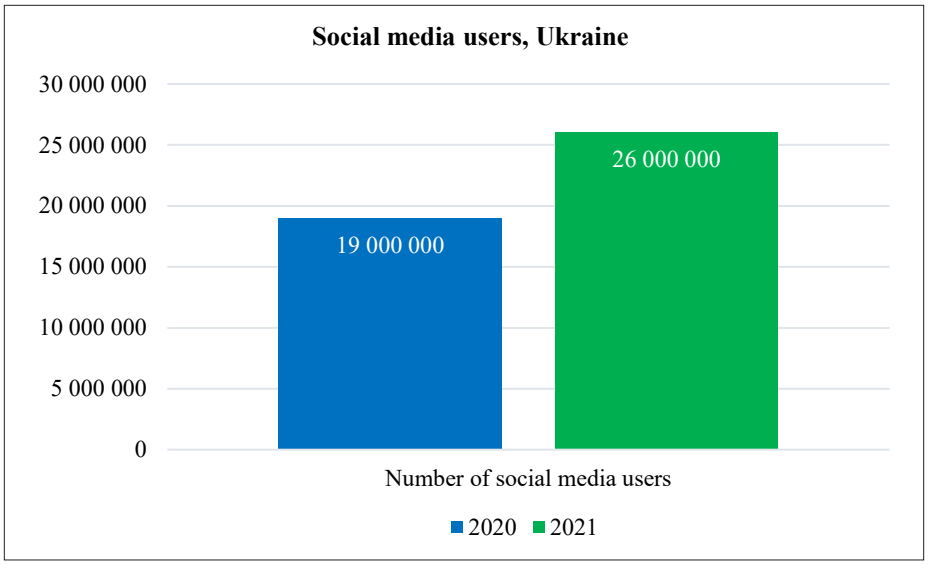


***Figure 1***. *The growth of the number of users of social networks in Ukraine in 2020-2021*
***Source***: *[31; 32]*

If in January 2020 a little more than 40% of the population of Ukraine was registered in social networks, now this figure has increased to 60%. According to the above research, in 2021, 30,000.000 people (67% of the population) use the Internet in Ukraine [32].

The most popular social networks in Ukraine [33]:

- YouTube covers 96% of the country's population;
- Instagram is used by 14 million Ukrainians (an increase of 22% compared to 2020);
- Facebook is popular among 16 million Ukrainians;
- 16% of users from Ukraine are registered in TikTok.

The growth trends of Internet users are also relevant in the context of the global economy, the number of Internet users in the world has increased by 280 million since 2020 [33].

By the end of 2020, the majority of Ukrainians continue to buy online through marketplaces, that is, integrative platforms. According to the research of Hubber, which unites more than 1200 marketplaces, the main trends of e-commerce in the Ukrainian market and a list of the most popular products were identified. In December 2020, the average check increased by 23% compared to December 2019. In 2020, the average check increased by 9.3% and amounted to UAH 600.64. In general, the growth of trade turnover in 2020 was 50.2%, which confirms the relevance of the matter. In Eastern Europe, the share of online commerce in total retail sales increased to 10% [20]. According to Euromonitor International's research, the largest growth in e-commerce was recorded in Ukraine. In comparison with the indicators of 2019, the growth of product e-commerce in Ukraine in 2020 amounted to 107%. This is due to the cooperation of food delivery services and retailers [34].

Most experts agree that the share of e-commerce in the sales structure will grow over the next five years [18; 20].

The main stimulators of the growth of the Internet services market in Ukraine are:

- the growth of the number of Internet and smartphone users in Ukraine;
- restrictions caused by COVID-19;
- increased confidence of the country's population in digital payment systems;
- expanded delivery opportunities and improved quality of the delivery service;
- growth of individual consumption;
- the competition growth and, as a result, the increase in reliability of Internet entrepreneurs;
- development of innovative technologies.

The mechanism of building a brand promotion strategy includes the following mandatory steps. The most important stages of brand promotion to the market are comprehensive market analysis, the definition of marketing goals, and promotion tools [15].

The key stages of developing a brand promotion strategy are:

1. Analysis of the market and the company's position in the market. It is important to properly study the company's position in the market, competitive analysis, and study trends in consumer behaviour.
2. Definition of goals. Development of attitude, demand, loyalty, knowledge, sales.
3. Segmentation of consumers. Identification of the target audience for whom the company's services and products are necessary to meet their needs.
4. Determining the budget.
5. The choice of tactics (the optimal list of Internet promotion tools).

