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ANALYTICAL CRITERION FOR THE STRENGTH OF BONDED-DISPERSED GELS DURING PIPELINE TRANSPORTATION

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Abstract. Modern pipeline systems, both main and industrial, allow transporting a wide range of liquid and gaseous substances, including a variety of solid bulk materials, minerals, building materials and mixtures. However, the development of pipeline transport systems today is hindered by the lack of theoretical developments in the implementation of practical engineering projects for the creation of both main and industrial product pipelines for various purposes. Therefore, the further development of the theory of flows of various substances in pipelines and the creation of universal methods for engineering calculations of design parameters of pipeline systems based on this theory are priority tasks for the further development of product pipeline transport. The studies were carried out in accordance with the condition of stochastic transformation of the coagulation-thixotropic structure of the gel flow into sol. Such a stochastic transformation of the coagulation-thixotropic structure can be observed both when reaching the mode that determines the turbulent motion of a viscous colloidal solution, and somewhat earlier – at the stages of the laminar flow regime of the solution. Based on the formal phenomenological analysis, it has been determined that during the transition of the laminar mode of motion of the Newton fluid flow in a cylindrical tube to the turbulent mode, the transported structured gel flow is guaranteed to collapse into a colloidal sol. Based on the example of a typical design calculation of a technological (production) pipeline for the transportation of motor oils of the SAE-10 and SAE-40 grades, the optimal conditional internal diameters of the product pipeline were determined. The compliance of the design structural parameters of the pipelines with the corresponding physical and mechanical properties of the transported liquids was established. The proposed methods of engineering calculations of design parameters for technical objects of pipeline transport should expand and supplement the regulatory documentation for the preparation of projects for the construction of both main product pipelines and technological "interoperable" production pipelines

Keywords: pipeline, flow, gel, laminar mode, turbulent mode, pipeline design parameters

*Corresponding author

INTRODUCTION

The accelerated development of pipeline transport systems in the second half of the 20th century is conditioned by its technical efficiency and significant operational advantages compared to other technologies for transporting various materials [1-3]. In particular, these are such advantages as: large capacity due to the continuity of the transport process [2]; the absence of intermediate operations that require the creation of special equipment and training of qualified support personnel [1; 3]; the absence of transport losses of material [2]; transport and environmental safety for the implementation of the transportation process and minimisation of landscape and destruction violations [2]; independence from weather and climatic conditions [3].

At the same time, the improvement of the technical capabilities of pipeline transport, the appearance and technical improvement of hydraulic transport systems [3] facilitated the significant expansion of the range of transported substances and materials [4; 5]. Modern pipeline systems, both main and industrial, allow transportating various solid bulk materials [2; 4], minerals [6], building materials and mixtures [2], industrial and household waste [3], chemical raw materials and substances [2; 7; 8], etc. However, prolonged stay in pipelines and changes in transportation modes lead to changes in the properties and characteristics of the transported substances and materials [7; 9; 10]. At the same time, these changes can both worsen and improve the quality of not only the materials transported by pipelines, but also the liquid "technological carrier of the transported material" [6; 11]. It is stochastic changes in the quality indicators of substances and materials transported in pipelines that necessitate in-depth experimental studies aimed at developing theoretical foundations and practical recommendations for the optimisation of the motion of pressure and gravity flows of gels and sols in pipelines [6; 11; 12].

During the operation of main oil pipelines, deposits in the form of resinous-paraffin compounds accumulate on the internal surfaces of pipes, and intense corrosion and stratification of metal is observed [12]. This leads to a decrease in the working cross-section of the pipeline, an increase in the absolute roughness of the inner walls of pipes, and consequently, to an increase in hydraulic resistance, a decrease in the service life of pipelines, and a reduction in the volume of petroleum products pumped [2]. To prevent these negative processes, from the moment the pipeline is put into operation and during the entire period of its service life, there is a need for periodic cleaning of the internal surfaces of pipes of main oil pipelines [1; 3; 13-15]. The use of so-called "gel pistons" has become widely used for cleaning the internal surfaces of product pipes [13; 15]. The basis for the manufacture of the gel piston is polyacrylamide (PAA), which is able to form a branched spatial structure, which gives viscoelastic properties to the "gel separator of petroleum products". As a result, the so-called gel piston creates a proppant effect and when it moves through the pipeline, it completely covers the internal working section of the pipe and all deposits of dirt and resinous-paraffin compounds are collected in the tail part of the piston in the course of its motion [12; 13; 15].

However, theoretical developments in the field of hydrodynamics of complex colloidal flows today are mostly semi-empirical [2; 12; 14] and are far from exhaustive and complete. It significantly complicates the application of these theoretical developments in the implementation of practical engineering projects for the creation of both main and industrial product pipelines for various purposes. As for experimental studies of hydrodynamics of complex colloidal flows, including methods of physical modeling of the dynamics of these flows, and corresponding engineering and technological equipment, such studies require significant capital expenditures [4; 6; 11] and fail to provide generalised universal results [2; 3].

Thus, the further development of the theory of dispersed flows of gels and soles in pipelines and the development of universal (generalised) methods of engineering calculations of design parameters of systems and individual technical objects of pipeline transport based on the appropriate analytical studies are priority tasks for the further development of product pipeline transport.

The purpose of the study is to ensure stabilisation of the quality indicators of substances and materials transported by pipeline transport systems.

MATERIALS AND METHODS

The study considers the motion of a viscous fluid between two parallel layers, which is caused by some infinitesimal shear stress (Fig. 1).

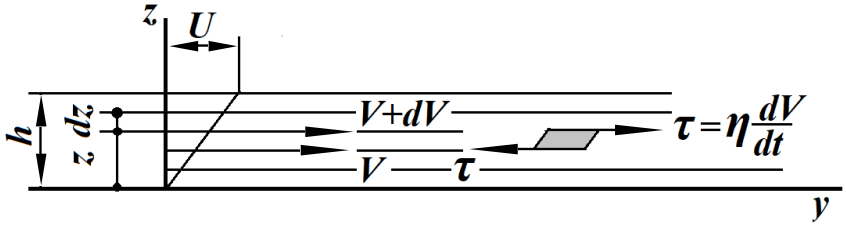

Figure 1. *Motion of a viscous structured liquid between two parallel layers*

Assume that the velocity of a liquid at a certain zdepth is v, which means that the change in this velocity over depth z (velocity gradient) will be dv/dz. In general (see Fig. 1) the velocity gradient will be defined as [13; 14]:

$$\frac{dv}{dz} = \frac{v}{h} = \frac{1}{h} \cdot \frac{du}{dt} = \frac{d\left(\frac{u}{h}\right)}{dt} \quad (1)$$

In equation (1), the value u/h is the offset gradient, which we will later denote as γ. And then it follows from equation (1) that the time derivative of the offset gradient $\dot{\gamma}$ is equal to the velocity gradient dv/dz:

$$\dot{\gamma} = \frac{dv}{dz} \quad (2)$$

Therefore, the tangential stress τ that occurs between the liquid layers will be proportional to the ratio of the velocity difference in the liquid layers to the distance dz between these adjacent infinitely closely located thin layers. Within each of these layers, it is assumed that the velocity in the liquid layer is a steady-state value and changes by a value dv only when crossing the boundary between neighboring layers. Then:

$$\tau = \eta \cdot \frac{dv}{dz} \quad (3)$$

where: dv – velocity difference in adjacent liquid layers; dz – distance between the midpoints of the adjacent liquid layers under consideration (layer thickness); η – dynamic viscosity, which is essentially a tangential stress, which is necessary to cause the liquid layers to move relative to each other at a speed equal to 1.

Given equations (3) and (1), the dynamic viscosity has the dimension of the product of tangential stress and time. Taking into account equation (2), the following is obtained:

$$\tau = \eta \cdot \dot{\gamma} \quad (4)$$

The resulting equation (4) is essentially a formalised expression of Newton's law of viscosity, which models (Fig. 2) phenomenological properties of a viscous rheological body [5; 12] and determines the dynamics of motion [5] of a viscous liquid in a cylindrical tube (Fig. 3).

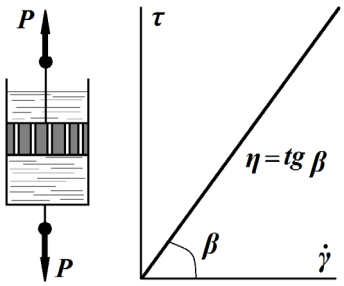

***Figure 2**. Model of a Newtonian rheological body (viscous fluid flow):*
P – shear forces applied to the model; η – dynamic viscosity of the liquid; τ – tangential stresses between the liquid layers; $\dot{\gamma}$ – derivative of the displacement gradient between the liquid layers

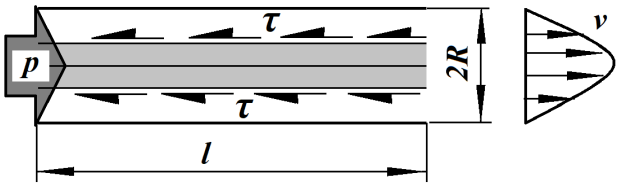

***Figure 3**. The motion of a viscous Newton fluid in a cylindrical tube*

Consider a cylindrical liquid column with radius r and length l. The side surface of such a column will be $2 \cdot \pi \cdot r \cdot l$, and the total resistance to fluid motion will be $2 \cdot \pi \cdot r \cdot l \cdot \tau$ (τ– tangential stresses between the liquid layers, see Fig. 2). If the specific pressure on the considered column of liquid with a radius r is p and, accordingly, the total pressure is equal to $p \cdot \pi \cdot r^2$, then the equilibrium condition for the considered column of liquid will be:

$$p \cdot \pi \cdot r^2 - 2 \cdot \pi \cdot r \cdot l \cdot \tau = 0 \quad (5)$$

from where:

$$\tau = \frac{p \cdot r}{2 \cdot l} \quad (6)$$

In equation (1), the value z is substituted with the radius r of the liquid column under consideration:

$$dv = \dot{\gamma} \cdot dr \quad (7)$$

From equation (3) and taking into account (6) and (7), the following is defined:

$$dv = \frac{p}{2 \cdot l \cdot \eta} \cdot r \cdot dr \quad (8)$$

and after integrating expression (8), the following is obtained:

$$v = \frac{p}{4 \cdot l \cdot \eta} \cdot r^2 + C \quad (9)$$

An arbitrary constant C can be determined if the boundary conditions for (9) assume that the liquid layer that is directly in contact with the inner wall of the pipe has a velocity $v = 0$. And then, if $r = R$ (Fig. 3) the following is obtained:

$$C = -\frac{p}{4 \cdot l \cdot \eta} \cdot R^2 \quad (10)$$

and, as a consequence:

$$v = -\frac{p}{4 \cdot l \cdot \eta} \cdot (R^2 - r^2) \quad (11)$$

The sign "–" in equation (11) means that the motion of fluid occurs in the opposite direction to the increase in pressure p. Therefore, it follows from equation (11) that the distribution of the fluid velocity over the longitudinal section of the cylindrical flow is delineated by a parabola with an extremum (maximum) lying on the longitudinal axis of the section. Assuming that $r \to 0$, then:

$$v_{max} = \frac{p}{4 \cdot l \cdot \eta} \cdot R^2 \quad (12)$$

v_{max} determines the flow rate of the fluid (productivity of the product pipeline Q) by the formula for the paraboloid of rotation (Poiseuil equation) [12]:

$$Q = \frac{1}{2} \cdot \pi \cdot R^2 \cdot v_{max} \quad (13)$$

From where, taking into account (12), the following is obtained:

$$Q = \frac{\pi}{8} \cdot \frac{p}{l \cdot \eta} \cdot R^4 \quad (14)$$

Thus, the obtained equation allows analysing the flow volumes in pipelines and the critical value of the flow rate in terms of the transition of the laminar flow regime to the turbulent one, determined by the Reynolds number:

$$Re = \frac{\rho \cdot v \cdot D_h}{\eta} = \frac{v \cdot D_h}{\nu} = \frac{Q \cdot D_h}{\nu \cdot A} \quad (15)$$

where: ρ– density of the liquid (colloidal gel); v – characteristic flow rate; D_h– hydraulic diameter (inner diameter of the product line); η – dynamic viscosity of the fluid (colloidal gel); ν – kinematic viscosity of the fluid (colloidal gel); Q – flow rate (product pipeline capacity Q); A – internal cross-sectional area of the pipe.

At the same time, the transition of the laminar flow mode to the turbulent one is guaranteed to lead to the destruction of the transported structured gel flow into a colloidal sol.

RESULTS AND DISCUSSION

Admittedly, the main sign of the destruction of the coagulation-thixotropic gel system is the destruction of the spatial structure formed by the dispersed component (phase) of the colloidal solution. And the nature and moment of onset of such destruction are determined mainly by the internal diameter $2R$ (or D_h and A) of the product pipeline, its productivity Q, flow rate v, characteristics of the coagulation-thixotropic gel system ρ, η, ν, specific pressure p in the product pipeline, tangential stresses τ and the velocity gradient dv/dz.

The condition for stochastic transformation of the gel transported by the pipeline (coagulation-thixotropic structure) into sol is the destruction of its spatial structure, which is formed by the dispersed phase of the colloidal solution. Such a stochastic transformation of the coagulation-thixotropic structure can be observed both when reaching the mode that determines the turbulent motion of a viscous colloidal solution, and somewhat earlier – at the stages of the laminar flow regime of the solution. In this case, the average movement speed of the colloidal solution in the pipe according to the Poiseuil equation in accordance with (13) and (14) will be:

$$v_{avg} = \frac{Q}{\pi \cdot R^2} = \frac{1}{8} \cdot \frac{p}{\eta \cdot l} \cdot R^2 \quad (16)$$

Given that the values of the tangential stresses can be determined from the dependence (6) and for $r = R$, the following is obtained:

$$v_{avg} = \frac{1}{4} \cdot \frac{\tau}{\eta} \cdot R \quad (17)$$

If the maximum tangential stress that causes stochastic destruction of the spatial structure of the dispersed phase of a colloidal solution is τ_{max}, then, consequently, (17), the following is obtained:

$$v_{cs}^{(1)} = \frac{1}{4} \cdot \frac{\tau_{max}}{\eta} \cdot R \quad (18)$$

where: $v_{cs}^{(1)}$ – critical velocity of the laminar mode of movement of a gel colloidal solution at which the spatial structure of its dispersed phase is destroyed in a pipeline with an internal pipe radius R.

The critical rate of transition of the laminar mode of motion of a gel colloidal solution to the turbulent mode of motion, which leads to the destruction of its spatial structure, according to the Reynolds criterion Re (15), will be:

$$v_{cs}^{(2)} = \frac{Re}{2} \cdot \frac{\eta}{\rho \cdot R} \quad (19)$$

where: $v_{cs}^{(2)}$ – critical rate of transition of the laminar mode of motion of the gel colloidal solution to the turbulent mode, at which the spatial structure of the dispersed phase of the solution is guaranteed to be destroyed in a pipeline with an internal pipe radius R.

Equation (18) shows that the critical velocity of the motion of gel colloidal solution at which the spatial structure of the dispersed phase is destroyed under laminar conditions in the pipeline increases with the internal pipeline diameter. On the other hand, as follows from equation (19), the rate at which the movement of the viscous gel in the pipeline acquires signs of turbulence, which is guaranteed to cause the destruction of the coagulation-thixotropic structure of the colloidal solution, is higher.

Upon equating (18) and (19), the following is obtained:

$$\frac{1}{4} \cdot \frac{\tau_{max}}{\eta} \cdot R = \frac{Re}{2} \cdot \frac{\eta}{\rho \cdot R} \quad (20)$$

Having defined the internal radius of the pipeline at which both critical velocities are equal to each other as the critical radius R_{cs}, the following is obtained:

$$R_{cs} = 2 \cdot \eta \cdot \sqrt{\frac{Re}{2 \cdot \rho \cdot \tau_{max}}} \quad (21)$$

A graphical interpretation of dependencies (18), (19), and (21) is shown in Figure 4.

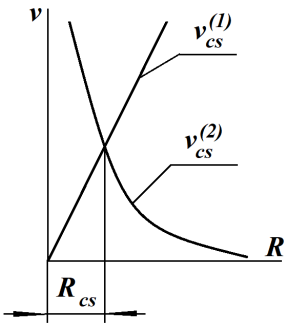

Figure 4. Critical flow rates of the coagulation-thixotropic structure of a colloidal solution in a product pipeline

Following from the analysis of Figure 4, at $R<R_{cs}$, the coagulation-thixotropic structure of the colloidal solution in the pipeline is destroyed, it occurs before the

movement of the liquid flow reaches the turbulent regime. At the same time, at $R>R_{cs}$, the turbulent regime, the gel flow begins at a certain velocity value v_{cs}, which is still safe to prevent stochastic destruction of the coagulation-thixotropic structure of the gel.

To prevent the stochastic destruction of coagulation-thixotropic structures of gel flows in pipelines, it is necessary to distinguish several important characteristic values of tangential stresses τ:

– the elastic limit τ_{el}, which in this case coincides with the yield strength and at $\tau<\tau_{el}$, the flow of a colloidal solution with a coagulation-thixotropic structure is viscous, cannot be observed;

– conditional limit $\tau_{м}$ of the initial strength of the structure; up to this limit, the spatial coagulation-thixotropic structure is preserved without destruction;

– conditional yield strength τ_{fB} (according to Bingham); beyond this limit, uncontrolled avalanche-like stochastic destruction of the coagulation-thixotropic structure begins (Fig. 5);

– the limit τ_{B} of structural viscosity, upon reaching which there is a gradual transition to a viscous flow of "Newtonian fluid";

– the conditional limit τ_{cm} of ultimate destruction of a coagulation-thixotropic structure (ultimate structural strength); at $\tau>\tau_{cm}$, a dispersed system (solution), as a rule, can only be in the form of sol and reveals only the properties of a rheological Newton body (viscous fluid flow).

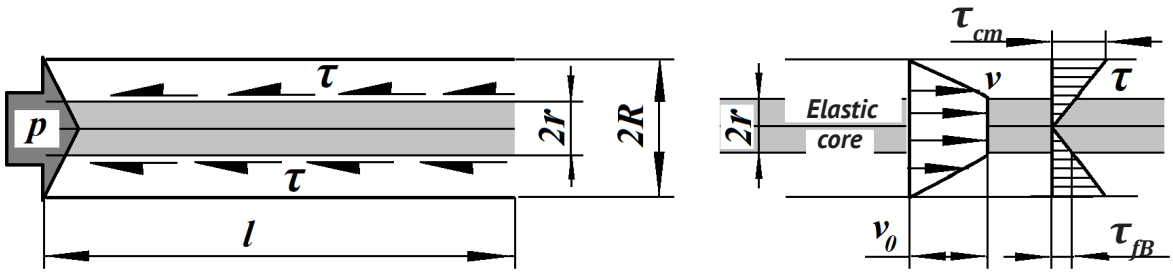

Figure 5. *Movement of the Bingham rheological body in the cylindrical tube of the product pipeline*

Consequently, the nature of deformation of the structure of a gel-like coagulation-thixotropic colloidal solution during transportation in the pipe of the product pipeline continuously changes. The "rheological models" (rheological characteristics) and corresponding mechanical properties of such structures change.

Next, the study considers the possibility of practical application of the obtained analytical results at the design stage of technological (production) pipelines for transportation of SAE-10 and SAE-40 engine oils. The main physical characteristics of these lubricants are as follows: dynamic viscosity – $\boldsymbol{\eta = 0.065}$ $\boldsymbol{(Pa \cdot c)}$ for the SAE-10 brand and $\boldsymbol{\eta = 0.319}$ $\boldsymbol{(Pa \cdot c)}$ for the SAE-40 brand; density – $\boldsymbol{\rho = 800}$ $\boldsymbol{\left(kg/m^3\right)}$ for both brands; destruction limit of the coagulation-thixotropic structure of the oil – τ_{cs} = ***0.02*** **(*Pa*)** – pressure-free gravity flow and τ_{cm} = ***20*** **(*Pa*)** flow movement created in the pipe by pumps SP1, SP2 and GP3; Reynolds criterion – ***Re = 2500***.

The results of design calculations of technological (production) pipelines for transportation of SAE-10 and SAE-40 engine oils are presented in Table 1.

Table 1. *Results of design calculations of optimal pipeline diameters for the transportation of SAE-10 and SAE-40 engine oils*

Property indicator	SAE-10 engine oil		SAE-40 engine oil	
	flow motion generated by pumps SP1, SP2 and GP3	gravity-fed flow motion	flow motion generated by pumps SP1, SP2 and GP3	gravity-fed flow motion
Dynamic viscosity ($\boldsymbol{Pa \cdot c}$)	0.065	0.065	0.319	0.319
Density, kg/m^3	800	800	800	800
Structure destruction limit, ***Pa***	0.2	20	0.2	20
Reynolds criterion	2500	2500	2500	2500
Flow radius, ***m***	0.5	0.05	1.2	0.13
Optimal product pipeline diameters, mm: – minimum – maximum		100 not limited		250 not limited

The above example of design calculation shows the possibility of further development and creation of a universal regulatory framework that would be clearly focused on the needs of designers of pipeline transport systems for main product pipelines and for purely technological "interoperable" production pipelines. At the same time, such technological pipelines under certain production conditions would not only maintain the quality indicators of the transported materials, but under certain transportation modes they could perform specific production functions, such as certain technological operations aimed at obtaining finished products.

CONCLUSIONS

The proposed analytical method of engineering optimisation of the design diameter of the transport pipeline, based on the strength criterion of bound-dispersed coagulation-thixotropic gel structures, allows establishing optimal technical characteristics of the pipeline at the design stage, in particular, the conditional internal diameter of the pipe, steel (cast iron) product pipelines. The basis for such optimisation was the basic physical properties of the transported material (density, kinematic and dynamic viscosity, tangential shear stresses), as well as the structural and technological parameters of the pipeline (productivity or technological flow rates, speed of the transported gel, specific pressure in the product pipeline). Optimised structural and technological parameters of "interoperable" production pipelines provide not only transport functions through technological transitions, but can also be included in production processes as direct technological operations.

Further studies of dispersed flows of gels and soles in pipelines should be aimed at improving universal (generalised) methods of engineering calculations of design parameters of systems and individual technical objects of pipeline transport and the development of appropriate regulatory documentation. Such measures would ensure the automation of design work at the stage of preparation of projects for the construction of both main product pipelines and technological "interoperable" production pipelines.

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АНАЛІТИЧНИЙ КРИТЕРІЙ МІЦНОСТІ ЗВ'ЯЗАНО-ДИСПЕРСНИХ ГЕЛЕЙ ПРИ ТРАНСПОРТУВАННІ ЇХ У ТРУБОПРОВОДАХ

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Анотація. Сучасні трубопровідні системи, як магістральні, так і промислові, дозволяють транспортувати широку номенклатуру не лише рідких і газоподібних речовин, але й різноманітні тверді сипкі матеріали, корисні копалини, будівельні матеріали та суміші тощо. Однак, розвиток трубопровідних транспортних систем в сучасних умовах стримується недостатністю теоретичних напрацювань за реалізації практичних інженерних проектів створення як магістральних, так і промислових продуктопроводів різного призначення. Отже, подальший розвиток теорії потоків різноманітних речовин у трубопроводах і створення на підставі цієї теорії універсальних методів інженерних розрахунків проектних параметрів трубопровідних систем є пріоритетними завданнями для подальшого розвитку продуктопровідного транспорту. Дослідження виконувались відповідно до умови стохастичного перетворення коагуляційно-тиксотропної структури гелевого потоку в золь. Таке стохастичне перетворення коагуляційно-тиксотропної структури може спостерігатись як за досягнення режиму, що визначає турбулентний рух в'язкого колоїдного розчину, так і дещо раніше – на стадіях ламінарного режиму течії розчину. На підставі формально-феноменологічного аналізу визначено, що під час переходу ламінарного режиму руху потоку рідини Ньютона у циліндричній трубі в турбулентний режим гарантовано відбувається руйнування транспортованого структурованого гелевого потоку в колоїдний золь. На підставі прикладу типового проектного розрахунку технологічного (виробничого) трубопроводу для транспортування моторних олив марок SAE-10 та SAE-40 визначено оптимальні умовні внутрішні діаметри труб продуктопроводу, встановлено відповідність проектних конструкційних параметрів трубопроводів відповідним фізико-механічним властивостям транспортуємих рідин. Пропоновані методи інженерних розрахунків проектних параметрів технічних об'єктів трубопровідного транспорту мають розширити та доповнити типову нормативну документацію підготовки проектів будівництва як магістральних продуктопроводів, так і технологічних «міжопераційних» виробничих трубопроводів

Ключові слова: трубопровід, потік, гель, ламінарний режим, турбулентний режим, проектні параметри трубопроводу

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SIMULATION OF THE PROCESS OF CAVITATION TREATMENT OF LIQUID FEED

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Abstract. The same fractional composition and uniformity of distribution of raw material components of plant origin in the mixture are the main criteria for the liquid feed quality. This is ensured by the homogenisation and dispersion of feed components using cavitation treatment. The purpose of the study is to simulate the process of cavitation treatment of liquid feed with a rotary cavitation disperser-homogeniser and substantiate its rational design and technological parameters. The task is to create such a rotary cavitation disperser-homogeniser, which allows simultaneously performing technological processes of dispersion, emulsification, and homogenisation of mixture components in a liquid medium with higher productivity, quality, and lower energy consumption. As a result of modelling the action of a rotary cavitation disperser-homogeniser in the Star CCM+ software, the distributions and dynamics of velocities of the liquid phase of the mixture and the pressure and concentration of the gaseous phase of liquid in the diffuser are established, which indicates the presence of cavitation. This confirms the operability of the developed design and technological facilities for the preparation of liquid feed and indicates the expediency of further research to substantiate its technological parameters. As a result of numerical modelling of the operation process of a rotary cavitation disperser-homogeniser, the dependences of the maximum (max) and minimum (min) movement speed of the liquid phase of the mixture in the inlet V_{in} and in the diffuser V_{rot} on the rotor speed n, inlet diameter D_{in} and the number of resonators N_{hole} are determined. The qualitative criterion for evaluating the cavitation phenomenon in the developed equipment is the maximum and minimum cavitation number X_{max} and X_{min}, which depends on the rotation speed of the rotor n, the inlet diameter D_{in} and the number of resonators N_{hole}. The value of the cavitation number X_{min} = 0.08 and X_{max} = 0.57 is achieved at n = 2725 rpm, D_{in} = 0.049 m, N_{hole} = 48, which corresponds to a film flow of liquid with a stable separation of the cavitation cavity from the rest of the continuous flow (film cavitation)

Keywords: feed production, cavitation, disperser-homogeniser, numerical modelling, parameters, speed, pressure

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INTRODUCTION

Providing animals with high-quality feed at a competitive price in accordance with a balanced diet determines the effective operation of animal husbandry. One of the factors of the unstable development of animal husbandry in Ukraine is the supply of poor-quality feed [1]. The development of new and improvement of conventional technical and technological support for feed production for organic animal husbandry should be carried out taking into account the criteria of efficiency, energy and resource saving and competitiveness of its products. This is possible by improving the quality of the feed base with the help of technological and technical innovations [2; 3].

The value of liquid feed is determined by the appropriate technological operations during their preparation. Liquid feed should have a high degree of uniformity in the fraction composition. In this regard, feed grinding should be provided with the same fractional composition for each of the components of plant raw materials that are part of the feed. In addition, the feed must be homogeneous in the distribution of components in the liquid mixture. That is, the mixing process should be provided with a high coefficient of variation in the distribution of components of raw materials of vegetable origin in the mixture volume. Prepared liquid feed should preserve nutrients and vitamins, do not contain substances that can adversely affect the health and productivity of the animal, and also ensure a waste-free transformation of plant raw materials. That is, the technological process of feed preparation must meet the specified conditions [4; 5].

These conditions correspond to the processes of homogenisation and dispersion of feed components using cavitation treatment. According to [6], dispersion is a technological process that results in dispersed systems (suspensions, powders, aerosols, emulsions) formed by grinding and redistributing components of a solid material, liquid, or gas. For a heterophase system, a decrease in the degree of inhomogeneity of the phase and component distributions occurs during the technological process of homogenisation [6]. The physical process of cavitation is determined by the build-up and collapse of bubbles (cavities) in liquid media with the release of a large amount of energy (shock wave) [7]. Bubbles resulting from cavitation contain liquefied steam. A decrease in the pressure in the liquid and an increase in its velocity leads to the phenomenon of hydrodynamic cavitation. The bubble formed as a result of hydrodynamic cavitation moves with the flow of liquid into the high-pressure zone. Further, as a result of collapse, the bubble emits a shock wave. By its nature, hydrodynamic cavitation has the same mechanism of action as a shock wave in air that occurs when a solid body overcomes a sound barrier. The cavitation phenomenon is local in nature and occurs within the appropriate conditions [8]. In the process of cavitation treatment, the feed components are crushed under the action of a shock wave.

Based on the analysis [9-11], it was established that the production of liquid feed and feed supplements based on cavitation treatment is effective. Cavitation dispersion improves the biochemical qualities of liquid feed. This process allows using any components of plant origin. Cavitation treatment affects the protein complex of plant components. This ensures a high degree of fat emulsification, which leads to an increase in its digestibility by animals (by 6.3%). As a result of cavitation dispergation, the extraction of biologically active substances and soluble proteins is accelerated. That is, the obtained biochemically prepared liquid feeds are highly efficient when fed to farm animals of all kinds.

Thus, the scientific and practical task is to ensure the value of liquid feed by applying technological processes of dispersion, homogenisation with cavitation treatment of feed components in the preparation process.

The purpose of the study is to simulate the process of cavitation treatment of liquid feed with a rotary cavitation disperser-homogeniser and substantiate its rational design and technological parameters.

MATERIALS AND METHODS

To implement the process of cavitation dispersion and homogenisation of liquid feed, the following design and technological scheme of the corresponding technical means is proposed, which is shown in Figure 1 [12; 13].

To perform the simulation, a CAD model grid of the area between the rotor, stator, and working chamber of a rotary cavitation disperser-homogeniser with a base cell size of 0.001 m was constructed in the Star CCM+ software package. The geometric parameters of the rotor and stator of a rotary cavitation dispersant-homogeniser were used for modelling, which is shown in Figure 2-3. The working chamber was adopted with a diameter of 340 mm and a height of 270 mm. The absolute roughness of the rotor and stator surfaces – $\varepsilon = 2.5 \cdot 10^{-6}$ m.

Numerical simulations were performed using the Eulerian multiphase model, multiphase interaction, and the volume of fluid method (VOF). The motion of the liquid phase follows the k-ε model of turbulence. To determine the flow of the liquid phase and the presence of the cavitation phenomenon, the mixture is taken as a medium of two phases (liquid-gas). In addition, the gas is represented as the gaseous phase of a liquid (steam). It is accepted that the liquid phase in the process of motion had a constant density, and the gas was real and obeyed the Van der Waals equation. The gas-liquid phase interaction corresponds to the model of cavitation (Schnerr-Sauer) and volume of fluid (VOF-VOF) [14-16].

For this numerical simulation, the iteration period was 0.001 ms. At the initial point in time, the area between the stator and the rotor was filled only with liquid, that is, its content was $\alpha_f = 1$. At the initial time, the temperature was 300 K (27°C), the pressure was 101.3 kPA. Accepted: constant liquid density $\rho_f = 997.6$ kg/m^3, dynamic viscosity $\mu_f = 8.88 \cdot 10^{-4}$ Pa·s, saturation pressure

p_f = 2338 Pa, molecular weight M_f = 18 kg/kmol, thermal conductivity coefficient λ_f = 0.62 W/(m·K), specific heat capacity C_f = 4181 J/(kg·K). In turn, the gaseous phase of the liquid has a dynamic viscosity $\mu_g = 1.267 \cdot 10^{-5}$ Pa·s, a molecular weight M_g = 18 kg/kmol, a thermal conductivity coefficient λ_g = 0.0253 W/(m·K), and a specific heat capacity C_g = 1938 J/(kg·K).

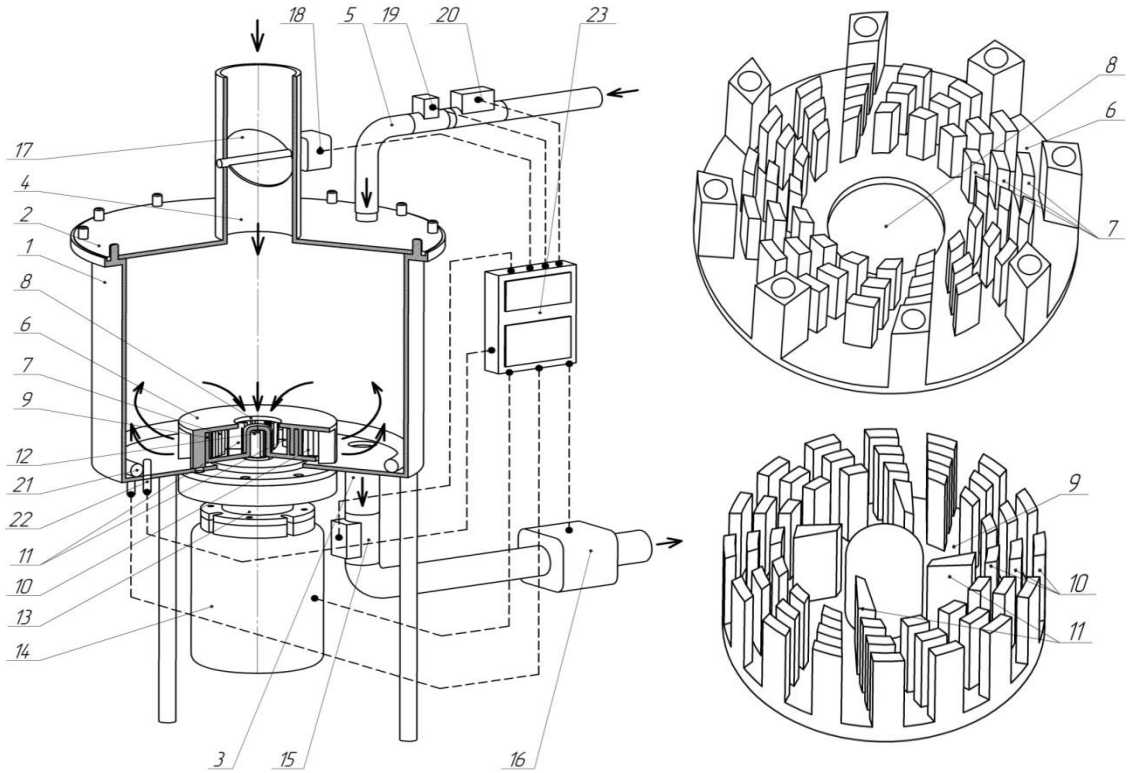

***Figure 1**. Design and technological scheme of a rotary cavitation disperser-homogeniser:*
1 – loading tank; 2 – tank cover; 3 – outlet pipe; 4 – loading sleeve; 5 – branch pipe for liquid components; 6 – stator; 7 – diffuser; 8 – through-hole; 9 – rotor; 10 – resonators; 11 – blades; 12 – shaft; 13 – bearing unit; 14 – asynchronous electric motor; 15 – electric crane; 16 – electric pump; 17 – flap; 18 – stepper motor shaft; 19 – liquid flow sensor; 20 – electric tap; 21 – heater; 22 – temperature sensor; 23 – control unit

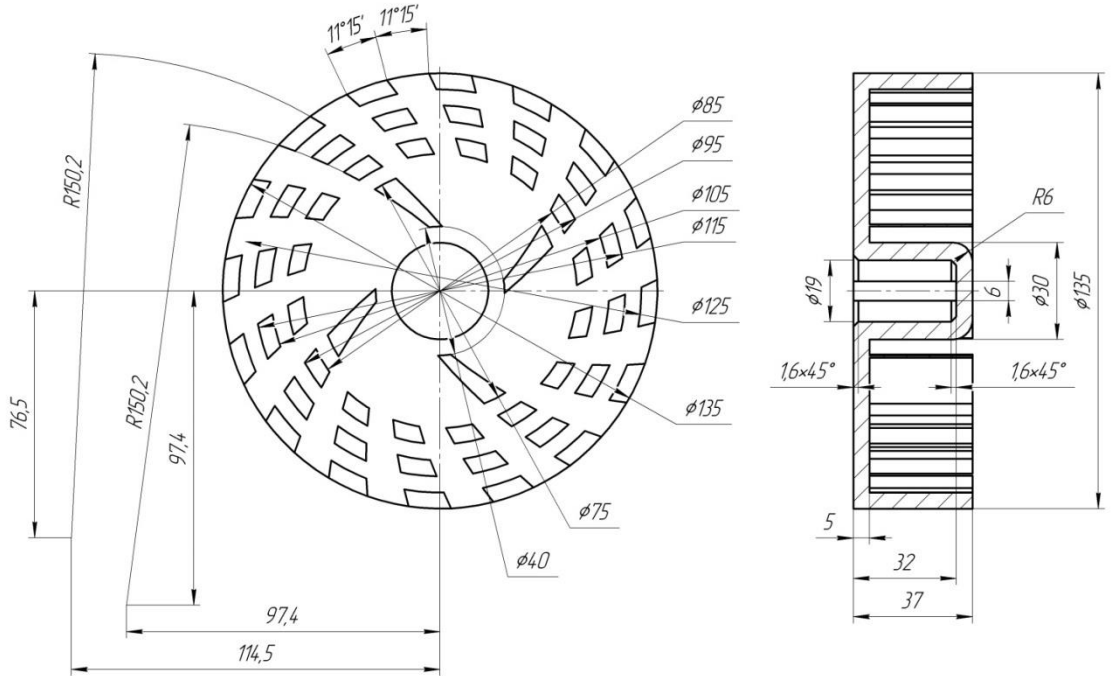

***Figure 2.** Geometric dimensions of the rotor of the rotary cavitation disperser-homogeniser*

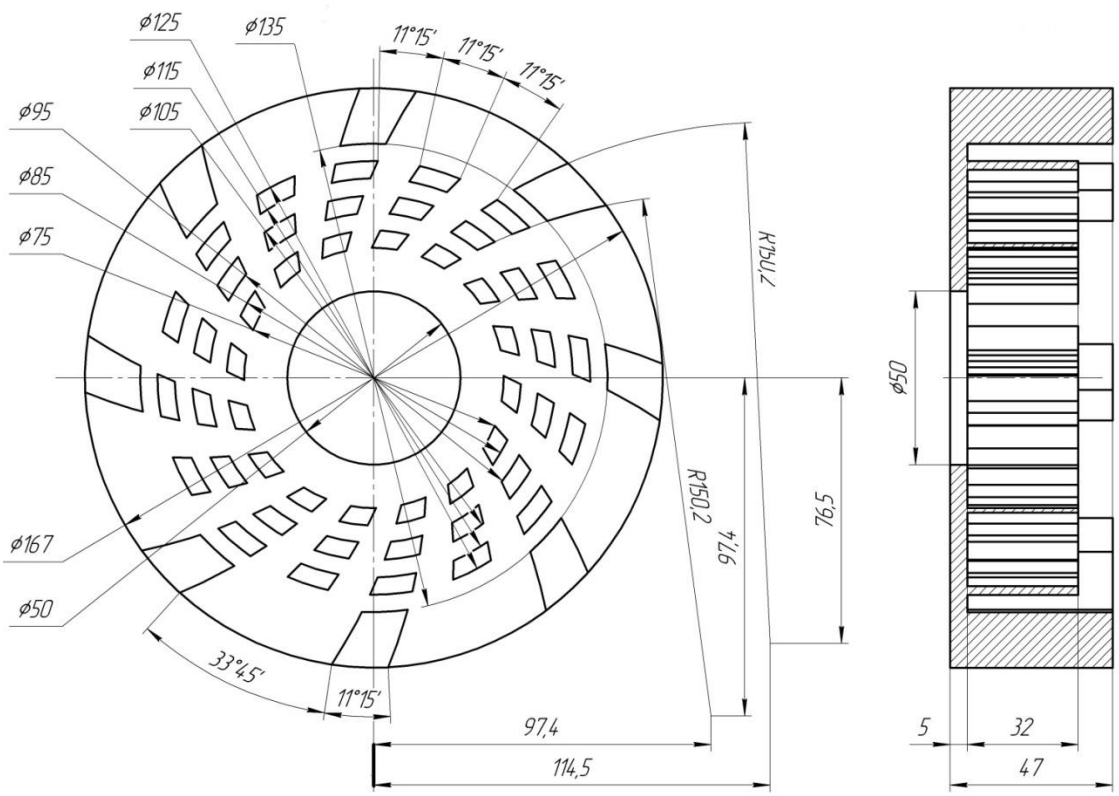

Figure 3. *Geometric dimensions of the stator of the rotary cavitation disperser-homogeniser*

The 3D model grid of the area between tank and working bodies of the cavitation disperser-homogeniser in Star CCM+ is shown in Figure 4.

The rotor speed n, the Inlet diameter Din, and the number of resonators Nhole were selected as research factors. The limits and intervals of research factors are shown in Table. 1.

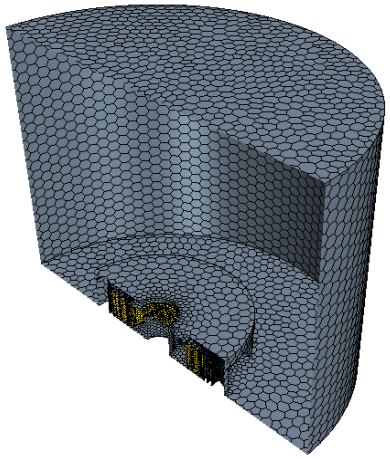

Figure 4*. The 3D model grid of the area between the tank and working bodies of the cavitation disperser-homogeniser in Star CCM+*

Table 1*. Limits and intervals of numerical modelling factors*

Level	Rotor speed n, rpm. (x_1)	Inlet diameter D_{in}, m (x_2)	Number of resonators N_{hole} (x_3)
Upper (+1)	3000	0.06	48
Average (0)	2250	0.05	32
Lower (-1)	1500	0.04	16
Interval	750	0.01	16

In the process of numerical modelling, it was determined for each experiment:

– maximum movement speed of the liquid phase of the mixture in the inlet $V_{in\ max}$;

– maximum movement speed of the liquid phase of the mixture in the diffuser $V_{rot\ max}$;

– maximum pressure of the liquid phase of the mixture in the inlet $P_{in\ max}$;

– maximum pressure of the liquid phase of the mixture in the diffuser $P_{rot\ max}$;

– minimum pressure of the liquid phase of the mixture in the diffuser $P_{rot\ min}$.

The qualitative criterion for evaluating the cavitation phenomenon in the developed equipment is the maximum and minimum cavitation number X_{max} and X_{min}, which is calculated using the equations (1-2):

$$X_{max} = \frac{2(P_{rotmax} - P_s)}{\rho V_{rotmax}}, \quad (1)$$

$$X_{min} = \frac{2(P_{rotmin} - P_s)}{\rho V_{rotmin}}, \quad (2)$$

where: P_{rot} – hydrostatic pressure of the incoming flow in the diffuser, Pa; P_s – saturated vapour pressure of the liquid (for water vapour P_s = 2314.4 Pa); ρ – density of the medium (for water ρ = 997 kg/m³); V_{rot} – flow rate in the diffuser, m/s.

When the flow of a two-phase medium reaches the maximum velocity, at the moment when the pressure in the flow becomes equal to the pressure of vaporisation (saturated vapours), the cavitation phenomenon occurs. The specified velocity corresponds to the value of the cavitation criterion X, which determines the type of flow:

– at $X > 1$ – continuous (single-phase) flow;

– at $X \approx 1$ – two-phase cavitation flow;

– at $X < 1$ – film flow;

– at $X << 1$ – supercavitation.

The criterion for the dispersion productivity is the value of the mass flow of the mixture, which is calculated using the equation (3):

$$Q = V_{in\ max}\rho S_{in} = V_{in\ max}\rho\pi D_{in}^2, \quad (3)$$

where S_{in} – area of the entrance opening, m².

The higher the value of Q, the greater the mass of the mixture per unit time to be dispersed. Rational design and mode parameters of the cavitation disperser-homogeniser can be achieved if the productivity of the dispersing process is maximised while minimising the value of the cavitation number.

The simulation was performed by iterating through all levels of factors. The total number was 27 experiments. After that, a second-order regression model was calculated using the Mathematica software.

RESULTS AND DISCUSSION

Based on the results of numerical modelling, the distribution of the velocity of movement of the liquid phase in the working chamber of a rotary cavitation disperser-homogeniser is obtained (Fig. 5). This visualisation shows that the entire mixture is captured by the rotor in the through-hole of the stator and passes through diffusers and resonators, in which the dispersion process takes place.

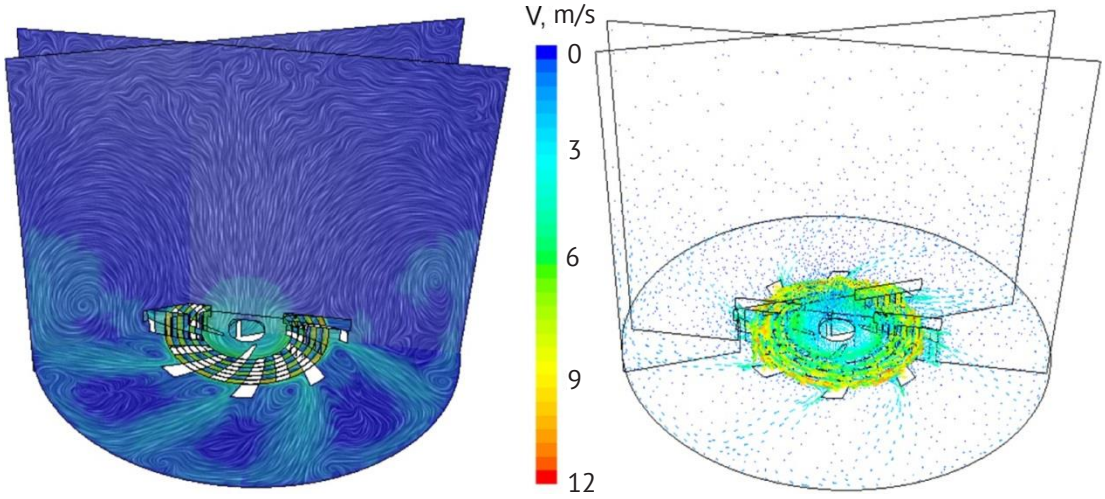

Figure 5. *Distribution of movement velocity of the liquid phase of the mixture in the working chamber of the rotary cavitation disperser-homogeniser*

Figure 6 shows the distribution and dynamics of pressure in the diffuser of a rotary cavitation disperser-homogeniser. This visualisation shows that the average difference between the maximum and minimum pressure values in the diffuser is more than 90 kPa. At the same time, such a pressure change occurs in 0.004 seconds. This allows stating that the phenomenon of hydraulic shock occurs in the diffuser, which contributes to the dispersion process.