The authors have developed an integrative model for implementing the brand strategy in the Internet services market, combining the key stages of brand management and basic tools (Fig. 2).

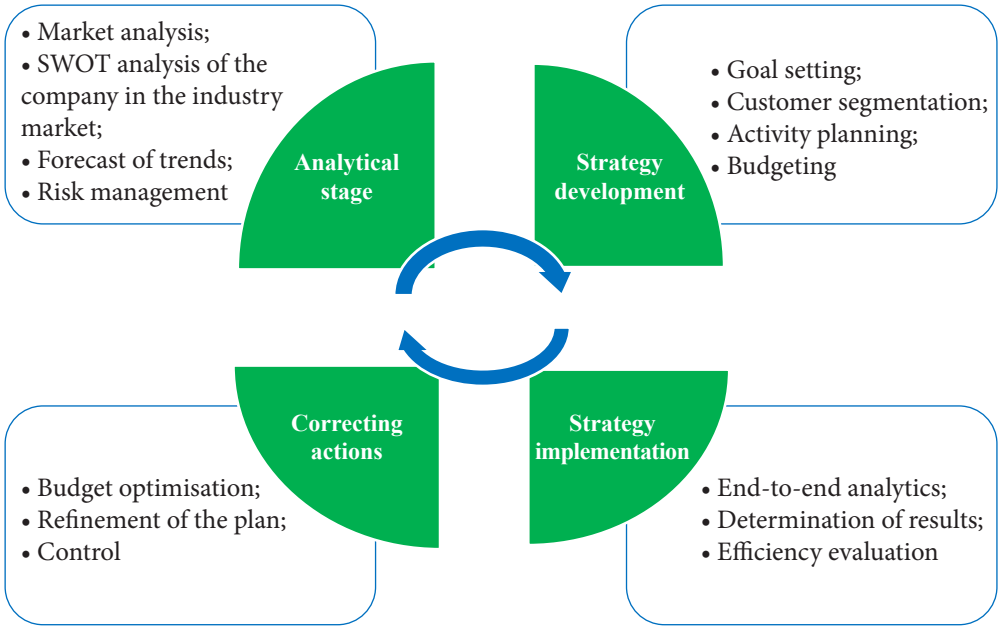


***Figure 2**. Integrative model of brand management implementation in the Internet services market*
***Source**: developed by the authors*

After forming a detailed programme, it is necessary to perform high-quality tasks of the plan according to the selected control tools, considering the data of end-to-end analytics. To build a strategy, a sufficient level of qualification of the team and up-to-date market analysis data are required. Digital marketing technologies are a mechanism of communication with partners and investors and a channel of communication with consumers. One of the key tools for promoting a company is a website. The site serves as a virtual business signature of the organisation and a kind of electronic showcase of goods and services. The use of a wide range of tools allows providing a high-quality presentation of the site in search engines. The key tasks that the site solves are: retaining a potential buyer for as long as possible and encouraging them to make a purchase or transfer their contact details for further communication with the client by sales specialists. Depending on the marketing goals and advertising budgets, it is important to include the following tools in the implementation of a comprehensive strategy in different proportions:

• Search Engine Optimisation (SEO, or Searching Engine Optimisation). In this context, a special role is played by the so-called organic promotion, that is, the use of words and phrases that are popular among users in search engines, which allows displaying site materials in the first search lines.

• Social Media Marketing (SMM, or Social Media Marketing). Marketing Sherpa statistics showed that 95% of consumers choose social networks as one of the key tools for interacting with the brand. Social media accounts, along with the website, act as a trademark of the company, a tool for communicating with the brand and collecting feedback from customers [35].

• Contextual and targeted advertising. Advertising in social networks and search engines is one of the most effective methods of attracting customers, while the high digitalisation of these tools allows for effective analytics and timely adjustment of the strategy in the conditions of necessary changes (Fig. 3).