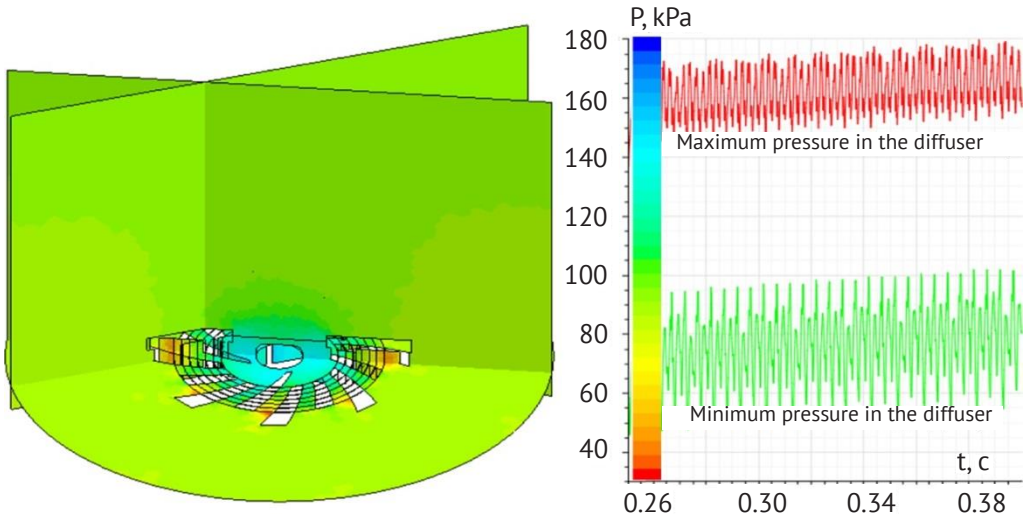

***Figure 6**. Pressure distribution and dynamics in the diffuser of a rotary cavitation disperser-homogeniser*

Based on the results of simulation and processing of the obtained data in the Mathematica software, regularities of changes in the value of the maximum velocity of movement of the liquid phase of the mixture in the inlet are obtained from research factors in encoded form (4):

$$V_{in\,max} = 4.72 + 1.00333\,x_1 - 3.03551\cdot10^{-15}\,x_1^2 + 1.09667\,x^2 - 5.2384\cdot10^{-16}\,x_1\,x_2 + 0.1\,x_2^2 - 0.271667\,x_3 - 0.01\,x_1\,x_3 - 0.0275\,x_2\,x_3 + 0.085\,x_3^2 \quad (4)$$

Statistical processing of equation (4) is presented in Table 2. As a result of the analysis of Table 2, corresponding reduction of insignificant coefficients according to the Student's t-test and decoding of equation (4), the study has finally obtained the dependence of the change in the maximum velocity of the liquid phase of the mixture in the inlet on the research factors (5):

$$V_{in\,max} = -0.665 + 15.1667\,D_{in} + 1000\,D_{in}^2 + 0.00133778\,n - 0.0296354\,N_{hole} - 0.171875\,D_{in}\,N_{hole} + 0.000332031\,N_{hole}^2 \quad (5)$$

***Table 2**. Statistical processing of equation (4)*

Coefficient	Value	Error	Student's t-test	Probability
a_{00}	4.72	0.0193396	244.059	$1.41494\cdot10^{-31}$
a_{10}	1.00333	0.00895249	112.073	$7.81436\cdot10^{-26}$
a_{20}	1.09667	0.00895249	122.499	$1.7257\cdot10^{-26}$
a_{30}	-0.271667	0.00895249	-30.3454	$3.01715\cdot10^{-16}$
a_{12}	$-5.2384\cdot10^{-16}$	0.0109645	$-4.7776\cdot10^{-14}$	1
a_{13}	-0.01	0.0109645	-0.912033	0.374504
a_{23}	-0.0275	0.0109645	-2.50809	0.0225708
a_{11}	$-3.03551\cdot10^{-15}$	0.0155062	$-1.95762\cdot10^{-13}$	1
a_{22}	0.1	0.0155062	6.44905	$5.99957\cdot10^{-6}$
a_{33}	0.085	0.0155062	5.48169	0.00004052

The maximum movement speed of the liquid phase of the mixture in the inlet $V_{in\,max}$ = 7.3 m/s is achieved at n = 3000 rpm., D_{in} = 0.06 m, N_{hole} = 16. Graphical interpretations of dependency (5) are shown in Figure 7.

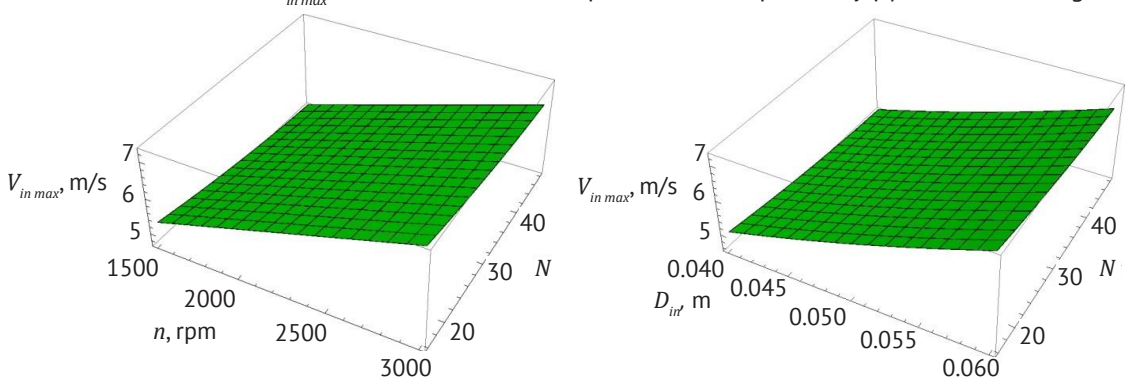

***Figure 7**. Dependence of the maximum movement speed of the liquid phase of the mixture in the inlet $V_{in\,max}$ on the rotation speed of the rotor n, the diameter of the inlet Din and the number of resonators N_{hole}*

Based on the results of simulation and processing of the obtained data in the Mathematica software, regularities of changes in the value of the maximum velocity of movement of the liquid phase of the mixture in the diffuser are obtained from research factors in encoded form (6):

$$V_{rot\,max} = 17.2533 + 6.31667\,x_1 - 2.34467\cdot10^{-14}\,x_1^2 + 0.178333\,x_2 - 4.13185\cdot10^{-15}\,x_1\,x_2 + 0.135\,x_2^2 + 2.33333\,x_3 + 1.11\,x_1\,x_3 - 0.1525\,x_2\,x_3 + 0.36\,x_3^2 \quad (6)$$

Statistical processing of equation (6) is presented in Table 3. As a result of the analysis of Table 3, corresponding reduction of insignificant coefficients according to the Student's t-test and decoding of equation (6), the study has finally obtained the dependence of the change in the maximum velocity of the liquid phase of the mixture in the diffuser on the research factors (7):

$$V_{rot\,max} = 0.845 + 17.8333\,D_{in} + 0.00546222\,n - 0.152292\,N_{hole} + 0.0000925\,n\,N_{hole} + 0.00140625\,N_{hole}^2 \quad (7)$$

***Table 3**. Statistical processing of equation (6)*

Coefficient	Value	Error	Student's t-test	Probability
a_{00}	17.2533	0.164711	104.749	$2.46127\cdot10^{-25}$
a_{10}	6.31667	0.0762462	82.8457	$1.31798\cdot10^{-23}$
a_{20}	0.178333	0.0762462	2.33891	0.0318103
a_{30}	2.33333	0.0762462	30.6026	$2.6202\cdot10^{-16}$
a_{12}	$-4.13185\cdot10^{-15}$	0.0933821	$-4.42467\cdot10^{-14}$	1
a_{13}	1.11	0.0933821	11.8866	$1.16332\cdot10^{-9}$
a_{23}	-0.1525	0.0933821	-1.63307	0.120836
a_{11}	$-2.34467\cdot10^{-14}$	0.132062	$-1.77543\cdot10^{-13}$	1
a_{22}	0.135	0.132062	1.02225	0.320993
a_{33}	0.36	0.132062	2.72599	0.0143729

The maximum movement speed of the liquid phase of the mixture in diffuser $V_{rot\,max}$ = 27.5 m/s is achieved at n = 3000 rpm., D_{in} = 0.06 m, N_{hole} = 48. Graphical interpretations of dependency (5) are shown in Figure 8.

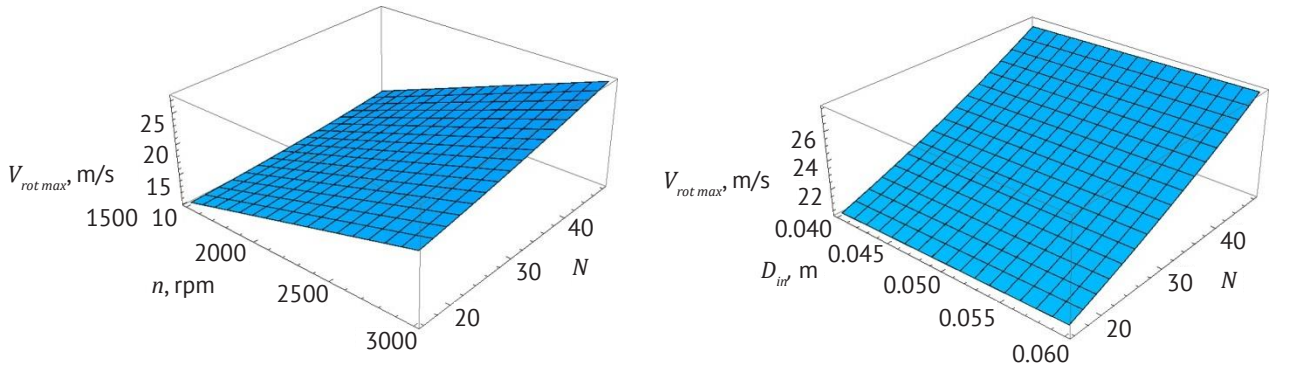

***Figure 8**. Dependence of the maximum movement speed of the liquid phase of the mixture in the diffuser $V_{rot\,max}$ on the rotation speed of the rotor n, the diameter of the inlet D_{in} and the number of resonators N_{hole}*

Based on the results of simulation and processing of the obtained data in the Mathematica software, regularities of changes in the value of the maximum pressure of the liquid phase of the mixture in the inlet are obtained from research factors in encoded form (8):

$$P_{in\,max} = 124.551 + 15.6894\,x_1 - 1.81164\,x_1^2 + 5.46905\,x_2 + 0.524858\,x_1\,x_2 - 0.323984\,x_2^2 + 5.3878\,x_3 + 0.04055\,x_1\,x_3 + 1.21828\,x_2\,x_3 + 3.88243\,x_3^2. \quad (8)$$

Statistical processing of equation (8) is presented in Table 4. As a result of the analysis of Table 4, corresponding reduction of insignificant coefficients according to the Student's t-test and decoding of equation (8), the dependence of the change in the maximum pressure of the liquid phase of the mixture in the inlet on the research factors (9) was found:

$$P_{in\,max} = 50.7694 + 303.249\,D_{in} + 0.0354123\,n - 3.22069\cdot10^{-6}\,n^2 - 1.01458\,N_{hole} + 7.61425\,D_{in}\,N_{hole} + 0.0151657\,N_{hole}^2 \quad (9)$$

The maximum pressure of the liquid phase of the mixture in the inlet $P_{in\,max}$ = 154.4 kPa is reached at n = 3000 rpm., D_{in} = 0.06 m, N_{hole} = 48. Graphical interpretations of equation (9) are shown in Figure 9.

***Table 4**. Statistical processing of equation (8)*

Coefficient	Value	Error	Student's t-test	Probability
a_{00}	124.551	0.666684	186.821	$1.328 \cdot 10^{-29}$
a_{10}	15.6894	0.308615	50.8382	$5.14025 \cdot 10^{-20}$
a_{20}	5.46905	0.308615	17.7213	$2.13958 \cdot 10^{-12}$
a_{30}	5.3878	0.308615	17.458	$2.72515 \cdot 10^{-12}$
a_{12}	0.524858	0.377974	1.38861	0.182879
a_{13}	0.04055	0.377974	0.107282	0.915821
a_{23}	1.21828	0.377974	3.22318	0.0049921
a_{11}	-1.81164	0.534536	-3.38918	0.00348852
a_{22}	-0.323984	0.534536	-0.606104	0.552454
a_{33}	3.88243	0.534536	7.26317	$1.3255 \cdot 10^{-6}$

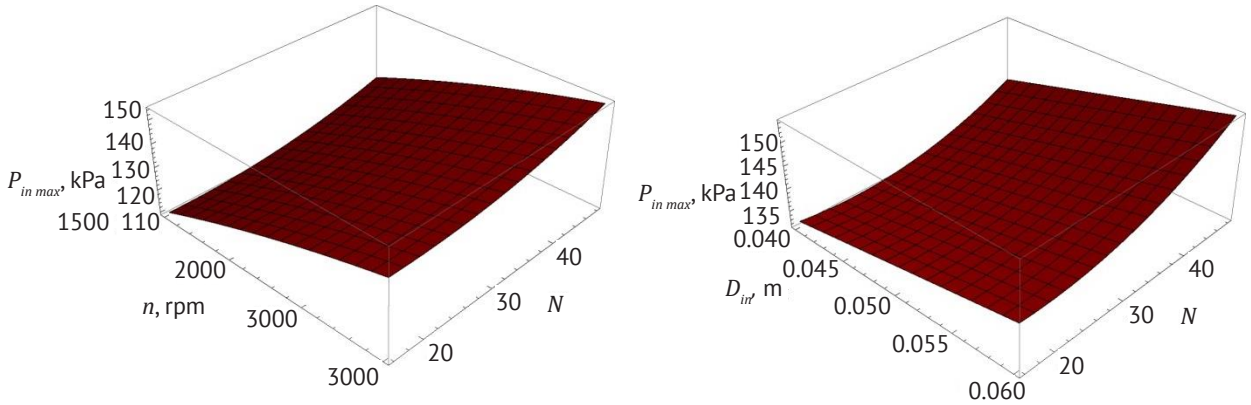

***Figure 9**. Dependence of the maximum pressure of the liquid phase of the mixture in the inlet $P_{in\ max}$ on the rotation speed of the rotor n, the diameter of the inlet D_{in} and the number of resonators N_{hole}*

Based on the results of simulation and processing of the obtained data in the Mathematica software, regularities of changes in the value of the maximum pressure of the liquid phase of the mixture in the diffuser are obtained from research factors in encoded form (10):

$$P_{rot\ max} = 171.763 + 19.3513\ x_1 - 3.90839\ x_1^2 + 3.98246\ x_2 - 0.357417\ x_1\ x_2 - 0.0684029\ x_2^2 + 6.15596\ x_3 + 0.0130833\ x_1\ x_3 - 1.56583\ x_2\ x_3 + 2.63001\ x_3^2 \quad (10)$$

Statistical processing of equation (10) is presented in Table 5. As a result of the analysis of Table 5, the corresponding reduction of insignificant coefficients according to the Student's t-test and decoding of equation (10), the dependence of the change in the maximum pressure of displacement of the liquid phase of the mixture in the diffuser on the research factors was obtained (11):

$$P_{rot\ max} = 41.1716 + 711.412\ D_{in} + 0.0570688\ n - 6.94825 \cdot 10^{-6}\ n^2 + 0.216568\ N_{hole} - 9.78644\ D_{in} N_{hole} + 0.0102735\ N_{hole}^2 \quad (11)$$

***Table 5**. Statistical processing of equation (10)*

Coefficient	Value	Error	Student's t-test	Probability
a_{00}	171.763	0.780301	220.125	$8.17623 \cdot 10^{-31}$
a_{10}	19.3513	0.361209	53.5736	$2.11995 \cdot 10^{-20}$
a_{20}	3.98246	0.361209	11.0254	$3.63528 \cdot 10^{-9}$
a_{30}	6.15596	0.361209	17.0427	$4.01849 \cdot 10^{-12}$
a_{12}	-0.357417	0.442389	-0.807924	0.430295
a_{13}	0.0130833	0.442389	0.0295743	0.976751
a_{23}	-1.56583	0.442389	-3.53949	0.00251884
a_{11}	-3.90839	0.625632	-6.2471	$8.84795 \cdot 10^{-6}$
a_{22}	-0.0684029	0.625632	-0.109334	0.914218
a_{33}	2.63001	0.625632	4.20376	0.000596762

The maximum pressure of the liquid phase of the mixture in the inlet $P_{in\ max}$ = 154.4 kPa is reached at n = 3000 rpm., D_{in} = 0.06 m, N_{hole} = 48. Taking into account the research factors alternately at the specified level, graphical interpretations of the dependence (11) are shown in Figure 10.

Based on the results of simulation and processing of the obtained data in the Mathematica software, regularities of changes in the value of the minimum pressure of the liquid phase of the mixture in the diffuser are obtained from research factors in encoded form (12):

$$P_{rot\ min} = 54.5321 - 19.3513\ x_1 + 3.90839\ x_1^2 + 2.097\ x_2 + 0.357417\ x_1\ x_2 + 0.47866\ x_2^2 - 2.45528\ x_3 - 0.0130833\ x_1\ x_3 - 0.401844\ x_2\ x_3 - 2.22782\ x_3^2 \quad (12)$$

Statistical processing of equation (12) is presented in Table 6. As a result of the analysis of Table 6, the corresponding reduction of insignificant coefficients according to the Student's t-test and decoding of equation (12), the dependence of the change in the minimum pressure of displacement of the liquid phase of the mixture in the diffuser on the research factors was obtained (13):

$$P_{rot\ min} = 133.276 + 209.7\ D_{in} - 0.0570688\ n + 6.94825\cdot10^{-6}\ n^2 + 0.403501\ N_{hole} - 0.00870244\ N_{hole}^2. \quad (13)$$

The maximum pressure of the liquid phase of the mixture in the inlet $P_{in\ max}$ = 37.2 kPa is reached at n = 3000 rpm., D_{in} = 0.06 m, N_{hole} = 16. Taking into account the research factors alternately at the specified level, graphical interpretations of the dependence (13) are shown in Figure 10.

***Table 6**. Statistical processing of equation (12)*

Regression coefficient	Value of regression coefficient	Standard error	t-statistic	P-Value
a_{00}	54.5321	0.641455	85.0131	$8.50496\cdot10^{-24}$
a_{10}	-19.3513	0.296936	-65.1699	$7.69801\cdot10^{-22}$
a_{20}	2.097	0.296936	7.06212	$1.90842\cdot10^{-6}$
a_{30}	-2.45528	0.296936	-8.26873	$2.32092\cdot10^{-7}$
a_{12}	0.357417	0.363671	0.982803	0.339486
a_{13}	-0.0130833	0.363671	-0.0359758	0.971721
a_{23}	-0.401844	0.363671	-1.10497	0.284567
a_{11}	3.90839	0.514308	7.59932	$7.29443\cdot10^{-7}$
a_{22}	0.47866	0.514308	0.930687	0.365044
a_{33}	-2.22782	0.514308	-4.33169	0.000453011

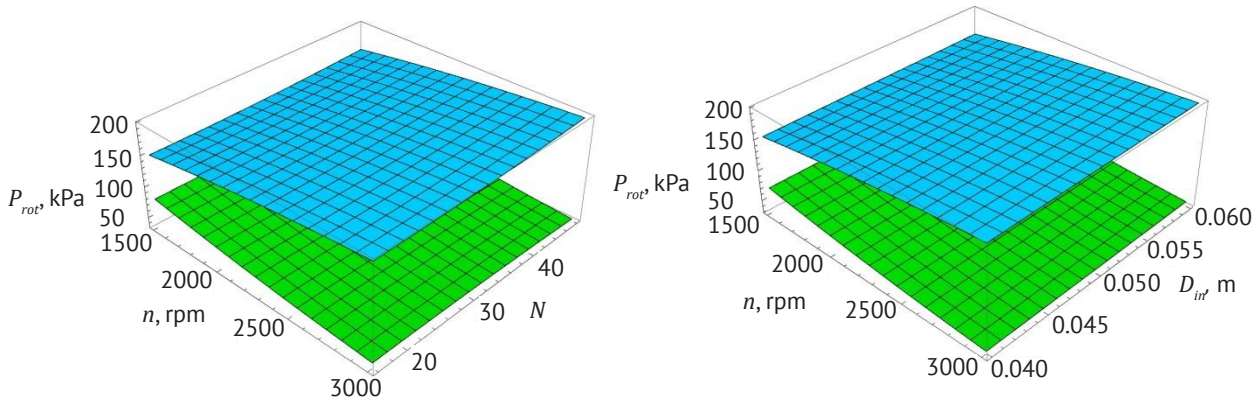

***Figure 10**. Dependence of the maximum and minimum pressures of the liquid phase of the mixture in the diffuser $P_{rot\ max}$, $P_{rot\ min}$ on the rotation speed of the rotor n, the diameter of the inlet D_{in} and the number of resonators N_{hole}*

As a result of calculating the maximum and minimum cavitation numbers using equations (1) and (2), the corresponding regression equations (14-15):

$$X_{max} = 8.85738 - 0.0046054\ n + 6.90585\cdot10^{-7}\ n^2 - 0.0626404\ N_{hole} + 0.0000113792\ n\ N_{hole} + 0.000297945\ N_{hole}^2 \quad (14)$$

$$X_{min} = 6.00697 - 0.00363865\ n + 5.73414\cdot10^{-7}\ n^2 - 0.0385963\ N_{hole} + 0.0000106933\ n\ N_{hole} + 0.0000802344\ N_{hole}^2 \quad (15)$$

The value of the cavitation number X_{min} = 0.08 and X_{max} = 0.57 is achieved at n = 2725 rpm., D_{in} = 0.049 m, N_{hole} = 48. Taking into account the research factors alternately at the specified level, graphical interpretations of dependencies (14)-(15) are shown in Figure 11.

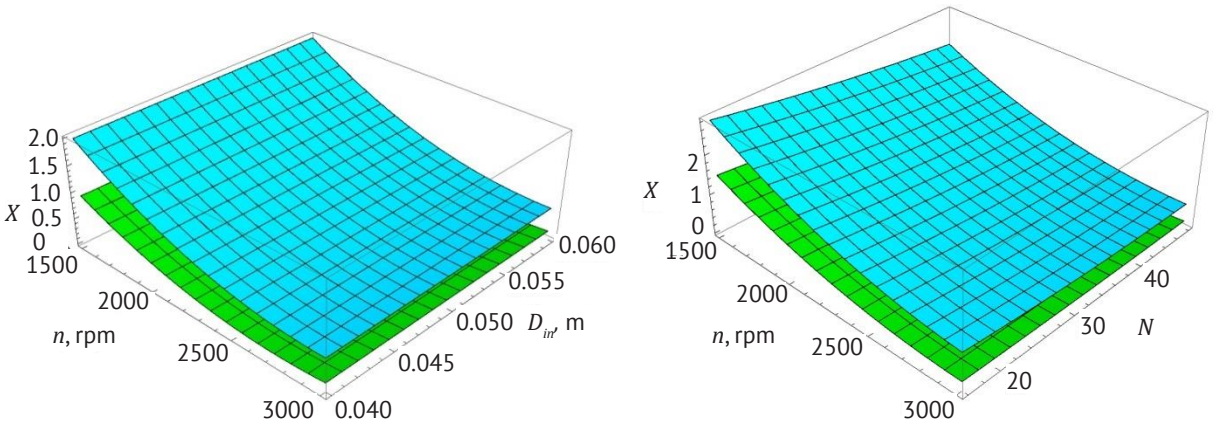

Figure 11. *Dependence of the maximum and minimum cavitation numbers X_{max}, X_{min} on the rotor speed n, the inlet diameter D_{in}, and the number of resonators N_{hole}*

CONCLUSIONS

As a result of modelling the action of a rotary cavitation disperser-homogeniser in the Star CCM+ software, the distributions and dynamics of velocities of the liquid phase of the mixture and the pressure and concentration of the gaseous phase of liquid in the diffuser are established, which indicates the presence of cavitation. This confirms the operability of the developed design and technological facilities for the preparation of liquid feed and indicates the expediency of further research to substantiate its technological parameters.

As a result of numerical modelling of the operation of a rotary cavitation disperser-homogeniser, the dependences of the maximum (max) and minimum (min) movement speed of the liquid phase of the mixture in the inlet V_{in} and in the diffuser V_{rot} on the rotation speed of the rotor n, the diameter of the inlet D_{in} and the number of resonators N_{hole} are determined. The maximum movement speed of the liquid phase of the mixture in the inlet $V_{in\ max}$ = 7.3 m/s is achieved at n = 3000 rpm., D_{in} = 0.06 m, N_{hole} = 16. In turn, the maximum movement speed of the liquid phase of the mixture in the diffuser $V_{rot\ max}$ = 27.5 m/s is achieved at n = 3000 rpm., D_{in} = 0.06 m, N_{hole} = 48. As a result of numerical modelling of the operation process of a rotary cavitation disperser-homogeniser, the dependences of the maximum (max) and minimum (min) pressures of the liquid phase of the mixture in the Inlet P_{in} and in the diffuser P_{rot} on the rotor speed n, the diameter of the inlet D_{in} and the number of resonators N_{hole} are determined. The maximum pressure of the liquid phase of the mixture in the inlet $P_{in\ max}$ = 154.4 kPa and in the diffuser $P_{rot\ max}$ = 154.4 kPa is reached at n = 3000 rpm., D_{in} = 0.06 m, N_{hole} = 48.

The qualitative criterion for evaluating the cavitation phenomenon in the developed equipment is the maximum and minimum cavitation number X_{max} and X_{min}, which depends on the rotation speed of the rotor n, the inlet diameter D_{in} and the number of resonators N_{hole}. The value of the cavitation number X_{min} = 0.08 and X_{max} = 0.57 is achieved at n = 2725 rpm, D_{in} = 0.049 m, N_{hole} = 48, which corresponds to a film flow of liquid with a stable separation of the cavitation cavity from the rest of the continuous flow (film cavitation).

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СИМУЛЯЦІЯ ПРОЦЕСУ КАВІТАЦІЙНОЇ ОБРОБКИ РІДКИХ КОРМІВ

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Анотація. Однаковий фракційний склад та однорідність розподілу компонентів сировини рослинного походження у суміші є основними критеріями якості рідкого корму. Це забезпечується процесами гомогенізації та диспергування компонентів кормів із застосуванням кавітаційної обробки. Метою досліджень є проведення симуляції процесу кавітаційної обробки рідких кормів роторним кавітаційним диспергатор-гомогенізатором і обґрунтування його раціональних конструктивно-технологічних параметрів. Поставлено задачу створення такого роторного кавітаційного диспергатор-гомогенізатора, який дозволяє одночасно виконувати технологічні процеси диспергування, емульгування та гомогенізації компонентів суміші в рідкому середовищі з більш високою продуктивністю, якістю і меншими енерговитратами. У результаті симуляції роторного кавітаційного диспергатор-гомогенізатора в програмі Star CCM+ встановлено розподіли і динаміки швидкостей руху рідкої фази суміші, тиску та концентрації газоподібної фази рідини в дифузорі, що свідчить про наявність кавітації. Це підтверджує працездатність конструктивно-технологічної схеми розробленого технічного засобу для приготування рідких кормів і свідчить про доцільність подальших його досліджень з обґрунтування конструктивно-технологічних параметрів. У результаті чисельного моделювання процесу роботи роторного кавітаційного диспергатор-гомогенізатора визначено залежності максимальної (max) і мінімальної (min) швидкості переміщення рідкої фази суміші у вхідному отворі V_{in} і у дифузорі V_{rot} від частоти обертання ротора n, діаметра вхідного отвору D_{in} і кількості резонаторів N_{hole}. Якісним критерієм оцінки явища кавітації у розробленому обладнанні є максимальне і мінімальне число кавітації X_{max} і X_{min}, яке залежить від частоти обертання ротора n, діаметра вхідного отвору D_{in} і кількості резонаторів N_{hole}. Значення числа кавітації X_{min} = 0,08 і X_{max} = 0,57 досягається при n = 2725 об/хв., D_{in} = 0,049 м, N_{hole} = 48, що відповідає плівковому потоку рідини зі стійким відділенням кавітаційної порожнини від решти суцільного потоку (плівкова кавітація)

Ключові слова: кормовиробництво, кавітація, диспергатор-гомогенізатор, чисельне моделювання, параметри, швидкість, тиск

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COMPARATIVE ASSESSMENT OF SOME PHYSICAL AND MECHANICAL PROPERTIES OF WOOD OF DIFFERENT SCOTS PINE CLIMATYPES

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Abstract. For a more efficient and rational use in the production of Scots pine wood of various geographical origin, it is necessary to know its physical and mechanical properties. The purpose of this study was to determine the physical and mechanical properties of wood of 17 climatic ecotypes of Scots pine and to carry out a comparative analysis of the indicators obtained for the studied climatypes separately and when they are grouped into subspecies in accordance with the classification of L.F. Pravdin. The range of the geographical origin of the places of seed procurement is from 47 to 62° north latitude and from 22 to 85° east longitude. The modern density universal testing machine MTS INSIGHT 100 was used for research. As a result of the research, it was found that the density of wood in an absolutely dry state varies from 370 kg/m^3 (Kursk climatype) to 524 kg/m^3 (Volgograd climatype), and at 12% humidity – from 397 kg/m^3 (Kursk climatype) to 550 kg/m^3 (Volgograd climatype). The index of the strength of wood of the studied climatypes for compression along the fibres was from 32 MPa (Kursk climatype) to 54 MPa (Volgograd climatype), and for static bending – from 55 to 92 MPa for the Vologda and Ulyanovsk climatypes, respectively. Distribution of Scots pine climatypes into subspecies in accordance with the classification of L.F. Pravdin and the obtained data on the physical and mechanical properties of wood have a certain pattern. The maximum density of wood at 12% moisture is typical for the European Scots pine subspecies is 497±8 kg/m^3, the minimum value of this indicator for the Siberian Scots pine subspecies is 423±30 kg/m^3. An intermediate position is occupied by the subspecies of Lapland pine and Forest-steppe pine with values of 483±16 and 464±12 kg/m^3, respectively. The strength index of wood in the studied subspecies for compression along the fibres ranged from 47±1 MPa (European subspecies) to 33±4 MPa (Siberian subspecies), in the Lapland pine subspecies – 44±2 MPa and somewhat lower in the Forest-steppe pine subspecies – 42±2 MPa. The maximum value of the static bending strength of wood is typical for the European pine subspecies – 78±4 MPa, and the minimum – for the Siberian pine subspecies – 61±14 MPa. This indicator turned out to be equal in subspecies of forest-steppe and Lapland pine and amounted to 72±4 MPa. The practical value of the work lies in identifying the existing differences and variability among climatypes according to the studied physical and mechanical properties of wood and selecting the most promising of them for further breeding purposes

Keywords: wood density, wood strength, static bending, variability

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INTRODUCTION

One of the most important indicators of the quality of Scots pine wood is its density and strength, which must be taken into account both in forest reproduction and in industrial use [1-4]. Density affects not only the physical, but also the mechanical properties of wood [5]. The density of wood is the most objective and universal indicator of its quality. In most cases, there is a clearly expressed direct correlation between the density and strength of wood. The higher the density, the higher the strength, and the degree of correlation reaches 0.8-0.9 [6].

Many scientists in their works note the existing significant differences among climatypes in survival rate [7], preservation [8], growth [9; 10], resistance to pests and diseases [11; 12], productivity [13], as well as in the composition of chlorophyll, the structure of needles [14; 15], the composition of essential oils, fruiting and other characteristics [16-18]. In this regard, there is interest in possible differences in the quality of wood in different climatypes, which are determined by indicators of physical and mechanical properties. Unique in this regard, experimental model objects are geographic plantations created by seed offspring of the most characteristic populations of different ecotypes (climatypes) in order to test them in new conditions. They serve as an object for studying the geographical variability of the hereditary properties of forest species. The first geographical plantations of Scots pine were established in Belarus in 1959 on an area of 8.7 hectares by V.G. Mishnev and E.D. Mantsevich. They consisted of 65 geographic variants with a geographic range of 48-62° north altitude and 22-111° east longitude. The detail history of the objects is described in the paper [19]. At present, the area of plantations is 6 hectares, the number of surviving variants is 44. These plantings served as the object of the research. To assess the physical and mechanical properties of wood, 17 climatypes were selected from the variants of the origin of the places of harvesting seeds in the range of 47-62° north latitude and 22-85° east longitude. The indicated geographical coordinates of the places of seed procurement are quite consistent with the classification of Scots pine into subspecies according to L.F. Pravdin [20].

The purpose of the research is to determine the physical (density of wood in an absolutely dry state, density of wood at 12% moisture) and mechanical (strength of wood for compression along the fibres and for static bending) properties of wood of various climatic ecotypes of Scots pine and conducting a comparative analysis of the obtained indicators. The novelty of the research lies in the fact that for the first time in Belarus the physical and mechanical properties of Scots pine wood of various origins at ripening age were determined in the range of geographical origin of seed harvesting places from 47 to 62° north latitude and from 22 to 85° east longitude.

MATERIALS AND METHODS

The geographical culture of Scots pine under study is located in the Negorelsky forestry of the Negorelsky training and experimental forestry enterprise, which is a branch of the Belarusian State Technological University and is geographically located in the Dzerzhinsky district of the Minsk region of the Republic of Belarus (50 km from Minsk). The age of Scots pine climatypes growing in geographical cultures at the time of the study is 60 years.

To assess the physical and mechanical properties of wood 17 climatypes were selected from the variants of the origin of the places of harvesting seeds in the range of 47-62 north latitude and 22-85 east longitude. The choice of climatypes for carrying out research with such a range of geographical coordinates of the places of harvesting seeds is due to the fact that the indicated parent stands are quite consistent with the classification of Scots pine into subspecies according to L.F. Pravdin [20]. Of the 5 subspecies of Scots pine (Lapland, European, Siberian, Steppe and Hooked) the studied climatypes were subdivided as follows: the subspecies Lapland (61-62° NL) included the Arkhangelsk and Leningrad climatypes, the European subspecies included 2 varieties – Western European (53-59°NL and 22-40°EL) with Vologda, Estonian, Latvian, Vitebsk and Minsk climatypes and Eastern European (54 NL and 48-58°EL) that includes the Ulyanovsk and Bashkir climatypes. The Siberian subspecies (57 NL and 85°EL) includes the Tomsk climatype. Also, due to the lack of representation of climatypes of the Steppe pine subspecies (Kustanai, Akmola, Pavlodar, Kokchetav and Semipalatinsk climatypes of Kazakhstan died at the early stages of growth), a subspecies of the Forest-steppe pine was conditionally distinguished (47-51°NL and 27-42°EL) with Belgorod, Kursk, Volgograd, Khmelnytsky, Poltava and Rostov climatypes. A subspecies such as hooked pine, isolated by L.F. Pravdin and growing in the Crimea and the Caucasus was not initially represented in geographical cultures. Thus, for a more logical analysis of the physical and mechanical properties of wood, the studied climatypes of Scots pine are distributed in accordance with the classification of L.F. Pravdin with minor changes.

To study the properties of wood in the model trees of each of the studied climatypes, was taken trunk sections 60 cm long at the same height – 6.5 m, after which samples were made from them to study the physical and mechanical properties of wood. The studied the following properties of wood: density of wood in an absolutely dry state and at 12% moisture content, strength of wood for compression along the grain and for static bending. The study of these properties was carried out in accordance with generally accepted methods: ISO 16483.0-78 Wood. Sampling methods and general requirements for physical and mechanical tests [21]; ISO 16483.1-84 Wood. Density determination method [22]; ISO 16483.3-84 Wood. Method for determining the ultimate strength in static bending [23]; ISO 16483.7-71 Wood. Moisture determination method [24]; ISO 16483.10-73 Wood. Method for determining the ultimate strength in compression along the fibres [25].

Wood samples on the site of Scots pine geographical

plantations were harvested in February 2020 (Fig. 1a), the determination of the physical and mechanical properties of wood was carried out in May 2020. During the research, a universal testing machine MTS INSIGHT 100 was used (Fig. 1b).

a) b)

Figure 1. *Taking of samples of Scots pine cuts of various origins in geographical cultures (a) to determine the physical and mechanical properties of wood using a universal testing machine MTS INSIGHT 100 (b)*

The use of a universal testing machine of this brand MTS INSIGHT 100 in such studies allows obtaining results with a sufficiently high accuracy, which served as the main criterion for choosing this equipment. The assessment of the reliability of the differences in the results obtained was carried out using the MS Excel software. To confirm or refute the hypothesis about attributing the studied indicators of the physical and mechanical properties of wood to the same set of average data, we calculated such a parametric criterion as the Student's t-test or the difference t-test. In this case, it allows finding the probability that both averages belong or not to the same population. Recalculation of indicators for standard humidity for samples with humidity at the time of testing was carried out according to the generally accepted formula [22; 26].

RESULTS AND DISCUSSION

Statistical processing of indicators for calculating the density of wood in an absolutely dry state is presented in Table 1.

Table 1. *Statistics of density of wood in an absolutely dry state*

Indicator	Density of wood by climatypes in an absolutely dry state, kg/m^3															
	Kr-1	Vt-4	Bl-5	Es-8	Vg-9	Lt-10	Bt-11	Gr-15	T-23	Ul-41	Rs-47	M-48	Ar-52	L-53	Pl-55	Vl-57	Kh-58
$\overline{X}$	369.65	480.53	457.21	492.08	524.09	475.19	502.58	478.32	398.50	469.63	472.52	431.48	460.59	442.49	396.98	389.26	423.47
$S_{\overline{X}}$	3.25	5.27	17.77	6.76	9.15	5.36	3.04	7.24	12.88	13.48	6.32	4.65	8.69	11.81	4.68	3.64	2.64

Table 1, Continued

Indicator	Density of wood by climatypes in an absolutely dry state, kg/m³															
	Kr-1	Vt-4	Bl-5	Es-8	Vg-9	Lt-10	Bt-11	Gr-15	T-23	Ul-41	Rs-47	M-48	Ar-52	L-53	Pl-55	Vl-57	Kh-58
S	19.25	27.87	47.01	23.43	47.52	19.33	14.26	27.09	40.72	52.19	27.55	14.71	27.47	35.42	19.29	14.11	9.88
Min	338.65	443.46	400.91	452.34	434.43	455.00	476.75	445.80	349.20	392.00	436.19	408.43	438.36	380.50	369.85	376.17	406.98
Max	429.39	557.60	525.78	528.40	623.81	526.13	543.65	543.34	455.40	541.62	531.03	448.09	511.18	488.34	433.71	417.33	436.19
$t_{05}S_{\bar{X}}$	6.61	10.81	43.47	14.89	18.80	11.68	6.32	15.64	29.13	28.90	13.28	10.52	19.65	27.22	9.92	7.81	5.70
P, %	0.88	1.10	3.89	1.37	1.75	1.13	0.61	1.51	3.23	2.87	1.34	1.08	1.89	2.67	1.18	0.94	0.62
V, %	5.21	5.80	10.28	4.76	9.07	4.07	2.84	5.66	10.22	11.11	5.83	3.41	5.96	8.00	4.86	3.62	2.33

***Note (names of climatypes)**: Kr-1 – Kursk, Vt-4 – Vitebsk, Bl-5 – Belgorod, Es-8 – Estonian, Vg-9 – Volgograd, Lt-10 – Latvian, Bt-11 – Buriat, Gr-15 – Grodno, T-23 – Tomsk, Ul-41 – Ulyanovsk, Rs-47 – Rostov, M-48 – Minsk, Ar-52 – Arkhangelsk, L-53 – Leningrad, Pl-55 – Poltava, Vl-57 – Vologda, Kh-58 – Kharkov*

It can be seen from the data presented that the average density of different climatypes is in the range of 370-524 kg/m³, i.e., the magnitude of the variation exceeds 150 kg/m³. Based on the literature data [27], which are averaged indicators calculated from highly variable values, the density of pine wood in an absolutely dry state is about 480 kg/m³. The variability of the indicator under consideration, which is characterised by the coefficient of variation (V), can be considered insignificant, since in most cases it does not exceed 10%. The relative error does not exceed 5%. Statistical processing of the data showed that in many cases the confidence intervals ($t_{05}S_{\bar{X}}$) of one population (climatype) overlap to some extent with those of another population. It was found that the density of wood of the Vitebsk (Vt-4) and Grodno (Gr-15) climatypes is within the same population, and the average sample of the Minsk (M-48) climatype significantly differs from the average of the climatypes Vt-4 and Gr-15. The average sample of the Belgorod climatype (Bl–5) does not significantly differ from the average of ten other studied climatypes. The average wood density of the Volgograd climatype (Bg-9) significantly differs from all other climatypes. The Kursk (Kr-1) and Buryat (Bt-11) climatypes do not significantly differ from the Tomsk (T-23) and Estonian (Es-8) climatypes. On average, the compared indices of the density of one climatype did not significantly differ from the analogous indices of any five other climatypes.

Since the density of wood directly depends on moisture content, it is generally accepted in wood science to carry out a comparative assessment of the properties of wood at a standard moisture content of 12%. The value of this density is difficult to obtain directly from experience, since it is very difficult to bring wood to a moisture content of exactly 12%. Therefore, the density of wood at 12% moisture content is calculated by the appropriate formulas, depending on the moisture content of the wood at the time of testing [22]. The average density of pine wood at this moisture content corresponds to 505 kg/m³ according to [26, 27]. According to some literature data [25], the density value from the indicated average value can fluctuate up or down, that is, from 350 to 650 kg/m³. The average density of pine wood by climatypes varies within 397-550 kg/m³. As for the values of statistical indicators, there is a similar situation with the previous calculations indicated in Table 1. This is explained by the fact that the values of the density indicators of wood at 12% moisture were found by recalculating similar indicators at moisture at the time of testing (Table 2) [22].

***Table 2**. Statistics of wood density at 12% moisture*

Indicator	Density of wood by climatypes at 12% humidity, kg/m³															
	Kr-1	Vt-4	Bl-5	Es-8	Vg-9	Lt-10	Bt-11	Gr-15	T-23	Ul-41	Rs-47	M-48	Ar-52	L-53	Pl-55	Vl-57	Kh-58
$\bar{X}$	396.50	509.14	488.60	521.07	550.39	502.53	530.01	509.47	423.22	496.59	498.82	459.06	489.96	474.38	423.56	415.21	452.17

Table 2, Continued

Indicator	Density of wood by climatypes at 12% humidity, kg/m³															
	Kr-1	Vt-4	Bl-5	Es-8	Vg-9	Lt-10	Bt-11	Gr-15	T-23	Ul-41	Rs-47	M-48	Ar-52	L-53	Pl-55	Vl-57	Kh-58
$S_{\bar{X}}$	3.47	5.35	17.80	7.46	9.38	5.13	3.13	7.84	13.13	13.76	6.49	4.46	9.08	11.97	4.98	4.05	2.95
S	20.52	28.30	47.09	25.83	48.76	18.51	14.66	29.35	41.51	53.28	28.30	14.12	28.73	35.90	20.55	15.68	11.03
Min	364.04	470.65	431.13	478.86	458.65	482.90	505.24	474.29	371.49	409.32	465.54	437.84	467.12	414.30	396.26	396.94	434.74
Max	461.13	589.19	557.33	561.23	654.61	551.34	573.89	580.04	480.70	569.05	559.76	472.05	543.21	521.03	461.36	444.11	466.67
$t_{05}S_{\bar{X}}$	7.05	10.97	43.56	16.41	19.29	11.19	6.50	16.94	29.70	29.50	13.64	10.10	20.55	27.59	10.56	8.68	6.37
$P, \%$	0.87	1.05	3.64	1.43	1.70	1.02	0.59	1.54	3.10	2.77	1.30	0.97	1.85	2.52	1.18	0.97	0.65
$V, \%$	5.18	5.56	9.64	4.96	8.86	3.68	2.77	5.76	9.81	10.73	5.67	3.07	5.86	7.57	4.85	3.78	2.44

As is known, the mechanical properties of wood are closely related to density, which characterises its ability to resist the action of external mechanical forces. These properties of wood are highly dependent on its moisture content; therefore, the evaluation and comparison of the results of mechanical tests are carried out at a standard 12% moisture content.

Statistical processing of the calculation data for the compressive strength of wood along the fibre at 12% moisture content is presented in Table 3.