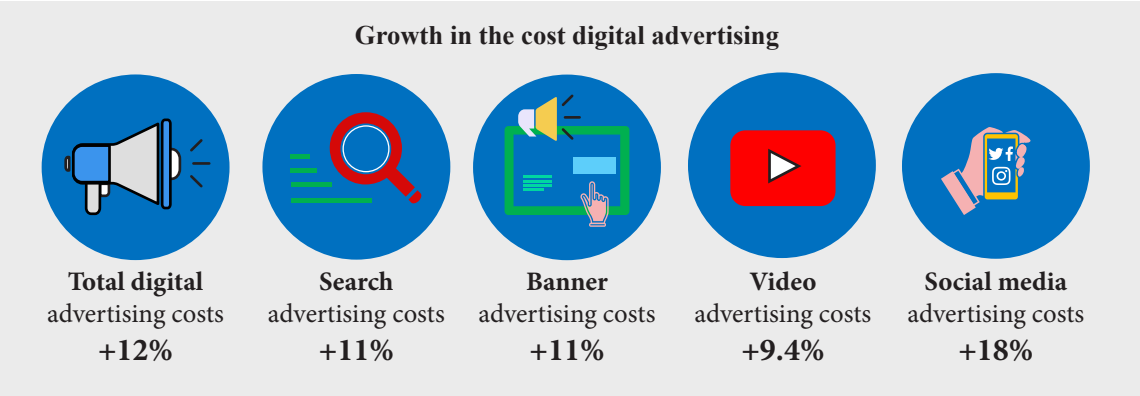


***Figure 3**. The growth in the cost of digital advertising in the world in 2020-2021*
***Source**: WebMarketing company data [29]*

• Display advertising. Interactive advertising messages on Internet sites allow establishing associations with the brand and increasing flows to the site (lead generation).

• Mail marketing. Use of e-mail newsletters based on one's own or partner client databases.

• Viral marketing. Modern social platforms such as Tik Tok, Reels, Snapchat allow creating advertising formats that provide mass organic coverage. Examples of such formats are "challenges" (trends launched by bloggers, repeated by a large number of users), creative videos.

• Influencer marketing. Attracting opinion leaders to promote the brand shows positive results in the B2C market, while it is the format of native advertising that is optimal in this context.

The use of the above tools allows providing a wide reach of consumers and reducing the company's advertising costs. The key importance in this aspect is the use of end-to-end analytics and the suitable integration of analytical tools into the operational work on the implementation of the brand promotion strategy. An example of a brand-focused marketing strategy is Apple. Maintaining the image and reputation of a leader in the mobile device market contributes to the fact that customers become brand ambassadors in the long term. In the context of the digitalisation of the economy, the brand is an essential part of the company's capital. The role of mastering the theoretical foundations of brand management is growing. Despite this, in the literature and scientific research, this issue has begun to be studied relatively recently and is poorly structured. The term "brand" appeared in the methodology relatively recently as well. Hereinafter several approaches to the fundamental concept of brand management – the term "brand" is considered.

Various definitions of a brand are presented in the economic literature.

1. "A brand is a name or symbol that identifies a product". The key characteristic is the identification of the product and its difference from competitors [36].

2. "A brand is a set of perceptions in the eyes of the consumer" [16]. This approach is as close as possible to modern interpretations of the term, which includes associations that arise in the consumer regarding the product.

3. A brand is "a set of names and other symbols used to identify a product and a "promise" that is given to the buyer" [14]. In this definition, the key feature of the brand is the manufacturer's promise.

4. "A brand is a product that meets the functional needs of some users and provides them with some additional value that can satisfy certain psychological needs and encourage them to buy" [19]. This approach focuses on added value.

Ambler's definition is closely related: "A brand is an individualised product to which the buyer attributes increased value" [23]. All researchers agree that owning a brand gives a company competitive advantages, without which it is impossible to achieve the company's marketing goals. A high level of brand confidence and consumer loyalty contributes to maintaining a stable level of sales and reducing the costs of promoting goods and services. The fame and recognition of the company is an indisputable advantage, in times of crisis, the consumer frequently makes a decision in favour of recognisable brands that enjoy trust. A brand is a complex concept in marketing that requires an integrated approach. The desired brand image on the part of the company and its current perception by consumers may not coincide, which means that this concept is multidimensional and provides a multivariate interpretation of the term "brand". To understand the principles of developing an effective brand strategy for the Internet services market, it is advisable to analyse various Western approaches.

L. Chernatony, a leading foreign expert in the field of brand management [25], notes that if a brand is understood exclusively from the standpoint of the company or consumers, this can lead "to the creation of an unbalanced strategy and shorten the brand's lifespan" [25]. Thus, not only marketers but also consumers themselves take an active part in creating and implementing the strategy. Consumers perceive the brand, are not exclusively passive recipients, the planned image does not always coincide with the perceived image (brand image).

Doyle provides an effective classification of potential problems in the development of a brand management strategy, which can also be attributed to the field of Internet services. The main problems in establishing customer feedback and communicating the planned brand image to the consumer are weak positioning, messages from other competitors, ineffective messages, other signals regarding the brand, incorrect media choice or other restrictions [24]. To develop an effective strategy in the field of Internet services, it is necessary to consider the risk of these factors. Competitive messages. Consumers regularly contact thousands of messages, notice no more than 5%, and respond to less than 1% [24]. To get through to the consumer, an effective advertising policy is necessary.

Weak brand positioning. It is necessary to avoid the blurry brand image, since in this case, it may not resonate with the consumer. Other signals regarding the brand. At times the consumer may receive conflicting information about the brand, so companies need to control all the information transmitted. Ineffective messages. Marketers should clearly segment the audience and present their message about the brand identity and its essence in an accessible form. Wrong choice of marketing communications tools. The wrong choice of brand promotion tools leads to disastrous consequences. The key task of brand management is to search for advertising channels that allow achieving the maximum coincidence of the designed and perceived brand images [37].

The American Marketing Association (AMA) in 1960 proposed one of the most cited definitions of a brand in the business literature: "A brand is a name, term, sign,

symbol or design, as well as their combinations, that identify one seller's goods or services as distinct from those of competitors". [27]. The above emphasises the importance of visual brand symbols. Nevertheless, the essential difference of the brand is not only in the visual elements but also in the content, unique values. In various branding models, the brand is safer in the consumer's mind, that is, it is a risk reduction tool [25]. In applied terms, this means that marketers need to present the brand to the consumer in such a way as to minimise the perceived risks in relation to the purchased product or service. The interpretation of the brand as added value considers the benefits that are appreciated by consumers. The added value implies that the brand has advantages in comparison with competing brands. This encourages the buyer to make a purchase.

Therewith, it is important that brands can have not only undeniable functional advantages but also emotional attractiveness of the brand. Additional services that can save time or money can also become added value. It is obvious that for the successful implementation of a marketing strategy, it is necessary to use those formats of providing added value that are important for the client, and not for the company. The source of information about customer preferences is customer surveys. In terms of methodology, the approach to understanding a brand as a brand contract (communication) is of great interest. The author of this approach is an American specialist S. Davis [28]. "A branded contract is a list of all obligations (promises) assumed by the brand, which are fulfiled by the company, but the list is compiled and evaluated in the external environment, i.e., in the market" [28].

When forming a strategy, it is essential to consider that during the period of its implementation, it may require reformulating the brand's promises in connection with changes in the market. In the context of the active development of e-commerce, companies operating in the Internet services market must respond quickly to the changing environment and constantly strengthen the added value of the brand. For a proper study of added value, it is necessary to consider methodological approaches to understanding "brand value". Several models of brand evolution are presented in the special economic literature, among which B. Schmitt's model of empirical marketing deserves special attention. The researcher notes that in the conditions of increasing competition and the constant growth in consumer demands, brands need to use innovative approaches that go beyond conventional marketing techniques. Brand management should focus on the study of people's sensory experiences and the empirical experience of consumers [21]. The main features of the conventional approach are the priority on the functional properties of the brand; appeal to rational purchase motives; emphasis on competition among narrowly defined product categories.

Thus, conventional marketing characterises an analytical and rational approach. Brands in this aspect act mainly as identifiers. An alternative to this approach is empirical marketing, which allows considering the potential of the brand as a source of sensory and cognitive associations that establish a loyal attitude to the brand [30].

B. Schmitt [21] identifies four main features of empirical marketing: emphasis on the empirical experience and emotions of consumers; recognition of rational and emotional motives of consumption. The main difference between empirical marketing and conventional marketing is the shift in emphasis towards the emotions of customers. For effective brand management and its promotion strategy, branding specialists need an integrative approach, ensuring a holistic positive impression of consumers about the brand, which involves the perception of the functional properties of a product or service and an empirical perception. The study of marketing goals of branding allows outlining the functions of the selected goals in relation to the brand: defining the strategy and tactics of communication with the consumer; developing visual attributes of the brand and the verbal concept of their presentation; selecting the forms of presentation and channels of communication with the consumer, considering their interests, socio-demographic characteristics, based on detailed segmentation of the target audience; establishing communication strategies. Strategies may differ, depending on priorities, subjective approaches of the company's stakeholders, previous experience. Marketers and brand managers need to ensure maximum compliance between the form and content of the brand and between the expected image of the brand and its actual characteristics. Thus, effective branding is the result of proper planning of verbal and visual brand identifiers, deep study of its content elements and readiness for changes, the ability to quickly integrate into a changing environment, apply innovative marketing methods and unconventional approaches to promotion, using a full-fledged analytical approach.