***Table 3**. Statistics of the compressive strength of wood along the fibre at 12% moisture*

Indicator	Compressive strength of wood in terms of climatypes along the fibre at 12% moisture content, MPa															
	Kr-1	Vt-4	Bl-5	Es-8	Vg-9	Lt-10	Bt-11	Gr-15	T-23	Ul-41	Rs-47	M-48	Ar-52	L-53	Pl-55	Vl-57	Kh-58
$\bar{X}$	31.84	48.80	40.48	48.93	53.63	47.49	49.84	46.26	33.35	46.47	48.47	42.03	47.41	40.61	36.43	38.71	42.46
$S_{\bar{X}}$	0.39	0.65	3.16	0.99	1.23	0.73	0.86	0.75	1.71	2.01	0.84	0.64	1.19	0.89	0.68	0.69	0.56
S	2.33	3.45	8.35	3.44	6.37	2.63	4.04	2.81	5.41	7.79	3.66	2.03	3.75	2.66	2.82	2.68	2.10
Min	26.97	42.77	28.79	43.30	42.51	43.31	39.27	43.16	27.02	34.25	43.34	38.70	43.44	35.39	32.48	35.98	38.97
Max	36.59	58.96	52.53	55.14	64.55	51.92	54.03	50.72	42.61	58.11	54.66	44.77	54.69	42.83	41.67	43.80	46.69
$t_{05}S_{\bar{X}}$	0.80	1.34	7.72	2.18	2.52	1.59	1.79	1.63	3.87	4.32	1.77	1.45	2.68	2.04	1.45	1.49	1.21
$P, \%$	1.24	1.33	7.80	2.03	2.29	1.54	1.73	1.63	5.13	4.33	1.73	1.53	2.50	2.18	1.88	1.79	1.32
$V, \%$	7.32	7.06	20.63	7.02	11.89	5.54	8.11	6.08	16.23	16.77	7.56	4.84	7.91	6.54	7.73	6.94	4.94

It should be noted that the compressive strength of wood along the fibres is the most characteristic of the mechanical properties of wood and the most important in practical terms. According to some literature data [6], this indicator can vary from 27 to 63 MPa, with an average value of 46 MPa. The obtained average strength indicators of the tested samples of all climatypes were in the range of 32-54 MPa. Analysing the statistical indicators of calculating the compressive strength of wood along the fibres, it is easy to see that they have a certain

similarity with those of calculating the density of wood. For example, the strength of wood of the Belgorod climatype (Bl-5) does not reliably differ from ten others and the Latvian one (Lt-10) from seven others.

But at the same time, there are certain differences. For example, wood of the Buryat climatype (Bt-11) does not have significant differences in strength from five other climatypes, while in terms of wood density it does not differ significantly only from the Estonian climatype (Es-8). The strength indicators of the Belarusian climatypes turned out to be significantly different (the values of the density indicators of wood at 12% humidity were found by recalculating similar indicators at humidity at the time of testing).

The test results and statistical processing of the data for calculating the static bending strength of wood at 12% moisture content are presented in Table 4. Since the variability of the strength of wood in many variants turned out to be significant ($V>10\%$), and the value of the relative error in six cases exceeded 5%, a comparative analysis of the strength indicators of wood for static bending within climatypes was not carried out (Table 4).

***Table 4**. Statistics of the bending strength of wood at 12% moisture content*

Indicator	Static bending strength of wood by climatypes, MPa															
	Kr-1	Vt-4	Bl-5	Es-8	Vg-9	Lt-10	Bt-11	Gr-15	T-23	Ul-41	Rs-47	M-48	Ar-52	L-53	Pl-55	Vl-57	Kh-58
$\bar{X}$	59.36	90.25	73.83	87.42	89.21	76.20	71.19	80.34	60.84	92.44	86.46	73.35	76.59	68.11	63.15	54.85	60.04
$S_{\bar{X}}$	4.47	1.66	4.76	1.05	2.57	1.31	6.35	4.79	5.20	3.99	1.17	1.80	1.97	2.35	1.68	4.09	5.84
S	9.99	3.72	11.66	2.36	5.74	2.92	14.20	10.71	11.62	8.91	2.34	4.03	4.40	5.25	3.75	9.15	13.05
Min	47.95	83.90	63.30	85.25	80.35	71.72	46.54	71.83	50.72	86.08	83.52	68.86	71.71	61.74	59.31	40.18	39.71
Max	75.09	93.75	89.98	90.31	94.71	79.19	82.98	98.19	75.26	107.53	88.61	77.61	82.90	75.40	68.84	64.93	68.98
$t_{05}S_{\bar{X}}$	12.41	4.62	12.24	2.92	7.13	3.63	17.63	13.30	14.43	11.07	3.72	5.00	5.47	6.51	4.66	11.36	16.20
$P, \%$	7.53	1.84	6.45	1.21	2.88	1.72	8.92	5.96	8.54	4.31	1.35	2.46	2.57	3.44	2.66	7.46	9.72
$V, \%$	16.83	4.12	15.80	2.69	6.43	3.84	19.95	13.33	19.10	9.64	2.70	5.49	5.75	7.70	5.95	16.68	21.73

The obtained indicators of the physical and mechanical properties of wood of various climatypes of Scots pine, grouped in accordance with the classification of L.F. Pravdin into subspecies, have a certain pattern. The maximum density of wood at 12% moisture is typical for the European Scots pine subspecies is 497±8 kg/m^3, the minimum value of this indicator for the Siberian Scots pine subspecies is 423±30 kg/m^3. An intermediate position is occupied by the subspecies of Lapland pine and Forest-steppe pine with values of 483±16 and 464±12 kg/m^3, respectively. The strength index of wood in the studied subspecies for compression along the fibres ranged from 47±1 MPa (European subspecies) to 33±4 MPa (Siberian subspecies), in the Lapland pine subspecies – 44±2 MPa and somewhat lower in the Forest-steppe pine subspecies – 42±2 MPa. The maximum value of the static bending strength of wood is typical for the European pine subspecies – 78±4 MPa, and the minimum – for the Siberian pine subspecies – 61±14 MPa. This indicator turned out to be equal in subspecies of forest-steppe and Lapland pine and amounted to 72±4 MPa (Table 5).

***Table 5**. Indicators of physical and mechanical properties of Scots pine wood by subspecies*

Name of the climatype and subspecies (varieties) of Scots pine	Geographic coordinates, °		Indicator		
	North latitude	East Longitude	ρ_{12}, kg/m^3	σ_{cs}, MPa	σ_{bs}, MPa
Scots pine Lapland subspecies					
Leningrad	61	34	474±28	41±2	68±6
Arkhangelsk	62	43	490±21	47±3	77±5
By Lapland subspecies	61-62	34-43	483±16	44±2	72±5

Table 5, Continued

Name of the climatype and subspecies (varieties) of Scots pine	Geographic coordinates, °		Indicator		
	North latitude	East Longitude	ρ_{12}, kg/m³	σ_{cs}, MPa	σ_{bs}, MPa
Scots pine Western European variety					
Vologda	59	40	415±9	39±1	55±11
Estonian	58	27	521±16	49±2	87±3
Latvian	57	22	503±11	47±2	76±4
Vitebsk	55	29	509±11	49±1	90±5
Minsk	54	27	459±10	42±1	73±5
Grodno	53	24	509±17	46±2	80±13
By Western European variety	53-59	22-40	489±9	46±1	77±5
Scots pine Eastern European variety					
Ulyanovsk	54	48	497±30	46±4	92±11
Bashkir	54	58	530±7	50±2	71±19
By Eastern European variety	54	48-58	516±13	48±2	82±11
By forest subspecies	53-59	22-58	497±8	47±1	78±4
Scots pine forest-steppe subspecies					
Belgorodsky	51	38	489±44	40±8	74±12
Kursk	51	34	397±7	32±1	59±12
Volgograd	51	42	550±19	54±3	89±7
Khmelnitsky	50	27	452±6	42±1	60±16
Poltava	49	33	424±11	36±1	63±5
Rostov	47	40	499±14	48±2	86±4
By forest-steppe subspecies	47-51	27-42	464±12	42±2	72±5
Scots pine Siberian subspecies					
Tomsk	57	85	423±30	33±4	61±14
By Siberian subspecies	57	85	423±30	33±4	61±14

Note: *ρ_{12} is the density of wood at 12% moisture content, σ_{cs} is the compressive strength of wood along the grain, σ_{bs} is the static bending strength of wood*

From the data presented, it can be seen that in some cases the averages of the studied indicators for subspecies overlap with confidence intervals, that is, they admit the hypothesis that the obtained averages relate to the same population. To test this hypothesis, a parametric test – Student's *t*-test (difference *t*-test) was calculated, which allows finding the probability that both means obtained relate to the same population. If this probability p is below the significance level (p <0.05), then it is considered that the samples belong to two different populations (Table 6).

Table 6. *Values of actual t-criteria of differences among the subspecies of Scots pine in terms of density and strength of wood*

Scots pine subspecies	The actual value of the probability p by indicators for the subspecies			
	Lapland	Forest	Forest-steppe	Siberian
Density of wood at 12% moisture (ρ_{12})				
Lapland	–	0.098	0.055	0.001
Forest	0.098	–	0.000	0.000
Forest-steppe	0.055	0.000	–	0.015
Siberian	0.001	0.000	0.015	–
Compressive strength of wood along the fibre (σ_{cs})				
Lapland	–	0.050	0.101	0.000
Forest	0.050	–	0.000	0.000
Forest-steppe	0.101	0.000	–	0.000
Siberian	0.000	0.000	0.000	–

Table 6, Continued

Scots pine subspecies	The actual value of the probability p by indicators for the subspecies			
	Lapland	Forest	Forest-steppe	Siberian
	Static bending strength of wood (σ_{bs})			
Lapland	–	0.055	0.821	0.091
Forest	0.055	–	0.058	0.024
Forest-steppe	0.821	0.058	–	0.113
Siberian	0.091	0.024	0.113	–

This parametric test (Student's *t*-test) allows finding the probability that both means relate to the same population. If this probability p is below the significance level (p<0.05), then it is generally accepted that the samples belong to two different populations.

Analysing the obtained average values of the density of pine wood by subspecies, it should be noted that this indicator for the Lapland pine subspecies does not statistically differ from the analogous indicators of pines of the forest and forest-steppe subspecies (t_{fact}=0.098 and 0.055, respectively). A similar situation is observed when comparing the compressive strength of wood along the fibres (t_{fact}=0.050 and 0.101, respectively). As for the strength of wood for static bending, no significant differences were also found among pine subspecies, despite the greatest difference between the Lapland and forest-steppe (t_{fact}=0.821) and forest-steppe and Siberian (t_{fact}=0.113) pines.

CONCLUSIONS

Thus, summing up the results of the study performed to identify differences in the physical and mechanical properties of pine wood (density at 12% moisture content, compressive strength along the fibres, strength in static bending) of 17 different climatypes, it should be noted that in most cases the statistical significance of differences between wood of different climatypes was not found. The similar situation can be traced when comparing the studied properties of wood of various subspecies of pine, identified by L.F. Pravdin. This is due to the fact that wood, which is of plant origin, has a fairly high variability of its properties. This natural feature of wood is determined by its age, growing conditions, hereditary characteristics and other factors that manifest themselves in the process of tree growth. Moreover, it should be noted that most researchers point to a significant variability of wood properties within the breed. The nature of the variability of indicators of some properties of wood can be judged by such a statistical indicator as the coefficient of variation (variability). The smallest variability within the species is characteristic of wood density indicators and is 2.8-10.2%. For the strength in compression along the fibres, the variability varies from 4.8% to 20.6%, for the strength in static bending it is 2.7-21.7%. Ultimately, it can be assumed that an infinitely large number of sample tests are probably required to achieve an acceptable level of confidence in the difference between the studied parameters.

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ПОРІВНЯЛЬНА ОЦІНКА ДЕЯКИХ ФІЗИКО-МЕХАНІЧНИХ ВЛАСТИВОСТЕЙ ДЕРЕВИНИ РІЗНИХ КЛІМАТИПІВ СОСНИ ЗВИЧАЙНОЇ

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Анотація. Для більш ефективного і раціонального використання у виробництві деревини сосни звичайної різного географічного походження необхідно знати її фізико-механічні властивості. Метою дослідження є визначення фізичних (щільність деревини в абсолютно сухому стані, щільність деревини за 12 % вологості) і механічних (міцність деревини за стискання вздовж волокон і на статичний вигин) властивостей деревини 17 кліматичних екотипів сосни звичайної та проведення порівняльного аналізу отриманих показників у досліджуваних походжень окремо і за їх групування у підвиди відповідно до класифікації Л.Ф. Правдіна. Діапазон географічного походження місць заготівлі насіння – від 47 до 62° північної широти і від 22 до 85° східної довготи. Для проведення досліджень була використана сучасна універсальна випробувальна машина MTS INSIGHT 100. В результаті досліджень встановлено, що щільність деревини в абсолютно сухому стані варіює в межах від 370 кг/м^3 (курський кліматип) до 524 кг/м^3 (волгоградський кліматип), а при 12 % вологості – від 397 кг/м^3 (курський кліматип) до 550 кг/м^3 (волгоградський кліматип). Показник міцності деревини досліджуваних кліматипів на стискування вздовж волокон становив від 32 МПа (курський кліматип) до 54

МПа (волгоградський кліматип), а на статичний згин – від 55 до 92 МПа у вологодського і ульяновського кліматипів відповідно. Розподіл кліматипів сосни звичайної на підвиди проведено відповідно до класифікації Л.Ф. Правдіна і отримані дані фізико-механічних властивостей деревини мають певну закономірність. Максимальна щільність деревини при 12 % вологості характерна для підвиду сосни звичайної європейської і становить 497±8 кг/м3, мінімальне значення даного показника у підвиду сосни звичайної сибірської – 423±30 кг/м^3. Проміжне становище займає підвид сосни лапландської і сосни лісостеповій зі значеннями 483±16 і 464±12 кг/м^3 відповідно. Показник міцності деревини у досліджуваних підвидів на стискування вздовж волокон становив від 47±1 МПа (підвид європейська) до 33±4 МПа (підвид сибірська), у підвиду сосни лапландської – 44±2 МПа і трохи нижче у підвиду сосни лісостеповій – 42±2МПа. Максимальне значення показника міцності деревини на статичний згин характерно для підвиду сосни європейської – 78±4 МПа, а мінімальне – у сосни підвиду сибірської – 61±14 МПа. Цей показник виявився однаковим у підвидів сосни лісостепової і лапландської і становив 72±4 МПа. Практична цінність роботи полягає у виявленні наявних відмінностей і мінливості серед кліматипів з досліджуваних фізико-механічних властивостей деревини та проведення відбору найбільш перспективних з них для подальших цілей селекції

Ключові слова: щільність деревини, міцність деревини, статичний згин, мінливість

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CHARACTERISTICS OF NATURAL OAK FORESTS OF IN SE "KHMILNYTSKE LISOVE HOSPODARSTVO" AND IMPLEMENTATION OF MEASURES FOR THEIR REGENERATION

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Abstract. As a consequence of the intensive economic use of oak forests in the region, the share of stands of natural origin is significantly reduced, which requires an in-depth study of their condition, productivity, and natural restoration processes. The purpose of this study is to investigate the state, structure, and reforestation processes of oak forests for their further natural reproduction. Generally accepted methods in forestry and comparative ecology were used to compare the dynamics and condition of the studied stands with the reference ones. The paper presents the findings of the study of the productivity and state of natural forests within the state enterprise "Khmilnytske lisove hospodarstvo". It was found out that natural oak stands are represented by 7 forest types, mainly in fresh hornbeam oak forest (area – 471 hectares). According to the results obtained, it was found that natural oak stands of vegetative origin predominate within the studied enterprise (528.6 ha). They are mainly represented by forests of the 11th age class (188.0 ha). High-bonitat oak forests of the 1st quality class predominate. Mature and over-mature stands have slightly lower productivity (2nd quality class, stand density of 0.6-0.7). The largest total reserve is characterised by stands of the 11th age class. The maximum average reserves are typical for stands of the 9th age class (290 m^3/ha). The greatest share of oak in stand composition (9-10 units) was found in stands of 9-10 age classes. The study shows that the natural renewal of oak is concentrated mainly in fresh sudubrava (fresh hornbeam sudubrava) in plantings in the presence of Scots pine and common oak. The density of natural renewal is 1-3 thousand units/ha. The practical value of the study is conditioned by the possibility of introducing the basic principles of forestry aimed at growing stable high-yield stands of common oak through more complete utilisation of natural renewal

Keywords: common oak, natural plantings, modal stands, high-bonitat stands, forest types, reforestation, natural regeneration

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INTRODUCTION

Oak forests (*Quercus spp.*) are recognised by the European community as one of the most significant in the history of mankind and world culture [1]. These forests are formed by highly-priced stands, which have had a significant impact in the historical aspect of providing the means of life to humanity in its natural space [2]. The presence of old-aged oak trees is one of the most well-known features of temperate forests [2-4]. Oak forests are also important for preserving biodiversity in many countries and regions, as they support the viability of a large number of living organisms, as well as animal populations that largely depend on the seed productivity of trees [5; 6]. An important aspect is the influence of animals on the spread of acorns, in particular, birds and mouse-like rodents, which contribute to the creation of new trees and plantings [2; 7]. Old-aged oak trees with thick bark and hollow trunks are particularly important for maintaining the population of invertebrates, fungi, lichens and mosses [8; 9]. Up to 1,500 species can be localised on old oak trees [10], many of which are Red Book species [11].

At a young age, there is significant competition between herbaceous vegetation and shrubs or related tree species. European hornbeam has a significant impact in the region. Researchers note a significant impact of other tree species depending on the forest type and associated species [12-15]. These competitive relationships significantly increase in more fertile environments and become extreme.

Along with hornbeam and maple, beech in its respective forest site types can be an extremely influential competitor. In particular, such trends were observed in the foothill zone. These trends are also found in European forests [12]. Common oak is rather demanding for lighting [13; 16; 17] and largely depends on lighting for its successful natural regeneration[14-16; 18].

Natural renewal of oak by seed in deciduous forests dominated by shade-tolerant species is often very limited or absent altogether. So, oak, as a tree species, is mainly considered as not able to recover in natural conditions [1; 7]. In European countries, mass drying and deterioration of oak trees often occurs, which leads to a decrease in their share in the structure of forest stands.

The share of oak stands in European countries varies. In Ukraine, the share of oak forests is one of the largest – up to 40%. Oak forests in Sweden account for 1.2% of the total forest area. Oak stands are common in a wide range of growing conditions. Natural regeneration can occur in pine stands, dry conditions with high soil acidity, as well as in deciduous forests on rich or well-moistened soils. Often, a sufficient amount of natural oak regeneration can be observed in pine forests [19].

In Europe, tendencies of deterioration and drying of oak stands are often observed. It is believed that the deterioration and drying of oak stands is conditioned by the influence of pathogenic organisms, pollution, climatic influences, in particular, drought. Degradation and drying of natural oak stands is not considered catastrophic if 0.5-3.0% of trees fall off [20]. According to research by Swedish scientists in the southern part of the country, the annual decline of oak trees averaged 1.7% or lower (1.1%) for stands aged 200 years or more. With the growth of the share of oak trees in the plantation, the dropout increases to 3.2% [3; 20].

The illumination intensity in the shaded areas of the oak stands can be at the level of 1% relative to the illumination intensity of the open space. Successful renewal by seeds requires about 20% illumination relative to the open space [6; 21; 22]. Partial drying in oak forests leads to the establishment of a mosaic structure and breaks in the shaded areas. Often, significant periodic drying of old-aged trees in oak forests is considered as a factor of their further natural regeneration [20]. Partial damage to oak forests by pests, diseases, and other factors can contribute to the activation of recovery processes [13; 23].

Intensive drying and degradation of oak stands can lead to successive changes in forest ecosystems [24]. Significant damage to forest stands and outbreaks of bacterial diseases, in particular Dutch elm disease, can significantly change the species composition of deciduous, in particular, oak forests. However, the development of gaps in the tents of forest stands can be an alternative to activating the growth and development of oak forests and their subsequent genesis [21].

The purpose of this study was to investigate the state, structure, and reforestation processes of oak forests for their further natural reproduction.

LITERATURE REVIEW

The problem of balanced forest management based on the principles of close to nature forestry is relevant in the context of modern challenges regarding the growth of the level of anthropogenesis of the environment and the deterioration of forest ecosystems. To date, several regional strategies have been developed in accordance with the specifics of forestry in Europe, North America, Africa, Asia and tropical countries [25-27]. The strategy of sustainable forestry management was also adopted in Ukraine [28-31]. Forestry management today is regulated by appropriate criteria and indicators [25-31]. These criteria ensure the most environmentally oriented forest management. Despite this, management in forests of natural or artificial origin does not differ [32].

Unfortunately, Ukraine lacks or has a limited legal framework for natural forests, their identification and use. In recent years, only the first steps have been taken to identify them in the Carpathian region [32]. However, there are currently no clear criteria and indicators for identifying such forests. There are also no developed criteria for assessing their condition and genesis. The basics of management and economic activity in natural forests in Ukraine have not been developed. Measures

for the use, conservation, and extended reproduction of natural forests should be carried out in the context of forest-type zoning, types of forest-growing conditions and types of forest [33]. The main focus in the economic use of natural forests should be on their natural regeneration [34-37].

The common one enters the reproduction period as early as the age of 10. Earlier fruiting is typical for related and clone plantations [38]. The maximum seed productivity in oak stands is observed in 50-60 years [14]. Gradually, the seed yield increases, reaching a maximum in the ripening age and early ripeness period. The high germination rate of oak seeds contributes to the appearance of seedlings in the amount necessary for the restoration of populations and cyclical alternation of generations.

Most Ukrainian researchers consider the lack of illumination to be the main reason for unsatisfactory natural regeneration [14; 15; 36; 37]. For successful growth and development of self-seeding, sufficient lighting for plant stand should be provided, which is optimal for the canopy density of 0.6-0.7 and below [14]. Most foreign scientists also consider a sufficient level of illumination to be the key factor in the successful natural regeneration of common oak [12; 16-18].

Other factors are competition, as a result of which self-seeding of oak can be largely suppressed, stunted and dried out. At a young age, there is significant competition between herbaceous vegetation and shrubs or associated tree species. European hornbeam has a significant impact in the region. Researchers note a significant impact of other tree species depending on the forest site type and associated species. These competitive relationships significantly increase in more fertile environments and become extreme [12-17]. Along with hornbeam and maple, beech in its respective forest site types can be an extremely influential competitor. In particular, such trends were observed in the foothill zone. These trends are also found in European forests [12].

In low-density plantings, the dryness of the forest floor has a negative impact on the emergence of oak seedlings [40]. Some studies note the possibility of natural regeneration of common oak after continuous logging [41]. According to the majority of the authors, an important aspect of the natural regeneration of stands is the presence of active fruiting, timely care [2; 6; 14; 16; 36; 41; 42].

MATERIALS AND METHODS

The study was conducted during 2018-2020. The work included performing both desk and field research. The survey of the forest fund and characteristics of natural oak forests was carried out by analysing the forest management materials of the enterprise (mensurational descriptions, forest inventory map, etc.). Characteristics of the structure of natural oak forests is based on the analysis of the management plan of SE "Khmilnytske lisove hospodarstvo". When dividing plantings by forest types, the developed methodological approaches and the established list of forest types were used [33]. The distribution of forest stands by origin (artificial, natural, seed, regrowth) was carried out based on the available information from mensurational descriptions in the context of each forestry. Information on the distribution of forest sites within forest-type regions, districts and sectors was also used. Determination of forest types was carried out in accordance with the given list [33]. Based on the mensurational descriptions, a sample was also made of sites older than 120 years, which are particularly important centres of biodiversity conservation. The analysis of optimal and modal stands was performed graphically based on forest management materials and regulatory data [43].

In some areas, temporary test areas (TA) were established according to generally accepted taxation methods [44] with additional determination of qualitative indicators in accordance with the methodological developments [32]. The land plots were linked to geographical coordinates (using GPS) and to the quarterly network. For each tree on the test area, the following were determined: trunk diameter by 1.3 m in two mutually perpendicular directions; selection category; Kraft's growth class; tree condition; presence of defects and damage; bark type, belonging to certain phenological forms, presence of flowering, fruiting. Taxational indicators of growing stock were calculated using standard methods [44]. During the survey of forest stands, the scale of selection categories was used, which represents a modification of the Veresin scale [38].

Test areas were laid in the most typical part of the plantation. In the case when the object included allocations that differ significantly from each other (if the species composition in the composition of the plantation differs by 2 units or more, stand density by 0.2 or more, quality class by 2 classes or more, age of the stand by 30 years or more, etc.), two test areas were laid [44]. Forest stands (quarter, compartment) were selected based on the latest forest management materials available in the forestry (forestry enterprise), and a reconnaissance survey of the entire object, which was carried out simultaneously with the survey of its external borders. A complete list of all trees on test areas (TA) with a diameter of more than 8 cm was made to measure their diameters and determine whether they belong to the first or second (third) storeys. For trees of the 1st storey, the Kraft's growth class, selection category, and general tree condition were determined. The average height was determined using a standard taxation method: measuring 15-25 trees in proportion to their number in each degree of thickness; plotting a height curve. Diameters were measured with an accuracy up to 1 cm, heights – up to 1 m.

Assessment of technological processes of timber logging and its impact on the components of forest

phytocenoses within the enterprise was carried out based on the existing technological maps and field surveys of areas with existing logging operations. Assessment of natural regeneration was carried out based on a preliminary analysis of taxation materials and temporary test areas, which are laid down according to conventional methods in forest taxation [44].

RESULTS AND DISCUSSION

Forestry and ecological characteristics of the research object

According to forest-type zoning, the territory of the forestry belongs to the forest-steppe zone and to the Dniester-Dnieper forest-economic district. It is a part of the Central Podolsk Forest-Economic district, which is characterised by the presence of forest strips and massifs on water sections and separate tracts among steppe plots. It is characterised by unstable, variable soil moisture, wide distribution of grey podzolic soils and chernozems, mixed composition of flora and fauna. The stands belong to mixed deciduous forests [7].

The climate in the forestry area is temperate continental with sufficient precipitation. Among the climatic factors that negatively affect the growth and development of woody vegetation, the following can be noted: variable soil moisture, periodic droughts and dry winds; heavy precipitation that repeats every 5-10 years, early autumn and late spring frosts; snowless winter periods in the presence of frosts [9]. Information on the distribution of natural oak stands by forest type is shown in Figure 1.

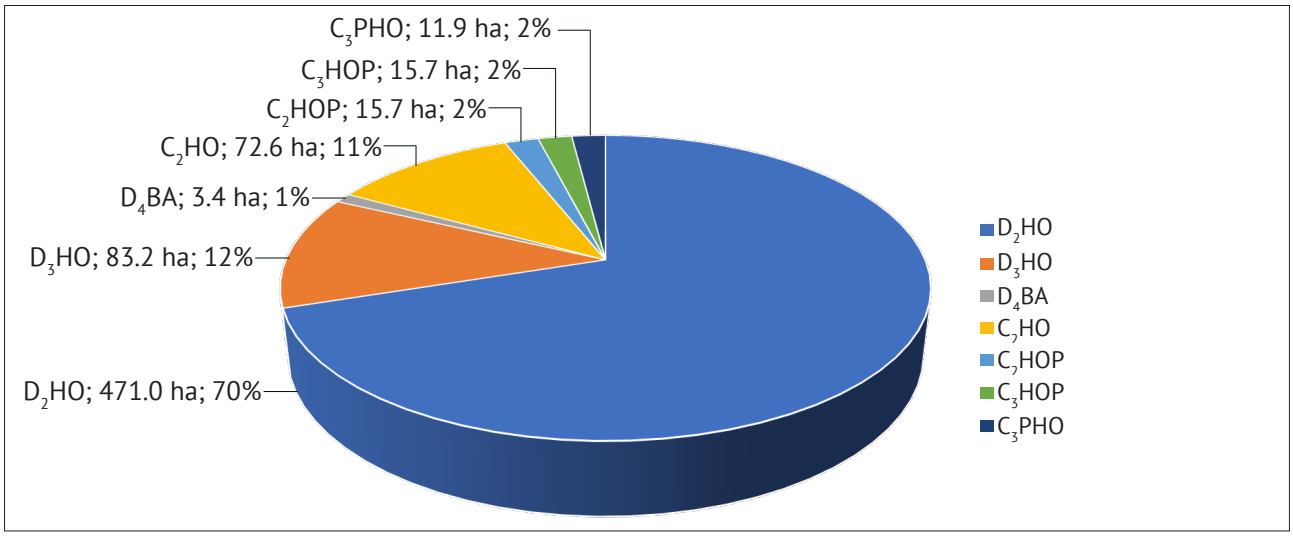

***Figure 1**. Forest type localisation of natural oak stands in SE "Khmilnytske lisove hospodarstvo"*
***Source**: mensurational descriptions of SE "Khmilnytske lisove hospodarstvo"*

According to Figure 1 natural oak forests of the enterprise are concentrated in 7 forest types. The largest areas of stands are represented by fresh hornbeam oak forest – 471 hectares (70%). 83.2 hectares of plantings (12%) are concentrated in the wet hornbeam oak forest. Slightly smaller areas – 72.6 hectares (11%) – are stands of fresh hornbeam sudubrava. Information about the origin of natural oak stands is shown in Figure 2.

According to Figure 2 within the enterprise, natural oak stands mainly of vegetative origin predominate. The area of such stands is 528.6 hectares (78%). The area of stands of seed origin is 148.9 hectares (22%).

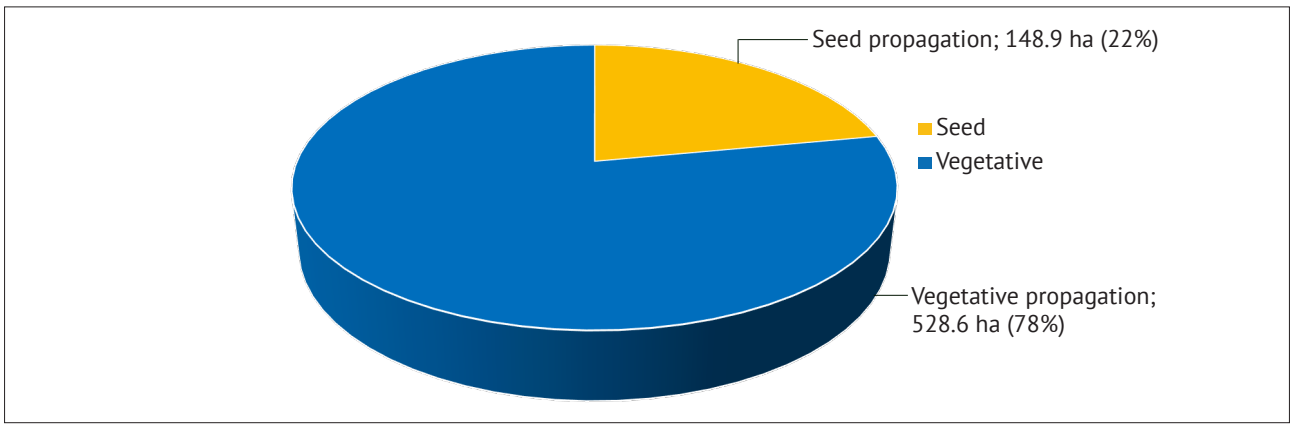

***Figure 2**. Origin of natural oak forests in SE "Khmilnytske lisove hospodarstvo"*
Source: *mensurational descriptions of SE "Khmilnytske lisove hospodarstvo"*

Taxational specifications of natural oak forests of SE "Khmilnytske lisove hospodarstvo"

Preserving biological and genetic diversity is one of the main and most important functions of natural oak forests. Old-aged forests are particularly important for preserving biodiversity. The study analysed the presence of sites of old-aged forests in the conditions of the enterprise. The data is shown in Table 1. Plots of stands aged 120 years or more are located in the Kozyatynske, Bereznyanske, and Litynske forestry departments. The total number of such land plots is 20. The total area of stands over 120 years old and over 4.0 hectares is 297.8 hectares. These are forest stands are mainly represented by common oak (Co) with European hornbeam (Eh), small-leaved linden (Sll), European ash (Ea), Norway maple (Nm). The surveyed stands also include Scots pine (Sp), Norway spruce (Ns), white birch (Wb), black adler (Ba), Dutch beech (Db).

***Table 1**. Taxational specifications of plots older than 120 years, with an area of more than 4 hectares within the enterprise*

Sq/species	Area, ha	Plant composition	Age, years	Height, m	Diameter, cm	Quality class	Density	Forest site type	Stand volume per 1 ha, m^3
Kozyatynske forestry department									
16/6	12.5	8Co1Eh1Ea	121	27	48	2	0.60	D_2-hO	280
16/9	14.5	9Co1Ea	121	28	44	2	0.70	D_2-hO	330
17/10	4.8	10Co+Bc+Eh	121	27	48	2	0.55	D_2-hO	260
19/5	14.0	10Co+Eh+Nm	126	28	48	2	0.60	D_2-hO	280
22/2	9.0	10Co+Nm+Eh	126	28	48	2	0.70	D_2-hO	300
23/7	15.0	9Co1Nm+Eh	121	27	48	2	0.70	D_2-hO	300
23/10	5.6	10Co+Ea+Nm	121	27	48	2	0.50	D_2-hO	230
24/1	7.3	9Co1Nm+Eh	121	27	48	2	0.60	D_2-hO	260
24/3	16.0	10Co+Eh+Nm	121	27	48	2	0.50	D_2-hO	230
Total	98.7	–	122	27	48	2	0.60	–	274
Bereznyanske forestry department									
19/1	4.4	6Co2Eh2Eh	126	28	48	2	0.55	D_2-hO	190
Total	4.4	–	126	28	48	2	0.55	–	190
Litynske forestry department									
18/4	22.0	10Co+Sll+Eh	121	30	44	1	0.60	D_2-hO	330
18/12	4.2	6Co4Eh	136	30	48	2	0.70	D_2-hO	320
23/1	29.0	10Co+Sll+Eh	146	30	48	2	0.50	D_2-hO	240
26/3	8.8	7Co2Sll1Eh	126	30	48	2	0.70	D_2-hO	350
42/2	37.4	4Co5Eh1Sll	121	30	44	2	0.65	D_2-hO	320
52/4	12.7	5Co3Sll1Eh+Nm	126	28	44	2	0.60	D_2-hO	290
53/2	33.0	4Co5Sll1Eh+Nm	126	30	40	1	0.70	D_2-hO	360
53/5	11.0	6Co3Sll1Eh	126	30	40	2	0.60	D_2-hO	320
54/9	14.2	6Co2Sll2Eh	121	28	40	2	0.60	D_2-hO	280
54/14	23.3	6Co2Sll2Eh	121	28	40	2	0.70	D_2-hO	350
Total	195.6	–	127	29	44	1.8	0.63		316
Total for enterprise	298.7	–	125	28	46	1.9	0.62	O_2HO	291

***Source**: mensurational descriptions of SE "Khmilnytske lisove hospodarstvo"*

The distribution of stands by age class in the enterprise is shown in Table 2.

According to the table, the largest area of plantings of the 11th age class is 188.0 hectares. A significant area of stands of the 8th age class is also 107.5 hectares. The smallest areas are occupied by natural oak stands of the 4th age class – 4.8 hectares. Despite the significant areas of forest stands of the 8th age class, a minimum proportion of oak is observed – 2 units. The largest proportion of oak is present in stands of the 12th and 14th age classes (9-10 units).

The enterprise's natural oak forests are mostly high-bonitat (the 1st quality class prevails). Mature and over-mature stands have slightly lower productivity (2nd quality class). The predominant stand density – 0.6 – 0.7. Mature and over-mature stands are characterised by a decrease in average density to 0.5-0.6. The lowest density of natural oak stands of the 14th age class – 0.5.

The largest total reserve is characterised by stands of the 11th age class. This is conditioned by their large area and fairly high productivity. The maximum average stand volume of the 9th age class – 290 m³/ha. Naturally, the smallest stand volume was found in plantings of the 4th age class (105 m³/ha). Natural forest stands are characterised by a significant decrease in average stand volume starting from the 10th age class. The average growth rate – 1.7-3.9 m³/ha. The lowest increment in mature and over-mature stands –1.7-2.0 m³/ha. The peak increment is observed in the 7th age class – 3.9 m³/ha.

Data on the distribution of stocks of modal and optimal stands are presented in Figure 3.

***Table 2**. Distribution of natural oak stands by age classes in the conditions of SE "Khmilnytske lisove hospodarstvo"*

Age classes	Average stand composition	Area, ha	Average quality class	Average stand density	Total stand volume, m³	Average stand volume m³/ha	Mean increment, m³/ha
4	6Sll2Co1Nm1Ea	4.8	1.0	0.70	504.0	105.0	3.0
5	4Sp3Ns1Co1Eh1Wb	25.8	1.0	0.66	3922	152.6	3.4
6	4Ns3Sp2Co1Eh	38.9	1.1	0.68	10114.0	260.0	4.7
7	4Co2Eh1Db2Nm1Bc	89.7	1.5	0.67	23124.6	257.8	3.9
8	2Ea2Co2Eh1Nm1Sp1Wb	107.5	1.2	0.61	29068.0	270.4	3.6
9	4Co4Eh2Ea	43.4	1.6	0.63	12586.0	290.0	3.4
10	5Co2Ea2Eh1Nm	87.3	1.9	0.63	23745.6	272.0	2.8
11	7Co2Ea1Eh	188.0	2.3	0.62	45872.0	244.0	2.3
12	9Co1Nm+Eh	59.1	2.0	0.53	14249.0	241.1	2.0
14	10Co+Eh+Nm	29.0	2.0	0.50	6960.0	240.0	1.7
Total/average		673.5	1.5	0.62	172740.4	243.3	3.3

***Source**: mensurational descriptions of SE "Khmilnytske lisove hospodarstvo"*

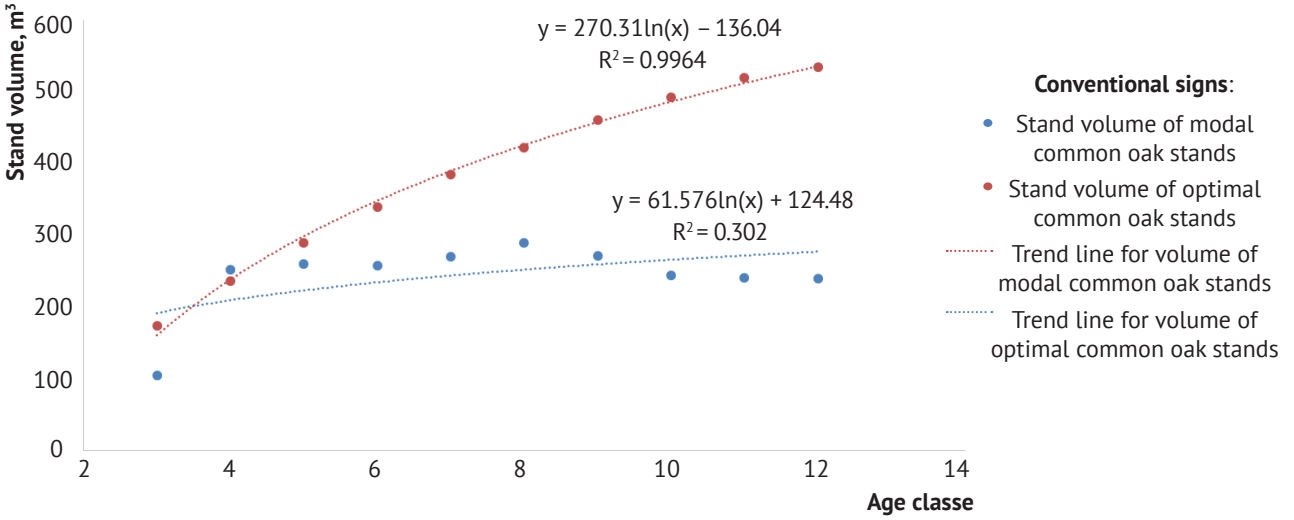

***Figure 3**. Dynamics of modal and optimal reserves of natural oak forest stands of SE "Khmilnytske lisove hospodarstvo"*
***Source**: mensurational descriptions of SE "Khmilnytske lisove hospodarstvo"*

According to Figure 3 starting from the 4th age class, there is a significant decrease in modal reserves compared to optimal ones. With increasing age, this difference increases significantly. Data on the distribution of stands by the share of oak in the stand composition are shown in Table 3.

According to the table, the greatest share of oak in the stand composition (9-10 units) is characteristic for stands of 9-10 age classes. The lowest share of oak was observed in stands of 80 years of age. In these stands, the share of oak can be reduced to 1-2 units. Table 4 shows the distribution of natural stands by density in the conditions of the enterprise.

***Table 3**. Distribution of plantings by share of natural oak in the stand composition in the conditions of the SE "Khmilnytske lisove hospodarstvo"*

Share of oak in stand composition (units)	Average age of plantings	Area, ha	Average quality class	Average stand density	Total stand volume	Average stand vol-ume per hectare	Mean increment, m³/ha
9-10	100	178.0	2.1	0.63	44215	248.4	2.4
7-8	82	53.1	2.0	0.62	12553	236.4	2.8
6-5	76	52.5	2.0	0.65	13556	258.2	3.3
4-3	86	102.1	1.9	0.65	27332	267.7	3.1
2-1	82	287.8	2.0	0.61	66827	232.2	2.8
Total/average	85	673.5	2.0	0.63	164483	248.6	2.9

***Source**: mensurational descriptions of SE "Khmilnytske lisove hospodarstvo"*

***Table 4**. Distribution of oak stands of natural origin by completeness in the conditions of SE "Khmilnytske lisove hospodarstvo"*

Stand density	Average stand composition	Average age of stand	Area, ha	Average quality class	Total stand volume, m³	Average stand volume per ha m³/ha	Mean increment, m³/ha
0.3-0.4	5Co2Ns2Sp1Ea	113	2.4	2	20712.9	183.3	1.6
0.5-0.6	4Co3Ea2Ec1Nm	82	205.9	1.7	19852.2	242.1	2.9
0.7-0.8	4Co1Ea1Ec1Nm1Sll1Sp1Ns	70	272.9	1.8	19131.0	273.3	3.9
0.9-1.0	3Ea2Co2Eh1Nm1Ba1Db	32	2.2	1.5	4640.0	145.0	4.5

***Source**: mensurational descriptions of SE "Khmilnytske lisove hospodarstvo"*

According to the above data, the low-density oak stands are mostly of old. The average age of such stands is 113 years. Along with this, their area is insignificant and is only 2.4 hectares. The area of high-density oak stands is also insignificant and amounts to only 2.2 hectares. The largest area is represented by stands with a density of 0.7-0.8. These stands are mostly 70 years old. Significant areas of oak forest are represented by stands with density of 0.5-0.6 – 205.9 ha, which are mostly 80 years old.

Data on the distribution of stands by quality class are shown in Table 5.

According to Table 5, stands of 1-2 quality classes predominate. The area of natural oak forests of 1-2 quality classes – 640.4 hectares. Low-bonitat plantings (3-4 quality classes) cover an area of only 33.1 hectares.

***Table 5**. Distribution of natural oak stands by quality class in the conditions of SE "Khmilnytske lisove hospodarstvo"*

Quality class	Average stand composition	Average age of stand	Area, ha	Average stand density	Average stand volume per ha m³/ha	Mean increment, m³/ha
I-II	4Co2Ea1Ec1Nm1Sp1Ns	73	640.4	0.65	260.5	3.5
III-IV	9Co1Eh	108	33.1	0.58	214.3	1.98

***Source**: mensurational descriptions of SE "Khmilnytske lisove hospodarstvo"*

Reforestation processes in the enterprise environment
Technological processes of timber logging within the enterprise include: felling trees manually, without the use of machines; pruning branches, unloading for sorting; skidding sorting by wheeled tractors with jaw grippers; loading and removal of sorting and wood by cars. Cutting areas with viable undergrowth that provides reforestation, as well as cutting areas designed for growth renewal, are developed mainly from October 1 to April 1, which ensures its maximum preservation.

The surveyed areas of complete cutting indicate the predominance of artificial reforestation. Along with this, for the creation of forest crops, natural regeneration of the forest is used, in particular, common oak, if any, is available on the plots. In stands with a predominance of oak, areas with existing undergrowth are noted. The undergrowth of common oak is mainly concentrated in fresh and moist hornbeam sudubravas (Table 6).

***Table 6**. Taxational specifications of natural oak stands with the existing oak undergrowth*

Sq/stratum	Area, ha	Stand composition	Age, years	Height, m	Diameter, cm	Quality class	Stand density	Stand volume per 1 ha	Forest type	Undergrowth		
										Stand	Age	Density, thousand units/ha
Kozyatynske forestry department												
28/1	2.3	5Sp4Ns1Co	74	28	36	1A	0.6	400	C_2-h-oP	8Eh2Co	15	2.0
28/13	1.8	9Wb1Co+TC+Db	50	21	22	1A	0.6	160	C_3-h-oP	10Co	15	1.0
38/9	1.7	9Sp1Co	49	21	22	1A	0.7	330	C_2-h-oP	10Co	15	1.0
38/11	1.4	9Sp1Co	51	21	22	1A	0.7	320	C_2-h-O	10Co	10	2.0
29/7	1.0	10Co+Wb	105	23	32	3	0.7	250	C_2-h-O	4Eh2Co2Bc2Sll	20	3.0
29/13	1.8	10Co+Wb	105	23	32	3	0.5	180	C_2-h-O	4Eh2Co2Bc2Sll	20	3.0
29/14	1.3	10Co+Wb	105	23	32	3	0.7	250	C_2-h-O	4Eh2Co2Bc2Sll	20	3.0
Shyrokogrebelske forestry rebartment (cutting)												
58/5	0.6	5Ba2Co2Eh1Nm+Sll+BP+Db	6	2	2	1	0.7	5	D_4Ba	5Eh2Co1Nm1Wb1Sll	10	1.0

***Source**: field materials (materials of temporary test areas)*

According to Table 6, the natural regeneration of common oak is mainly concentrated in fresh sudubravas. Of the 8 surveyed plots, 6 are represented by fresh hornbeam sudubrava. Other areas are localised in wet hornbeam sudubrava and wet black poplar grud. The density of young growth is 1-3 thousand units/ha. This is mainly a undergrowth of 10-20 years of age with a composition of oak of 2-10 units.

CONCLUSIONS

The structure of natural oak forests is dominated by forest stands of vegetative origin (528.6 ha, or 78%). Forest stands aged 120 years or more are located in the Kozyatynske, Bereznyanske, and Litynske forestry departments. The total area of such stands – 297.8 hectares. The greatest share of oak in the stand composition (9-10 units) is typical for plantings of 9-10 age classes. The lowest share of oak was observed in stands of 80 years of age. In these stands, the share of oak can be reduced to 1-2 units. According to the table, the largest area of stands of the 11th age class – 188.0 ha. A significant area is occupied by stands of the 8th age class – 107.5 ha.

The enterprise's natural oak forests are mostly high-bonitat (the 1st quality class prevails). Mature and over-mature stands have slightly lower productivity (2nd quality class). The predominant stand density – 0.6-0.7. Mature and over-mature stands are defined by a decrease in the average density to 0.5-0.6; the lowest density of natural oak stands of the 14th age class – 0.5. The maximum average stand volume of the 9th age class – 290 m^3/ha. Naturally, the smallest stand volume was found in plantings of the 4th age class (105 m^3/ha). Natural forest stands are characterised by a significant decrease in average stand volume starting from the 10th age class. The mean increment rate – 1.7-3.9 m^3/ha. The lowest increment in mature and over-mature stands –1.7-2.0 m^3/ha. The peak increment is observed in the 7th age class – 3.9 m^3/ha.

In stands with a predominance of oak, areas with existing undergrowth are noted. The undergrowth of common oak is mainly concentrated in fresh and moist hornbeam sudubravas (Table 6). The density of young growth is 1-3 thousand units/ha. This is mainly an undergrowth of 10-20 years, both with a predominance and a share of 2-3 oak units.

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ХАРАКТЕРИСТИКА ДУБОВИХ ЛІСІВ ПРИРОДНОГО ПОХОДЖЕННЯ ДП «ХМІЛЬНИЦЬКЕ ЛГ» ТА ОСОБЛИВОСТІ ЗАПРОВАДЖЕННЯ ЗАХОДІВ ЩОДО ЇХ ВІДТВОРЕННЯ

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Анотація. У результаті інтенсивного господарського використання дубових лісів регіону значно скорочується частка деревостанів природного походження, що вимагає проведення поглибленого дослідження їх стану, продуктивності та процесів природнього відновлення. Мета наукової роботи – дослідити стан, структуру та лісовідновні процеси дубових лісів для їх подальшого природного відтворення. Для проведення досліджень застосовувалися загальноприйняті методики в лісівництві та методи порівняльної екології для зіставлення динаміки та стану досліджених деревостанів з еталонними. У статті представлені результати досліджень щодо продуктивності та стану природних лісів у межах державного підприємства «Хмільницьке лісове господарство». Було з'ясовано, що природні дубові насадження представлені 7-ма типами лісу, переважно у свіжій грабовій діброві (площа – 471 га). Відповідно до отриманих результатів встановлено, що в межах досліджуваного підприємства переважають природні дубові деревостани вегетативного походження (528,6 га). В основному вони представлені насадженнями 11-го класу віку (188,0 га). Переважають високо-бонітетні дубові насадження 1-го класу бонітету. Стиглі та перестійні насадження мають дещо нижчу продуктивність (2-й клас бонітету, повнотою 0,6–0,7). Найбільшим загальним запасом характеризуються насадження 11-го класу віку. Максимальні середні запаси характерні для деревостанів 9-го класу віку (290 м^3/га). Встановлено, що найбільша участь дуба у складі деревостанів (9–10 одиниць) у насадженнях 9–10 класів віку. У результаті проведених досліджень виявлено, що природне поновлення дуба зосереджене переважно у свіжих сугрудах (свіжа грабова судіброва) у насадженнях за участю сосни звичайної та дуба звичайного. Густота природного поновлення становить 1–3 тис. шт/га. Практична цінність роботи полягає у можливості запровадження основних засад ведення лісового господарства, спрямованих на вирощування стійких високопродуктивних деревостанів дуба звичайного шляхом більш повного використання природного поновлення

Ключові слова: дуб звичайний, природні насадження, модальні деревостани, високобонітетні деревостани, типи лісу, лісовідновлення, природне поновлення

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COMPARATIVE ASSESSMENT OF ECONOMIC TRAITS OF PIGS OF DIFFERENT BREEDS AND BREED COMBINATIONS

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Abstract. On the territory of Ukraine, for decades, the pig industry has traditionally remained one of the main reserves for ensuring the financial well-being of the population. Among the factors contributing to the profitability of pig breeding enterprises, a significant role is played by the breeding capacity of sows, since it guarantees the receipt of livestock for rearing and fattening. An indisputable condition for ensuring the efficiency of pig production is to increase the fattening and meat characteristics of pigs. With this in mind, the purpose of the study is to investigate the above-mentioned economic traits of pigs, which is currently an urgent task. The research was preceded by the establishment of three groups of sows and young stock, numbering 10 animal units each, located in similar economic conditions. According to the investigational plan, three groups of pigs are provided depending on the genotype: control group 1 – Large White (LW); experimental group 2 – Landrace (L); experimental group 3 – 1/2LWx1/2L (maternal base – Large White, paternal – Landrace). As a result of the conducted studies, it was found out that the local pig population obtained from crossing purebred animals of the Large White and Landrace breeds prevailed in terms of productivity over the original parent forms. From them, on average for three farrowing operations, the largest number of piglets at birth and the highest multiplicity were obtained. An unreliable correlation was found between the characteristics of the reproductive ability of sows and the number of farrowing. The correlation coefficient between the farrowing number and the number of piglets at birth had a negative value – -0.013; for fertility – positive – +0.038; for the offspring size – +0.014; milking capacity – +0.044. At the age of 1, 2, 3, 5, and 6 months, local young stock had the highest live weight, and the Large White pigs had the lowest values with significant differences (P≤0.05-0.001). The Landrace pigs had the highest live weight at birth and at the age of 4 months, and the Large White pigs had the lowest live weight (P≤0.05-0.001). The findings allow increasing the efficiency of the pig industry and prove the expediency of interbreeding in order to increase the economic traits of pigs

Keywords: sows, breeding capacity, young stock, live weight, Large White breed, Landrace breed, local livestock population, correlation

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INTRODUCTION

The ability of the state to provide the population with high-quality food products is guaranteed by the availability of appropriate resources, among which the pig industry covers the demand for meat consumption by 35%. Transformational changes on the way to the European integration aspirations of the agricultural sector of Ukraine cause changes in the development and functioning of the pig industry [1; 2]. On the territory of Ukraine, pig breeding has always been one of the main sources of profit and prosperity of the state. In the history of Ukrainian animal husbandry, there were times when the share of pork in total meat production reached 55-60% [3].

The market situation forces pig breeding enterprises to look for ways to reduce the cost of production and improve its quality [4]. Therefore, today, the development of pig breeding, as an industry with a large production potential, is marked by an in-depth use of available resources and provides for the introduction of well-organized breeding work [5]. Currently, 12 stud pig breeds are bred at farms of Ukraine, which serve as maternal and paternal forms in breeding and can improve the pork production indicators [6].

In addition, to increase productivity and improve the desired characteristics of pigs, crossing and hybridization are widely used, but it is necessary to take into account the different level of manifestation of the phenomenon of heterosis in offspring [7]. A number of scientists report that the use of specialized breeds, types and lines for crossing pigs contributes to the growth of fattening and meat characteristics, but does not lead to a significant improvement in the parameters of the reproductive ability of sows [5; 8; 9]. However, there are also opposing views on the influence of growth intensity on the meat qualities of pigs [4]. It is important to establish links between the productive characteristics of pigs, especially when improving breeds based on meat characteristics [10].

It is also worth noting that the reproductive qualities of sows largely determine the production efficiency since they provide the necessary supply of livestock for rearing and fattening. Hence, increasing the efficiency of using sows and obtaining high fertility is one of the main vectors of pig breeding, along with the development of new criteria for evaluating, selecting and predicting the reproductive qualities of sows [11; 12].

The most common on the territory of Ukraine are two breeds of pigs – the Large White and Landrace [6]. The widespread use of the Large White pigs in the breeding process is conditioned by their high breeding value for the main productive characteristics [13-15]. Along with this, studies have proven that the Landrace pigs are also characterized by high productive characteristics, so they can be used as paternal and maternal forms in various variants of crosses [4; 7; 16]. Reproductive indicators and the duration of use of the Large White and Landrace breeds can be improved by introducing modern breeding techniques [17; 18].

Therefore, taking into account the above, *the purpose of the study* was to investigate the parameters of the breeding capacity of sows and the dynamics of the live weight of young stock of the Landrace and Large White breeds and the local livestock obtained from their crossing.

MATERIALS AND METHODS

In the furtherance of this goal, materials on the breeding and productive use of pigs in the SE RS "Nova Peremoha" of the Lyubarsky District of Zhytomyr Oblast were processed. The study was carried out in 2017-2020. The digital material was processed using the variational statistics [19; 20]. As for the results of mathematical calculations, they were considered statistically reliable if P≤0.05 (*), p≤0.01 (**), and P≤0.001 (***). The mathematical data was processed using the Microsoft Office Excel software package.

For the research, 3 groups of sows and 3 groups of young stock with 10 animal units each were established. According to the investigational plan, three groups of pigs are provided depending on the genotype: control group 1 – Large White (LW); experimental group 2 – Landrace (L); experimental group 3 – 1/2LWx1/2L (maternal base – Large White, paternal – Landrace) – Table 1.

***Table 1**. Genotypic composition and number of animal groups for research*

Animal group	1	2	3
Animal genotype	LW	L	1/2LWx1/2L
Number of animals in a group	10	10	10

***Note**: hereinafter LW – Large White pig breed; L – Landrace breed*

The selected experimental animals were similar in age and live weight, and were also in the same conditions of keeping, feeding, use, and care.

For the study, the breed of animals was established according to breeding certificates and materials of breeding and zootechnical accounting. Feeding of experimental animals was carried out according to the rations characteristic of the farm placement zone, balanced in terms of nutrient content and in accordance with zootechnical standards. The breeding capacity of sows was studied by the following indicators: fertility (determined by the number of live born, viable piglets per farrowing); offspring size (average weight of one piglet in the offspring at birth); milking capacity (live weight of the nest at 21 days of age) [21]. The live weight of young pigs was studied based on the results of individual weighing after birth and at the age of 1, 2, 3, 4, 5 and 6 months.

RESULTS AND DISCUSSION

Effective use of sows in the process of reproduction is one of the main directions in pig breeding [11; 12], which determines the relevance of studying the parameters of the breeding capacity of sows. Based on this, the analysis of indicators of the breeding capacity of sows of different breeds and breed combinations for several farrowing was carried out.

According to the results of the first farrowing received from sows, the reproducible qualities of sows were good (Table 2).

***Table 2**. Indicators of the breeding capacity of sows of different genotypic groups for the first farrowing*

Attributes and units of measurement	Animal groups (M)			Difference between groups					
	1	2	3	1-2		1-3		2-3	
	LW	L	1/2LW 1/2L	d	t_d	d	t_d	d	t_d
Number of newborn piglets, units	11.25± 0.299	12.11± 0.323	12.51± 0.451	-0.86	1.95	-1.26	2.33	-0.40	0.72
Fertility, units	10.48± 0.268	11.12± 0.268	11.88± 0.298	-0.64	1.69	-1.40	3.49	-0.76	1.90
Offspring size, kg	1.49± 0.032	1.60± 0.031	1.51± 0.029	-0.11	2.47	-0.02	0.46	0.09	2.12
Milking capacity, kg	64.23± 1.789	65.22± 1.998	65.37± 0.996	-0.99	0.37	-1.14	0.56	-0.15	0.07

***Note**: hereinafter, M – arithmetic mean, d – the difference between the arithmetic mean, and t_d – the validity of the difference*

Among the studied traits, the number of piglets at birth and their size, fertility, and milking capacity reached the highest values in local sows of genotypic group 3 (1/2bx1/2L). The latter with a significant difference prevailed purebred sows and the genotypic group 1 (Large White breed) in terms of the number of offsprings by 1.26 units (P≤0.05), fertility – by 1.4 units (P≤0.01), but in terms of milking capacity, there was no probable advantage between sows of different groups (Table 2).

The biggest size of offspring was observed in the first farrow of the purebred Landrace pigs, which, according to the investigational plan, were assigned to the II genotypic group. Their significant advantage over sows of control group 1 was 0.11 kg (P≤0.05) and group 3, respectively, 0.09 kg (P≤0.05). To achieve this goal, the parameters of the reproductive function of sows were analyzed based on the results of the second farrowing (Table 3). As a result of the analysis, the following features were revealed: most newborns were obtained from group 1, animals of group 3 were characterized by the highest fertility and milking capacity, while the animals of group 2 were distinguished by the offspring size. However, as for establishing the reliability of comparing indicators, a significant advantage was found only for the offspring size of sows from group 2 over 1 (0.11 kg at p≤0.05). No statistically significant differences were found for the other features studied (Table 3).

***Table 3**. Indicators of the breeding capacity of sows of different genotypic groups for the second farrowing*

Attributes and units of measurement	Animal groups (M)			Difference between groups					
	1	2	3	1-2		1-3		2-3	
	LW	L	1/2LW 1/2L	d	t_d	d	t_d	d	t_d
Number of newborn piglets, units	12.68± 0.439	11.87± 0.347	12.48± 0.501	0.81	1.45	0.20	0.30	-0.61	1.00
Fertility, units	11.09± 0.348	11.10± 0.351	11.86± 0.368	-0.01	0.02	-0.77	1.52	-0.76	1.49
Offspring size, kg	1.50± 0.027	1.61± 0.030	1.59± 0.039	-0.11	2.73	-0.09	1.90	0.02	0.41
Milking capacity, kg	64.61± 1.865	65.53± 1.182	65.77± 1.293	-0.92	0.42	-1.16	0.51	-0.24	0.14

As a result of the assessment of sows of the studied breeds and breed combinations in terms of reproductive qualities for the third farrowing, certain differences were established between them (Table 4). Thus, purebred Large White pigs of the first experimental group were noted by the lowest fertility and the offspring size, lowest milking capacity; the smallest number of piglets born was observed in sows of the Landrace breed, which belonged to group 2. At the same time, the best parameters of breeding capacity, namely the largest number of piglets at birth, fertility, and milking capacity were observed in the local sows of group 3, and the biggest size – in animals of group 2 by genotype.

***Table 4**. Indicators of reproductive capacity of sows of different genotypic groups for the third farrowing*

Attributes and units of measurement	Animal groups (M)			Difference between groups					
	1	2	3	1-2		1-3		2-3	
	LW	L	1/2LW 1/2L	d	t_d	d	t_d	d	t_d
Number of newborn piglets, units	12.51± 0.589	11.91± 0.671	13.08± 0.464	0.60	0.67	-0.57	0.76	-1.17	1.43
Fertility, units	10.47± 0.355	10.54± 0.388	11.69± 0.389	-0.07	0.13	-1.22	2.32	-1.15	2.09
Offspring size, kg	1.50± 0.022	1.69± 0.158	1.61± 0.024	-0.19	1.19	-0.11	3.38	0.08	0.50
Milking capacity, kg	65.02± 0.872	65.81± 1.894	65.97± 1.098	-0.79	0.38	-0.95	0.68	-0.16	0.07

A significant advantage of animals of group 3 over group 1 in terms of fertility and the offspring size was established (P≤0.05-0.01), over animals of group 2 – only in terms of the number of offspring (P≤0.05). According to the rest of the considered indicators, the difference obtained between sows of different genotypic groups did not have statistically significant values.

Analysis of the parameters of the breeding capacity of sows of different breeds and breed combinations on average for all three farrowing showed the presence of differences between them (Table 5). According to the findings of the conducted studies, the largest number of piglets at birth and fertility were observed in local sows of the genotypic group 3. While animals of the Landrace breed, assigned to genotypic group 2, were characterized by the biggest size and milking capacity. However, when comparing the above-mentioned indicators of sows of different experimental groups, significant differences were established only for two of them – the number of offsprings and fertility in groups 1 and 3 (P≤0.05).

***Table 5.** Indicators of breeding capacity of sows of different genotypic groups on average for three farrowing*

Attributes and units of measurement	Animal groups (M)			Difference between groups					
	1	2	3	1-2		1-3		2-3	
	LW	L	1/2LW 1/2L	d	t_d	d	t_d	d	t_d
Number of newborn piglets, units	12.13± 0.532	11.95± 0.487	12.69± 0.398	0.18	0.25	-0.56	0.84	-0.74	1.18
Fertility, units	10.68± 0.344	10.98± 0.236	11.77± 0.345	-0.30	0.72	-1.09	2.24	-0.79	1.89
Offspring size, kg	1.50± 0.028	1.64± 0.088	1.60± 0.028	-0.14	1.52	-0.1	2.53	0.04	0.43
Milking capacity, kg	64.48± 1.209	65.73± 1.605	65.66± 1.181	-1.25	0.62	-1.18	0.70	0.07	0.04

There is an unreliable correlation between the parameters of the breeding capacity of sows and the number of their farrowing. Thus, between the farrowing number and the number of newborn piglets, the correlation coefficient had a negative value – -0.013, between the farrowing number and fertility – a positive value – +0.038; between the farrowing number and offspring size – +0.014; between the farrowing number and milking capacity – +0.044.

When studying the economic traits of pigs of

different breeds and breed combinations, it was also aimed to investigate the dynamics of live weight of young stock at birth and at the age of 1, 2, 3, 4, 5, and 6 months (Table 6).

Purebred animals of the Landrace breed from genotypic group 2 had the highest live weight at birth and at 4 months of age, while the Large White pigs of group 1 had the lowest values. At the age of 1, 2, 3, 5 and 6 months, the highest live weight was observed in local young stock of the experimental group 3, the lowest live weight – in the Large White breed belonging to group 1. As a result of establishing the levels of reliability of differences, a significant advantage was revealed at the age of 1, 2, 3 and 5 months in animals of the genotypic group 3 over group 1 (P≤0.05-0.001); at the age of 2 and 3 months – a highly reliable advantage over group 2 (P≤0.001); a significant advantage in live weight at birth and at age of 4 months in young stock of group 2 over group 1 (P≤0.05).

***Table 6**. Dynamics of live weight of young pigs of different genotypic groups*

Attributes and units of measurement	Animal groups (M)			Difference between groups					
	1	2	3	1-2		1-3		2-3	
	LW	L	1/2LW 1/2L	d	t_d	d	t_d	d	t_d
At birth	1.47± 0.019	1.57± 0.031	1.50± 0.023	-0.10	2.75	-0.03	1.01	0.07	1.81
1st month	7.78± 0.213	8.15± 0.451	8.64± 0.249	-0.37	0.74	-0.86	2.62	-0.49	0.95
2nd month	20.13± 0.755	21.04± 0.562	25.27± 0.758	-0.91	0.97	-5.14	4.80	-4.23	4.48
3rd month	35.49± 0.627	33.44± 0.871	39.03± 1.019	2.05	1.91	-3.54	2.96	-5.59	4.17
4th month	49.97± 0.776	53.05± 1.209	51.48± 1.287	-3.08	2.14	-1.51	1.00	1.57	0.89
5th month	73.71± 1.134	76.28± 0.989	78.51± 1.603	-2.57	1.71	-4.80	2.44	-2.23	1.18
6th month	94.55± 1.591	96.49± 1.407	98.96± 1.815	-1.94	0.91	-4.41	1.83	-2.47	1.08

Thus, a comparison of the productive characteristics of pigs of different breeds and breed combinations showed the superiority of local pigs over purebred animals of the Large White and Landrace breed. The studies by L.P. Hryshyna and O.O. Krasnoshchok[4], M.M. Poruchnik [12], R.P. Shvachka and N.G. Povod [22], E.I. Karateeva and A.N. Rudenko [23] show similar results in terms of the main indicators of breeding capacity of local sows. The advantage of local livestock over the original parental forms in terms of meat qualities was also noted by A.I. Kislinska and G.I. Kalinichenko [24], S. Voitenko and B. Shaferivsky [25], M.O. Petrenko and S.L. Voitenko [26], R.P. Shvachka and N.G. Povod [22].

CONCLUSIONS

According to the investigated characteristics of productivity, the local pig population with the 1/2LWx1/2L genotype prevailed over purebred Large White and Landrace pigs. Thus, on average for three farrowing operations, the largest number of piglets at birth and highest fertility were obtained. An unreliable correlation was established between the characteristics that characterize the reproductive ability of sows and the number of farrowing received from them: between the farrowing number and the number of piglets at birth, the correlation coefficient had a negative value – -0.013, between the farrowing number and fertility – positive – +0.038; between the farrowing number and the offspring size – +0.014; between the farrowing number and milking capacity – +0.044. At the age of 1, 2, 3, 5, and 6 months, local young stock had the highest live weight, and the Large White pigs had the lowest values with significant differences (P≤0.05-0.001). The Landrace pigs had the highest live weight at birth and at the age of 4 months, and the Large White pigs had the lowest live weight (P≤0.05-0.001).

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ПОРІВНЯЛЬНА ОЦІНКА ПРОДУКТИВНИХ ОЗНАК СВИНЕЙ РІЗНИХ ПОРІД І ПОРОДНИХ ПОЄДНАНЬ

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Анотація. На території України впродовж десятиліть галузь свинарства традиційно залишається одним із головних резервів забезпечення фінансового добробуту населення. Серед факторів, що сприяють дохідності свинарських підприємств, вагома роль належить відтворній здатності свиноматок, позаяк гарантує надходження поголів'я для вирощування і відгодівлі. Беззаперечною умовою забезпечення ефективності виробництва продукції свинарства є підвищення відгодівельних і м'ясних ознак свиней. З огляду на це, метою досліджень було вивчення вищезазначених продуктивних ознак свиней, що наразі є актуальним завданням. Проведенню досліджень передувало формування трьох груп свиноматок і молодняку, чисельністю 10 голів кожна, що знаходилися в аналогічних господарських умовах. Відповідно до схеми досліду передбачено три групи свиней залежно від генотипу: I контрольна – велика біла (ВБ); II дослідна група – ландрас (Л); III дослідна група – 1/2ВБх1/2Л (материнська основа – велика біла, батьківська – ландрас). У результаті проведених досліджень з'ясовано, що помісне поголів'я свиней, отримане від схрещування чистопородних тварин великої білої та породи ландрас, переважало за ознаками продуктивності вихідні батьківські форми. Так, у середньому за три опороси від них було одержано найбільшу кількість поросят при народженні та найвищу багатоплідність. Між ознаками відтворної здатності свиноматок і номером їх опоросу виявлено недостовірний кореляційний зв'язок: між номером опоросу та кількістю поросят при народженні коефіцієнт кореляції мав від'ємне значення та становив -0,013, багатоплідністю – додатне і складав +0,038; великоплідністю – +0,014; молочністю – +0,044. У 1-, 2-, 3-, 5- та 6-місячному віці найвищу живу масу мав помісний молодняк за найнижчих значень тварин великої білої породи за достовірних різниць (P≤0,05–0,001). Найбільшу живу масу при народженні та у 4-місячному віці мали тварини породи ландрас, найменшу – великої білої (P≤0,05–0,001). Встановлені результати досліджень дозволяють підвищити ефективність галузі свинарства та доводять доцільність проведення міжпородного схрещування з метою підвищення продуктивних ознак свиней

Ключові слова: свиноматки, відтворна здатність, молодняк, жива маса, велика біла порода, порода ландрас, помісне поголів'я, кореляція

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PROGNOSTIC VALUE OF VASCULAR INVASION IN BREAST TUMOURS IN SHE-DOGS (PILOT STUDY)

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Abstract. Breast tumours are the most common neoplasm in intact she-dogs. However, breast tumours in she-dogs differ significantly in morphological features and biological behaviour, so the definition of prognostic factors is relevant. A study on tumour cell dissemination in breast tumours in she-dogs by migration of these cells into blood and lymphatic vessels depending on their histological characteristics and disease stage was conducted. The study of the problem was performed on the basis of the clinic of modern veterinary medicine "Best" in Zaporizhzhia. She-dogs with breast neoplasms of different ages and breeds were used as objects in the proven absence of signs of metastatic lesions of other organs and tissues, including lungs, abdominal organs and bones. The presence of cancer cells in the vessels was determined by the tumour clots formed by them, fixed to the endothelium. The study revealed the presence of angioinvasion regardless of the clinical stage of the tumour process. In this case, the dissemination of tumour cells by migration into lymphatic vessels was observed only in the second clinical stage of breast tumours. In patients with stage 1 breast cancer in the vast majority of cases (66.7% of patients) angioinvasion is registered in the micropapillary invasive carcinomas (ICD-O code 8507/2). Tumour cells in blood vessels were verified in simple cribriform carcinoma (ICD-O code 8201/3) in more than 80% of she-dogs with stage 3 breast cancer. In contrast to the above groups, in patients with stage 2 cancer, migration of tumour cells into both blood and lymphatic vessels was found. Most often the signs of angio- and lymphoinvasion were found in invasive carcinoma mixed type (ICD-O code 8562/3), tubulopapillary carcinoma (ICD-O code 8503/3), and tubular carcinoma (ICD-O code 8211/3) – in 34.1% and 36.8%, 19.3% and 26.3%, 17.0% and 10.5% of cases, respectively. The obtained results allow predicting the probability of penetration of tumour cells into blood and lymphatic vessels with a high degree of reliability, which in the future can better predict the biological behaviour of breast tumours

Keywords: dogs, neoplasia, breast, metastasis

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INTRODUCTION

It is a proven fact that in breast tumours, lymph node involvement is one of the most important predictors of clinical outcome in humans and animals [1; 2]. Lymphovascular invasion, which means the identification of tumour cells in the space lined with endothelium, in the primary site of a tumour or around it, is considered by oncologists as an invasion of blood vessels [3]. However, data on the prognostic significance of vascular invasion, proliferation index and angiogenesis in relation to the development of metastases and survival in sick dogs remain ambiguous [4]. As a small number of tumour cells are able to survive outside their microenvironment, the mere presence of tumour cells in the blood vessel lumen does not guarantee the development of metastatic lesions; therefore, although vascular invasion in the form of tumour emboli is not uncommon, it is not known whether it affects the development of metastases and life expectancy in dogs [5-7]. In addition to it is important to remember that during histological examination vascular invasion sometimes may not be detected, mainly due to the rarity of tumour emboli in the tumour tissue array [8], and in 20% of cases of lymphovascular invasion it may differ in evaluation of the same material given by different pathologists [9].

The question of the probability of angio- and lymphoinvasion in neoplasms of different types remains debatable. In the study by Yoshimura et al. [10] vascular invasion was more common in simple solid carcinomas, and much less common in malignant myoepitheliomas and biphasic carcinomas; in another study by Yoshimura *et al.* [11] vascular invasion was registered in 40.5% of simple solid breast cancers. However, in another study, it was registered only in 15.1% of malignant breast tumours [12], which corresponds with the results obtained by Seung *et al.* [13] – 14.8%; according to Pastor et al. [14] it was registered in 28.6% of cases and according to the study by Monteiro et al. [15] – in 33.3% of cases. Probably, the unresolved issue is due to the lack of a unified methodological approach.

Thus, despite the significant number of publications on predicting the course of the disease in breast tumours and the main stages of cancer cell dissemination, the mechanisms of angio- and lymphoinvasion, which are predictors of the aggressiveness of breast tumours, remain insufficiently studied in oncogenesis. Notably, in practice, in the vast majority of cases, the prognosis of the disease and the choice of treatment measures is made without considering the vascular invasion, which causes insufficient effectiveness of the protocols.

The purpose of this study was to determine the role of angio- and lymphoinvasion as predictors of malignancy at different stages of breast tumours in she-dogs.

LITERATURE REVIEW

Breast tumours, most of which are malignant, are the most common neoplasms in intact she-dogs, mostly middle-aged and older (8-11 years) [16; 17]. The incidence rate fluctuates significantly, depending on the spay at an early age. The main cause of death from breast cancer in she-dogs is metastasis to the lungs. Breast carcinomas have heterogeneous clinical behaviour in the rate of metastasis, recurrence, impact on life quality and expectancy [4].

Recurrence of breast cancer may occur partially due to a lack of understanding of the early stages and mechanisms involved in the breast cancer metastasis, especially the effects of neoplastic inflammatory cells, including tumour macrophages, on the invasion process [18].

In the study by Diessler *et al.* [4] vascular invasion was negatively correlated with life expectancy and lymph node involvement; similar results are presented by Rasotto *et al.* [19]. The same data were obtained in the study of breast tumours in women; in addition, the study by Mohammed *et al.* [20] shows that vascular invasion is more common in tumours larger than 1.5 cm, and that oestrogen-negative and progesterone-negative tumours are more likely to have significant vascular invasion than hormone-positive tumours. Lymphovascular invasion is also more common in Her2-positive tumours [21]. Studies by Monteiro *et al.* [15; 22] showed that vascular invasion correlates with the number of tumour-associated macrophages, which is confirmed by the data obtained by Seung *et al.* [21]. Separation of tumour cells from the main tumour mass and their intravasation into blood vessels usually occurs in areas of the largest accumulation of macrophages [23]; the study by Carvalho *et al.* [24] shows that high expression of COX-2 is correlated with the tumour emboli formation. However, according to studies by Santos *et al.* [25], vascular invasion does not depend on the degree of nuclear pleomorphism, one of the criteria for malignancy [19], which in its urn correlates with life expectancy.

Despite the large number of publications of lympho- and angioinvasion for breast tumours in dogs, does not reveal unambiguous data on the prognostic value of this process. Therefore, further research is needed to target the biological behaviour of tumour tumours that are healthy to invade blood vessels.

MATERIALS AND METHODS

The research was conducted in accordance with the requirements of the European Convention for the Protection of Vertebrate Animals [26] and the Law of Ukraine "On Protection of Animals from Cruelty" [27]. Ethics Committee approval was received for this study from the Animal Researches Committee of the Dnipro State Agrarian and Economic University, Ukraine (Approval number: 2019/02). The research was conducted on the basis of "Best" veterinary clinic (Zaporizhzhia). The objects of study were dogs of different breeds and crossbreeds, the average age was 8.6 years (from 3.5 to 16), in which during 2019-2020 were diagnosed with breast tumours.

At the same time, clinical and special (X-ray, ultrasound diagnostics, determination of hemostasiological status) research methods in such patients ruled out the presence of metastatic foci in other organs and tissues. The clinical stage of the tumour process was determined by the TNM classification according to Owen [28]. This study included dogs with I-III stages of the tumour process.

In the first stage, the tumour was removed from she-dogs by electrosurgery in the amount of regional or unilateral mastectomy. Pieces were excised from the tumour node(s), unaffected breast tissue and regional lymph nodes: axillary and additional lymph nodes – for lesions of I or II milk package, inguinal – for lesions IV or V, axillary, additional and inguinal – for lesions of III milk package. To facilitate the identification of lymph nodes in the surgical material was injected intradermally 0.2-0.4 ml of 0.05% aqueous solution of methylene blue before 7-10 minutes surgery in areas I or V of milk packets. Pieces of tissue were fixed for 48-72 hours in 10% neutral buffered formalin according to Lily. Subsequently, the tissues were passed through ascending alcohols, chloroform, chloroform-paraffin and paraffin and poured into paraffin. Sections 5-6 μm thick were made on a rotary microtome MPS-2 (Micromed Ukraine). Paraffin sections were dewaxed in xylene and stained with hematoxylin and eosin according to the method of Horalskyi *et al*. [29]. Microscopy was performed using an Olympus BX43 microscope (Olympus, Japan). Tumours were histologically verified according to the classification of Goldschmidt *et al*. [30] and coded according to the World Health Organisation's International Classification of Disease for Oncology system (ICD-O) [31] to facilitate comparison with existing human and animal cancer registries. The presence of cancer cells in the form of tumour emboli in the lumen of blood and lymphatic vessels was also identified.

RESULTS

According to the data obtained, a high level of malignancy in breast tumours should be assumed in the case of tumour cells dissemination in the first stage of the disease (Table 1). Among them, infiltrative tubular carcinoma was verified in one third of cases, but the maximum risk of disease progression was found in patients with tubulopapillary invasive carcinoma, as in this case the probability of diagnosing tumour cells in the lumen of blood vessels is two times higher. Notably, in both cases only signs of angioinvasion were registered.

Table 1. *Angioinvasion in the first stage of malignant tumours of the breast in she-dogs*

Histologic type	Detection frequency	
	n	%
Tubulopillary invasive carcinomas (ICD-O code 8503/3)	4	66.7
Tubular carcinoma (ICD-O code 8211/3)	2	33.3
Total	6	100

Most often, the presence of tumour cells in the vessels is detected in stage 2 breast cancer (Table 2). Only in such patients, in contrast to she-dogs with stage 1 cancer and stage 3 cancer, lymphoinvasion was verified although the presence of cancer cells in lymphatic vessels is registered only in certain types of tumours. About a third of cases of angio- and lymphoinvasion were registered in she-dogs with invasive carcinoma mixed type on the background of approximately the same frequency of tumour emboli detection. The high risk of dissemination of tumour cells into vessels was found in tubulopapillary carcinoma, but it is slightly lower – by a factor of 1.8 and 1.4, respectively. In 10% of cases, cancer cells in blood and lymph vessels were verified in tubular and solid carcinomas. In micropapillary invasive and simple cribriform carcinomas, tumour emboli were registered in both angio- and lymphoinvasion in about 5% of patients. In the case of ductal carcinoma, the probability of cancer cells dissemination through lymphatic vessels, compared with blood ones, is 5 times higher.

Table 2. *Vascular dissemination of cancer cells in the second stage of breast cancer in dogs*

Histologic type	Tumour cells (microemboli)			
	Blood vessels		Lymphatic vessels	
	n	%	n	%
Carcinoma mixed type (ICD-O code 8562/3)	32	36.4	7	36.8
Tubulopapillary carcinoma (ICD-O code 8503/3)	17	19.3	5	26.3
Tubular carcinoma (ICD-O code 8211/3)	15	17.0	2	10.5
Solid carcinoma (ICD-O code 8230/3)	8	9.1	2	10.5
Micropapillary invasive carcinomas (ICD-O code 8507/2)	4	4.5	1	5.3
Simple cribriform carcinoma (ICD-O code 8201/3)	4	4.5	1	5.3

Table 2, Continued

Histologic type	Tumour cells (microemboli)			
	Blood vessels		Lymphatic vessels	
	n	%	n	%
Ductal carcinoma (ICD-O code 8500/3)	1	1.1	1	5.3
Anaplastic carcinoma (ICD-O code 8021/3)	3	3.4	–	–
Total	88	100	19	100

Among the studied stage 2 breast tumours there are histological types that are characterised by invasion only into blood vessels on the background of significant fluctuations in their registration frequency. In particular, compared with anaplastic carcinoma, in which cancer cells in blood vessels are verified relatively rarely (1.1%), the probability of angioinvasion is 2.1 times higher in carcinomas of mixed type, 4.1 times higher in mucinous carcinoma, and 6.2 times higher in tubular carcinoma.

Certain patterns of tumour cells dissemination in stage 3 breast cancer have been understood (Table 3). In contrast to stage 2 cancer, tumour cells in conglomerates were verified in a small number of histological types and only in blood vessels. In the vast majority of cases, angioinvasion is found in simple cribriform carcinoma (83.3%), while in anaplastic carcinoma the probability of detecting tumour cells outside the neoplasm is 5 times lower.

Table 3. *Angioinvasion in the third stage of malignant neoplasms of the breast in she-dogs*

Histologic type	Detection frequency	
	n	%
Simple cribriform carcinoma (ICD-O code 8201/3)	5	83.3
Anaplastic carcinoma (ICD-O code 8021/3)	1	16.7
Total	6	100

Histologically, in anaplastic carcinoma of any stage only angioinvasion was recorded, whereas in stage 2 simple cribriform carcinoma, the presence of tumour cells in the lymphatic vessels was detected.

DISCUSSION

The analysis of reports and results of our research on the pathogenetic mechanisms of breast tumours in she-dogs proves their multi-vector nature and the need for further, more detailed study of carcinogenesis mechanisms in order to improve diagnosticating and identifying therapeutic targets for better treatment [32]. Vascular invasion, as a predictor of breast malignancy in she-dogs, allows predicting an unfavourable prognosis based on the correlation of high levels of tumour-associated macrophages with the clinical stage (P<0.001), tumour type (P=0.016), tumour size (P=0.013), the presence of tumour emboli in lymphatic and blood vessels (P=0.031), proliferation rates (P=0.009), lymph node metastases (P=0.003), vascular microdensity (P=0.008), invasive profile (P=0.002), and unfavourable prognosis (P<0.018) [15].

The results of studies presented by Rasotto *et al.* [33] also show that carcinomas and malignant myoepitheliomas are characterised by more aggressive behaviour, manifested by a higher incidence of vascular and lymph node invasion, a higher rate of visceral metastases, and a risk of death due to disease progression affected by Ki-67 overexpression.

The predictive significance of lymphoinvasion in breast tumours in she-dogs is confirmed by its correlation with the expression of DERL-1, a transport protein for the export of incorrectly folded proteins from the endoplasmic reticulum (ER) and apoptosis inhibitor [34].

Angioinvasion, which accompanies oncogenesis, is facilitated by circulating myeloid suppressor cells, which change the molecular pathways in tumour cells significantly due to increased expression of angiogenic factors and subsequent induction of angiogenesis by endothelial cells, epithelial mesentery, epithelial-mesenchymal transition, as well as increased migration of tumour cells [35].The data obtained are confirmed by the results of studies by Santos et al. [7], according to which highly proliferative tumours and tumours with invasive growth are characterised by a significant metastatic ability and, accordingly, an unfavourable prognosis on the background of short survival time and recurrence-free periods.

To understand the mechanisms of cancer cells dissemination, we consider the studies aimed at clinical aspects, the study of malignant transformation, histogenesis, epithelial-mesenchymal interactions to be relevant. They can standardise the criteria for diagnosis and breast tumour treatment. Individualisation of protocols will allow for more adequate disease management, thereby improving the she-dogs' survival and quality of their life [36].

The correlation of vascular invasion (r=0.76, P=0.043) with overexpression of vimentin filaments,

which participate in the mechanisms of epithelial-mesenchymal transition, established for breast tumours in dogs, confirms the obtained data on cancer cell dissemination into blood and vessels in malignant tumours [37].

Areas of tumour invasion show a higher level of hematoxylin-eosin staining and complete loss of α-SMA and p63 immunoreactivity, which in combination with the clinical stage and histological grade can be used for individual assessment of breast tumour [38]. The results are consistent in breast tumour with the correlation of lymph node status with histological grade, vascular invasion, proliferation index, expression of VEGFR-2, and microvascular density [4].

In this case, overexpression of vascular growth factor, which accompanies the progression of the tumour process, stimulates the proliferation, migration and survival of endothelial cells. The inverse correlation of VEGFR-1 with metastases to regional lymph nodes was proven. However, its prognostic significance for tumour cell dissemination and termination of disease remains unclear [39]. Along with the lesion size, histological grade, ERα-negativity, high Ki-67 proliferation index and absence of EGFR, the migration of tumour cells and lymph node involvement are of clinical importance [40].

In contrast to the tumour size and the histological type, which according to Chocteau *et al.* [41] correlate with early cancer mortality, but do not affect the conditional survival of patients significantly, lymphovascular invasion and regional lymph node involvement reflect the life expectancy of animals after treatment. In order to randomise patients in clinical experiments evaluating the efficacy of adjuvant chemotherapy, a histological classification based on lymph node status and lymphovascular invasion was proposed [42].

It is advisable to supplement the histological determination of the tumour emboli presence in blood and lymphatic vessels with a multi-marker study of seven RNA markers based on polymerase chain reaction with reverse transcription, which increases the sensitivity of detection of circulating tumour complexes up to 77.5% [43]. That means that the presence of circulating tumour cells in the peripheral blood is a prognostic factor for the survival of patients with breast tumours; the use of mRNA markers allows determining their spatio-temporal location, which makes it possible to assess the level of aggression and biological behaviour of the tumour more accurately [44].

Thus, the activation of the metastatic cascade, which is clinically manifested by the presence of tumour emboli in blood and lymphatic vessels, is proliferation, dedifferentiation, and loss of intercellular contacts. However, the complex molecular pathways and gene expression changes associated with these mechanisms in breast tumours are still largely unclear, so such researches remain relevant.

CONCLUSIONS

The determination of the tumour clinical stage does not always fully reflect the tumour aggressiveness. Detection of angio- and lymphoinvasion in tumours allows predicting the biological behaviour of the tumour and evaluating the therapeutic efficacy of conservative protocols more accurately. The presence of tumour emboli in the vessels increases the risk of both metastasis and recurrence (due to "contamination" of the surgical wound). Therefore, the most aggressive is stage 2 of neoplasia process, which is characterised by the maximum risk of metastasis and recurrence.

Histological types of breast tumours in she-dogs with a high risk of disease progression were determined (infiltrative tubular invasive and cribriform carcinomas), due to their angio- and lymphoinvasion at different disease stages. Verification of tumour emboli in mastopathy proves the potential aggressiveness of its biological behaviour. The results obtained prove the expediency of a comprehensive pathomorphological assessment of breast tumours with specification of structural disorders, in particular the determination of angio- and lymphoinvasion for more accurate disease prognosis.

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ПРОГНОСТИЧНЕ ЗНАЧЕННЯ СУДИННОЇ ІНВАЗІЇ ЗА ПУХЛИН МОЛОЧНОЇ ЗАЛОЗИ У СУК (ПІЛОТНЕ ДОСЛІДЖЕННЯ)

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Анотація. Пухлини молочної залози є найпоширенішим новоутворенням у некастрованих сук. Однак пухлини молочної залози у сук відрізняються значним різноманіття за морфологічними особливостями та біологічною поведінкою, відтак визначення факторів прогнозу є актуальним. Проведено дослідження дисемінації ракових клітин за новоутворень молочної залози у сук шляхом міграції в кровоносні та лімфатичні судини залежно від їх гістологічної характеристики та стадії захворювання. Вивчення проблеми здійснювали на базі клініки сучасної ветеринарної медицини «Best» міста Запоріжжя. У якості об'єктів використовували сук із неоплазіями молочної залози різного віку та порід за доведеної відсутності ознак метастатичного ураження інших органів і тканин, зокрема легень, органів черевної порожнини та кісток. Наявність ракових клітин у судинах визначали за утвореними ними пухлинними згустками, фіксованими до ендотелію. У результаті дослідження встановлено присутність ангіоінвазії незалежно від клінічної стадії пухлинного процесу. Водночас дисемінація пухлинних клітин шляхом міграції в лімфатичні судини спостерігалась тільки за другої клінічної стадії новоутворень молочної залози. У пацієнтів із новоутвореннями молочної залози на першій клінічній стадії в абсолютній більшості випадків (66,7 % пацієнтів) ангіоінвазія реєструється в мікропапілярних інвазивних карциномах (код МКБ-О 8507/2). У сук із раком молочної залози третьої стадії більш ніж у 80 % тварин наявність ракових клітин у кровоносних судинах верифікували за простої крибриформної карциноми (код МКБ-О 8201/3). У пацієнтів з другою клінічною стадією новоутворень молочної залози встановлено міграцію пухлинних клітин як у кровоносні, так і лімфатичні судин. При цьому найбільш часто ознаки ангіо- та лімфоінвазії встановлено за інвазивної карциноми змішаного типу (код МКБ-О 8562/3), тубулопапілярної карциноми (код МКБ-О 8503/3) та тубулярної карциноми (код МКБ-О 8211/3) – в 34,1 і 36,8; 19,3 і 26,3; 10,2 і 10,5 % випадків, відповідно. Отримані результати дозволяють із високим ступенем достовірності прогнозувати імовірність проникнення проникнення пухлинних клітин у кровоносні та лімфатичні судини, що надалі може краще прогнозувати біологічну поведінку пухлин молочної залози

Ключові слова: собаки, новоутворення, молочна залоза, метастазування

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PHOTOSYNTHETIC POTENTIAL OF SPRING BARLEY PLANTS IN THE STEPPE ZONE

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Abstract. Today, an increase in the real potential of grain crops, including spring barley, is a necessary condition for elements of crop cultivation technologies. Therefore, given the limited resource potential of spring barley crops, their fastidiousness to the soil, considerable attention should be paid to the photosynthetic potential of plants and the standardised application of mineral fertilisers. The aim of the study was to improve the elements of the technology of growing promising varieties of spring barley by establishing the mineral nutrition effect on the photosynthetic activity of plants in the conditions of the Luhanska Oblast. This study provides examples of improving some technologies for growing promising varieties of spring barley and determines the optimal norms for applying mineral nutrition to ensure the high photosynthetic potential of these plants in the climatic conditions of the steppe zone of Ukraine. It was found that the use of ammonium nitrate had a positive effect on the leaf area, increasing it by 1-2.2 thousand m^2/ha compared to the control for all varieties studied. The combined use of diammonium phosphate and ammonium nitrate contributed to an increase in the leaf area by 2-4.4 thousand m^2/ha compared to the control variant. Simultaneous application of ActiBION increased the total leaf area for all samples studied by 3.8-6.4 thousand m^2/ha. The best indicators among the studied varieties were observed on the six-row variety Helios and the double-row variety Stalker. The six-row variety Vakula and the two-row variety Adapt showed slightly lower results. Further research implies the study of the influence of photosynthetic activity of promising varieties of spring barley on crop productivity in the steppe zone of Ukraine. The findings can be recommended for production as one of the elements in the technology of growing spring barley in the climatic conditions of the Luhanska Oblast

Keywords: photosynthetic potential, spring barley, Helios, Vakula, Adapt, Stalker

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INTRODUCTION

The development and improvement of existing technologies for growing grain crops, in particular spring barley, in steppe conditions is currently the main priority area of agricultural production [1; 2]. One of the ways to increase the yield of spring barley is to create conditions under which the crop reaches potential [3]. Spring barley is one of the key grain crops cultivated in Ukraine and is the fourth in the world in terms of production, making the country one of the world leaders (top five) [4].