## CONCLUSIONS

Strategic brand management is a time-consuming process consisting of several stages, including market analysis and appropriate setting of marketing goals. The most successful and cost-effective approach is to create a strong brand. All stages of the development and implementation of the branding strategy in the Internet services market should be based on detailed analytics, preliminary (market analysis, analysis of the company's position in the industry market) and operational during the implementation of the strategy. Special attention should be paid to determining the company's goals for brand promotion, including providing the consumer with complete and reliable information about the brand, increasing awareness and loyalty of the target audience, attracting a new audience or retaining the old one, establishing feedback from the company with customers.

Creating a brand marketing strategy based on

communication goals requires appropriate segmentation of the audience, a compilation of a tactical list of digital marketing tools. The role of the brand's "trademark" in the Internet space is performed by the website and social media accounts. An effective brand promotion strategy includes an appropriate layout of various digital marketing methods: display advertising, search engine optimisation, targeted and contextual advertising. The role of viral marketing has grown, creating an associative flow in relation to the brand. Instagram, Tik Tok, Likee, and Coub social media platforms are useful in this regard. When formulating a brand strategy, a certain percentage of the advertising budget should be planned in favour of attracting influencers, owners of pages in social networks with high coverage. The influence of social networks is constantly growing: the share of e-commerce through social networks is increasing. A considerable proportion of customers prefer to communicate with the brand on social networks, which brings the tool of community management in social media marketing to the fore along with online advertising. One of the trends is the popularisation of chatbots that allow automating the sales process and enable communication between the buyer and the seller.

Internet branding is not the only way to promote a brand, the role of offline tools continues to play a key role, however, this type of promotion plays a predominant role in the Internet services market. Modern trends in e-commerce in Ukraine confirm that the relevance of effective branding in the Internet services market will continue to grow. The increase in the share of mobile traffic and the level of Internet penetration in the regions, the development of e-commerce in the regions contribute to the transformation of online stores into marketplaces and the emergence of additional services that are valuable for the client.

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## Стратегічне управління брендом на ринку інтернет-послуг

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**Анотація**. Цифрові технології стали невід'ємною частиною нашого життя, ринок інтернет-послуг швидко розвивається в усьому світі, що вимагає від бізнес-компаній виходу в кіберпростір. Перебування в інтернеті давно стало обов'язковою частиною бізнесу не лише для великих транснаціональних компаній, а й для невеликих регіональних і локальних бізнес-структур. Важливо не просто наявність сайту чи групи у соціальних мережах, необхідна комунікаційна стратегія бренду. Актуальність теми обумовлена необхідністю підвищення конкурентоспроможності компаній України у сфері інтернет-маркетингу. Мета статті полягає у розробці типових рекомендацій для стратегічного просування бренду на ринку інтернет-послуг, а також дослідженні найефективніших інструментів просування та каналів комунікації з аудиторією у кіберпросторі. Провідними методами дослідження проблеми стали соціологічні й статистичні методи. Застосовано технології системного аналізу та моделювання. У межах статті проаналізовано найкращі міжнародні та галузеві практики брендингу в кіберпросторі, проаналізовано ринок електронної комерції України, структуровано основні тенденції його розвитку. Матеріал статті формулює механізм розробки та впровадження стратегії позиціонування бренду на ринку електронної комерції, основні характеристики успішного брендингу, структурує рекомендації щодо застосування маркетингових технологій у мережі інтернет. Значним компонентом дослідження є аналіз інструментів цифрового маркетингу та каналів комунікації над ринком інтернет-послуг. Матеріали статті становлять практичну значущість для бізнес-спільноти, фахівців у сфері зв'язків із громадськістю, маркетингу, реклами, відділів продажу та інших фахівців у галузі менеджменту. Ефективний бренд-менеджмент інтернет-послуг дозволяє підвищити комерційні результати бізнесу, а також дає додаткові конкурентні переваги

**Ключові слова**: просування бренду, стратегія брендингу, бренд-менеджмент, ринок інтернет-послуг, електронна комерція

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