According to analysts, the export production of barley in Ukraine will be at the level of 9.4 million tonnes. The country can provide 20% of the world's total crop [5; 6]. Therefore, today the Ukrainian farmers must take into account both the rapid market of products and the problems that they directly face in the field. Thus, given the limited resource potential of the plant, changing weather conditions, the fastidiousness of barley to the soil and the crop productivity, it is necessary to pay considerable attention to: establishment of the optimal density of productive stem; phytosanitary condition of the field; the choice of fertiliser systems and retardant protection; development of the root system and photosynthetic potential of plants [6-8]. Many Ukrainian scientists agree with this statement: I.D. Tkalich, E.I. Mamadova, O. V. Bochevar et al., – note the fact that improvement of the nutrition background has a positive effect on the height of plants, the length of the ear, the number of productive shoots, etc. [9; 10].

As a result of the action of trace elements, plants become more resistant to drought, low temperatures, diseases and damage by harmful organisms, so one of the factors in the development of photosynthetic activity of spring barley crops is the norm of mineral nutrition, taking into account the poorly developed root system. The results of experiments conducted in the steppe zone indicate that all structural elements of the crop depend on fertiliser. Therefore, to achieve high yields, a balanced mineral nutrition and full photosynthetic productivity of plants are required [8; 10; 11].

Photosynthetic productivity of spring barley crops is the result of processes that produce energy-rich complex and diverse organic compounds from simple substances and depends on disease damage, resulting in a shortage of crops [9; 11; 12]. Therefore, an effective fertiliser system contributes to the normal course of the physiological state of the plant, its assimilation of nutrients, moisture and their transformation during photosynthesis into spare substances of the grain. Directly, one of the indicators of photosynthetic activity of plants is the area of the leaf surface. Therefore, the intensity of this process and the duration of its operation are crucial factors in the photosynthetic productivity, determining the size and quality of the crop [10; 11].

Thus, for spring barley crops, taking into account their anatomical and morphological structure during the growing season, it is necessary to create such conditions that optimally contribute to the formation of the leaf apparatus, and therefore effective photosynthetic activity in general.

The aim of the study was to investigate the influence of both conventional and new mineral fertilisers on the photosynthetic activity of spring barley crops, thereby improving the elements of technologies for growing promising spring barley varieties in the steppe zone of Ukraine.

LITERATURE REVIEW

Today, due to sharp climate changes, modern agronomic science faces an important question: an increase in the content of finished organic matter in plants during photosynthesis. According to the researchers, this is possible by changing the mineral nutrition, humidity, and seeding rates. Such measures can significantly increase the total percentage of PAR (photosynthetic active radiation) [7-9]. According to scientists, in the steppe zone the assimilation potential of plants is at the level of 0.5 million m^2/day. However, if proper agricultural techniques are followed, it can be increased to 2 million m^2/day [13]. Therefore, both the fertiliser system and all agricultural equipment should provide for the maximum provision of plants with the necessary root nutrition elements in a timely manner to increase the entire vegetation mass. As it increases, the total area of the leaf will also increase, which will ensure that the plant absorbs solar radiation.

Therefore, in spring barley crops, it is necessary to achieve their optimal density, since the growth of the photosynthetic apparatus can gradually lead to mutual shading of leaves, deterioration of aeration of crops and complicate the process of transferring carbon dioxide to the atmosphere. For its part, this will worsen photosynthetic conditions and reduce the efficiency of increasing fertiliser and water supply levels [14; 15]. According to researchers, this problem can be solved by placing rows from West to East, so the row spacing will be shaded by growing plants. In addition, the moisture capacity of crops will be preserved and the number of weeds will be reduced [14-16].

According to long-term studies by A.A. Nichiporovich, O.G. Andreichenko et al., yield and crop productivity are influenced by three main factors: photosynthetic productivity, respiration and translocation. It is known that photosynthesis and respiration are closely related, the more active the one, the more active is the other [10; 11].

Using the photosynthesis, plants absorb the entire mass of carbon dioxide from the external environment, due to which 42-45% of the mass of organic matter is formed [1]. Photosynthetic activity of a set of plants in grain crops includes a number of very important components: the area of photoactive foliage, the rate of its growth, the duration and intensity of

leaf work, the coefficient of use of headlights in specific environmental conditions. The key factor that very often suppresses the development of plants is their insufficient resistance to adverse environmental conditions, which mainly determines the amount of solar energy absorbed, the volume of carbohydrate synthesis, and so on. First of all, such processes are observed when the optimal sowing time is violated, associated with various circumstances, most often with an acute lack of moisture in the soil, violations of the nutrient regime, poor-quality seed material, etc. [10; 13]. Therefore, there is reason to assert that the active introduction of the varieties most adapted to the conditions of the region, as well as the standardised application of mineral fertilisers, will contribute to better growth and development of spring barley crops [12; 14].

According to numerous studies conducted in different countries, it was found that microelement compounds, getting into the plant, are directly involved in the processes of metabolism, affecting all phases of ontogenesis and the timeliness of their course [12; 17; 18].

This study suggests that the issue of applying the optimal rate of conventional and modern mineral fertilisers, according to various predecessors, as well as taking into account the genetic properties of the spring barley plant variety in the steppe zone of Ukraine, remains open.

Thus, taking into account the above-mentioned problems, there is a need to establish changes in the indicators of photosynthetic activity in crops depending on various factors, in particular, the conditions of insufficient moisture in the Luhanska Oblast.

MATERIALS AND METHODS

Experimental studies were carried out in 2018-2020 at the experimental plots of the Department of Biology and Agronomy, in the department of scientific and technical training of the Taras Shevchenko National University of Luhansk (Luhanska Oblast, Starobilsk district) located in an agroclimatic area with insufficient moisture. The soils of the experimental sites were represented by ordinary chernozems on loess rocks with a thickness of humus layer of 65-80 cm. The weather conditions were not the same. In terms of the degree of moisture content, they were close to the long-term average. The average annual precipitation was 474.7 mm. The average air temperature (March – August) over the years of the study was in the range of 15-16°C, which is 1.37°C more than the long-term average [19].

The predecessor of spring barley was sunflower. Technological techniques that were not studied were generally accepted for the region. In particular, tillage included peeling stubble with an LDG-15 Husker to a depth of 10-12 cm after harvesting the predecessor, ploughing with a PN-4-35 plough to a depth of 20-22 cm. The main tillage, which was studied in experiments on spring barley, was carried out in autumn with a non-polar (chisel) – deep digger Catros 4000 to a depth of 12-14 cm.

Spring tillage was carried out with an AK-8.5 cultivator to a depth of 6-8 cm. For seed treatment, Vencedor solution (1 l per 100 kg) was used, which is a two-component contact-system fungicide with growth-regulating properties. Sowing of seeds was carried out at the end of March, with a seed-fertiliser seeder SZ-5.4. Seeding rates were 4.0-5.5 million tonnes. seeds per 1 hectare, the optimal depth of seed embedding was 4-5 cm. Mineral fertilisers were applied simultaneously with sowing. The experiment was laid down in three-fold repetition. The sown area of the plot was 25 m^2, the accounting area was 20.6 m^2.

Promising six-row regionalised varieties Helios, Vakula, and two-row – Adapt and Stalker – were sown:

1. Helios. (Originator: CJSC "Selena"; in the State Register of plant varieties of Ukraine since 2006). The weight of 1000 seeds is 47.8-49.9 g. It is recommended for growing in the steppe, forest-steppe and Polesia zones. Intensive-type variety. The average yield is 50.8-55.1 ctr/ha, the potential yield of the variety is 89 ctr/ha [20].

2. Vakula. (Originator: Breeding and Genetic Institute – National Centre for Seed Science and Variety Research of the UAAS; in the State Register of plant varieties of Ukraine since 2006). Weight of 1000 seeds – 44 g. The variety is suitable for growing in conditions of drought and high soil acidity. The average yield is 48.4 ctr/ha, the potential yield is 105 ctr/ha.

3. Adapt. (Originator: Breeding and Genetic Institute – National Centre for Seed Science and Variety Research of the UAAS; in the State Register of plant varieties of Ukraine since 1998). The weight of 1000 seeds – 47-63 g. The variety is bred for severe drought conditions. The yield is 50-75 ctr/ha.

4. Stalker – (originators: Breeding and Genetic Institute – National Centre for Seed Science and Variety Research of the UAAS; in the State Register of plant varieties of Ukraine since 1997). Weight of 1000 grains – 50-55 g. The variety was bred under the breeding programme for increased adaptability to the conditions of the arid steppe. The yield under production conditions – 55-70 ctr/ha [21].

Barley was harvested in the phase of full grain ripeness by a combine. The work started when the grain humidity reached 14%. The study used a modern and more powerful combine harvester NEW HOLLAND CX 60.90.

The scheme of the experiment with spring barley included the following options:

Factor A – variety:

1. Helios
2. Vakula
3. Stalker
4. Adapt

Factor B – fertiliser background:

1. Without fertilisers
2. Ammonium nitrate NH_4: NO_3 1:1 at a rate of 200 kg/ha
3. Diammonium phosphate $(NH_4)_2HPO_4$, N:P 18:46, at the rate of 100 kg/ha + ammonium nitrate NH_4: NO_3 1:1 at a rate of 100 kg /ha
4. ActiBION (N-9, P_2O_5 – 20, K_2O – 12, SO_3 – 15,

CaO – 16, Mg – 2, Mn – 0.01, B – 0.1, Fe – 0.5 at a rate of 100 kg/ha + ammonium nitrate NH_4NO_3 at a rate of 100 kg/ha.

For a comprehensive assessment of technologies, phenological observations, biometric records, etc. were carried out. Records, measurements and related observations were carried out in accordance with the methods of field research, according to the method of state variety testing of agricultural crops [22]. Photosynthetic activity was determined using the method described by A. A.Nichiporovich [10; 11]

The results obtained were processed.

RESULTS AND DISCUSSION

During the study, it was found that the use of the proposed options for background nutrition of spring barley affected the total area of the leaf surface of plants. Active growth of vegetative mass was observed before and during the earing phase, after passing this stage of ontogenesis, they had some downward tendencies. It was at this time that the required leaf area was formed, as the main photosynthetic organ of plants, accumulating a sufficient amount of carbohydrates and dry vegetative mass and, accordingly, net photosynthetic productivity. Thus, the two-row Stalker variety under control had a leaf surface area of 47.8 thousand m^2/ha, which is 1.0 thousand m^2/ha more than the Adapt variety. The introduction of ammonium nitrate led to an increase in the area of both varieties from 0.8 to 1.0 thousand m^2/ha, respectively, the combined introduction of diammonium phosphate and ammonium nitrate increased the leaf surface from 1.6 to 2.0 thousand m^2/ha. The complex use of ActiBION at a rate of 100 kg/ha and ammonium nitrate at a rate of 100 kg/ha contributed to an increase in the leaf area from 2.2 to 2.8 thousand m^2/ha, respectively, compared to the control.

Studies have shown that six-row varieties in comparison with two-row varieties had a tendency to increase the leaf surface area. Among them, the Helios variety showed 48.8 thousand m^2/ha, and the Vakula variety – 47.8 thousand m^2/ha. When fertilised only with ammonium nitrate, the area increased from 0.4 in the Vakula variety to 1.8 thousand m^2/ha in the Helios variety. The combined use of diammonium phosphate and ammonium nitrate positively changed the area from 1.6 thousand m^2/ha (Vakula variety) to 1.8-1.8 thousand m^2/ha (Helios variety). The maximum increase in leaf area was observed in the Helios variety when using ActiBION and ammonium nitrate, which is 0.4 more than in the Vakula variety compared to the control (Table 1, Figure 1).

Table 1. *Leaf surface area of spring barley crops depending on the varietal characteristics and mineral nutrition in the earing phase (average for 2018-2020), thousand m^2/ha*

Varieties	Mineral nutrition background	Ontogenesis phase (earing)
Helios	Without fertilisers (control)	48.8
	Ammonium nitrate 200 kg/ha	50.6
	Diammonium phosphate 100 kg/ha + ammonium nitrate 100 kg/ha	52.4
	ActiBION 100 kg/ha + ammonium nitrate 100 kg/ha	54.2
Vakula	Without fertilisers (control)	47.8
	Ammonium nitrate 200 kg/ha	48.2
	Diammonium phosphate 100 kg/ha + ammonium nitrate 100 kg/ha	49.8
	ActiBION 100 kg/ha + ammonium nitrate 100 kg/ha	51.2
Stalker	Without fertilisers (control)	47.8
	Ammonium nitrate 200 kg/ha	48.8
	Diammonium phosphate 100 kg/ha + ammonium nitrate 100 kg/ha	50.8
	ActiBION 100 kg/ha + ammonium nitrate 100 kg/ha	53.6
Adapt	Without fertilisers (control)	46.8
	Ammonium nitrate 200 kg/ha	47.6
	Diammonium phosphate 100 kg/ha + ammonium nitrate 100 kg/ha	49.2
	ActiBION 100 kg/ha + ammonium nitrate 100 kg/ha	51.4

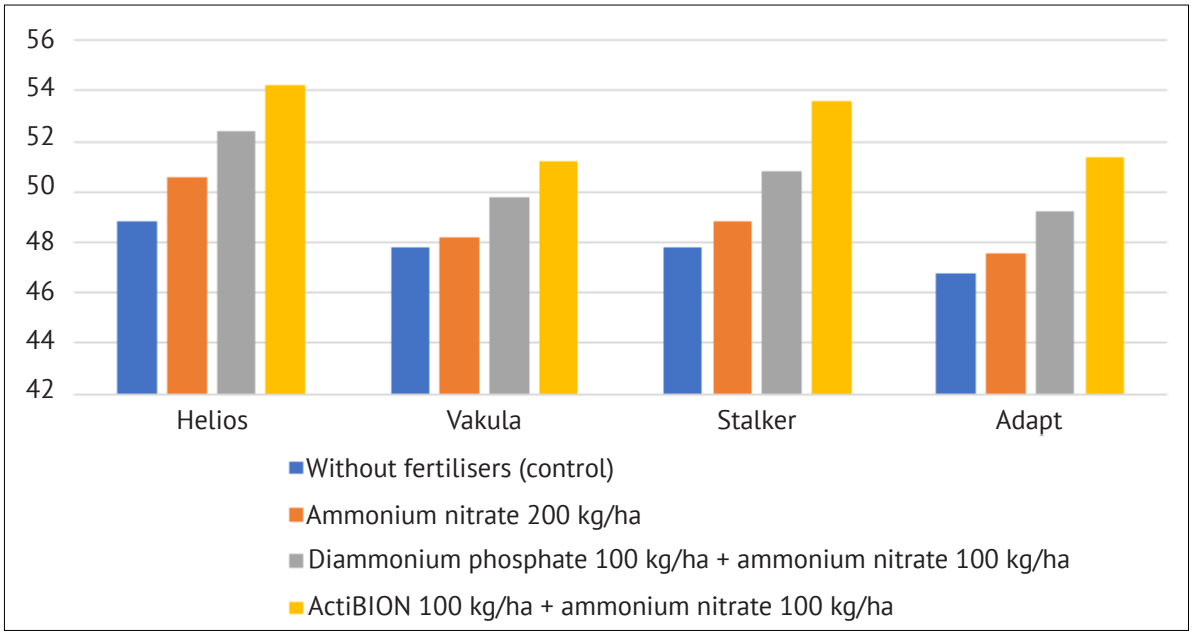

Figure 1. *Dynamics of changes in the leaf surface area of spring barley crops depending on the varietal characteristics and mineral nutrition in the earing phase (average for 2018-2020), thousand m²/ha*

Analysing the data obtained, it can be argued that the development of the leaf surface of spring barley was positively influenced by both varietal characteristics of crops and the introduction of mineral fertilisers. The best indicators were obtained with the combined use of ActiBION at a rate of 100 kg/ha and ammonium nitrate at a rate of 100 kg/ha on Helios and Stalker varieties.

Notably, before the onset of the earing phase, the lower leaves of spring barley plants, in all the proposed variants of the experiment, dried up. Thus the main role in the process of photosynthesis, and therefore photosynthetic activity in general, was assumed by the upper leaves. Therefore, it can be argued that the introduction of mineral fertilisers has become a necessary factor in the full supply of the plant with the necessary elements that play an important role in the metabolic processes in the plant (Fig. 2).

Figure 2*. Helios spring barley plants in the earing phase (2020)*

Source*: author's research*

Based on the findings and taking into account the varietal characteristics of spring barley plants, the authors investigated the photosynthetic potential of crops using the method of A.A. Nichiporovic [10; 11]. Taking into account that the growing season of the studied varieties depended more on their varietal characteristics and hydrothermal conditions in the studied years than on the factors studied, data on the growing season were taken on average for the years of the study (Table 2).

Table 2. *Photosynthetic potential of spring barley crops depending on the varietal characteristics and mineral nutrition in the earing phase (average for 2018-2020), thousand m²/ha*

Varieties	Mineral nutrition background	Ontogenesis phase (earing)
Helios	Without fertilisers (control)	2.93
	Ammonium nitrate 200 kg/ha	3.04
	Diammonium phosphate 100 kg/ha + ammonium nitrate 100 kg/ha	3.15
	ActiBION 100 kg/ha + ammonium nitrate 100 kg/ha	3.25
Vakula	Without fertilisers (control)	2.87
	Ammonium nitrate 200 kg/ha	2.90
	Diammonium phosphate 100 kg/ha + ammonium nitrate 100 kg/ha	2.99
	ActiBION 100 kg/ha + ammonium nitrate 100 kg/ha	3.07
Stalker	Without fertilisers (control)	2.39
	Ammonium nitrate 200 kg/ha	2.44
	Diammonium phosphate 100 kg/ha + ammonium nitrate 100 kg/ha	2.54
	ActiBION 100 kg/ha + ammonium nitrate 100 kg/ha	2.68
Adapt	Without fertilisers (control)	2.34
	Ammonium nitrate 200 kg/ha	2.38
	Diammonium phosphate 100 kg/ha + ammonium nitrate 100 kg/ha	2.46
	ActiBION 100 kg/ha + ammonium nitrate 100 kg/ha	2.57

On average, over the years of the study, against the background of no fertiliser in all varieties studied, the indicator ranged from 2.34 to 2.93 million m²/ha×day. The introduction of ammonium nitrate provided an increase in this indicator for all varieties from 2.38 to 3.04 million m²/ha×day. Diammonium phosphate and ammonium nitrate provided a tendency to increase the photosynthetic potential from 2.46 to 3.15 million m²/ha×day, depending on the variety.

The greatest photosynthetic potential of crops was observed with the complex application of ActiBION at a rate of 100 kg/ha and ammonium nitrate at a rate of 100 kg/ha. Thus, on average, it was 2.57 million m²/ha×days for the Adapt variety, 2.68 million m²/ha×days for the Stalker variety, 3.07 million m²/ha×days for the Vakula variety, and 3.25 million m²/ha×days for the Helios variety compared to the control (Table 2).

CONCLUSIONS

Taking into account the peculiarities of the growth and development of the spring barley crop and constant changes in zonal conditions, elements of the technology for growing promising varieties of spring barley were improved by studying the effect of mineral nutrition on the photosynthetic activity of plants. The study shows that the value of the photosynthetic potential largely dependeds on the varietal characteristics of the crop, on the type and rate of fertiliser, which create conditions for normal growth and development. Therefore, the introduction of mineral fertilisers in all the investigated samples improved the nutritional conditions of spring barley and, accordingly, increased the leaf surface. Studies have established that the complex application of ActiBION and ammonium nitrate maximised the photosynthetic potential of spring barley crops. The best performance was observed in the six-row Helios variety and the two-row Stalker variety.

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ФОТОСИНТЕТИЧНИЙ ПОТЕНЦІАЛ РОСЛИН ЯЧМЕНЮ ЯРОГО В УМОВАХ ЗОНИ СТЕПУ

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Анотація. На сьогодні підвищення реального потенціалу зернових культур, зокрема і ячменю ярого є необхідною умовою елементів технологій вирощування сільськогосподарських культур. Тому, враховуючи обмежений ресурсний потенціал рослин ячменю ярого, вибагливість його до ґрунту, потрібно чималу увагу приділяти фотосинтетичному потенціалу рослин і нормованому внесенню мінеральних добрив. Метою досліджень було вдосконалення елементів технології вирощування перспективних сортів ячменю ярого шляхом встановлення впливу мінерального живлення на фотосинтетичну діяльність рослин в умовах Луганської області. У представленій статті наведені приклади вдосконалення деяких елементів технологій вирощування перспективних сортів ячменю ярого та визначено оптимальні норми внесення мінерального живлення для забезпечення високого фотосинтетичного потенціалу цих рослин у кліматичних умовах зони Степу України. Встановлено, що застосування аміачної селітри позитивно впливало на площу листа, збільшуючи її на 1-2,2 тис. м^2/га у порівнянні з контролем по всіх сортах, що вивчалися. Сумісне використання діамонію фосфату та аміачної селітри посприяло збільшенню площі листка на 2-4,4 тис. м^2/га порівняно з контрольним варіантом. Одночасне внесення препарату ActiBION збільшили загальну площу листків по всіх зразках, що вивчалися на 3,8-6,4 тис. м^2/га. Найкращі показники серед сортів, що досліджувалися, спостерігали на шестирядному сорті Геліос і дворядному сорті Сталкер. Шестирядний сорт Вакула та дворядний сорт Адапт показали дещо менші результати. Подальші результати полягають у вивченні впливу фотосинтетичної діяльності посівів перспективних сортів ячменю ярого на його продуктивність у зоні Степу України. Результати дослідження можуть бути рекомендовані у виробництво як один із елементів у технології вирощування ячменю ярого в кліматичних умовах Луганської області

Ключові слова: фотосинтетичний потенціал, ячмінь ярий, Геліос, Вакула, Адапт, Сталкер

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BIOLOGICAL FEATURES OF THE DISTRIBUTION OF ROOT SYSTEMS OF PERENNIAL LEGUME GRASSES IN THE CONTEXT OF CLIMATE CHANGE

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Abstract. The key factor in the choice of perennial legume grasses in the face of climate change is their drought resistance, because the development of roots directly affects this property, as well as determines their fertility. The purpose of the study was to establish what morphological and biological characteristics of grass roots ensure economic characteristics in the context of climate change. Methods of observation, comparison, and field experiment were used. The study found that the roots of alfalfa have the greatest depth in the soil, spread in the horizontal direction, the thickness of the root neck and lateral roots, which ensures plasticity, durability, and productivity of its crops. The roots of white melilot have the greatest depth in the soil, the thickness of the root neck, central root and lateral roots, their spread in the horizontal direction, which affects the drought and frost resistance of crops. The roots of birdsfoot trefoil are distinguished by the greatest number of renewal buds on the root neck, the smallest depth, and the thickness of the root neck, which affects productive longevity and the possibility of growth in poor and acidic soils. The roots of eastern galega have the greatest depth of the main plant, distribution in the horizontal direction, the thickness of the central root, which affects productive longevity and high biological plasticity. The roots of Hungarian sainfoin are distinguished by the greatest distribution in the horizontal direction and the deepest placement of the main branching, which affects high biological resistance to adverse growing conditions. It was also found out that the roots of meadow clover have the smallest spread radius in the horizontal plane, the thickness of the central and lateral roots, which determines the possibility of its cultivation in the field crop rotation. These findings would facilitate the selection of perennial legume grasses to achieve their full potential in the face of climate change

Keywords: plants, roots, underground development, morphology, years of vegetation

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INTRODUCTION

One of the key factors when choosing perennial legume grasses in the face of climate change is their adaptability to periodic lack of moisture during the growing season, which depends on the development of the root system of grasses. At the same time, placing crops of perennial legume grasses on poor and acidic soils limits the growth of their roots and reduces drought resistance [1]. It is known that the processes that occur in the vegetative organs of plants have a direct connection with the function of their underground part. The larger the volume and length of the root system, the greater the aboveground mass of the plant. A well-developed root system contributes to the efficient use of nutrients and moisture from the soil [2].

In arid conditions, in the year of sowing with clean cultivation, the roots of alfalfa penetrate to a depth of 120-140 cm. With sufficient moisture supply, the root system does not need to penetrate deeply. In general, the root of alfalfa penetrates to a depth of 10 m or more [3]. The root system of meadow clover penetrates the soil from 20 cm per year of sowing and up to 150-200 cm in general. Hungarian sainfoin has a well-developed root system that penetrates up to 150-200 cm [4]. Birdsfoot trefoil is less resistant to drought than alfalfa. Its root system is well branched and penetrates up to 1.5 m deep and is well adapted to acidic and poor soils [5]. Eastern galega is also drought-resistant but develops well in soils with high water retention capacity [1]. White melilot has a well-developed root system, which determines its drought resistance. In white melilot, the root is thickened in the upper part, with well-developed lateral roots, penetrates deeply into the soil, reaching the subsoil [6].

The issue of the distribution of root systems of traditional perennial legume grasses in the context of climate change has been studied in the works of many scientists. In particular, G.P. Kvitko investigated the influence of the development of root systems on soil fertility indicators [5]; P.S. Makarenko studied the distribution of plant roots in grass mixtures [6]; O.L. Kirilesko considered the development of root systems of perennial legume grasses on sloping lands [7]; I. Zabarna examined the morphology of meadow clover roots [8]. K. Schnidtke, R. Rauber analysed the influence of root development on the intensity of their absorption of heavy metals from the soil [9]; P.K. Ghosh and T.K. Maiti studied the relationship between the root systems of perennial legumes and their nodule bacteria [10]; M. Marczak, A. Mazur, P. Koper, K. Zebracki and A. Skorupska investigated the symbiotic productivity of grass roots [11]; G.G. Stevens, M.A. Perez-Fernandez, R.J.L. Morcillo, A. Kleinert, P. Hills, D.J. Brand, E.T. Steenkamp and A.J. Valentine studied the peculiarities of growth and development of the roots of perennial legume grasses in conditions of nutrient deficiency in the soil [12]; T. Suzaki, N. Takeda, H. Nishida, M. Hoshino, M. Ito, F. Misawa, Y. Handa, K. Miura and M. Kawaguchi studied the development of root systems of perennial legume grasses in the absence of symbiotic bacteria in the soil [13]; C. Jacob, B. Carrasco, A.R. Schwember analysed the achievements of selection and biotechnology of perennial legumes [14]; M.A. Adams, N. Buchmann, J.I. Sprent, T.N. Bucley and T.L. Turnbull examined the effects of moisture and nitrogen on the spread of root systems of grass [15]. For the most part, they indicate a powerful development of the root system. At the same time, the influence of climate change conditions on the morpho-biological features of the root systems of perennial legumes and their adaptation to adverse environmental conditions has been rather neglected.

Alfalfa is a traditional forest-steppe crop, has been grown in this region for a long time, is well adapted to the soil and climatic factors and changes in growing conditions, and characterised by plasticity and durability. However, the use of other types of perennial legume grasses should be complementary to alfalfa, using their biological and economic advantages in local soil and climatic conditions. Thus, Hungarian sainfoin is characterised by high biological resistance to adverse growing conditions; white melilot has good drought and winter hardiness. Birdsfoot trefoil is characterised by productive longevity and the ability to grow on poor and acidic soils. Eastern galega is characterised by productive longevity and high biological plasticity [16].

Therefore, the *purpose* of this study was to establish what morphological and biological characteristics of the root systems of perennial legume grasses ensure their ecological and economic features in the context of climate change.

MATERIALS AND METHODS

Field research was conducted during 2013-2017 at the research farm "Agronomichne" of the Vinnytsia National Agrarian University. The experimental site was located on gray podzolic medium loamy soil. Agrochemical composition of the soil: humus content – 2.0%, hydrolysed nitrogen (according to Kornfield) – 133 mg/kg of soil, mobile phosphorus (according to Chirikov) – 390 mg/kg of soil, mobile potassium (according to Chirikov) – 64 mg/kg of soil, hydrolytic acidity – 2.53 mg-EQ/100 g of soil, reaction of pH salt of soil solution – 6.0.

Studies were conducted with the following types of perennial legume grasses: alfalfa (*Medicago sativa* L.), red clover (*Trifolium pratense* L.), Hungarian sainfoin (*Onobrychis arenaria* Kit.), white melilot (*Melilotus albus* L.), birdsfoot trefoil (*Lotus corniculatus* L.) and eastern galega (*Galega orientalis* Lam.). Grasses were sown in early spring using a clean cultivation way using a post-emergence herbicide. The green mass was harvested at the beginning of the flowering phase. Determination of the distribution features of the roots of perennial legume grasses in the soil was carried out by dry

excavation [17; 18]. Quantitative parameters of root systems were determined using a measuring tape and caliper in four repetitions.

During the 2013 calendar year, 652 mm of precipitation fell, which is 18 mm more than the long-term average (634 mm), with an average annual temperature of 9.0°C, which is 2.0°C more than normal (7.0°C). The growing season began in the first ten days of April and lasted until the end of the second ten days of November. During the growing season, the amount of precipitation was 429 mm. In 2014, precipitation was 550 mm, which was 87% of the long-term average. The average annual temperature was 8.6°C, which is 1.6°C higher than normal. The growing season began in the first ten days of March and lasted until the end of the first ten days of November. During the growing season, the amount of precipitation was 442 mm.

In 2015, 368 mm of precipitation fell, which was 58% of the long-term average. The average annual temperature was 9.3°C, which is 2.3°C higher than normal. The growing season began in the end of March and lasted until the second ten days of November. During the growing season, 235 mm of precipitation fell. In 2016, the average annual temperature was 9.0°C, which is 2°C higher than normal. The amount of precipitation during the year was 469 mm, which was 26% less than normal. The growing season began in early April and lasted until the end of September. 2017 was characterised by an average annual temperature of 9.1°C, which was 2.1°C higher than normal. The amount of precipitation for the year was 503 mm, which corresponds to 80% of the long-term norm.

Thus, the most favourable growing conditions, taking into account the temperature regime and humidity level, were in 2014, which corresponds to the second year of vegetation of perennial legume grasses. The least favourable growing conditions were typical observed in 2016, when the grasses were growing for the fourth year.

RESULTS AND DISCUSSION

Features of initial aboveground and underground growth of perennial legume grasses

Observations of the germination of root systems of perennial legume grasses have shown that the roots of alfalfa and white melilot begin to germinate most quickly – on the 2nd-3rd day after sowing, later – red clover, Hungarian sainfoin, and at the latest – birdsfoot trefoil (Table 1).

Table 1. *Dynamics of early growth of underground and aboveground parts of perennial legume grasses, M±m*

Perennial legume grasses	Height, cm depending on the day after sowing				
	5		10		15
	underground growth	aboveground growth	underground growth	aboveground growth	underground growth
Alfalfa	2.1±0.2	0.6±0.2	2.5±0.2	1.1±0.2	4.2±1.0
Red clover	2.2±0.1	0.2±0.1	2.6±0.2	0.6±0.1	2.9±0.4
Hungarian sainfoin	2.7±0.3	0.5±0.2	3.7±0.3	3.5±0.3	7.1±2.1
White melilot	1.7±0.2	0.3±0.1	2.2±0.2	0.8±0.1	3.3±0.9
Birdsfoot trefoil	0.3±0.1	0.1±0.05	0.8±0.1	0.4±0.1	2.5±1.0
Eastern galega	0.6±0.1	0.2±0.05	1.3±0.2	1.5±0.2	4.7±1.6

Source*: compiled based on the author's own research*

The results of studies showed that on the fifth day after sowing, the length of the roots of perennial legume grasses was 0.3-2.7 cm. Hungarian sainfoin had the greatest root length, which was 89% longer than birdsfoot trefoil, which crops had the smallest root length.

On the 10th day after sowing, the root length of perennial legume grasses was 0.8-3.7 cm. It remained the largest in plants of Hungarian sainfoin, which was 78.4% more than in plants of birdsfoot trefoil, which had the smallest root length. Starting from the 10th day, the growth of aboveground parts of legumes and perennial grasses begins. The ratio between the length of roots and aboveground seedlings in most plants was 6.5-8.0, in alfalfa – 4.2, and in red clover – 13.0 with a predominance of underground parts.

15 days after sowing, the length of the roots was 2.5-7.1 cm, and aboveground seedlings – 0.4-3.5 cm. In all indicators, Hungarian sainfoin plants prevailed. The ratio between the length of the underground and aboveground parts of plants decreased to 2.0-6.3. At this time, the root system grew more intensively in comparison with the aboveground part in red clover, birdsfoot trefoil and white melilot, and the aboveground part – in Hungarian sainfoin, eastern galega and alfalfa. The growth rate of the roots of perennial legume grasses for the first 5 days was highest in Hungarian sainfoin – 0.54 cm/day, while in birdsfoot trefoil – 0.06 cm/day.

During the second five-day period, the rate of root growth was 0.08-0.20 cm/day. It was the highest in the Hungarian sainfoin plants, and the smallest – in alfalfa

and red clover. During this period, the intensity of root growth decreases in all types of legume grasses, with the exception of birdsfoot trefoil and eastern galega. The greatest decrease in growth was observed in alfalfa and Meadow Clover – by 5.5-5.3 times, compared to the first five-day period. This is conditioned by the beginning of aboveground growth. Plants of birdsfoot trefoil and eastern galega increased the average daily growth, compared to the first period, by 1.7 and 1.2 times – up to 0.14-0.10 cm/day and had, respectively, the smallest growth of the aboveground part of the plant, compared to other plants.

In the third observation period, the average daily growth of root systems of plants was 0.22-0.68 cm/day, except for red clover, where this indicator was 0.06 cm/day. The largest gains were observed in Hungarian sainfoin and eastern galega. The intensity of root growth at this time increased by 2.2-4.9 times compared to the second five-day period, especially in the eastern galega.

The highest average daily root growth in the third observation period was noted in eastern galega, birdsfoot trefoil and Hungarian sainfoin. The intensity of their growth in the eastern galega and birdsfoot trefoil increased from the first to the third periods, while in the Hungarian sainfoin it decreased in the second period compared to the first. Alfalfa, red clover and white melilot had the greatest root gains in the first observation period.

Morphological and biological features of root system development

The intensity of growth and development of root systems of perennial legume grasses depends on the value of symbiotic nitrogen fixation of nodule bacteria, the intensity of absorption of nutrients and water from the soil, the size of the formed aboveground crop. From an agroecological standpoint, the size of the root system determines the amount of organic matter that will return to the soil and replenish the supply of nutrients, and it also affects the agroecological resistance of the agrocenosis of legumes to unfavorable abiotic and biotic factors. The complex of morphological features of the distribution of plant root systems includes such parameters as the spread of roots in depth, the horizontal radius of root growth from the stem, and the depth of the main mass of branching of the plant root system.

The greatest depth of penetration of the root system into the soil thickness in the first year of vegetation was reached by alfalfa and white melilot, respectively, 83 and 82 cm, while the root system of birdsfoot trefoil reached a depth of 44 cm. The radius of horizontal root distribution, relative to the central root, was the largest in alfalfa plants – 25 cm, and the smallest – in red clover – 9 cm. The biggest depth of the main mass of branching of the root system was in eastern galega plants – 28 cm and Hungarian sainfoin – 23 cm, and the smallest – in alfalfa – 15 cm. A special feature of the root system of white melilot is its extremely high fragility, which may determine the biennial nature of the plant (Fig. 1).

Eastern galega, in addition to the root system itself, which is characterised by strong fibrousity, which determines its durability, also has root shoots, which are autonomous centres of emergence of individual plants. At the end of the first year of vegetation, the eastern galega plant forms up to 7-9 shoots. The maximum radius of their penetration from the central root is 25 cm, and the thickness is 3 mm. On such a shoot there can be up to 7 buds.

Figure 1. *Root system of eastern galega (A), white melilot (B), alfalfa (C), Hungarian sainfoin (D) on the first year of growth*

The main organ for restoring the vegetation of legume grasses and accumulating spare nutrients is the root neck. The productivity and durability of the herbage depends on the features of its development. The greatest thickness of the root neck in the year of sowing was observed in white melilot – 12 mm and alfalfa – 11 mm, and the smallest – in eastern galega – 5 mm and red clover – 6 mm (Table 2).

Table 2. *Morphology of root systems of perennial legumes depending on the growing season, M±m*

Perennial legume grasses	Years of growth	Depth of root penetration, cm	Root system radius, cm	Depth of the main mass of branching, cm	Thickness, mm			Number of buds on the root neck, pcs.
					root neck	central root	side roots	
Alfalfa	1	83±3	25±3	15±1	11±1	4±1	1.5±0.2	12±3
	2	258±9*	28±3	26±2	18±2	5±1	2.0±0.2	25±4
	3	432±4*	37±2	34±2	25±3	7±2	2.1±0.2	34±3
	4	813±15*	42±3	40±3	33±3	9±2	2.3±0.2	41±4
Red clover	1	51±2	9±1	18±1	6±2	2±1	0,8±0,2	14±2
	2	167±7	20±2	24±2	9±2	4±1	0.9±0.2	28±3
Hungarian sainfoin	1	65±3	15±2	23±2	8±2	4±1	1.0±0.2	13±2
	2	178±6	23±3	35±2	15±2	7±2	1.3±0.2	26±3
	3	269±5*	34±3	39±3	22±3	10±2	1.4±0.2	35±3
	4	311±9*	39±3	47±3	29±3	14±2	1.6±0.2	42±4
White melilot	1	82±4	20±2	18±1	12±2	6±1	3.0±0.2	6±1
	2	260±7*	30±3	31±2	17±2	6±1	3.0±0.2	6±1
Birdsfoot trefoil	1	44±3	18±2	21±2	7±1	3±1	1.1±0.2	33±3
	2	87±6	21±2	25±2	7±1	3±1	1.2±0.2	51±4
	3	101±8	22±2	27±2	11±2	4±1	1.2±0.2	70±4
	4	129±8	24±2	29±2	13±2	5±1	1.4±0.2	89±4
Eastern galega	1	52±4	16±1	28±3	5±2	4±1	1.0±0.2	8±2
	2	108±8	27±2	32±3	11±2	5±1	1.0±0.2	12±2
	3	119±7	31±3	37±3	17±2	9±1	1.1±0.2	16±3
	4	122±8	31±3	42±3	23±3	14±2	1.3±0.2	20±3

***Note**: reference data established in accordance with the literature sources listed below*
***Source**: compiled based on the author's own research and [5-7]*

An important indicator of the root neck is the number of buds on it, which are able to form a vegetative shoot next year. The largest number of them at the end of the growing season of the first year was observed in the birdsfoot trefoil – 33 pcs., which determines its intensive regrowth and three mowings during the first year of growth. The smallest number of buds was observed on the root neck of white melilot – 6 pcs., which, accordingly, determines its biennial nature and unsatisfactory regrowth with low mowing.

The greatest thickness of the middle part of the central root in the year of sowing was: in white melilot – 6 mm; and the smallest – 2 mm – in red clover. The average thickness of the lateral roots was also the largest in white melilot – 3.0 mm, and the smallest – 0.8 mm – in red clover.

Summing up the findings on the development of root systems of perennial legume grasses in the first year of vegetation, it should be noted: the greatest depth of root penetration into the soil and its greatest horizontal branching relative to the central root was observed in alfalfa and white melilot. However, the depth of the main mass of root branching in these crops was the smallest; the relatively shallow root system of eastern galega, Hungarian sainfoin, birdsfoot trefoil, and red clover in the year of sowing is compensated by an increase in the depth of the main mass of its branching. In plants of birdsfoot trefoil – also partially by a large radius of horizontal root spread relative to the central root. The greatest thickness of the root neck, central root, and side roots are noted in those types of perennial legumes in which the root system penetrates deeper.

At the end of the second year of vegetation of grasses, the depth of penetration of their roots increased significantly. The root system of white melilot and alfalfa was most deeply penetrated into the soil – up to 260-258 cm. The root system of birdsfoot trefoil was the least deep in the soil – up to 87 cm, which is 3 times less than that of white melilot and alfalfa. There was a similar tendency of root penetration into the soil of

these species of leguminous grasses in depth with the first year of research on grasses that have the largest and smallest depth of penetration into the soil.

The radius of horizontal distribution of root systems of legumes in the second year of vegetation also increased. It was the largest in the plants of white melilot – 30 cm and eastern galega – 27 cm. The lowest horizontal root distribution was observed in red clover and birdsfoot trefoil – 20-21 cm, which is 1.5 times less than in white melilot. Compared to the first year of study, the horizontal distribution of eastern galega roots has significantly increased.

The greatest depth of the main mass of branching of the root system was characteristic of plants of Hungarian sainfoin – 35 cm and eastern galega – 32 cm. The lowest depth of distribution of the main mass of roots was observed in red clover, birdsfoot trefoil and alfalfa – 24-26 cm, which is 1.4 times less than in Hungarian sainfoin.

The thickness of the root neck of perennial legume grasses in the second year of vegetation was 7-18 mm. The thickest root neck was characteristic of alfalfa and white melilot, and the thinnest – for birdsfoot trefoil. The number of buds on the root neck of plants was 6-51 pcs. and it did not depend on the thickness of the root neck. Most of the buds were on the neck of the birdsfoot trefoil, which had the thinnest root neck, and the least – on the root neck of the white melilot, which had the thickest root neck.

The thickness of the central root of legume grasses was 3-7 mm. It was thickest in the Hungarian sainfoin and white melilot, and the thinnest – in the birdsfoot trefoil. To a large extent, the thickness of the central part of the main root was directly proportional to the thickness of the root neck. The thickness of the lateral roots of legume grasses in the second year of vegetation increased slightly and amounted to 0.9–3.0 mm. The thickest were the lateral roots of white melilot plants, and the thinnest were those of red clover.

In the third year of vegetation of perennial legumes, the depth of penetration of their roots into the soil continued to increase and amounted to 100-432 cm. The roots of alfalfa were most deeply penetrated into the soil, and the roots of birdsfoot trefoil were the least deep. The radius of horizontal distribution of the root system of legume grasses was 22-37 cm. It was the largest in alfalfa plants, and the smallest – in birdsfoot trefoil. Compared to previous years of observation, the radius of the root system of alfalfa increases significantly.

The depth of the main mass of branching of the root system of legumes was 27-39 cm at the end of the third year of vegetation. It was largest in the Hungarian sainfoin and eastern galega, and the smallest – in the birdsfoot trefoil. The thickness of the root neck of legume grasses at the end of the third year of vegetation was 11-25 mm. It was the largest in alfalfa plants, and the smallest – in birdsfoot trefoil. The number of buds on the root neck continued to grow and amounted to 16-70 pcs. Most of them were in the birdsfoot trefoil, and the least – in the eastern galega.

The thickness of the central root of legume grasses was 4-10 mm. It was the largest in the plants of Hungarian sainfoin, and the smallest – in birdsfoot trefoil. The thickness of the lateral roots of legume grasses was 1.1–2.1 mm. It was the largest in alfalfa plants, and the smallest – in eastern galega.

In the fourth year of vegetation of perennial grasses, the depth of penetration of their roots was 122-813 cm. The root system of alfalfa was the deepest, and the least deep – in the eastern galega and birdsfoot trefoil. Compared to the previous year, the depth of penetration into the soil of the roots of the birdsfoot trefoil increased and the eastern galega – decreases.

The radius of horizontal distribution of the root system of legume grasses was 22-37 cm. It was the largest in alfalfa plants, and the smallest – in birdsfoot trefoil plants. The depth of the main mass of branching of the root systems of perennial grasses was 29-47 cm. It was the largest in the plants of Hungarian sainfoin, and the smallest – in birdsfoot trefoil.

The thickness of the root neck of plants in the fourth year of vegetation was 13-33 cm. It was the largest in alfalfa plants, and the smallest – in birdsfoot trefoil. The number of renewal buds on the root neck of plants was 20-89 pcs. Most of them were in the birdsfoot trefoil, and the least – in the eastern galega.

The thickness of the central root of legume grasses was 5-14 mm. The thickest root was observed in the plants of Hungarian sainfoin and eastern galega, and the thinnest – in birdsfoot trefoil. Compared to the previous year, the thickness of the central root in eastern galega has significantly increased. The thickness of the lateral roots of plants was 1.3-2.3 mm. It was the thickest in alfalfa plants, and the thinnest – in birdsfoot trefoil and easterm galega.

Dynamics of root system growth and development over all years of study

Analysing the change in the depth of root distribution of perennial legume grasses during all growing years, it was found that during the first two years, the depth of root distribution in all plants was similar. Starting from the third year, there was an intensive growth of alfalfa roots and a slowdown in the root growth of birdsfoot trefoil and eastern galega.

In the second year of vegetation, the depth of penetration of alfalfa roots increased 3.1 times, in the third year – 1.7 times, and in the fourth – 1.9 times. The depth of white melilot roots in the second year increased 3.3 times. The depth of red clover roots in the second year increased by 3.3 times, but their distribution in depth was much less than that of white melilot and alfalfa plants. The roots of Hungarian sainfoin developed similar to the deepening of red clover roots. Their depth in the second year increased by 2.7 times, in the third –1.5 times, and in the fourth – 1.2 times. The roots of birdsfoot trefoil and eastern galega were least widespread in depth: in the second year, their depth increased by 2.0-2.1 times, in the third year – 1.1-1.2 times, in the fourth – 1.0-1.3 times.

The dynamics of changes in the radius of horizontal distribution of grass roots during all the years of vegetation was more uniform. A significant increase in this indicator was typical for all types of perennial grasses during the first year of vegetation.

A significant increase in the root distribution radius in alfalfa plants occurred in the third year of vegetation – 1.3 times; Hungarian sainfoin plants – in the second and third years of vegetation – 1.5 times each; eastern galega plants – in the second year of vegetation – 1.7 times. A significant increase in the root distribution radius of red clover and white melilot was observed in the second year of vegetation – 1.5 times. The root radius of birdsfoot trefoil plants grew evenly throughout all the years.

The depth of distribution of the main mass of roots in alfalfa plants increased most rapidly: in the second year of vegetation – by 1.7 times, in the third year – by 1.3 times, in the fourth – by 1.2 times. Intensive growth of the depth of the main mass of Hungarian sainfoin roots was observed in the second year of vegetation – 1.5 times and in the fourth year – 1.2 times. The depth of the main mass of white melilot roots in the second year of vegetation increased 1.7 times. The remaining herbs changed the depth of the main mass of roots evenly.

The number of renewal buds on the root neck of perennial legume grasses increased evenly during the growing season. The most intensive increase in their number was characteristic of birdsfoot trefoil: in the second year of vegetation – 1.6 times, in the third year – 1.4 times, in the fourth – 1.3 times. In Hungarian sainfoin and alfalfa plants, the number of buds was similar over the years and increased by 2.1 times in the second year, by 1.4 times in the third year, and by 1.2 times in the fourth year. The number of buds on the root neck of red clover in the second year of vegetation increased by 2 times, and in white melilot, during the two years of vegetation, no changes were observed. The number of buds in eastern galega plants increased 1.3-1.5 times each year.

CONCLUSIONS

Based on the conducted studies and comparisons of biometric indicators of root systems of various types of perennial legumes, the following conclusions can be made:

– the root system of alfalfa is characterised by the largest: penetration into the soil, spread of the roots in a horizontal direction; thickness of the root neck during all the years of vegetation, thickness of the lateral roots during the third or fourth years of vegetation, but the smallest distribution in the soil of the main mass of root branching in the year of sowing and the following year of vegetation. Such features of the root system development ensure the plasticity, durability, and productivity of alfalfa;

– the root system of white melilot is characterised by the largest: penetration into the soil, thickness of the root neck, central root and lateral roots during all the years of vegetation, horizontal spread of roots in the second year of vegetation, but the smallest number of renewal buds on the root neck during all the years of vegetation. These features determine the high drought and frost resistance of white melilot;

– the root system of the birdsfoot trefoil has the largest number of renewal buds on the root neck during all the years of vegetation. However, the plant had the smallest penetration into the soil, thickness of the root neck and the central root during all the years, radius of horizontal root spread and the depth of the main mass of root branching in the second or fourth years of vegetation, which determines its productive longevity and ability to grow on low-productive and acidic soils;

– the root system of eastern galega iss characterised by the largest: depth of the main mass of roots in the soil in all years, the horizontal spread of roots in the second year of vegetation, the thickness of the central root in the fourth year, but the smallest: depth of roots in the soil in the fourth year, thickness of the root neck during the first year and thickness of the side roots during the second, third, and fourth years of vegetation, the number of renewal buds on the root neck during the third and fourth years of vegetation. Such characteristics determine the productive longevity and high biological plasticity of eastern galega;

– the root system of Hungarian sainfoin was characterised by the greatest: horizontal spread of roots and the deepest placement of the main mass of root branching in the third or fourth years of vegetation; thickness of the central root during the second to fourth years. Thus, Hungarian sainfoin plants form a powerful root system in the third and fourth year of vegetation, which determines high biological resistance to adverse growing conditions;

– the root system of red clover has the smallest radius of horizontal root distribution, the thickness of the central root and the thickness of the lateral roots during all the growing years, which affects the possibility of its cultivation in the field crop rotation.

Expanding knowledge about the biological and morphological features of the distribution of root systems of perennial legume grasses during the growing season and in comparison with each other would allow the researchers to understand the processes occurring in plants, as well as select the optimal types of legumes for certain purposes in the context of climate change.

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БІОЛОГІЧНІ ОСОБЛИВОСТІ ПОШИРЕННЯ КОРЕНЕВИХ СИСТЕМ БОБОВИХ БАГАТОРІЧНИХ ТРАВ В УМОВАХ ЗМІНИ КЛІМАТУ

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Анотація. Визначальним чинником при виборі бобових багаторічних трав за умов змін клімату є їх посухостійкість, адже розвиток коренів прямо впливає на цю властивість, а також визначає їх продуктивність. Метою досліджень було встановити, за рахунок яких морфологічно-біологічних характеристик коренів трав забезпечуються господарські особливості в умовах змін клімату. Застосовували методи спостереження, порівняння, польового досліду. З'ясовано, що корені люцерни посівної мають найбільше заглиблення у ґрунт, поширення у горизонтальному напрямі, товщину кореневої шийки та бічних корінців, що забезпечує пластичність, довговічність і продуктивність її посівів. Встановлено, що корені буркуну білого мають найбільше заглиблення у ґрунт, товщину кореневої шийки, центрального кореня і бічних корінців, їх поширення у горизонтальному напрямі, що впливає на посухо- і морозостійкість рослин. Обґрунтовано, що корені лядвенцю рогатого відзначаються найбільшою кількістю бруньок відновлення на кореневій шийці, найменшим заглибленням, товщиною кореневої шийки, що впливає на продуктивне довголіття та можливість росту на бідних і кислих ґрунтах. Виявлено, що корені козлятнику східного мали найбільше заглиблення основної маси, поширення у горизонтальному напрямі, товщину центрального кореня, що впливає на продуктивне довголіття і високу біологічну пластичність. Встановлено, що корені еспарцету піщаного відзначались найбільшим поширенням у горизонтальному напрямі та найглибшим розміщенням основної маси розгалужень, що впливає на високу біологічну стійкість до несприятливих умов вирощування. З'ясовано, що корені конюшини лучної мали найменший радіус поширення у горизонтальній площині, товщину центрального і бічних корінців, що визначає можливість її вирощування у польовій сівозміні. Зазначені наукові знання дозволять підібрати види бобових багаторічних трав для повної реалізації їх потенціалу за умов зміни клімату

Ключові слова: рослини, корені, підземний розвиток, морфологія, роки вегетації

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SOYBEAN PRODUCTIVITY DEPENDING ON THE ELEMENTS OF ORGANIC CULTIVATION TECHNOLOGY IN THE SHORT-TERM CROP ROTATION OF UKRAINIAN POLISSIA

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Abstract. Over the past decades, intensive farming has operated under conditions of progressive degradation of the soil cover, maintaining production levels only at the expense of inadequate expenditure of non-renewable energy resources. The soils have acquired irreversible excessive compaction in the sub-arable part of the profile, and the dehumification has acquired a threatening status. The humus content in the soils of Ukraine decreased by almost 25%, and the average annual losses amount to 0.6-0.7 t/ha. Therefore, the search for ways to guarantee the reproduction of soil organic matter, reliable control and restoration of the optimal humus status is extremely relevant. The purpose of the study is to activate natural nitrogen-fixing systems using a mix of green manure and by-products of agricultural crops of short-term leguminous crop rotation. Field experiments were conducted on light grey soils during 2018-2020 in the experimental field of Polissia National University in a leguminous short-term rotation system. This study uses general scientific methods to establish the area of research, plan and lay experiments, conduct observations and analysis; visual – during the implementation of phenological observations; field – to study the relationship with abiotic factors; physiological – to determine the symbiotic effectiveness of preparations of biological origin. The technology of growing agricultural crops in leguminous crop rotation, which ensures the supply of raw materials of organic origin and the accumulation of air nitrogen by root nodule bacteria, has been theoretically substantiated and improved. It is established that one hectare of crop rotation area receives 6.8 tonnes of dry organic raw materials, which corresponds to 78.3 kg/ha of biological nitrogen. It is found out that inoculation of soybean seeds with a preparation of biological origin – Optimise 400, and treatment of soybean crops at BBCH microstages 60-63 with a complex microfertiliser on a chelated basis Nanovit Super+Magnesium Sulphate contributes to the active development of nodule bacteria, the number and weight of which is 81-89 pcs per plant and 510-572 kg/ha. Thus, the active symbiotic potential was 34.2-38.9 thousand kg/day. It is proved that during the growing season soybeans generate 357-400 kg/ha of biological nitrogen in the air, which provides a seed yield of 2.96-2.64 t/ha and leaves 117-160 kg/ha of nitrogen in the soil. The practical value of this study lies in the possibility of enriching the soil with organic matter and the biological form of nitrogen

Keywords: soil fertility, crop rotation, seed inoculation, foliar dressing, soybean yield

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INTRODUCTION

Natural soil fertility deteriorates due to violations of scientifically based farming systems. The humus content in the soils of Ukraine decreased by almost 25%, and the average annual losses amount to 0.6-0.7 t/ha. The main reason for the loss of humus and nutrients is a catastrophic decrease in the application of organic fertilisers. The volume of production and application of organic fertilisers decreased by almost 15 times. If in 1990 the rate of application was about 10 t/ha per 1 ha, then in 2010 it was only 0.55 t/ha [1].

O.I. Furdychko [1] claims that the reduction of sown areas of legumes and perennial grasses, and a significant restriction on the application of organic fertilisers has led to the withdrawal from the cycle of almost 550 thousand tonnes of nitrogen. Due to the growth of the area under cultivation of energy crops, the intensive use of synthetic mineral fertilisers, the production of chemical plant protection products, the threat of chemical soil degradation and pollution of crop production increases. Threats of chemisation have led to the fact that the soil became "thin". The problem of intensive chemisation of soils was considered by many experts, in particular I.E. Ovsinskyi, one of the first to develop a system of agriculture that protects the soil from chemisation and allows obtaining environmentally friendly products [2].

The most important feature of ecological agriculture is the activation of natural nitrogen-fixing systems that accumulate biological nitrogen using leguminous crops [3]. In this regard, there is a need to find affordable and low-cost and economically justified measures to preserve and restore soil fertility, one of which is the mix of green manure with by-products of agricultural crops, especially straw, crop and root residues.

Straw contains macro- and microelements and becomes a source of plant nutrition after mineralisation in the soil. Approximately 180 kg of humus is synthesised from 1 tonne of straw. In addition, the straw of grain crops contains a large amount of nitrogen-free substances, which delays the biological processes of straw decomposition. For the mineralisation of straw, it is necessary to add 10-15 kg of mineral nitrogen or biogenic decomposers for each tonne [4].

Green fertiliser and bacterial preparations are the cheapest and best way to comprehensively restore soil fertility [5]. The use of green manure in combination with crushed straw, peat and partially with manure increases humus content in the soil by 0.10-0.12%, total nitrogen by 0.011%, mobile forms of phosphorus and potassium by 5-6 mg/100 g of soil [6]. The combined use of by-products of the predecessor and post-harvest crops of the cabbage green manure contributes to an increase in the humus content by 0.09% [7].

The potential of crop production can be fulfilled only through high soil fertility and improvement of its functional properties. Reproduction of soil fertility is one of the main levers for increasing the yield of various crops and the productivity of agricultural systems as a whole [8]. Symbiosis of legumes with nodule bacteria is one of the most effective systems of biological nitrogen fixation, which is of great ecological and practical importance. In rhizobium-legume symbiosis, a combination of global biological processes – nitrogen fixation and photosynthesis – is achieved, which normalises the nitrogen-carbohydrate balance of the plant organism [9; 10]. It is proved that nitrogen fixation occurs slowly at the initial stages, but by the phase of full flowering, the activity and raw weight of root nodules reaches maximum [11]. Under optimal conditions of symbiotic nitrogen fixation, soybean plants can absorb up to 200 kg of biological nitrogen per ha [12-14], the absorbed nitrogen is used to form the soybean crop and 25-40% remains in the soil with organic residues, increases the content of humus and nitrogen in it.

The purpose of the study – to investigate the elements of organic technology, providing the soil with organic raw materials of short-term crop rotation and the symbiotic efficiency of nodule bacteria and the intake of biological nitrogen from the atmosphere.

MATERIALS AND METHODS

The study was carried out in accordance with the methodology of scientific research in agronomy [15]. Weather conditions, especially in 2019-2020, were dry, during the period of bean formation, the hydrothermal coefficient ranged from 0.1-0.9, which negatively affected the yield of field crops in rotation.

Productivity of short-term crop rotation was studied according to the following scheme:

1. Clover.
2. Winter wheat with the use of by-products and post-harvest green fertiliser.
3. Soy with the use of stem mass for fertiliser.
4. Barley with clover undersowing.

Studies on the effect of nitrogen-fixing, phosphorus-mobilising and complex microfertilisers in the form of EDTA chelate on the symbiotic productivity of soybeans are presented in the scheme:

1. Control – free of mineral fertilisers and pesticides.
2. Inoculation of seeds with Optimise 400.
3. Inoculation of seeds with phosphoroenterin.
4. Foliar dressing with a complex chelated fertiliser – Nanovit Super + magnesium sulphate.
5. Inoculation of seeds with Optimise 400 + phosphoroenterin.
6. Seed inoculation with Optimise 400 + foliar dressing (Nanovit Super + magnesium sulphate).
7. Inoculation of seeds with Optimise 400 + phosphoroenterin + foliar dressing;

The sown area is 33.6 (3.6x11) m^2, the accounting area is 25 (2.5x10) m^2, four-time replication.

The formation of nodules during the growing

season was determined by the method of G. S. Posypanov (number and weight of nodules, nitrogen content and fixation) [16]. Elements of the technology of growing agricultural crops in a short-term crop rotation are generally accepted for the zone of sufficient moisture (Ukrainian Polissia).

Nanovit Super is a highly effective multicomponent preparation with a high NPK content of magnesium, sulphur, boron, copper, manganese, molybdenum, zinc soluble in water, based on EDTA chelate and organic components. Magnesium sulphite promotes growth and development, increases yields, the number of beans and seeds, increases resistance to drought, diseases, and pests, reduces the nitrate content. Mg – increases the chlorophyll content.

Optimise 400 is created based on the LCOPromote technologies, it contains the following components: an active component containing a pure culture of nitrogen-fixing bacteria (Bradyrhizobium japonicum); liquid components that extend the survival time of bacteria on seeds. The Optimise 400 promotes the colonisation of the soybean root system with nitrogen-fixing bacteria, the formation of nodules on the roots, regardless of environmental conditions, improves germination, root system development, increases yield and protein content in soybean seeds. This preparation can be used in a tank mixture with some seed protectants.

Nodules are formed 10 days earlier than when using other preparations, early closing of plants in the row spacing, increases competitiveness in relation to weeds, improves the resistance of soybeans to harmful organisms. Phosphoroenterin is designed to improve phosphorus nutrition from the soil. The strain of bacteria that make up the drug is able to decompose hard-to-dissolve organic phosphates. The consumption rate is 100 mg/ha. The drug is compatible with growth stimulants, microorganisms.

RESULTS AND DISCUSSION

Intensive use of mineral fertilisers contributes to an increase in yield, but is accompanied by a deterioration in the biological, physico-chemical and phytosanitary properties of the soil. Excess nitrogen leads to a decrease in the synthesising activity of microorganisms and, in particular, nitrogen-fixing bacteria and to an increase in the content of nitrates and nitrites. Therefore, modern crop rotations provide for the saturation with legumes to attract air nitrogen to the biological cycle and use them for green fodder and fertiliser. For this purpose, it is recommended to use local organic fertilisers, raw materials of crop residues, and green manure crops.

According to the results of the study conducted in 2018-2020, it was found out that the grinding and wrapping of by-products in combination with an intermediate form of green fertiliser, the introduction into the short-term crop rotation of perennial legumes (clover), legumes (soybeans), per 1 ha of crop rotation area receives 6.8 tonnes of dry weight, of which 5.3 tonnes of by-products (straw, crop and root residues), which in terms of mineral nitrogen is 78.3 kg/ha. The main share of organic raw materials falls on the embedding in the soil of by-products of winter wheat and post-harvest use of oilseed radish for green manure (Fig. 1).

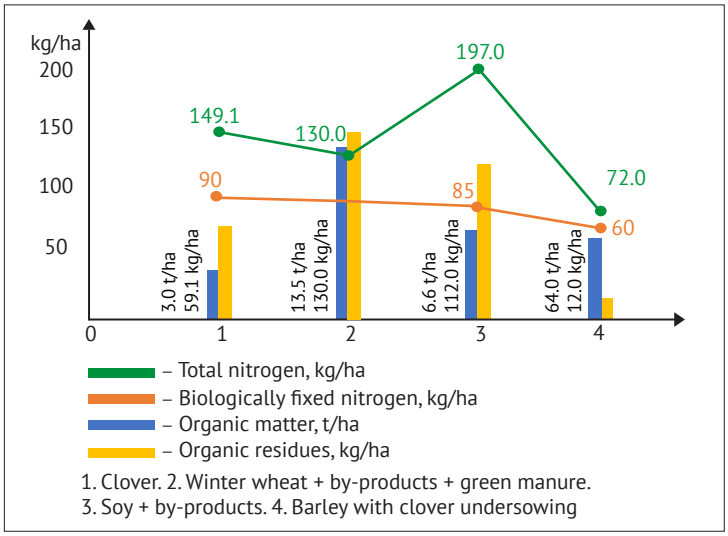

***Figure 1**. Intake of dry organic substance by weight and nitrogen in short term organic crop rotation*

The largest part of the supply of dry organic raw materials is obtained from by-products of straw, stubble and root residues and post-harvest sowing of oilseed radish for green fertiliser and is 13.5 t/ha and leafy soybean products, the share of which is 6.6 t/ha, that is, almost twice as much as clover and half as much as by-products of winter wheat with post-harvest green manure sowing. Calculations of nitrogen intake from by-products of winter wheat and green manure amount to 130 kg/ha, from soybeans – 112 kg/ha, and on average, 78.3 kg/ha is received per 1 ha of crop rotation area in 4-field crop rotation.

Biological fixation of air nitrogen by perennial legumes on average for 2018-2020 is 90 kg, and nodule bacteria fix 85 kg/ha. Figure 1 shows that the total nitrogen intake per 1 ha of crop rotation area is 137 kg/ha,

which is equivalent to 410 kg of ammonium nitrate. To form a soybean yield of 3.0 t/ha, 240 kg of nitrogen is needed, therefore, 170 kg of biological nitrogen remains in the soil with by-products for the next crop in the rotation.

The weight of nodules on the root system of soybeans, without the use of agrochemicals, pesticides, and preparations of biological origin, is only 0.56 g, in terms of 1 ha – 181 kg/ha. Inoculation of soybean seeds with the Optimise 400 nitrogen-fixing drug provides an increase in the weight of nodules on the root system twice and reaches 403 kg/ha, forming 302 kg of air nitrogen. Treatment of soybean crops in the flowering phase with a complex chelated EDTA microfertiliser against the background of sowing inoculated seeds, the number of nodules on the root system increases by 45-53 pcs, and their weight amounts to 510-572 kg/ha. The symbiotic active potential is 34.2-38.9 ths kg/day and the resulting nitrogen of biological origin is 357-400 kg, which is 230-273 kg more than the control variant. That is, nature provided 1.0-1.19 tonnes of nitrogen worth UAH 9-10 thousand.

The active symbiotic potential and total nitrogen depending on preparations of biological origin are shown in Figure 2.

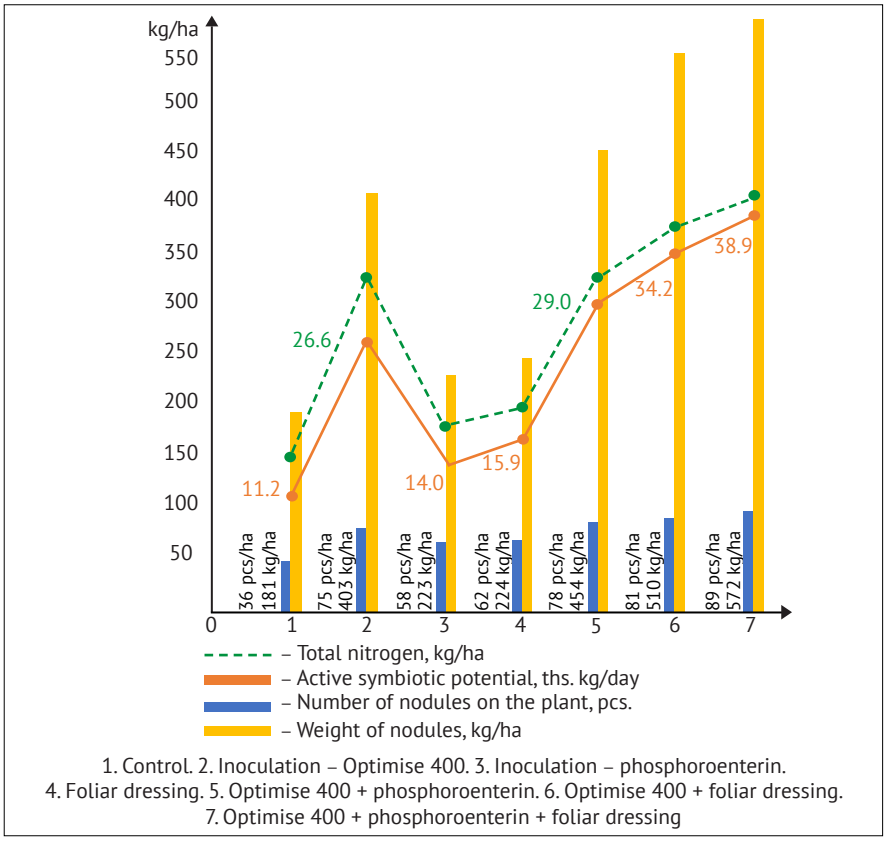

***Figure 2**. Symbiotic potential depending on preparations of biological origin*

Taking into account the fixation of air nitrogen by nodule bacteria: clover – 90 kg/ha; soybeans – 85 kg/ha, on average, 137.0 kg/ha of nitrogen is received per 1 ha of crop rotation area, which is equivalent to 410 kg/ha of ammonium nitrate worth about 4,000 UAH (Table 1).

***Table 1**. Productivity of short-term leguminous crop rotation (average for 2018-2020)*

Biological crop rotation	Yield of dry organic raw materials, t/ha				Biological nitrogen intake, kg/ha			
	Seeds	Straw, crop and root residues	Green manure	Organic matter	Organic residues	Biologically fixed nitrogen	Total nitrogen	Ammonium nitrate equivalent
1. Clover	–	3.0	–	3.0	59.1	90.0	149.1	446
2. Winter wheat + by-products + green manure	6.8	7.5	6.0	13.5	130.0	–	130.0	130
3. Soybean + by-products	2.3	6.6	–	6.6	112.0	85.0	197.0	590
4. Barley with clover undersowing	4.6	4.0	–	4.0	12.0	60.0	72.0	240
Total	–	21.1	6.0	27.1	313.1	235.0	548.1	1640
per 1 ha of crop rotation area, kg	–	5.3	1.5	6.80	78.3	58.7	137.0	410

The use of straw in combination with intermediate forms of green fertiliser is of great ecological importance. Straw, together with the green mass of manure, decomposes without polluting the soil with high concentrations of nitrate nitrogen and eliminates the leaching of trace elements into water bodies. The use of green manure contributes to the development of soil fauna, in particular, increases the vital activity of bacteria, earthworms and other soil organisms.

Spraying of soybean crops with complex fertilisers Nanovit Super + magnesium sulphate was carried out at BBCH microstages 60-65 (emergence of the first flower buds) before opening 50% of the flowers. According to the study results, it was found that preparations of biological origin have positively affected the activity of the process of forming a symbiotic apparatus.

Studying the action and interaction of nitrogen-fixing, phosphorus-mobilising preparations and complex microfertilisers on a chelated basis, it was found that nodule bacteria began to appear on the roots of soybean plants at BBCH microstages 12-13, which was not observed in the control group. Not all nodule bacteria formed on the roots are nitrogen-fixing, that is, active. If they have a pink colour, then they can be classified as active. Conversely, if the nodules are greenish or grey in colour, then nitrogen fixation does not occur in them.

During 2018-2020, at the BBCH microstages 61-71, the total number of nodules on the control variant was 36 pcs/ plant, of which active – 16 pcs/ plant (Table 2).

***Table 2**. Formation of the symbiotic potential of soybeans depending on biological preparations (bean filling phase (average for 2018-2020)*

Options	Seed yield, t/ha	Formation of nodules on the plant			Duration of active symbiosis, days	Symbiotic potential, thousand kg/day		Air nitrogen formation, kg/ha
		Quantity, pcs	Weight of nodules on the plant, g	Nodule weight, kg/ha		Total	Active	
Control	1.61	36	0.56	181	62	17.3	11.2	127
Inoculation – Optimise 400	1.99	75	1.12	403	66	30.8	26.6	302
Inoculation – phosphoroenterin	1.80	58	0.62	223	63	22.4	14.0	156
Foliar dressing	1.68	62	0.66	244	65	20.6	15.9	192
Optimise 400 + phosphoroenterin	2.21	78	1.18	454	64	33.2	29.0	318
Optimise 400 + foliar dressing	2.96	81	1.22	510	67	34.1	34.2	357
Optimise 400 + phospho-roenterin + foliar dressing	2.64	89	1.26	572	68	41.8	38.9	400
$LSD_{0.5}$	2018 – 0.07 t/ha; 2019 – 0.05 t/ha; 2020 – 0.10 t/ha							

Data in Table 2 shows that in the control group, the formation of nodules was the smallest, and their weight was only 0.56 g per plant. Taking into account the density of the stem before harvesting and the weight of nodules of one plant, it was determined that for the duration of 62 days, their total weight was 181 kg/ha, and the formation of symbiotic nitrogen from the air was 127 kg/ha, for the seed yield of 3.0 t/ha, it assimilates 240 kg. The weight of nodules on the root system is doubled and amounts to 1.12 g, with the duration of active symbiosis, the assimilation of biological nitrogen is 302 kg, of which 240 kg is used to form crops and 62 kg remains in the soil. Carrying out inoculation of soybean seeds with phosphoroenterin does not contribute to the activation of the development of nodule bacteria, since the strains of bacteria that make up the preparation are able to decompose hard-to-dissolve organic phosphates only in soils rich in organic matter.

During growth and development, soy unevenly consumes nutrients, from flowering to seed filling, it uses 78.5% nitrogen, and during this interphase period, nodule bacteria die. Thus, it is necessary to carry out foliar dressing with a multicomponent composition of macro- and microcomponents based on EDTA chelate. With the help of reduced nodule bacteria, soy is able to fix the biological nitrogen of the air, which ensures the yield of 4.0 t/ha.

The average yield of soybean grain in optimal weather conditions in 2018 was 2.73 t/ha, in arid conditions in 2019-2020, the yield indicators decreased by 0.88-1.17 t/ha. Treatment of soybean seeds with Optimise 400 inoculant provides an average yield increase of 0.38 t/ha for 2018-2020, spraying of crops at BBCH microstages of 61-71 with a complex chelated EDTA microfertiliser Nanovit Super + magnesium sulphate against the background of seed inoculation, the yield was 2.96 t/ha, which is 1.35 t/ha more compared to the control.

CONCLUSIONS

The results of studies conducted on light grey soils, seed treatment with inoculants, and foliar dressing with a multi-complex preparation Nanovit Super in a tank mixture with magnesium sulphate ensure a yield of environmentally friendly soybean products up to 3 t/ha. Short-term 4-field grain-legume crop rotation during the growing season forms the yield of dry organic matter per 1 ha of crop rotation area – 6.8 tonnes, the share of winter wheat straw and post-harvest crops of green fertiliser and soybean stem mass amount to 72%.

The nitrogen of organic residues – 78.3 kg/ha and the biologically fixed nitrogen of perennial legumes and soybeans per 1 ha of crop rotation area – 58.7 kg, thus, the total amount of nitrogen received – 137 kg/ha. Inoculation of soybean seeds with the nitrogen-fixing preparation Optimise 400 increases the growth of nodules on the root system by almost twice. High fixation of biological nitrogen was obtained by inoculation of seeds and foliar dressing with a complex chelated microfertiliser Nanovit Super + magnesium sulphite + phosphoroenterin, which amounts to 400 kg/ha.

Prospects for further study of the elements of organic soybean cultivation technology consists in analysing innovative biologic compounds based on live soil microorganisms and their metabolites, including Bio Stim-Niva degrader, nitrogen-fixing and phosphorus-mobilising biologics, in order to stabilise and reproduce soil fertility.

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ПРОДУКТИВНІСТЬ СОЇ ЗАЛЕЖНО ВІД ЕЛЕМЕНТІВ ОРГАНІЧНОЇ ТЕХНОЛОГІЇ ВИРОЩУВАННЯ В КОРОТКОРОТАЦІЙНІЙ СІВОЗМІНІ ПОЛІССЯ УКРАЇНИ

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Анотація. Інтенсивне землеробство протягом останніх десятиріч функціонувало в умовах прогресуючої деградації ґрунтового покриву, підтримуючи виробничий рівень лише за рахунок неадекватних витрат невідновлюваних ресурсів енергії. Ґрунти набули незворотнього надмірного ущільнення в підорній частині профілю, а процес дегуміфікації набрав загрозливого статусу. Вміст гумусу в ґрунтах України знизився майже на 25 %, а середньорічні втрати становлять 0,6–0,7 т/га. Тому пошук шляхів гарантованого відтворення органічної речовини ґрунту, надійного контролю та відновлення оптимального гумусового стану є надзвичайно актуальними. Мета наукових досліджень полягає в активізації природних азотфіксуючих систем з використанням зеленої маси сидератів у суміші з побічною продукцією сільськогосподарських культур коротко-ротаційної зернобобової сівозміни. Польові досліди проводилися на ясно-сірих ґрунтах впродовж 2018–2020 рр. на дослідному полі Поліського національного університету у коротко-ротаційній зернобобовій сівозміні. У статті використовуються загальнонаукові методи для встановлення напряму досліджень, планування і закладання дослідів, проведення спостережень та аналізу; візуальний – під час здійснення фенологічних спостережень; польовий – для дослідження взаємозв'язку з абіотичними чинниками; фізіологічний – для визначення симбіотичної ефективності препаратів біологічного походження. Теоретично обґрунтовано та удосконалено технологію вирощування сільськогосподарських культур у зернобобовій сівозміні, яка забезпечує надходження сировини органічного походження та накопичення азоту повітря бульбочковими азотфіксаторами. Встановлено, що на один гектар сівозмінної площі надходить 6,8 тонн сухої органічної сировини, що відповідає 78,3 кг/га біологічного азоту. З'ясовано, що проведення інокуляції насіння сої препаратом біологічного походження – азотфіксатором Оптимайз 400 і оброблення посівів сої за мікростадіями ВВСН 60-63 комплексним мікродобривом на хелатній основі Нановіт Супер + сульфат магнію сприяє активному розвитку бульбочкових бактерій, кількість і маса яких становить 81–89 шт. на рослину та 510–572 кг/га. Таким чином активний симбіотичний потенціал становив 34,2–38,9 тис. кг/діб. Доведено, що за вегетаційний період соя формує 357–400 кг/га біологічного азоту повітря, що забезпечує урожайність зерна 2,96–2,64 т/га і залишає в ґрунті 117–160 кг/га азоту. Практична цінність наукової роботи полягає в збагаченні ґрунту органічною речовиною та біологічною формою азоту

Ключові слова: родючість ґрунту, сівозміна, інокуляція насіння, позакореневе підживлення, урожайність сої

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CLUSTER ANALYSIS OF *TRITICUM L.* SAMPLES OF DIFFERENT ECOLOGICAL AND GEOGRAPHICAL ORIGIN

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Abstract. This research paper is devoted to the application of cluster analysis for evaluating samples of soft spring wheat by elements of crop structure. The purpose of the study is to analyse the intraspecific and interspecific variability of morphological features of samples of spring wheat of various ecological and geographical origin according to 8 morphological features. Observations were carried out in 2018-2020 in the training and experimental production centre "Doslidne pole" of the Kharkiv National Agrarian University named after V.V. Dokuchaev. The cluster analysis of the collection of spring wheat samples, which included 76 samples of various ecological and geographical origin, allowed the study to assess the following features: the presence of awns, the colour of awns, the colour of ear scales, the pubescence of leaves, the pubescence of the subcrown internode, the pubescence of the ear internode, the colour of caryopsis, the colour of straw. The results of analysis of the phylogeny of various types of spring wheat by cluster analysis using morphological markers to determine homogeneous groups are presented, and the affected tree of systematic formation of clustering groups is established. Based on the cluster analysis, two separate groups of soft spring wheat samples were identified according to the complex of plant productivity elements. Samples are grouped into each cluster depending on the quantitative characteristics of the crop structure and their interaction with each other. In general, all samples over the years of study showed good results, namely based on "colour of awns", of particular note are the samples of the *Tr. persicumspecies*. According to the results obtained, all samples have good indicators, and cluster analysis of soft spring wheat samples allowed identifying groups of plants that exceed the parent forms in the optimal set of economically valuable traits, which would allow for a more purposeful selection of valuable forms based on certain traits

Keywords: model, clustering, cluster, dendrogram, evaluation, spring wheat

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INTRODUCTION

Morphological aspects of spring wheat productivity are very important in scientific research, in particular, how exactly morphological features affect the food qualities of the investigated crop. It is the value of morphological features that allows establishing varieties of spring wheat. According to morphological features, wheat species are grouped into two groups: common wheat and spelt. Ecological polymorphism of spring wheat samples can serve as a source of variations for use in breeding, causing the formation of updated forms of economically valuable wheat plants with improved properties. Imperfect genetic information about hereditary material can reduce the effectiveness of breeding activities, since it is not possible to create seed material that is more resistant to adverse factors. Therefore, the conservation of genetic resources and the assessment of their diversity is very important in further studies [1; 2].

To obtain reliable results, when choosing a specific method of cluster analysis, classification was chosen to get more detailed information about the morphological features of the studied samples. Cluster analysis is the only method for organising objects that have the same characteristics. It is used when studying the structure of aggregates of socio-economic indicators or objects: enterprises, regions, sociological questionnaires, collectives. The main purpose of cluster analysis is to divide the set of objects and features under consideration into homogeneous groups or clusters. Cluster analysis is widely used in marketing research. If it is necessary to classify a set of certain information into groups for further processing, cluster analysis is very effective. An achievement of cluster analysis is the ability to split objects not by one parameter, but by a number of features. Also, cluster analysis, unlike most mathematical and statistical methods, does not impose any restrictions on the type of objects under consideration, and allows studying a set of data of arbitrary nature [3; 4].

The analysed literature data on grain production in the world for the period 1965-2019 [5] indicate that the area of grain crops almost does not change, but their yield during this period increased from 1.49 to 3.29 t/ha, or 2.2 times. It was the highest in the EU countries – 5.60 t/ha, the lowest – in the CIS countries – 1.95 t/ha [6]. According to some researchers, the contribution of breeding to yield growth reaches 50% [7; 8], and the study of morphological indicators by cluster analysis of genotypes is a very relevant issue. A very important world-class task is to search for highly productive genotypes for arid conditions, especially cereals. A negative trend is recognised as a drop in yields in South-Eastern Europe [9; 10].

The purpose of the study is to investigate the intraspecific and interspecific variability of the collection of spring wheat samples of various ecological and geographical origin in the conditions of the eastern forest-steppe of Ukraine by 8 morphological features. For the furtherance of this goal, the following *tasks* were set: to assess the genetic divergence of the investigated plant material; based on the results obtained, to draw a conclusion about the phylogenetic relationships between the spring wheat species involved in this study.

MATERIALS AND METHODS

The source material was represented by 76 samples of *Triticum aestivum* (10 pcs.) and *Triticum durum* (10 pcs.); sparsely distributed: (*Monococcum* (8 pcs.), *boeoticum* (1 pc.), *sinskajae* (1 pc.), *timopheevii* (1 pc.), *militinae* (1 pc.), *dicoccum* (9 pcs.), *ispahanicum* (1 pc.), *persicum* (2 pcs.), *turgidum* (3 pcs.), *aethiopicum* (1 pc.), *spelta* (9 pcs.), *compactum* (4 pcs.) and *amphidiploid samples* (15 pcs.). The source material was obtained from the National Centre for Plant Genetic Resources of Ukraine (NCPGRU) and has a number of economically valuable features. Samples were introduced from different ecological and geographical areas (Table 1-3), differ not only in economically valuable characteristics (weight of 1000 seeds, duration of the growing season, plant height, etc.), but also is characterised by different gradations of morphological features (presence or absence of awns, colour of awns, colour of caryopsis, colour of straw, pubescence of leaves, pubescence of the ear internode, pubescence of the subcrown internode).

Table 1. *Characteristics of the studied samples Triticum aestivum and Triticum durum*

No.	National catalogue number	Institution registration number	Sample name	Variety	Country of origin*
			Triticum aestivum		
1	UA0100098	IR 08517S	Sunnan	*var. lutescens*	SWE
2	UA0101113	IR 11742S	Prokhorovka	*var. lutescens*	RUS
3	UA0104110	IR 12602S	Kharkivska 30	*var. lutescens*	UKR
4	UA0106145	IR 13173S	L 501	*var. lutescens*	RUS
5	UA0110938	IR 15164S	Simkodamironivska	*var. lutescens*	UKR
6	UA0111008	IR 15206S	Yrym	*var. erythrospermum*	KAZ

Table 1, Continued

No.	National catalogue number	Institution registration number	Sample name	Variety	Country of origin*
			Triticum aestivum		
7	UA0105661	IR 12049S	CIGM.250-	*var. erythrospermum*	MEX
8	UA0110937	IR 14892S	Fito14/08	*var. erythrospermum*	UKR
9	UA0110936	IR 14891S	Fito33/08	*var. erythrospermum*	UKR
10	UA0111123	IR 15595S	L 685-12	*var. lutescens*	UKR
			Triticum durum Desf		
11	UA0201229	IR 12313S	Zolotko	*var. muticohorde-iforme*	UKR
12	UA0201199	IR 13580S	Orenburgskaya 21	*var hordeiforme*	RUS
13	UA0201431	IR 14943S	Nurly	*var. hordeiforme*	KAZ
14	UA0201201	IR 14045S	Slavuta	*var. leucomelan*	UKR
15	UA0200923	IR 12773S	Bukuria	*var. melanopus*	UKR
16	UA0201428	IR 14941S	Altyn Shygys	*var. hordeiforme*	KAZ
17	UA0201386	IR 14438S	Metiska	*var. melanopus*	UKR
18	UA0201452	IR 15566S	Novatsia	*var hordeiforme*	UKR
19	UA0201453	IR 15548S	Diana	*var. hordeiforme*	UKR
20	UA0201426	IR 14937S	Kustanayskaya 80	*var. hordeiforme*	KAZ

Note: **SWE – Sweden; RUS – Russia; UKR – Ukraine; KAZ – Kazakhstan; MEX – Mexico*

Table 2. *Characteristics of the studied samples of the genus Triticum L.*

No.	National catalogue number	Species	Variety	Country of origin*
21	UA0300104	*monococcum*	*var. vulgare*	BGR
22	UA0300221	*monococcum*	*var. monococcum*	AZE
23	UA0300223	*monococcum*	*var. vulgare*	ALB
24	UA0300254	*monococcum*	*var. monococcum*	ARM
25	UA0300282	*monococcum*	*var. monococcum*	HUN
26	UA0300310	*monococcum*	*var. hohensteinii*	GEO
27	UA0300311	*monococcum*	*var. nigricultum*	SYR
28	UA0300313	*monococcum*	–	HUN
29	UA0300008	*dicoccum*	*var. aeruginosum*	RUS
30	UA0300327	*dicoccum*	*var. aeruginosum*	RUS
31	UA0300407	*dicoccum*	*var. nudidicoccum*	UKR
32	UA0300406	*dicoccum*	*var. nudirufum*	UKR
33	UA0300199	*dicoccum*	*var.pseudogunbadi*	IRN
34	UA0300009	*dicoccum*	*var.serbicum*	RUS
35	UA0300183	*dicoccum*	*var.serbicum*	RUS
36	UA0300021	*dicoccum*	*var. volgense*	KAZ
37	IU070615	*dicoccum*	*var.submajus*	BGR
38	UA0300238	*spelta*	*var.subbaktiaricum*	UZB
39	UA0300304	*spelta*	*var.album*	AUS

Table 2, Continued

No.	National catalogue number	Species	Variety	Country of origin*
40	UA0300387	*spelta*	*var.caeruleum*	CAN
41	UA0300388	*spelta*	*var.duhamelianum*	CAN
42	UA0300391	*spelta*	*var.caeruleum*	CAN
43	UA0300392	*spelta*	*var.alefeldii*	CAN
44	UA0300398	*spelta*	*var.arduini*	UKR
45	UA0300443	*spelta*	*var.caeruleum*	RUS
46	UA0300546	*spelta*	*var.caeruleum*	RUS
47	UA0300240	*compactum*	*var.erinaceum*	ARM
48	UA0300354	*compactum*	*var.pseudoicterinum*	GRC
49	UA0300368	*compactum*	*var.humboldtinflatum*	CHN
50	UA0300528	*compactum*	*var.kerkianum*	GEO
51	UA0300110	*turgidum*	*var. plinianum*	KGZ
52	UA0300237	*turgidum*	*var.rubroathrum*	GRC
53	UA0300376	*turgidum*	–	BGR
54	UA0300490	*persicum*	*var. persicum*	GEO
55	UA0300495	*persicum*	*var. rubiginosum*	GEO
56	UA0300402	*boeticum*	*var. boeticum*	UKR
57	UA0300224	*sinskajae*	*var. sinskajae*	RUS
58	UA0300545	*timopheevii*	*var. nigrum*	BLR
59	UA0300257	*militinae*	*var. militinae*	RUS
60	IU0700070	*ispahanicum*	*var. ispahanicum*	IRN
61	IU070589	*aethiopicum*	*var.nigriviolaceum*	ERI

***Note**: *RUS – Russia; UKR – Ukraine; KAZ – Kazakhstan; GRC – Greece; BGR – Bulgaria; Aze – Azerbaijan; ALB – Albania; arm – Armenia; HUN – Hungary; GEO – Georgia, SYR – Syrian Arab Republic; BLR – Belarus, IRN – Iran; KGZ – Kyrgyzstan; UZB – Uzbekistan; AUS – Australia; CAN – Canada; ERI – Eritrea*

***Table 3**. Characteristics of the studied samples of the genus Triticum L.*

No.	National catalogue number	Sample name	Parentage	Country of origin	Institution of origin
62	UA0500004	PAG-12	*T. persicum* x *T. monococcum*	RUS	VIPI
63	UA0500007	PAG-20	*T. timococcum* x *T. monococcum*	RUS	VIPI
64	UA0500008	PAG-31	*T. dicoccum* i-329428, Poland x *T. monococcum* k-20636, Spain	RUS	VIPI, DRS VIPI
65	UA0500009	PAG-32	*T. dicoccum* k-14055, Armenia x **T. monococcum** i-452639, Czech Republic	RUS	VIPI, DRS VIPI
66	UA0500010	PEAG	*T. dicoccum* i-244569, Germany x *Ae. Tauschii* l-110	RUS	VIPI, DRS VIPI
67	UA0500014	*Triticum* x *kiharae*	*T. timococcum* x *Ae. Tauschii*	JPN	

Table 3, Continued

No.	National catalogue number	Sample name	Parentage	Country of origin	Institution of origin
68	UA0500018	*Haynatricum*	AD (*T. dicoccum-D. villosum*)	RUS	Moscow Timiryazev Agricultural Academy
69	UA0500022	AD8	*T. dicoccum* x *Ae. triuncialis*	AZE	ANAS Genetic Research Institute
70	UA0500023	PAG-13	*T. dicoccum* x *T. monococcum*	RUS	VIPI
71	UA0500024	PAG-39	*T. dicoccum* x k-150007, Poland x *T. sinskajae*	RUS	VIPI, DRS VIPI
72	UA0500025	*Triticum* x *timococcum*	*T. timopheevii* x *T. monococcum*	RUS	Moscow Timiryazev Agricultural Academy
73	UA0500026	*Triticum* x *sinskourarticum*	*T. sinskajae* x *T. urartu*	ARM	Armenian Agriculture University
74	UA0500043	PAG-4	*T. durum v. Stebutii* k-16477 x *T. monococcum v. macedonicum* k-18140	RUS	VIPI
75	UA0500044	PAG-7	*T. durum* x *T. monococcum*	RUS	VIPI
76	UA0300107	–	*T. timopheevii* x *timopheevii*	–	–

***Note**: *RUS – Russia; AZE – Azerbaijan; ARM – Armenia; JPN – Japan*

Observations were carried out in 2018-2020 in the training and experimental production centre "Doslidne pole" of the Kharkiv National Agrarian University named after V.V. Dokuchaev. Sowing was carried out at the optimal time for the crop in the first ten days of April. Collection samples were sown manually under a marker, in two rows 1 m long each with row spacing of 0.15 m, at the rate of 100 grains per linear meter. The registered area of the site for each sample was 1 m2. All phenological observations were carried out in accordance with the guidelines for studying wheat collections [11; 12]. To assess the intraspecific and interspecific variability of spring wheat, 30 plants of each study sample were analysed annually. Thus, 60 plants of each spring wheat sample were analysed over three years, and the total number was 6390 plants per year.

Observation, accounting, and biometric measurements were carried out in accordance with the "methodology for conducting an examination of plant varieties of the grain group for difference, uniformity, and stability" [12]. During phenological observations, the sowing period, emergence, phases of 2-3 leaves, tillering phase, tubing phase, flag leaf, earing, flowering, milk-wax ripeness, maturation were recorded [13; 14]. To group spring wheat genotypes using cluster analysis by traits, Euclidean distances were performed in STATISTICA 10. The obtained data was encoded and entered into a matrix for further processing of the results. Statistical analysis was performed using the Statistica 10 software.

To assess the intraspecific and interspecific diversity of spring wheat, the Shannon index was used, which allows assessing the heterogeneity of populations (1):

$$H` = -\sum \frac{nt}{N} ln \frac{nt}{N} \quad (1)$$

where H' – Shannon diversity index; nt – total number of species or intraspecific diversity; N – total number of detected individuals. The Shannon index is an informational indicator that has found wide application in the study of the species richness of biocenoses and the genetic diversity of plant organisms [15].

The frequency of morphological features was calculated in the CONVERT 1.31 software. The Shannon diversity index, Pielou alignment index, and standard deviation were calculated in Microsoft Excel. Genetic distances *Nei* and a phylogenetic tree were calculated using the *Phylip-3.69* software package. The reliability of the resulting phylogenetic relationship tree was verified using *bootstrap* analysis in 1000-fold repetition.

RESULTS AND DISCUSSION

In the period from 2018-2020, the morphological variability of the spring wheat collection was assessed, which showed the presence of polymorphism in all the studied features using cluster analysis. Analysis of the phenotypic variability of collection samples of spring wheat showed the presence of polymorphism of all studied features.

The advantage of the cluster analysis method is that the mathematical apparatus allows finding and selecting a pile of objects (points) that exists in the same space based on a simultaneous grouping by a large number of features [16; 17]. Using a dendrogram, it is possible to build and analyse information about the nature of relationships between samples at cluster levels and can detail relationships within its genotype [13; 2].

The cluster analysis allowed distributing the studied samples of the genus *Triticum L.* into three clusters. In the cluster analysis, the following characteristics were

chosen as the basis of the groupings: *awnedness – awnlessness*, awnlessness is the dominant feature to awnedness; *pubescence of spikelet scales*, this feature is mono- or digenic; *the colour of spikelet scales*. Dark colour is dominant relative to light; the *colour of the awns* – white, red, and black. The diversity of spring wheat varieties is controlled by one or more genes; *grain colour* – white, red, green, blue, purple (Fig. 1).

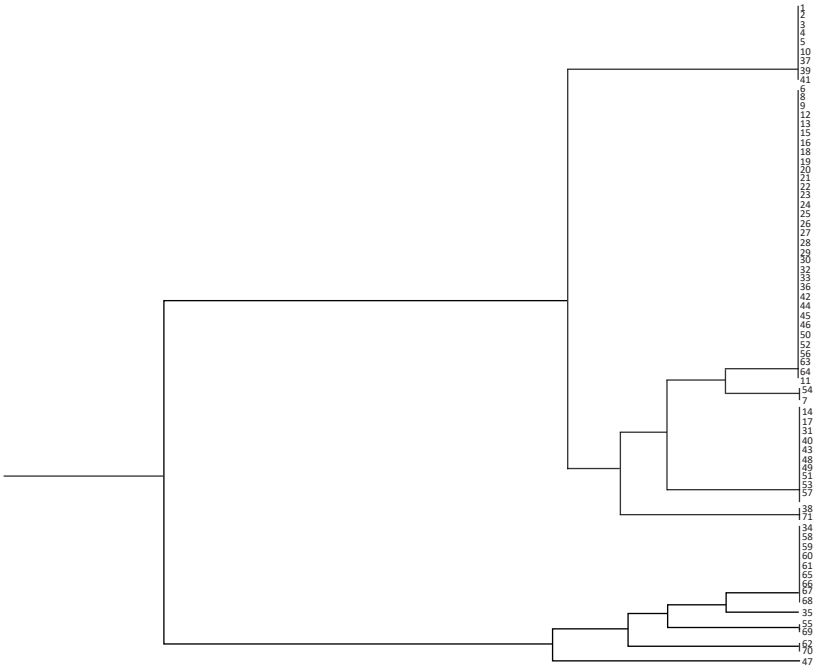

Figure 1. *Dendrogram of phylogenetic relationships between the studied samples of spring wheat based on the analysis of morphological features*

Note*: Triticum aestivum 1-10; Triticum durum Desf 11-20; Triticum monococcum 21-28; Triticum dicoccum 29-37; Triticum spelta 38-46; Triticum compactum 47-50; Triticum turgidum 51-53; Triticum persicum 54-55; Uncommon 56-61; Amphidiploid samples 62-76*

The main differential factors as a result of the conducted studies were: the presence or absence of awns, the colour of awns, the pubescence of ear scales, the pubescence of the subcrown internode, the pubescence of the ear internode, the colour of caryopsis, the colour of straw, the species affiliation of samples.

The first cluster contained a large number of samples, which can be divided into two subclusters. This cluster includes samples of the following species: ***Triticum aestivum***: Sunnan (Sweden); Prokhorovka (Russia); Kharkivska (Ukraine); L 501 (Russia); Simkodamyronivska (Ukraine); L685-12 (Ukraine); ***Triticum spelta*** UA0300304 (Australia); UA0300388 (Canada); UA0300392 (Canada). Characteristic phenotypic features of this cluster are: absence of awns, white colour of grain, white colour of ear scales, white colour of straw, no pubescence of all organs, but in the studied populations there were samples with other gradations of features. Collection samples were characterised by the greatest similarity and within this cluster were located on the same branch of the phylogenetic tree, which can be observed on the dendrogram.

Also, a common node in this block was formed by samples of ***Triticum aestium*** and ***Triticum durum*** species, namely: Yrym (Kazakhstan), Fito 14/08 (Ukraine), Fito 33/08 (Ukraine), Orenburgskaya 21 (Russia), Nurly (Kazakhstan); Bukuria (Ukraine); Altyn Shygys (Kazakhstan); Novatsiya (Ukraine); Diana (Ukraine); Kostanay 80 (Kazakhstan).

This cluster also includes samples of ***Triticum monococcum*** UA0300104 (Bulgaria); UA0300221 (Azerbaijan); UA0300223 (Albania); UA0300254 (Armenia); UA0300282 (Hungary); UA0300310 (Georgia); UA0300313 (Hungary); ***Triticum dicocum*** UA0300327 (Russia); UA0300407 (Ukraine); UA0300406 (Ukraine); UA0300199 (Iran); UA0300009 (Russia); ***Triticum spelta*** UA0300238 (Uzbekistan); UA0300387 (Canada); UA0300546 (Russia); ***Triticum compactum*** UA0300240 (Armenia); UA0300354 (Greece); ***Triticum turgidum*** UA0300376 (Bulgaria); ***Triticum persicum*** UA0300495 (Georgia); ***Triticum timopheevii*** UA0300545 (Belarus); ***Triticum durum x Triticum monococcum*** UA0500043 (Russia); UA0500044 ***Triticum durum x Triticum monococcum*** (Russia).

The second cluster contained samples of different species, namely: ***Triticum durum*** UA0201229 (Ukraine); a rare sample of spring wheat IU070589 (Eritrea); ***Triticum aestivum*** UA0105661 (Mexico); ***Triticum durum*** UA0201201 (Ukraine); UA0201386 (Ukraine); ***Triticum dicoccum*** UA0300199 (Iran); T*riticum spelta* UA0300391 (Canada); ***Triticum spelta*** UA0300443 (Russia); ***Triticum compactum*** UA0300528 (Georgia); ***Triticum turgidum*** UA0300237 (Greece); ***Triticum persicum*** UA030049 (Georgia); ***Triticum ispahanicum*** IU0700070 (Iran); ***Triticum militinae*** UA0300257 (Russia); ***Triticum spelta*** UA0300387 (Canada); ***Amphidiploid sample*** UA0500010 (Russia). Characteristic features of this cluster are: the presence of awns, white colour of awns, no pubescence of all organs, white colour

of grain, white color of straw. The third cluster contained the following samples: ***Triticum dicoccum*** UA0300021 (Kazakhstan); ***Triticum persicum x Triticum monococcum*** UA0500004 (Russia); ***Triticum timococcum x Triticum monococcum*** UA0500007 (Russia); ***Triticum dicoccum x Triticum monococcum*** UA0500009 (Russia); ***Triticum dicoccum x Ae. Tauschii*** UA0500010 (Russia); ***Triticum dicoccum-D.villosum*** UA0500018 (Russia); ***Triticum dicoccumю x Ae. triuncialis*** UA0500022 (Azerbaijan); ***Triticum dicoccum*** UA0500024 (Russia); ***Triticum dicoccum*** IU070615 (Bulgaria); Rarte samples: UA0300224 (Russia); Amphidiploids: ***Triticum x kiharae T. timococcum*** UA0500014 ***x Ae. Tauschii*** (Japan); UA0500025 ***Triticum x timococcum Triticum timopheevii x Triticum monococcum*** (Russia). UA0300107 ***Triticum timopheevii x Triticum timopheevii*** UA0300368 ***Triticum compactum*** (China).

Characteristic features of this cluster are: the presence of awns, white colour of awns, white colour of ear scales, pubescence of leaves, pubescence of the ear internode, pubescence of the subcrown internode [16] (Table 4).

Table 4. *Distribution of spring wheat traits by clusters*

Trait	Cluster		
	I	II	III
Presence of awns	Absent	Present	Present
Awns colour	–	White	White
Ear scales colour	White	White	White
Leaf pubescence	Absent	Absent	Pubescent
Subcrown internode pubescence	Absent	Absent	Pubescent
Ear internode pubescence	Absent	Absent	Pubescent
Caryopsis colour	White	White	White
Colour of straw	White	White	White

The results obtained on the basis of an assessment of the variability of morphological features confirm the genetic closeness of the species involved in the study. This may mean that the most likely scenario for the development of spring wheat species is the presence of a common ancestor, which marked the beginning of domestication of other forms. At the same time, the distribution of populations of different spring wheat species in each cluster, phenotypically different from the main population of samples of a particular group, indicates insufficient differentiating ability of morphological features.

All studied morphological features were polymorphic in spring wheat samples. The number of gradations of manifestation of each trait varied from 2 to 8. The maximum Shannon diversity index (H') in spring wheat samples was recorded based on the colour of awns in samples of *Tr. persicum*, it was (H'=0.98). According to this feature, spring wheat samples from most of the countries were characterised by the highest level of variability. A significant level of polymorphism in the total number of spring wheat samples was also distinguished by the presence of awns. In samples of *Tr. spelta* and *Tr. aestium* the maximum value of the Shannon index was 0.67, respectively. The least variable in the spring wheat samples were the signs of straw colour and grain colour (H'=0.0, respectively).

The total level of polymorphism of spring wheat samples by morphological features according to the Shannon index was 0.69.

Characteristics of spring wheat plants that were included in the first cluster when evaluating the indicator "presence of awns" samples of *Triticum aestium*, namely samples of Sunnan of Swedish selection, Prokhorovka of Russian selection and Kharkivska of Ukranian selection, have well-defined awns, also the first cluster included samples of Simkodamironivska of Ukrainian selection, L 685-12 of Ukrainian selection and sample UA0300304 of Austrian selection on the indicator pubescence of the subcrown internode and pubescence of the ear internode. According to the indicator of caryopsis straw colour, all the studied samples were included in the same cluster, because they had no differences.

According to a number of researchers, it is quite effective to conduct cluster analysis using various indicators to determine the parameters of difference and uniformity. Estimating the rearrangement of cluster structures is a rather cumbersome task and requires, in addition to morphological and morphometric, the use of other research methods [18].

CONCLUSIONS

Based on the conducted studies using cluster analysis in the technology of the breeding process during 2018-2020, samples and constant breeding lines were identified, balanced on economically useful traits, which can be used as promising breeding material, and parent components during hybridisation. The diversity of collection samples of spring wheat at the interspecific and intraspecific level was also assessed.

Based on the results of the study, it was confirmed that the advantage of cluster analysis in relation to statistical analysis is that cluster analysis allows identifying varieties and breeding lines by the balance on economically useful traits, and in the statistical analysis, it is possible to select and distinguish only certain quantitative features by their level of formedness and variability and yield.

In addition, the genetic similarity or remoteness of genotypes can be assessed using cluster analysis based on quantitative traits. The highest level of variability was observed in the sign of Awns colour in samples of *Tr. persicum* and was 0.98. Therefore, as a result of the research, the genetic structure of the collection of spring wheat samples of various ecological and geographical origin was assessed by morphological features. During the research, it was observed that the sample of spring wheat samples has a similar level of variability in these indicators. In the process of clustering spring wheat samples of different ecological and geographical origin, groupings were analysed, and the correspondence of each wheat sample to a specific cluster was evaluated. The data obtained can complement information about the genetic collection of spring wheat.

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КЛАСТЕРНИЙ АНАЛІЗ ЗРАЗКІВ *TRITICUM L.* РІЗНОГО ЕКОЛОГО-ГЕОГРАФІЧНОГО ПОХОДЖЕННЯ

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Анотація. Стаття присвячена застосуванню кластерного аналізу для оцінки зразків м'якої ярої пшениці за елементами структури врожаю. Метою дослідження є аналіз внутрішньовидової та міжвидової мінливості морфологічних ознак колекційних зразків пшениці ярої різного еколого-географічного походження за 8 морфологічними ознаками. Спостереження проводилися в 2018–2020 роках у навчально-дослідному виробничому центрі «Дослідне поле» Харківського національного аграрного університету ім. В.В. Докучаєва. Проведений кластерний аналіз колекції зразків пшениці ярої, до якої ввійшло 76 зразків різного еколого-географічного походження, дозволив одержати оцінку таких ознак: наявність остюків, забарвлення остюків, забарвлення колосових лусок, опушеність листків, опушеність стеблового міжвузля, опушеність колосового міжвузля, забарвлення зернівки, забарвлення соломини. Викладено результати аналізу філогенії різних видів пшениці ярої методом кластерного аналізу з використанням морфологічних маркерів з метою визначення однорідних груп і сформовано уражене дерево систематичного утворення кластеризаційних груп. За результатами проведеного кластерного аналізу виділено дві окремі групи зразків пшениці ярої м'якої за комплексом елементів продуктивності рослини. У кожен кластер зразки групуються залежно від кількісних ознак структури урожаю і їх взаємодії один з одним. Загалом усі зразки за роки дослідження показали гарні результати, а саме за ознакою «забарвлення остюків», особливо варто відмітити зразки виду *Tr. persicum*. Відповідно до отриманих результатів роботи всі зразки мають гарні показники, і кластерний аналіз зразків м'якої ярої пшениці дозволив виділити групи рослин, що перевершують батьківські форми по оптимальному набору господарсько-цінних ознак, що дозволить більш цілеспрямовано вести відбір цінних форм за певними ознаками

Ключові слова: модель, кластеризація, кластер, дендрограма, оцінка, пшениця яра

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THE CONTENT OF CHLOROPHYLL AND NUTRIENTS IN APPLE LEAVES DEPENDING ON LONG-TERM FERTILISER

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Abstract. An indicator of the condition of plants, depending on the growing conditions, is the state of their leaf apparatus, which is described by the content of chlorophyll and nutrients in the leaf. The leaf of an apple-tree provides synthesis of organic substances, productivity of fruit trees depends on features of its vital activity. As a method of diagnosing the mineral nutrition of fruit crops, the chemical analysis of the leaves is important, the indicators of which reflect the levels of plant nutrients. The results of studies of chlorophyll content and nutrients in the leaves of apple trees of Calville Blanc d'hiver on seed and Idared on seed and vegetative M4 rootstocks in re-grown plantations on mineral nutrition, created by long-term (over 86 years) application of various systems of comfort podzolized soil. Long-term use of organic and organo-mineral fertiliser systems contributed to an increase in chlorophyll content (*a+b*) in the leaves of Idared apple trees on seed and clone M4 rootstocks and Calville Blanc d'hiver on seed rootstock at different age periods of growth and fructification, which conditioned their further productivity. The content of macronutrients in the leaves of the studied cultivar combinations depended on the age of plantations and fertiliser options. In the most productive period of fructification in the leaves of Idared trees on seed and vegetative rootstocks, the nitrogen content in the areas of fertiliser options was within optimal limits. Among the studied rootstocks in the variant without fertilisers, the highest nitrogen content in the leaves was described by trees on the seed rootstock. In the leaf of the Calville Blanc d'hiver variety, the nitrogen content on the seed rootstocks in the studied variants was within the optimal range, and among the fertiliser variants the highest was for the application of mineral fertilisers. The content of phosphorus and potassium in the leaves of the trees of the studied rootstock combinations in the areas of fertiliser variants was within optimal limits

Keywords: Calville Blanc d'hiver, Idared, leaf, soil fertiliser, green pigments, age periods of fructification

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INTRODUCTION

The chemical composition of the vegetative organs of a plant reproduces the conditions of its nutrition, and its quantitative and qualitative features are crucial for plants to pass the corresponding phases of vegetation [1]. An indicator of the state of plants, depending on the growing conditions, is the state of their leaf apparatus, which is characterised by the content of chlorophyll and nutrients in the leaf. The apple leaf provides the synthesis of organic substances, and the productivity of fruit trees depends on the characteristics of its vital activity [2-4].

The pigmental system of leaves is one of the most important indicators of photosynthetic activity of plants. Its main components are green pigments – chlorophylls "*a*" and "*b*". Their accumulation in leaves, as well as in the entire plant, further affects the synthesis of biomass and, accordingly, the formation of tree harvest [5; 6]. In the studies [7; 8] on determining the content of chlorophyll in apple leaves, it was established that its concentration depends both on the cultivar, rootstock, period of determination, and on the conditions and level of mineral nutrition of fruit plants. It was also found that with a decrease in the rootstock spread, the chlorophyll content in the leaves of apple trees decreases [9].

Chemical analysis of leaves is important as a method for diagnosing mineral nutrition of fruit crops, the indicators of which reflect the levels of mineral nutrition elements in plants. Using this method, one can determine the excess of fertilisers applied, as well as their digestibility by trees. The content of the main elements of mineral nutrition in the organs of fruit trees depends on the cultivar, rootstock, age of plantings, load of trees with fruits [2; 10-12]. Optimal levels of content indicators of N, P_2O_5 and K_2O in the leaves of apple trees are, respectively, 1.8-2.5, 0.13-0.29, and 0.9-1.8% [13; 14].

Studies of the impact of long-term (since 1931) application of various fertiliser systems on the chemical composition of apple tree leaves that are re-grown on the site of an uprooted orchard are relevant. The passage of physiological processes in leaves has a significant connection with the accumulation of plant mass, so they play a leading role in the formation of the expected and future (laying generative formations) harvest. A decrease in the content of chlorophyll in the leaves negatively affects the condition of the plant, leads to a weakening of the shoots' growth. Enriched mineral nutrition backgrounds formed from long-term fertilisation have different effects on the physiological state and overall productivity of plantings. No studies were conducted on the content of pigments (the sum of chlorophylls "*a*" and "*b*") and nutrients (N, P_2O_5, and K_2O) in leaves during the age periods of growth and fructification of apple trees of various cultivar-rootstock combinations, depending on the long-term use of organic, organo-mineral, and mineral fertiliser systems. The experiment in which the research was conducted is a scientific object that is a national heritage "A unique research agroecosystem of the apple orchard of the Uman National Horticultural University".

The purpose of the study was to establish the effect of long-term fertiliser on the content of chlorophyll and nutrients in the leaves when re-growing apple trees of various cultivar-rootstock combinations.

MATERIALS AND METHODS

To study this question, the authors of the paper conducted research in a long-term experiment with various apple orchard fertiliser systems at Uman National University on dark gray podzolised soil with a humus content in layers of 0-20 and 20-40 cm, respectively, 2.41 and 2.23%, nitrogen (by nitrification capacity with 14-day composting) – 13.4 and 12.9 mg/kg of soil, P_2O_5 and K_2O (according to the Egner – Riem – Domingo method) 18.4 and 14.6, 28.9 and 27.4 mg/100 g of soil, pH – 5.2 and 5.3, the sum of the absorbed bases – 25.0 and 26.0 mg-eq/100 g of soil.

The experiment was founded by Professor S.S. Rubin in 1931. It was carried out over a 50-year period, after which it was reconstructed by uprooting old trees in 1982 and planting new ones in 1984, while preserving the previous variants and plots with the studied fertiliser systems, on which apple cultivars Idared and Calville Blanc d'hiver were planted on the seed rootstock and Idared on the vegetative M4 with a feeding area of 7x5 m. The scheme of long-term research included four options: without fertilisers (control), $N_{120}P_{120}K_{120}$, Manure 40 t/ha, 20 t/ha of manure + $N_{60}P_{60}K_{60}$.

During the research period, manure and phosphorous and potash mineral fertilisers were applied in the specified doses every other year in autumn while plowing the soil in row spacing, nitrogen – annually in spring while cultivating in half the norms. The soil in the experimental orchard was kept by a steam system. The content of chlorophyll in the leaves was determined by spectrometric method with extraction with ethanol, and elements of mineral nutrition – with wet combustion [15].

RESULTS AND DISCUSSION

Research data (Table 1) indicate that long-term fertilisation systems of apple plantations had different effects on the content of pigments in the leaves. During the period of growth and fructification (1994-1997), the amount of chlorophyll (*a*+*b*) in the leaves of the Idared apple tree on seed and clone M4 rootstocks was the highest in the variant with organic fertilisers, respectively, 283.0 and 269.6 mg/100 g of raw weight.

***Table 1**. The effect of rootstocks and fertiliser on the content of the sum of chlorophylls (a+b) in the leaves of the Idared apple tree, mg/100 g of raw weight*

Rootstock	Fertiliser variant	Indicators in different age periods of fructification		
		Growth and fructification period, 1990-1996	Fructification and growth period, 1997-2003	Fructification period, 2004-2016
Seed	Without fertilisers (control)	230.6	159.2	143.7
	Manure 40 t/ha	283.0	163.3	150.1
	20 t/ha of manure + N_{60} P_{60} K_{60}	266.4	174.5	152.0
	N_{120} P_{120} K_{120}	260.7	172.5	149.3
Clone M4	Without fertilisers (control)	228.5	155.1	140.7
	Manure 40 t/ha	269.6	160.5	152.1
	20 t/ha of manure + N_{60} P_{60} K_{60}	257.0	168.3	151.8
	N_{120} P_{120} K_{120}	250.7	165.7	150.1
	HIP_{05}	*10.3*	*6.1*	*5.9*

The period of fructification and growth (1997-2003) was characterised by a decrease in the amount of chlorophylls in all experimental variants, and the highest content was with organo-mineral fertiliser. During the period of full fructification of trees, the content of the sum of chlorophylls (*a+b*) significantly decreased compared to previous periods, and among the studied variants, it was the highest in the variant with the introduction of organo-mineral (152.0 mg/100 g), and on Clone M4 – in areas with the application of organic fertilisers (152.1 mg/100 g). Analysing the data on the amount of chlorophylls in the areas of the control variant (without fertilisers), there is a greater accumulation of chlorophyll in the leaves of trees on the seed rootstock compared to the vegetative one.

Analysing the data on the amount of chlorophylls in the variant without fertilisers, it can be noted that trees on the seed rootstock were distinguished by a significantly higher accumulation of chlorophyll in the leaves. In the leaves of the Calville Blanc d'hiver cultivar during growth and fructification, significantly more accumulation of the amount of chlorophylls was observed in the variant with organic fertilisers (255.2 mg/100 g) compared to other variants (Table 2). The introduction of organo-mineral fertilisers contributed to a greater accumulation of the amount of chlorophylls (*a+b*) in the leaves during fructification and growth and fructification. A significant excess of the indicator was noted only with the control.

***Table 2**. The content of the sum of chlorophylls (a+b) in the leaves of Calville Blanc d'hiver apple trees on the seed rootstock, depending on fertiliser mg/100 g of raw weight*

Fertiliser variant	Indicators in different age periods of fructification		
	Growth and fructification period, 1990-1996	Fructification and growth period, 1997-2003	Fructification period, 2004-2016
Without fertiliser (control)	234.9	141.7	140.5
Manure 40 t/ha	255.2	170.0	147.3
20 t/ha of manure + N_{60} P_{60} K_{60}	235.4	175.0	151.7
N_{120} P_{120} K_{120}	236.7	167.6	148.1
HIP_{05}	*11.4*	*7.2*	*5.1*

In the experiment, along with studying the content of pigments, the chemical composition of apple leaves was also studied depending on the fertiliser systems. The level of basic nutrients in trees plays an important role in the formation of the current year's harvest, and even more in the laying and differentiation of fruit formations for the next year's harvest, especially nitrogen. As the research results showed (Table 3), apple

leaves contained different amounts of nitrogen, phosphorus, and potassium in the fertilised areas of the experiment with fertiliser systems. The highest nitrogen content during the growth and fructification period of trees (1994-1996) was identified in the leaves of the Idared apple tree on both types of rootstocks in the version with half the norms of manure and full mineral fertiliser.

***Table 3**. The content of nutrients in the leaves of Idared apple trees depending on rootstocks and fertiliser in repeated cultivation, %*

Rootstock	Fertiliser variant	Indicators in different age periods of fructification								
		Growth and fructification period, 1990-1996			Fructification and growth period, 1997-2003			Fructification period, 2004-2016		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Seed	Without fertiliser (control)	2.72	0.35	1.74	2.06	0.40	1.28	2.22	0.17	0.98
	Manure 40 t/ha	2.89	0.37	1.85	2.17	0.42	1.34	2.37	0.20	1.02
	20 t/ha of manure + $N_{60}P_{60}K_{60}$	3.01	0.37	1.69	2.17	0.39	1.32	2.34	0.19	1.03
	$N_{120}P_{120}K_{120}$	2.91	0.35	1.74	2.11	0.39	1.30	2.30	0.18	1.04
Clone M4	Without fertiliser (control)	2.81	0.38	1.68	2.11	0.41	1.20	2.16	0.18	0.92
	Manure 40 t/ha	3.02	0.40	1.84	2.20	0.45	1.26	2.25	0.20	1.02
	20 t/ha of manure + $N_{60}P_{60}K_{60}$	3.07	0.35	1.80	2.22	0.42	1.25	2.27	0.21	1.04
	$N_{120}P_{120}K_{120}$	2.90	0.37	1.89	2.19	0.44	1.23	2.26	0.22	1.01
	HIP_{05}	*0.14*	*0.03*	*0.07*	*0.12*	*0.04*	*0.05*	*0.12*	*0.03*	*0.04*

In general, the nitrogen content at all the studied sites in the leaves of apple trees of this cultivar was significantly higher compared to the optimal content. The phosphorus content on all fertiliser backgrounds practically did not change, and compared to the optimal content, it was much higher. Fertilisation caused a significant increase in the potassium content in the leaves on the seed stock when applying organic fertilisers, and on M4 – mineral fertilisers compared to the control.

During the period of fructification and growth (1997-2003), a decrease in nitrogen content was observed for all experimental variants, and the highest content was observed for the application of organic and organo-mineral fertilisers on both types of rootstocks, respectively, 2.17, 2.20, and 2.22%. The phosphorus content decreased slightly compared to the previous period, although the indicators were higher than the optimal content. Potassium in the leaves was within the optimal level, and the introduction of 40 t/ha of manure contributed to a significant increase in this indicator in the leaves of the Idared cultivar on both types of rootstocks.

Analysing the data on the nitrogen content in the leaves, it can be noted that in 2004-2016 (the period of full fructification) in variants with systematic long-term fertilisation of the orchard with organic, organo-mineral, and mineral fertilisers which included nitrogen, its indicators exceeded the optimal levels for apple trees. In the control variant, the nitrogen content in the leaves was also within the optimal range, but significantly lower than in other variants. The content of P_2O_5 in the leaves of the apple tree was within the optimal level. Analysing the content of P_2O_5 in the leaves of Idared trees on seed and vegetative M4 rootstocks, one can note almost the same value (close to the lower limit of the optimal level). The potassium level in the leaves of experimental apple varieties was also within the optimal level, and the highest level was found in organic, organo-mineral, and mineral fertiliser systems, which significantly exceeded the indicators in the control version. The content indicators of K_2O in the control version were almost at the lower limit of the optimal level.

The highest content of nitrogen, phosphorus, and potassium in the leaves of the Calville Blanc d'hiver cultivar during the growth and fructification period of trees was in the variant of 20 t/ha of manure + $N_{60}P_{60}K_{60}$ (Table 4). All the studied variants in this period had higher indicators compared to the optimal ones. During the period of fructification and growth, significantly higher indicators of nitrogen and potassium in the leaves were with mineral fertiliser system ($N_{120}P_{120}K_{120}$), and phosphorus – with organic and organo-mineral fertiliser systems. During the period of full fructification, a similar effect of fertilisers on the content of nitrogen, phosphorus, and potassium in the leaves of the Calville Blanc d'hiver cultivar was observed as during the period of fructification and growth. In these studies, there is a tendency to decrease in the nitrogen and potassium

content in the leaves of the Idared apple tree on seed and vegetative M4 rootstocks and Calville Blanc d'hiver on the seed rootstock with increasing tree age. This is also confirmed by the data of other researchers [2; 10].

***Table 4**. The content of nutrients in the leaves of the Calville Blanc d'hiver tree on the seed rootstock depending on the fertiliser in repeated cultivation, %*

Fertiliser variant	Indicators in different age periods of fructification								
	Growth and fructification period, 1990-1996			Fructification and growth period, 1997-2003			Fructification period, 2004-2016		
	N	P_2O5	K_2O	N	P_2O5	K_2O	N	P_2O5	K_2O
Without fertiliser (control)	2.94	0.40	1.76	2.76	0.32	1.21	2.30	0.20	1.01
Manure 40 t/ha	3.05	0.43	2.01	2.85	0.36	1.27	2.47	0.21	1.12
20 t/ha of manure + N_{60} P_{60} K_{60}	3.10	0.41	1.79	2.92	0.36	1.26	2.45	0.25	1.14
N_{120} P_{120} K_{120}	3.09	0.39	1.89	3.01	0.31	1.31	2.50	0.23	1.15
HIP_{05}	*0.15*	*0.06*	*0.05*	*0.14*	*0.04*	*0.03*	*0.12*	*0.02*	*0.03*

CONCLUSIONS

Chlorophyll content (*a+b*) in the leaves of Idared cultivars on the seed and vegetative rootstock M4 and Calville Blanc d'hiver on the seed rootstock changed depending on the age of the plantings. Most of it was during the period of growth and fructification, and least of all – during the period of fructification. The use of various fertiliser options contributed to an increase in the chlorophyll content in the leaves. In the most productive period of fructification, the amount of chlorophyll (*a+b*) in the leaves of Idared apple tree on the seed rootstock was significantly higher in the variant with the introduction of organo-mineral (152.0 mg/100 g), and on the clone M4 – in areas with the application of organic fertilisers (152.1 mg/100 g). In the leaves of Calville Blanc d'hiver cultivar on the seed rootstock, a greater accumulation of the amount of chlorophylls was observed in the variant with the introduction of organo-mineral fertilisers, where the excess of control was 8.0%.

The content of macronutrients in the leaves of the studied cultivar-rootstock combinations also depended on the age of plantings and fertiliser options. During the fructification period, the nitrogen content in the leaves of Idared trees on seed and vegetative rootstocks in the areas of fertilised variants was within optimal limits at the level of 2.30-2.37 and 2.25-2.27%, respectively. Among the studied rootstocks in the fertiliser-free variant, trees on the seed rootstock were characterised by a high nitrogen content in the leaves. In the leaves of the Calville Blanc d'hiver cultivar on the seed rootstock, the nitrogen content on the studied variants was within the optimal range, and among the fertiliser options for applying mineral fertilisers. The content of phosphorus and potassium in the leaves of trees of the studied cultivar-rootstock combinations in the areas of fertiliser options was within optimal limits.

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ВМІСТ ХЛОРОФІЛУ ТА ЕЛЕМЕНТІВ ЖИВЛЕННЯ В ЛИСТІ ЯБЛУНІ ЗАЛЕЖНО ВІД ДОВГОТРИВАЛОГО УДОБРЕННЯ

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Анотація. Показником стану рослин залежно від умов вирощування є стан їх листкового апарату, який характеризується вмістом у листку хлорофілу та елементів живлення. Листок яблуні забезпечує синтез органічних речовин, від особливостей його життєдіяльності залежить продуктивність плодових дерев. Важливе значення, як метод діагностики мінерального живлення плодових культур має хімічний аналіз листя, показники якого відображають рівні забезпеченості рослин елементами мінерального живлення. Розглянуто результати досліджень вмісту хлорофілу та елементів живлення в листі дерев яблуні сорту Кальвіль сніговий на насіннєвій і Айдаред на насіннєвій і вегетативній М4 підщепах у повторно вирощуваному насадженні на фонах мінерального живлення, створених довготривалим (понад 86-річним) застосуванням різних систем удобрення на темно-сірому опідзоленому ґрунті. Довготривале застосування органічної та органо-мінеральної систем удобрення сприяло підвищенню рівня суми хлорофілів (*a+b*) у листі дерев сортів яблуні Айдаред на насіннєвій і клоновій М4 підщепах і Кальвіля снігового на насіннєвій підщепі в різні вікові періоди росту й плодоношення, що зумовлювало їх більшу продуктивність. Вміст макроелементів у листі досліджуваних сортопідщепних комбінувань залежав від віку насаджень і варіантів удобрення. У найбільш продуктивний період плодоношення в листі дерев сорту Айдаред на насіннєвій і вегетативній підщепах вміст азоту на ділянках удобрюваних варіантів був у оптимальних межах. Серед досліджуваних підщеп у варіанті без добрив, вищим вмістом азоту у листі характеризувалися дерева на насіннєвій підщепі. У листі сорту Кальвіль сніговий на насіннєвій підщепі вміст азоту на досліджуваних варіантах був у межах оптимального, а серед варіантів удобрення найвищим був за внесення мінеральних добрив. Вміст фосфору та калію в листі дерев досліджуваних сортопідщепних комбінувань на ділянках варіантів удобрення знаходився в оптимальних межах

Ключові слова: Кальвіль сніговий, Айдаред, листок, ґрунтове удобрення, зелені пігменти, вікові періоди плодоношення

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EVALUATION OF FLOWER DECORATIVE PLANTS CULTIVARS OF *NEMESIA VENT* IN THE CONDITIONS OF PODILLIA

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Abstract. Due to the lack of information about biomorphological features and cultivation technology of species of the genus *Nemesia Vent* they are still rarely found on the territory of Ukraine and thus are of great interest for cultivation and use for the design of flower beds. The purpose of the scientific work was to analyse the current world assortment of the genus *Nemesia Vent*, as well as to study the features of flowering, reproductive ability, agrotechnics of growing cultivars of nemesia strumosa, and assess the prospects of their use in decorative gardening in Ukraine. During the research of nemesia strumosa cultivars, laboratory and field research methods were used. It was proved that all the studied cultivars received high ratings of their decorativeness, since the plants under the experimental conditions had well-developed inflorescences, abundant and long-lasting flowering. The plants retained the brightness of their colour throughout the entire period of the flower's life, adapted well to growing conditions, were practically not affected by diseases, and in general were quite resistant to unfavourable conditions. The Orange Prince cultivar proved to be the best of all the cultivars studied in terms of the duration and intensity of flowering, which reached its maximum values on the 60th day from the beginning of the phase with the number of 35 flowers per plant. The studied cultivars can be used in greening health complexes, recreation areas, office territories, adjacent territories, as well as in the design of various types of flower beds. The results of the obtained research are primarily necessary when choosing use cases, developing agricultural technology and breeding programmes, and for carrying out research work aimed at meeting the needs of horticulture. Considering that they are grown both for the needs of the protected ground and open gardening, the study of these issues is a significant contribution for botanical science in general, primarily for decorative gardening in Ukraine, as well as for practical floriculture and landscape design

Keywords: *Scrophulariacea Juss*, *Nemesia strumosa*, world assortment, introduction, cultivars, floriculture, landscaping

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INTRODUCTION

The current stage of ornamental plant industry development and the solution of practical problems relevant for Ukrainian horticulture requires the increasing attraction of new types and cultivars of flower-decorative cultures for mass and individual gardening, as well as for the design of collection funds. The creation of large industrial centres and the growth of the urban population cause environmental degradation. In this regard, the need for mass recreation of the population in conditions that favourably affect health and psychophysical state increases [1; 2].

Among a wide range of flower-decorative cultures, plants of the genus *Nemesia Vent* family *Scrophylariaceae Juss* are among the most promising for introduction to Ukraine [3; 4]. They occupy one of the leading places in the world assortment of ornamental plants of the world flora. These include approximately 50 species of shrubs, subshrubs, annual and perennial plants with concolorous and variegated flowers with different shades. Unfortunately, flower-decorative plants of the genus *Nemesia Vent* at this stage of floriculture development are rare and are found only in private collections and as a seed material in a commercial offer, but based on the decorative qualities of these species and the variety of options for their use, these plants can be used to replenish the variety of flower-decorative cultures in Ukraine [3].

According to the author's opinion, decorative gardening in Ukraine is at a new stage, which requires attracting new types and cultivars of ornamental cultures since their available range in our country is still insufficient compared to the leading countries of the world. This approach is necessary both when solving issues in the field of direct use of ornamental plants in mass and individual gardening, and when solving problems related to the development of collection funds. Some of the most promising decorative species for landscaping various objects in Ukraine are species of the genus *Nemesia Vent L*.

From the author's point of view, the results of experiments allow assessing the level of adaptation of plants to the soil and climatic conditions of the selected zone and a specific area. That is why this work is the first stage on the way to creating source material for various areas of their subsequent practical implementation. The family of *Scrophulariaceae*, as a highly developed group of dicotyledon plants, is characterised by many progressive features, is included in the subclass of *Asteridae*, and takes a central position in order *Scrophulariales*; moreover, *Scrophulariaceae* received this position not only because this family is the largest in terms of the number of species, but also because it shows how close generic connections are with many families of the order, the border between which is often quite difficult to establish. *Scrophulariaceae* are common in warm and temperate areas of both hemispheres. The world assortment of decorative species of the Scrophulariaceae family is very wide – more than 1000 species. Among them are pond plants, trees, shrubs, herbaceous annuals and perennials. In the flora of Ukraine, approximately 162 species are known, united in 26 genera. *Herbaceous Scrophulariaceae* are characterised by a wide variety of life forms. Annuals make up approximately 30% of all species. Some of the genera of *Scrophulariaceae*, whose species are introduced into culture as garden plants, belong to hydrophytes and hygrophytes, and there are also a number of genera that belong to hemiparasites [2; 5; 6].

In Ukraine, the genus *Nemesia Vent* has been studied relatively little on both theoretical and applied aspects of botanical science. The most significant development of Ukrainian scientists is the study of the species composition, geography, and eco-coenotic aspects of this genus in Ukrainian flora. The second important aspect of Ukrainian authors' research is the introduction of certain species of the genus, generalisation of the world experience of their use in culture, and elaboration of cultivation features in certain climatic conditions on the territory of the state. The terms and individual requirements for growing certain cultivars of nemesia strumosa are determined based on a generalisation of the experience of their use in culture. There are data from phenological observations of these plants during their cultivation in the Polissia and Forest steppe areas. This information is an important basis for further development of research works and for the development of a pattern of experiments with these plants [1; 4].

Due to the needs of practice, the question of studying the techniques of growing ornamental species of this genus arises. In literary sources, the issue about genus *Nemesia Vent* is little covered. There are only data, mainly of popular scientific content, on the peculiarities of growing nemesia. Regarding Ukraine, only general recommendations for the care of certain species of *Nemesia Vent* are proposed [4; 7].

The purpose of the research was to evaluate the adaptability of nemesia strumosa cultivars for growing flowers in soil and climate zone of Ukraine, as well as the selection of options for their use for greening the Podillia area.

THEORETICAL OVERVIEW

The family *Nemesia Vent* includes more than 50 herbaceous and subshrub annuals and perennials, most of which grow wild in South Africa. In floriculture, nemesia strumosa (*Nemesia strumosa Beth*) and nemesia versicolour (*Nemesia versicolor E.Mey*) are most commonly used. A large number of garden hybrids have been obtained from nemesia strumosa and nemesia versicolour (*Nemesia x hibrida hort*), which are grown as annuals, seedlings [8-10].

Brief description of the most common species of the genus *Nemesia Vent*:

❖ *Nemesia strumosa* – an annual herbaceous plant with upright quadrangular stems, glabrous below and slightly pilose above, 10-40 cm high. The flowers are

unstandard, swollen, irregular in shape, up to 2.5 cm in diameter, collected in raceme inflorescences at the ends of the stems (Fig. 1). The flower colour is white, yellow, orange, red, purple, blue, they can be one- and two-coloured, often with a purple tint on the outer side. It is better to plant seeds for seedlings in the third decade of April, and it is necessary to make sure that soil does not dry out in the containers. In favourable conditions plants bloom at 40-45 day after the emergence of sprouts. They develop well in light, moderately fertile ground. The plant blooms from June to September, sometimes until mid-October in sunny areas [11-13].

Best cultivars: *Aurora*, up to 30 cm high, the flowers are large, scarlet-white, bicoloured, Fire King, up to 30 cm high, the flowers are of various colours, and *Orange Prince* – the flowers are orange. It is used for decorating flowerbeds, ridges, borders, as borders for flower beds, for decorating bowls, vases, baskets, and mini-flower beds, for floral arrangement, and as a container plant.

❖ *Nemesia versicolour* is an annual herbaceous plant. The stems are very branched, thin (Fig. 1). In a number of features, it resembles nemesia strumosa, although its flowers are slightly smaller and have a clearly visible spur. The maximum height of the plant is 25 cm. Propagated by seeds. Sprouts emerge on the eighth day. This is a light-demanding, cold-resistant, and rather low maintenance plant. Although most nemesias love the sun, they do not tolerate very hot weather. When the air is too hot, their greenery wilts, and if the soil dries up, plants die. Therefore, for their cultivation, one should choose places that are blown by the wind and make sure that the soil does not completely dry out. The distance between plants should be 5 cm. It is necessary to provide protection in case of frost return. Removal of flowers that lost their decorativeness prolongs the flowering period. It is recommended for flowerbeds, ridges, borders, for floral arrangement, and as a pot plant [14].

❖ *Nemesia x hibrida* – this includes cultivars of hybrid origin obtained from crossing Nemesia stromosa and Nemesia versicolor [9; 10]. An annual plant, branched from the base, 30-60 cm high. The leaves are oblong, almost lanceolate, serrated along the edge. Flowers are irregular in shape, rather large, with a double corolla up to 2 cm in diameter, collected in raceme inflorescences. Have a variety of flower colours (Fig. 1). It grows well in light, moderately fertile soils with a pH of 5.5. The flowering period is from June to August. It is used in flowerbeds, ridges, borders, for floral arrangement and as a pot plant [11].

❖ *Nemesia caerulea=Nemesia foetens* – flowers in nemesia are small – their diameter does not exceed 1.5 cm. The stems are approximately 40 cm high, initially upright, but later begin to bend under the weight of inflorescences. The colour of the petals can be varied: blue, dark blue, orange, pink, or almost white. They always have a bright yellow spot on the lower petal (dorsal sepal). This plant is propagated by seeds or stem cuttings. They love sunlight and fresh air. The soil should not be constantly moist. After the seed propagation, the flowering period lasts from July to September (Fig. 1).

❖ *Nemesia floribunda* – the sprouts of these plants reach a height of 40 cm and their flowers are much smaller than those of other species of this botanical genus, their diameter is 1.5 cm. The flower colour can be different: purple, blue, dark blue, pink, white. The flowering period of nemesia floribunda is from June to August (Fig. 1). Nemesia floribunda has a very delicate appearance. It is popular with flower growers who prefer the beauty of field flowers. Unfortunately, the seeds of these plants are almost impossible to find [3; 6].

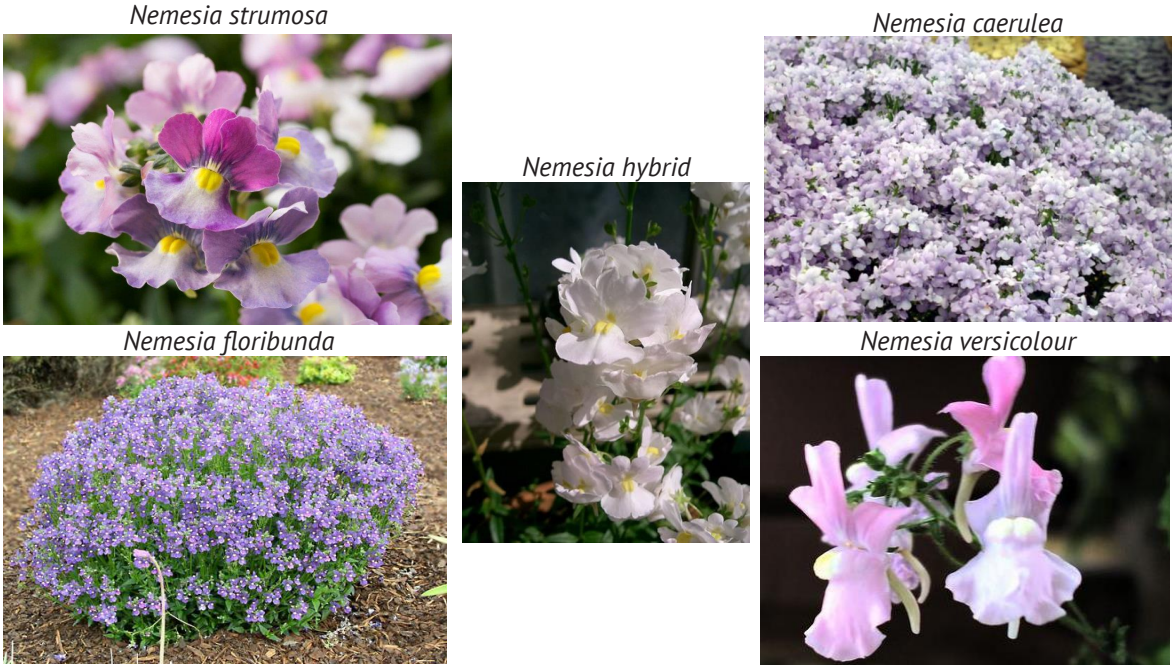

Figure 1. Flower-decorative species of the genus Nemesia Vent in the flowering

Despite a wide range of research on the morphobiological features of the studied species and the implementation of their practical introduction, many issues of biology of these species, especially those of interest for seed production and selection, that is, the creation of new highly decorative cultivars, adapted to local conditions, that are absent in Ukrainian floriculture.

MATERIALS AND METHODS

The research on the cultivation of ornamental species and cultivars of the genus *Nemesia Vent* in Podillia was held during 2019-2020. Seeds and vegetatively propagated planting material of these plants were obtained from the collection of the Department of flower-decorative plants of M.M. Hryshko National Botanical Garden in Kyiv, as well as from private collections. The study of cultivars of the genus *Nemesia Vent* were held on collection sections in the Botanical Garden "Podillia" of the Vinnytsia National Agrarian University.

The object of research was phenology, morphometry, a number of aspects of reproductive biology, namely the intensity of flowering in different periods of the generative period, the reproductive ability of different cultivars within the species, the biomorphological and systematic structure of the genus in the cultivated flora of Ukraine and the world. During phenological observations, the main phenophases, their calendar dates, and duration were recorded. Morphometry data were used to study the morphobiological features of growth and development, primarily the formation of plant structure under the influence of soil and climate conditions of Podillia.

The complex of obtained indicators is used as a scientific basis for the development of agricultural technology frameworks of the studied species and cultivars for various practical use in decorative gardening of Podillia as objects of seed production or components of decorative groups of flower beds of various types with the participation of these plants and determination of the place and role of each of them as factors of enriching the assortment and improving the quality of mass and individual gardening.

As the subject of research, 1 species and 5 cultivars of foreign selection were used, which differ primarily in the colour of flowers and the size of plants, in particular:

1. The Orange Prince cultivar. The height of the plants is 35-40 cm, the size of the flowers is 2-3 cm, collected in loose racemes at the ends of the stems, the colour of the flowers is orange, the fruit is a many-seeded box.

2. The White Knight cultivar. The height of the plant is 30-40 cm, the size of the flowers is 3 cm, collected in loose racemes at the ends of the stems, the colour of the flowers is white, the fruit is a many-seeded box.

3. Red and White cultivar. The height of the plant is 30-40 cm, the size of the flowers is 2.5 cm, collected in loose inflorescences at the ends of the stems, the colour of the flowers is variegated (the upper lip is red, the lower lip is white), the fruit is a many-seeded box.

4. The Fire King cultivar. The height of the plant is 30-40 cm, the size of the flowers is 2-3 cm, collected in loose inflorescences at the ends of the stems, the colour of the flowers is red, the fruit is a many-seeded box.

5. The Blue Treasure cultivar. The height of the plant is 18-30 cm, the size of the flowers is 2.5 cm, collected in loose inflorescences at the ends of the stems, the colour of the flowers is blue, the fruit is a many-seeded box.

The territory of the "Podillia" Botanical Garden, where plant cultivars of the *Nemesia strumosa* species were studied is part of the Podilske Pobuzhia area of the Forest steppe of Ukraine. According to the agroclimatic directory and Atlas of Ukraine, this territory belongs to the Vinnytsia-Nemirovsky agro-soil subdistrict of the Central Soil District of the Right-bank Ukraine. The climate conditions of this area are favourable for agriculture. The studies were conducted on grey forest soils typical of this area, middle loamy in mechanical composition. A valuable quality of the soil is the high content of calcium and magnesium carbonates (from 1.45 to 14.5%), which contribute to the accumulation and consolidation of nutrients, which leads to the formation of soils with a stable absorption complex. The loess capillarity provides a rise in moisture to the upper horizons, where the root system of plants is located.

The humus content is in the range of 2.2-2.4%, the reaction of the soil solution is slightly acidic pH (salt) is at the level of 5.2-5.4. In general, the soil and climatic conditions of the experimental site were favourable for growing flower-decorative plants of nemesia strumosa.

During the research of flower-decorative species of the genus *Nemesia Vent*, methods of field and laboratory experiments were used. The cultivation of plants of the studied species was carried out in a generally accepted way – seedling culture. The feeding area was 20x30 cm. The number of plants of each cultivar grown ranged from 15 to 50 plants. To obtain seedlings, the seeds were planted in seed boxes in a greenhouse, at a temperature of 16-20^{0}C, the transplanting was carried out in seedling pots. The mixture for planting and transplanting consisted of 3 parts humus, 1 part peat and 1 part sand (3:1:1) with a pH of 5.5-7. Care consisted of fertilising (during the growth of hoots and during the formation of inflorescences, with an NPK norm of 15-20 g per 10 liters of water) and maintaining sufficient soil moisture in dry periods (with a norm of 12-15 l/m^2). Seedlings were planted in the soil in early May, when the threat of frost passed. Harvesting of plants for seeds was carried out as they matured.

During the research, the author conducted a morphological description of nemesia strumosa cultivars (determined the shape of leaves, stems, roots, flowers, inflorescences), a comparative analysis by development phases, determined the real and potential seed productivity, duration, and intensity of flowering. The intensity of flowering was determined by the number of fully opened flowers that occurred during the daytime of one 24-hour period. A comparative cultivar assessment of

ornamental plants of nemesia strumosa was carried out, and the life form of plants was determined [15; 16].

The dominant task was to update the assortment with modern species. Accordingly, in this study, when conducting an assessment, the author used the method of searching and selecting options for using plants, taking into account their decorative qualities according to the requirements of this time.

RESULTS AND DISCUSSION

A complex cultivar assessment of nemesia strumosa

An assessment of cultivar material makes it possible to identify the best, most adapted cultivars and recommend them for further cultivar testing, which is carried out according to a separately approved methodology at the state level by a specially authorised service. According to its results, tested and evaluated objects enter the State Register of plant cultivars of Ukraine if they meet a specified level of criteria. Of the plants studied by the authors, nemesia strumosa cultivars were not included in the list of plants in this register. Therefore, for this purpose it is necessary to develop an appropriate method of cultivar assessment. The set of criteria proposed by the method is universal and allows a comprehensive assessment of cultivars, while taking into account both characteristics that determine decorativeness and commercial-biological qualities. Therefore, despite the fact that the task of this work did not apply to the development of recommendations for introducing cultivars of nemesia strumosa in the State Register mentioned above, these criteria were used for a comprehensive assessment of cultivars of this plant introduced in the conditions of Podillia. The description of nemesia strumosa cultivars and the results of their assessment by decorative qualities are given in Table 1.

***Table 1**. The general characteristics of Nemesia strumosa cultivars, that were tested in the conditions of Vinnytsia*

Cultivar	Number of days from planting to flowering	Plant height, cm	Number of inflorescences, pcs	Number of flowers in the inflorescence, pcs	Flower		Flowering time
					Diameter, cm	Colour	
The Orange Prince	72	30-40	6-8	6-8	3	Orange	June-October
The White Knight	74	30-40	6-7	6-7	3	White	June-September
Red and white	80	30-40	5-6	5-6	2.5	Variegated (upper lip is red, lower lip is white)	June-September
The Fire King	73	30-40	6-7	5-6	3	Red	June-September
The Blue Treasure	75	18-30	5-6	5-6	2.5	Blue	June-September

***Source**: formed based on the results of the author's own research*

Although nemesia strumosa is not a widespread culture in Ukraine, it is widely used in world horticulture. The high decorative value of brightly coloured inflorescences, a relatively long period of continuous flowering (from June to September, and sometimes until mid-October) contributes to the fact that flowers of this genus are often found in world floriculture. These qualities were fully manifested in the cultivars chosen by the author of the article for testing in Vinnytsia, which is confirmed by the results of phenological observations and accounting for their commercial-biological qualities in accordance with the methodology of conducting a cultivar examination of the decorative group for suitability for distribution in Ukraine [16]. Their results are presented in Table 2.

***Table 2**. The data of phenological observations during the testing of N. strumosa cultivars*

Cultivar name	Beginning of the growing season			Flowering				
	Planting	Emergence of sprouts	Mass rooting of seedlings	Beginning	Mass	End	Complete loss of decorativeness	End of the growing season
The Orange Prince	28.03	13.04	30.04	10.06	12.08	1.10	16.10	24.10
The White Knight	28.03	14.04	1.05	12.06	9.08	28.09	13.10	19.10
Red and white	28.03	12.04	1.05	15.06	17.08	21.09	7.10	13.10
The Fire King	28.03	13.04	29.4	13.06	8.08	24.09	8.10	16.10
The Blue Treasure	28.03	15.04	2.05	14.06	10.08	22.09	10.10	18.10

***Source**: formed based on the results of the author's own research*

Due to the improvement of people's well-being, the demand for flower products is increasing. All this elevates floriculture to an important branch of the national economy, so the study assessed cultivars for resistance to unfavourable weather conditions, diseases, and pests, which are shown in Table 3.

When processing the results of research on commercial-biological qualities, nemesia strumosa cultivars turned out to be quite resistant to unfavourable conditions. Almost all plants adapted well to the growing conditions, were not affected by diseases, and generally deserve high valuation. They also differ in average seed productivity (0.19-0.26 g/plant), but it should be noted that the seeds are very small (the number of seeds per 1g is 3.28 thousand pcs.). Based on this the conclusion can be made that the plants of these cultivars have a great potential for wider distribution in gardening in Ukraine. However, with any, even a sufficiently large set of criteria, such an assessment cannot be objective, since the author assessed the level of suitability of the studied species only by a set of commercial-biological indicators. The basis for determining the set of indicators of such assessment was the corresponding method [15; 16]. In order to obtain data that would comprehensively and simultaneously from different sides reflect the patterns of ontogenetic morphogenesis of different nemesia strumosa cultivars, plant observations were made on the phases of development. The phenological phases of the aerial part development of 5 cultivars were determined (Tables 4, 5).

***Table 3**. A record for commercial-biological qualities of N. strumosa cultivars*

Cultivar name	Re-sistance to unfa-vourable weather conditions	Resistance to diseases and pests	Sparse planting	Typicality of the cul-tivar	Flowering productivity, flowers/plant	Seed harvest, g/plant	Period of preservation of decorativeness of cut inflores-cences in water, days
The Orange Prince	High	High	Low	High	64	0.26	3-4
The White Knight	High	Average	Low	High	49	0.24	2-3
Red and white	High	High	Average	High	36	0.23	1-2
The Fire King	Low	Average	Low	High	42	0.21	2-3
The Blue Treasure	Low	Average	Average	High	36	0.19	1-2

***Source**: formed based on the results of the author's own research*

***Table 4**. Calendar dates of individual phenological growth phases in cultivars of the species N. strumosa in the conditions of Podillia*

Cultivar name	Date of planting	Sprouts, date			Leaf growth and formation of the shoot system, date	Budding, date	Flowering, date	Fructification, date
		Emergence	Mass	End				
The Orange Prince	28.03	13.04	16.04	23.04	24.04-28.05	29.05-9.06	10.06-1.10	2.10-31.10
The White Knight	28.03	14.04	17.04	25.04	26.04-27.05	28.05-11.06	12.06-28.09	29.09-30.10
Red and white	28.03	12.04	15.04	24.04	25.04-29.05	30.05-14.06	15.06-21.09	21.09-29.10
The Fire King	28.03	13.04	16.04	24.04	25.04-28.05	29.05-12.06	13.06-24.09	25.09-28.10
The Blue Treasure	28.03	15.04	17.04	25.04	26.04-27.05	28.05-13.06	14.06-22.09	23.09-27.10

***Source**: formed based on the results of the author's own research*

***Table 5**. The duration of individual phenological growth phases in cultivars of the N. Strumosa species in the conditions of Podillia*

Cultivar name	Seed germination period, days	Duration of the seedling phase, days	Leaf growth and formation of the shoot system, days	Budding, days	Duration of the period from planting to flowering, days	Flowering, days	Fructification, days
The Orange Prince	16	10	34	12	72	113	29
The White Knight	17	11	31	15	74	108	31
Red and white	15	16	34	15	80	98	38
The Fire King	16	9	33	15	73	103	33
The Blue Treasure	18	10	31	16	75	100	34

***Source**: formed based on the results of the author's own research*

Use cases in decorative gardening

Continuous improvement of flower design is an urgent problem for the entire world of gardening. In Ukraine, it is becoming particularly acute due to the significant lag of our state behind the world leading countries in terms of both the range of flower crops and their use cases. Therefore, the task of this study was to investigate the range of species and cultivars of the genus *Nemesia Vent* for various areas of their implementation in decorative gardening. Based on the analysis of the potential capabilities of these plants, variants of their use as promising species are proposed to enrich the taxonomic composition of the assortment and avoid monotony and uniformity of garden compositions. The richness of colour, high decorative effect, and long flowering period allow considering decorative species and cultivars of nemesia promising for their widespread introduction into floriculture in Ukraine.

To enrich the assortment, the author recommends one species of ornamental plants of nemesia strumosa, which differ in the colour of leaves and flowers, different in flowering time, which is especially important for ensuring a constantly high decorative value of flowerbeds. Due to the peculiarity of flowers and the abundance of flowering of this species, it can be used in our conditions to create ridges, compositions, decorative spots, alpine gardens, rock gardens, borders, arabesques, parterres, mini-flowerbeds, as a border for flowerbeds, as well as container plants in gardens, parks and hanging baskets (Table 6). Options for use of the studied species in decorative gardening are demonstrated in Figure 2.

***Table 6**. Biomorphological features and recommendations for the use of nemesia strumosa cultivars*

Cultivar name	Life form	Vegetation type	Plant height, cm	Duration of flowering, days	Recommendations for use
The Orange Prince	Annual	Summergreen	35-40	113	Compositions, ridges, borders, flower spots, rock gardens, container and ampelous culture
The White Knight	Annual	Summergreen	30-40	108	Flower spots, compositions, ridges, borders, pots, alpine gardens, rock gardens
Red and white	Annual	Summergreen	30-40	98	Borders, pots and baskets, as borders for flowerbeds, compositions, ridges
The Fire King	Annual	Summergreen	30-40	103	Flowerbeds, alpine gardens, rock gardens, compositions, ridges, borders, pot plant
The Blue Treasure	Annual	Summergreen	18-30	100	Decorative spots, group plantings, ridges, borders, for bowls and hanging baskets

***Figure 2**. The use for landscaping health complexes, recreation areas, offices, and adjacent territories*

Agrotechnics of growing nemesia strumosa

A necessary condition for successful practical use of plants is the development of the basics of agricultural technology in new growing conditions. Plants of the genus *Nemesia Vent* are grown only by seedling culture. The technology of growing seedlings is as follows:

1. Containers. Trays, boxes, and regular flower pots are used. Drainage holes or crevices are required. Containers are washed, clay pots are soaked overnight.

2. Compost. Peat-based compost is perfect – it is sterile, light, and homogeneous. The container is filled with compost and slightly compacted with a plank. The day before planting, the compost is sprayed with water – during planting it should be moist (but not wet). Seeds are planted not thickly, then sprinkled with a thin layer of compost (very small seeds do not need to be sprinkled) and pressed with a plank.

There are two methods of growing seedlings: *First* – the standard "under the glass" method. The tray or pot is covered with glass, and a sheet of thick paper is placed on top. It is kept at a temperature of 16-21°C. Every day, the glass is wiped and turned over. As soon as the sprouts appear, the paper is removed and the glass is lifted from one edge. After a few more days, the glass is removed completely and the container is moved closer to the light. The compost is kept moist.

Second – a simple "on the windowsill" method. A plastic bag is put on the pot or container and fixed with an elastic band. It is kept in a shaded place at a temperature of 16-21°C. As soon as the shoots appear, the bag is removed and the seedlings are moved to the windowsill, where direct sunlight does not fall. The pots are rotated regularly so that the flowers do not stretch out to one side. The compost is kept moist, but not wet.

3. Transplanting. As soon as the first pair of true leaves opens, the seedlings should be transplanted 4–4.5 cm into trays or pots filled with compost. For transplanting, seedlings are held at cotyledonous leaves, and not at stems. After transplanting, the container is placed in a dark place for a day or two.

4. Hardening. When the seedlings have taken roots after transplanting, they need to be seasoned to prepare for life in the open ground. To do this, one needs to increase the ventilation and move the container to a cool place or a greenhouse. Then they are put out on the street for a day. Before planting, the seedlings are left outside for a week.

Bedding. After hardening, the plants are planted in the open ground in spring in the period from April to June. In order for the plants to take roots, they are planted with soil that was in pots [17; 18].

To extend the duration of flowering, in the second half of summer (after the first wave of flowering), plants are rejuvenated by cutting. The dried stems that lost decorativeness are cut off, after which they grow back and bloom again, although less abundantly.

CONCLUSIONS

It was established that in the field of horticulture, the genus *Nemesia Vent* is represented by both a significant number of species (50) and a rich cultivar assortment, which is approximately 100 cultivars. When comparing with the cultivar assortment of the world leading countries, the cultivars of *Nemesia Vent* species are completely absent in Ukraine. According to preliminary data, plants of the *Nemesia strumosa* species can be considered a significant source for increasing the range of promising flower plants in the area of Podillia. To improve the range of flower plants, cultivars of nemesia strumosa species are of primary importance: Orange Prince, White Knight, Red and White, Fire King, and Blue Treasure.

As a result of investigating the flowering characteristics of the studied cultivars, it was established that the largest flowering period (113 days) and its significant intensity (35 pcs. flowers per plant) was observed in the Orange Prince cultivar, which is a priority for enriching cultivars in the Podillia area. It was determined that in all the studied cultivars, ontogenesis ends with a complete fructification with a seed productivity of 0.19 to 0.27 g per plant, with an amount of 3.16 to 3.39 thousand seeds per 1 g, which is a high indicator for the Podillia area.

The studied cultivars of the *Nemesia strumosa* species received high values on a set of indicators that determine their decorative effect and commercial-biological qualities. Therefore, they can be widely used in our conditions for creating ridges, compositions, decorative spots, alpine gardens, rock gardens, borders, arabesques, parterres, mini-flowerbeds, as a border for flowerbeds, as well as container plants in gardens, parks and for hanging baskets.

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ОЦІНКА СОРТІВ КВІТНИКОВО-ДЕКОРАТИВНИХ РОСЛИН ВИДУ *NEMESIA VENT* В УМОВАХ ПОДІЛЛЯ

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Анотація. Через брак відомостей про біоморфологічні особливості та технологію вирощування видів роду *Nemesia Vent* вони поки що рідко зустрічаються на території України і тим самим становлять величезний інтерес для їх вирощування і використання для оформлення квітників. Метою наукової роботи було проаналізувати сучасний світовий асортимент роду *Nemesia Vent*, а також дослідити особливості цвітіння, репродуктивну здатність, агротехніку вирощування сортів немезії зобовидної та оцінити перспективність варіантів їх використання в декоративному садівництві України. Під час досліджень сортів немезії зобовидної були використані методи лабораторних і польових досліджень. Обґрунтовано, що всі досліджувані сорти отримали високі оцінки їх декоративності, оскільки рослини в умовах експерименту мали добре розвинені суцвіття, рясне та тривале квітування. Рослини зберегли яскравість свого забарвлення протягом усього періоду життя квітки, добре адаптувались до умов вирощування, практично не уражались хворобами, загалом виявились достатньо стійкими до несприятливих умов. Сорт Помаранчевий принц проявив себе найкраще з усіх досліджуваних сортів по тривалості та інтенсивності цвітіння, яке досягало максимальних своїх значень на 60-й день від початку фази з кількістю квіток 35 штук на рослину. Досліджувані сорти можуть бути використані при озелененні оздоровчих комплексів, зон відпочинку, територій офісів, прибудинкових територій, а також при оформленні різних видів квітників. Результати отриманих досліджень є першочергово необхідними під час вибору варіантів використання, розробки агротехніки і селекційних програм та для здійснення науково-дослідних робіт, спрямованих на задоволення потреб садівництва. Враховуючи те, що вони вирощуються як для потреб закритого ґрунту, так і для зовнішнього квітникового оформлення, опрацювання даних питань становить вагомий внесок для ботанічної науки загалом, в першу чергу для декоративного садівництва України, а також для практичного квітникарства та ландшафтного дизайну

Ключові слова: *Scrophulariacea Juss*, *Nemesia strumosa*, світовий асортимент, інтродукція, культивари, квітникарство, садово-паркове будівництво

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INFORMATION MODEL FOR IMPROVING ACCOUNTING AND ANALYTICAL SUPPORT FOR ECONOMIC POTENTIAL MANAGEMENT

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Abstract. The relevance of the study is conditioned by the need to strengthen the management function of an agricultural enterprise that focuses on the principles of sustainable development and aims to modernise accounting and analytical support for managing economic potential. The purpose of the study is to form a strategy for the desired improvement of accounting and analytical support of the enterprise with an emphasis on: reporting on sustainable development; expansion of the analytical complex of indicators of economic potential, capacity and performance of an agricultural enterprise; improvement of accounting and analytical support of enterprises using this information model through updating the documentation of control and audit. The theoretical and methodological basis was formed by scientific methods based on the dialectic of knowledge and objective laws of the development of the economy, nature, and society. Economic and mathematical modelling, systematisation and synthesis helped to develop a strategy to improve accounting and analytical support for managing the economic potential of agricultural enterprises, taking into account the principles of sustainable development. This type of modelling can help to effectively modernise accounting and analytical support for managing the economic potential for agricultural enterprises. The developed information model of selective adaptation helps managers of various levels to monitor the implementation of business processes for improving accounting and analytical support for economic potential management, assess the degree of achievement of priority goals and compliance with the principles of sustainable development. One of the steps of long-term modernisation of accounting and analytical support for agricultural enterprises through the introduction of sustainable development reporting is proposed, which should include indicators and documents on managing the economic potential, economic capacity, and performance of agricultural enterprises. The advantage of this information model is the ability to calculate the complexity index of transformation of accounting and analytical support for economic potential management using the principles of sustainable development, which shows the level of complexity of future modernisation of these aspects

Keywords: economic power, efficiency, enterprise potential, agricultural production, agricultural organisations, agricultural sector

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INTRODUCTION

The process of shifting the priorities of agricultural production towards the principles of sustainable development covers more and more large and medium-sized agricultural enterprises in Ukraine. This thesis is confirmed, in particular, by the fact that information about the environmental and social activities of the enterprise appears in such reporting documents as the "Annual report" or "Management Report", as well as independent internal and external socio-environmental management reports. At this stage of development of the reporting system in Ukraine, there are clear standards for financial reporting: the composition of indicators, structure, metrics, etc. Therefore, reports related to aspects of sustainable development are classified as management non-financial reporting.

Speaking about the latest studies on the topic of non-financial reporting, in the context of sustainable development, there is an increase in the number of publications. In particular, it is worth noting the study by J.R.R. Tolkien., C.T. Oyadomari, B. Duque, E.K. Nisiyama, R.G. De Dultra-De-Lima, O.R. Mendonça Neto [1], which analysed the impact of the quality of non-financial reporting on management's perception of information and management decision-making. A similar study was conducted by W. Klinphanich [2], which determined the impact of the corporate governance reporting on the effectiveness of decisions made by an independent board of directors. Of particular note are such authors as N. Jaffar, A.S.M. Nor, Z. Selamat [3], C. de Villiers, E.R. Venter, P-C.K. Hsiao [4], whose work was devoted to the problems of integrated reporting, in particular its impact on increasing transparency, confidence, and value creation. The problems of economic potential and corporate social responsibility are considered in the works of Ukrainian scientists: T. Gagalyuk, V. Valentinov, F. Shaft [5], O.Yu. Yermakov [6], V.K. Savchuk [7], V.V. Prohorova, O.B. Bozhanova [8], L.M. Taranyuk [9].

Considering the problems of developing accounting and analytical support for managing the economic potential of agricultural enterprises, it can be noted that in the case of liberalisation of financial reporting forms, such data as integral indicators of economic potential and economic power can be placed in such a financial report as Form No. 2 "Statement of financial results (statement of comprehensive income)". If the trend in the development of reporting of agricultural organisations in Ukraine is aimed at strengthening the components of non-financial reporting, then a separate report can be devoted to the problem under study, including as part of the sustainable development reporting.

The expansion of the composition of non-financial reporting to reflect the activity of the enterprise in the social and environmental planes is considered by large latifundists of Ukraine as an option to improve their own reputation since in foreign practice the stability and success of the enterprise are associated not only with its economic indicators. The reputation of agricultural enterprises also depends on their use of technologies that harm the environment as little as possible. In addition, it is important to take care of local communities and their social needs. The need for such reports is also conditioned by the need for investment in Ukrainian enterprises, since investors are guided by an open business with minimal risky practices and production circumstances.

The purpose of the study is to form a strategy for the desired improvement of accounting and analytical support of the enterprise with an emphasis on reporting on sustainable development, expanding its analytical set of indicators of economic potential, capacity and effectiveness of an agricultural enterprise, as well as improving accounting and analytical support of enterprises using this information model through updating the documentation of control and audit.

The aim of the study provides for the development of recommendations for improving accounting and analytical support for managing the economic potential of agricultural enterprises aimed at activating their economic, socio-environmental activities.

In order to establish accounting and analytical support for managing economic potential and economic capacity, a model of selective adaptation of improving such support is proposed. The developed model of managing economic potential and economic capacity in compliance with the principles (and reporting) of sustainable development will help to form an approximate composition of expenses of an agricultural enterprise depending on the size, complications of its current business conditions and strategic priorities, which wants to improve accounting and analytical support for its activities. If there are several options for implementing changes in business processes at the enterprise, managers need to assess the complexity of their implementation. Thus, an additional advantage of this approach is the ability to calculate the complexity index of transformation of accounting and analytical support for managing economic potential and economic capacity, taking into account the principles of sustainable development, which shows the level of complexity of future modernisation of these aspects. The proposed forms of working documents for conducting procedures for optimal control over the indicators of economic potential, economic capacity and economic effectiveness and their reflection in the sustainable development report (or similar documents) will help to identify inaccuracies or deliberate distortions of indicators and avoid negative consequences if such events are detected.

MATERIALS AND METHODS

The theoretical and methodological basis was formed by scientific approaches based on the dialectic of knowledge and objective laws of the development of the economy,

nature, and society. Economic and mathematical modelling, systematisation and synthesis helped to develop a strategy to improve accounting and analytical support for managing the economic potential of agricultural enterprises, taking into account the principles of sustainable development.

The classification of enterprises according to Article 2 of the law "On accounting and financial reporting in Ukraine" (Table 1) was used. In accordance with the requirements of the above-mentioned Law, a management report must be submitted and published by medium and large enterprises.

***Table 1**. Classification of the size of agricultural enterprises*

Business categories	Classification criteria	
	Number of employees	Net income of the enterprise, euro (in UAH equivalent)
Microenterprises	up to 10	up to 700 thousand
Small enterpises	up to 50	up to 8 million
Medium-sized enterprises	up to 250	up to 40 million
Large enterprises	more than 250	up to 40 million

***Source**: [10]*

According the guidelines for drawing up a management report, it is recommended to create it in the following areas:

1) organisational structure and description of the company's activities;
2) performance results;
3) liquidity and liabilities;
4) environmental aspects;
5) social aspects and personnel policy;
6) risks;
7) research and innovation;
8) financial investments;
9) development prospects;
10) corporate governance [11].

The recommendations indicate that the list provided is not exhaustive, which allows managers of enterprises to expand it at will or as needed. This means that this instruction reveals the possibility of involving in such reporting a developed analytical set of indicators of economic potential, economic capacity and economic efficiency, which will effectively complement the business card of an agricultural enterprise for potential stakeholders. Due to the fact that the information model should be unified and contain possible options for improving accounting and analytical support for various agricultural organisations, it can be built using the principle of the "tree of goals (decisions)" method. This tool helps to determine possible directions for further development of the enterprise, or options for solving problems that arise during its activities [12].

A goal tree is a visualisation of relationships that reflects the division of the main objective into goals, tasks, and related individual actions. This tool can also be used by adding quantitative indicators that effectively complement the analysis process during decision-making. For the current model, the proposed tool is an opportunity to link the goals set with activities that need to be implemented in the framework of tactical planning [13, p. 136].

To strengthen the management function of an agricultural enterprise that focuses on the principles of sustainable development and aims to modernise the accounting and analytical support for managing economic potential and economic capacity, it is proposed to apply process-oriented management tools. This type of modelling can help to effectively modernise the accounting and analytical support for managing economic potential at agricultural enterprises. The proposed model helps managers of various levels to monitor the implementation of business processes for improving accounting and analytical support for managing economic potential and economic capacity, assess the degree of achievement of priority goals and compliance with the principles of sustainable development.

One of the steps of long-term modernisation of accounting and analytical support for agricultural enterprises through the introduction of sustainable development reporting is proposed, which should include indicators and documents on managing the economic potential, economic capacity, and performance of agricultural enterprises. To help agricultural producers, this study offers a model for improving accounting and analytical support for managing economic potential and economic capacity in compliance with the principles of sustainable development.

Model was tested in two agricultural enterprises. The main motivation for using the proposed model for the first mini-enterprise, farm "ORKHIDEYA-2006" was the desire of its manager to strengthen the composition of management tools, which has not changed for a long time, as well as to expand the array of business information about the enterprise with an emphasis on their environmental practices.

The next enterprise that decided to apply the developed model was the medium-sized agricultural enterprise LLC "Podillya+". The main goal of the policy of improving the accounting and analytical support of this enterprise is to develop a process for drawing up

a management report. In addition, it was decided to adapt the proposed idea of expanding the report with the help of an analytical set of indicators of economic potential, economic capacity, and economic efficiency.

RESULTS AND DISCUSSION

Development of an information model for improving accounting and analytical support for economic potential management

Since 2016, a new generation of modular standards for non-financial sustainable development reporting has been in effect, which are targeted by more than 5,000 companies from all over the world. 33 updated standards help to better adapt reports to the industry specifics of the enterprise, which is very important for agricultural producers. The largest agricultural holdings of Ukraine in 2018-2019, in accordance with the current legislation, reporting on various aspects of their activities in the form of a "management report" and other formats, including through the concept of sustainable development [14].

The current trend in management reporting on sustainable development is an increase in the integration rate of such reports, which may also mean the prospect of including indicators of economic power and economic potential in them. With an integrated management report rich in financial and non-financial information, which presents in detail and illustrates current achievements, the management model, the agricultural enterprise distinguishes itself favourably from its competitors. A structured description of the achievements and strategies of an agricultural producer in the economic, social and environmental spheres in the short and long term effectively reveals its real principles of operation and opens the way for cooperation with relevant partners and consumers [7].

In addition, the current harmonisation of Ukrainian legislation with European legislation is in favour of further development of sustainable development reporting in the context of structured reports with the inclusion of such management blocks as indicators of the agricultural enterprise potential. It was as a result of the activation of the harmonisation process that the management reporting was adapted for Ukrainian enterprises in 2018, which allowed Ukrainian companies to reveal their strengths to a wide range of users of management information [8].

High and stable indicators of the economic potential and economic capacity of the agricultural enterprise, its socio-environmental responsibility, designed in an optimal way and placed in the public domain for all interested – this is a tool for establishing an open and mutual dialogue with partners, investors, as well as local communities. The last point is particularly important for large and medium-sized agricultural producers in Ukraine, given the implementation of the first steps to lift the moratorium on the free sale of agricultural land. Small agricultural enterprises also pay attention to non-financial reporting, since the open and understandable profile of the farm allows attracting the attention of cooperative activists, grant donors and public organisations, which are very important for small communities [6].

A separate issue of management and sustainable development reporting is its verification, i.e. verification by investors and auditors. Major agricultural producers of Ukraine have also begun to carry out the process of verifying such reports, in particular the "Astarta" agricultural holding [15; 16]. Verified non-financial reporting provides a significant competitive advantage for agricultural organisations, since important social and environmental aspects of their activities are certified by independent specialists. It minimises the possibility of information distortion to maintain an exceptionally positive image of the producer and attract promising investment projects.

It is worth noting that the presence of new types of reporting at the enterprise leads to such difficulties in the work of employees involved in its organisation:

– attracting additional resources for data collection and analysis and filling out new reporting forms;

– a large amount of data, reports on the management and sustainability of large companies can last more than 250 pages;

– the requirements for such reporting change dynamically depending on the tactical goals and strategic characteristics of the enterprise, and so on.

Since resources for full-fledged management reporting, including sustainable development reporting, are essential, small agricultural organisations, family and private farms need to make a balanced decision in order to join the new trend and not waste resources that would help in the main production.

Thus, taking into account previous studies, it is logical to assume that one of the steps of promising modernisation of accounting and analytical support for agricultural organisations is the introduction of sustainable development reporting. It may include indicators and documents on the management of the economic potential and economic capacity of agricultural enterprises. However, different agricultural producers have different requests for the accounting and analytical support system at their enterprises and can allocate different amounts of resources to meet such needs. Accordingly, managers should make an informed and balanced decision to improve the choice of reporting system. To help agricultural producers in the outlined range of tasks, this study offers an information model for improving accounting and analytical support for managing economic potential and economic capacity in compliance with the principles of sustainable development.

Substantiation of the choice of improving such accounting and analytical support is relevant, since the manufacturer of agricultural products should update it in such a way that the proposed changes in the future

will bring positive effects. In particular, this includes improving the management analytical activities of the enterprise, contacts with new partners, improved marketing of products and services through reaching a new level of information content of the enterprise's activities [17].

In the conditions of the current crisis, the search for new forms of management, in particular, measures to improve accounting and analytical support for managing economic potential and economic capacity with the involvement of the principles of sustainable development, can give the agricultural organisation a competitive advantage that will help to stand out among similar enterprises, attract additional investment and generate additional income by accumulating the effects of changes in production and management spheres of activity [18].

In the context of dynamically changing business conditions, the principles of balanced economic, environmental and social activities and, accordingly, inevitable changes in the accounting and analysis processes are indicated by active trends in the world economy regarding the greening of production and transparent management of business entities at various levels. The "Green" movement in agricultural production in Ukraine has been developing by the activists since the mid-1970s. In particular, the study highlights the activities of the manufacturing department "Agroecologiya" of the Shishatsky district of the Poltava Oblast, which conducted experiments with land cultivation techniques to reduce the negative impact on the soil [19].

And already in 2007-2010 in Ukraine, there was a massive spread of various alternative agricultural technologies aimed at reducing the use of pesticides and mineral fertilisers in crop production and aggressive drugs in animal husbandry. Farmers have also started using plant-based alternatives to chemical plant protection products. Among the most popular alternative agricultural technologies in Ukraine, organic, biodynamic, biological and natural technologies are being developed. As of 2020, there were 500 operators of organic agricultural production and sale of organic products in Ukraine [20, p. 63].

As for the transparency of agricultural enterprises' activities, as a result of the evolution of business conditions, the composition of management and non-financial reporting has expanded. As a result, Ukraine introduced recommendations, and after the pilot period, the obligation to disclose certain aspects of the activities of agricultural enterprises in the management reporting. The main purpose of implementing and developing this type of reporting is to supplement the annual reporting with information that describes in detail the working conditions, location of production facilities, risks and other significant circumstances of the enterprise's activities.

The planned model of improving the accounting and analytical support for managing economic potential, as well as economic capacity with the involvement of the principles and reporting of sustainable development helps to reasonably form a strategy for changes in the agricultural organisation, which wants to improve the accounting and analytical support of its activities, depending on the size, complications of its current economic conditions and strategic priorities.

The overall process of improving the accounting and analytical support of agricultural enterprises can be represented in the form of a multi-level comprehensive transition from an outdated version to an updated one. This transition covers:

– identification of signs of agricultural organisation that are essential from the standpoint of regulation of updated aspects of accounting and analytical support;

– selection of the structure and content of changes in accordance with the goal of improving the accounting and analytical support of agricultural enterprises;

– selection of forms for implementing planned changes, in particular, software [8].

Accordingly, the proposed model for improving accounting and analytical support for economic potential management in compliance with the principles of sustainable development will have the following comprehensive direction of improvement: introduction of a set of indicators of economic potential, economic capacity and economic effectiveness within the framework of the introduction of sustainable development reporting, in particular the management reporting. This information model will include the following stages of decision-making on accounting and analytical support:

– filter according to the size of the enterprise and determination of the need for a management report;

– number of areas to disclose in the management report;

– option to attract the developed set of indicators of economic potential, economic capacity, and economic efficiency;

– creation of internal analyst working papers on reporting on sustainable development and indicators of economic potential, economic capacity and economic efficiency;

– form of implementation of innovation;

– terms of adaptation of improvements [5].

A graphical view of the information model is shown in Figure 1.

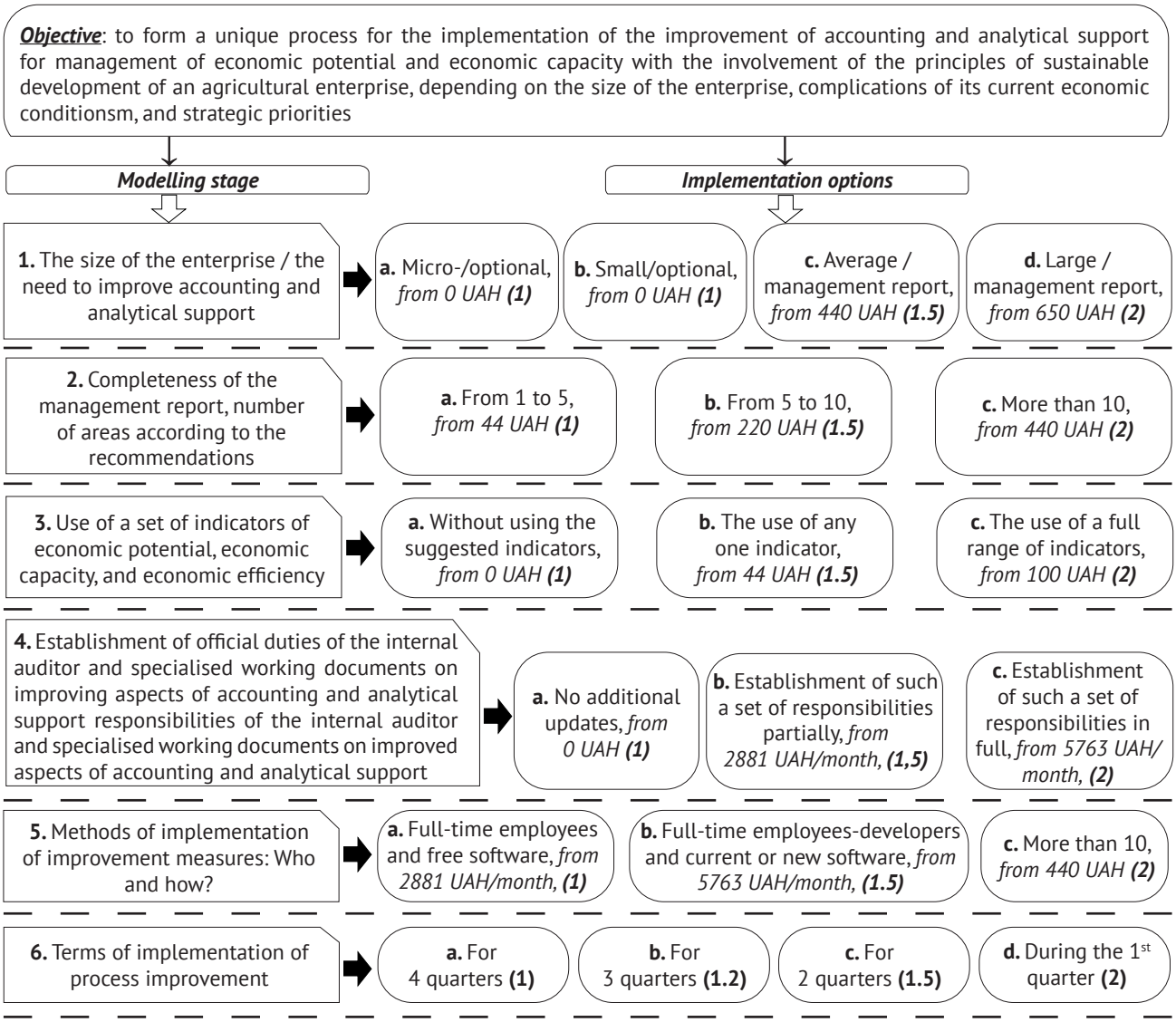

Figure 1. *Structure of the information model for improving accounting and analytical support for managing economic potential and economic capacity with the involvement of sustainable development reporting*

When implementing the proposed information model for the needs of the current study, the following decision-making stages and possible options were obtained:

– at the stage of filtering the studied enterprises according to the size of the enterprise and establishing the need to draw up a management report, you can offer 4 options to choose from: microenterprises or small agricultural formations that voluntarily introduce updates to the accounting and analytical support of their activities, as well as medium or large enterprises, as well as those that, according to the current legislation, must update it;

– according to the guidelines for filling out a management report, there is an approximate list of 10 areas that enterprise managers need to disclose in such a report, but it is not final and enterprises can add other information. And enterprises that make up this report on their own will can choose only a few areas from the proposed list. As a result, this stage will have the following options: from 1 to 5; from 5 to 10; and more than 10 areas;

– at the next stage, it is necessary to choose whether the company will attract the developed set of indicators of economic potential, economic capacity, and economic efficiency in whole or in part;

– next, it is necessary to choose whether to create an additional business process for the internal controller (auditor) and specialised working documents on inspections of reporting processes on sustainable development and indicators of economic potential, economic capacity, and economic efficiency. At this stage, the options are no additional updates, creating a full or partial set of responsibilities and specialised documents;

– at the stage of implementing innovations, it is necessary to decide who will perform it and how: employees of the enterprise in free software, full-time employees-developers using current software, or outsourcing companies;

– depending on the content of measures to improve accounting and analytical support, such a process can take place over one, two, three or four quarters. Such

time periods are proposed due to the continuous nature of accounting, so the main set of updates should be performed without interfering with accounting and reporting processes [17].

In the presence of several options for implementing changes in business processes at the enterprise, managers need to assess the amount of resources needed for their implementation. Thus, an additional advantage of this information model is the ability to calculate the index of resource intensity of the process of improving accounting and analytical support for managing economic potential and economic capacity with the involvement of the principles of sustainable development (IP), which estimates the approximate amount of resources for future modernisation of these aspects. This index helps to navigate the scope of work at each stage of implementation of planned measures to improve the accounting and analytical support of the agricultural organisation and approximate the amount of resources for their implementation. Such an index is calculated by multiplying the coefficients shown in parentheses at the end of the description of each option.

These coefficients are determined based on the practical observations during the study. They have values from 1 to 2 for each option, and as a result of the calculation, an index from the minimum value can be obtained. It will be equal to 1, and up to the maximum, which will be equal to 64.

An index with a value from 1 to 12 indicates a low amount of resources attracted to implement the selected improvement strategy, an index value from 13 to 32 illustrates the average amount of resources attracted to implement such a strategy, and an index from 33 to 64 indicates a high amount.

The minimum level of complexity of implementing measures to improve accounting and analytical support within the current model means that a mini-enterprise can partially use elements of the management report during the year and with minimal funds without indicators of the developed set of economic efficiency. In other words, the company can gradually update the reporting system over the course of a year, taking into account the principles of sustainable development, revealing up to 5 areas recommended by law with minimal monetary costs.

The maximum level of the index means that a large agricultural enterprise, in accordance with the requirements of the current legislation, makes a full management report, disclosing information in more than 10 areas, including those that were independently added by the managers of the studied enterprise. In addition, non-financial reporting will include indicators of economic potential, economic capacity, and economic efficiency. The implementation of such improvements should take place within one quarter by employees of the outsourcing company at market prices. Intermediate values of the index indicate various options for implementing improvements in accounting and analytical support of the studied enterprises, which will be considered using examples during testing.

The mechanism of using the developed information model by the studied agricultural enterprises to form a plan for improving accounting and analytical support for managing economic potential and economic capacity with the involvement of the principles and reporting of sustainable development has certain features. First, an enterprise interested in updating its accounting and analytical support package must decide on the specific purpose of such an update, as well as the amount of resources that it can allocate for the implementation of improvements.

The range of material costs for implementing steps to improve accounting and analytical support was determined based on monitoring data on market prices, working time costs and the minimum wage in Ukraine as of the beginning of 2020.

At Stage 1, when determining the size of the enterprise, it can be found that the amount of expenses of this stage is affected by the fact that it is necessary to draw up a management report and the approximate minimum wage for drawing up sections of the report. The amount of expenses may consist of the minimum payment of the accountant's salary for 10 hours of work (according to the number of areas of the report), payment of the unified social contribution (ESC) and other expenses, in particular for electricity and software. The option with an initial cost level of 0 UAH means that the company may not update anything at the current stage, or the update may take place within the current accounting process without attracting significant additional costs.

At the second stage, the cost of completing the task is associated with the same factors as at the first stage. The costs that the company will incur at the third stage, as well as at the previous two, depends on the time during which the responsible employee will study the methodology, make calculations, and draw up documentation on a set of indicators of economic potential, economic capacity, and economic efficiency, the level of his salary, as well as other additional costs.

The implementation of the fourth stage of the developed model is associated with the emergence of a new list of job responsibilities in accounting and auditing areas, where the minimum amount of expenses is half of the minimum wage of an employee who will perform all tasks for conducting analytical procedures. In particular those related to reporting on sustainable development and indicators of economic potential, economic power, and economic efficiency, ESC and additional costs.

The implementation of the existing concept of improvement, which was chosen by the company, is the fifth stage of the model of improving accounting and analytical support, which is being developed. The amount of costs that the enterprise will incur at this stage of the model may be the largest in the framework of its implementation process. Audit and control procedures are extremely important for maintaining the quality of accounting and analytical support for agricultural enterprises, so the cost of professional work and modern software is high. Thus, the costs of this stage include the salaries of professionals and modern software for performing work, drawing up final reports on the results of inspections. According to the results of market monitoring, the services of outsourcing companies can be the most expensive option for implementing improvements [9].

The last stage of the model is not directly related to monetary costs, but it indicates the time of implementation of changes, which means the intensity of resource outflow for the implementation of such changes. Focusing on the pace and structure of the work of most accounting services of agricultural organisations in Ukraine, it was decided that the most intensive improvement can be completed in one quarter, and the longest – in four. But in practice, such terms of implementation of the project to improve accounting and analytical support may change, since the enterprise operates in constantly changing conditions.

This information model was presented by various agricultural entities that are planning or have already taken into account the sustainable development goals, and are also trying to improve their own market positions not only at the expense of the production component. Aspects of accounting and analytical support for economic potential management also interested enterprise managers, in particular as another area of information disclosure in the management report. To test the developed model the studied enterprises used the following mechanism for its use:

– establishment of the company's goal in the context of improving its accounting and analytical support system;

– establishment of a strategy for implementing the improvement of its accounting and analytical support system in accordance with the established goal, using the proposed model;

– implementation of the selected strategy and its adjustment as needed.

Information model for improving accounting and analytical support for managing the economic potential of small farms "ORKHIDEYA-2006"

After getting acquainted with the details of modeling, which coincides with the development interests of several enterprises studied, managers tried to use this model to plan updates to their accounting and analytical systems.

The main motivation for using the proposed information model for the first mini-enterprise, farm "ORKHIDEYA-2006" was the desire of its manager to improve the composition of management tools, which has not changed for a long time, as well as to expand the array of business information about the enterprise with an emphasis on their environmental practices.

The main areas of activity of this enterprise are crop production, provision of services and advice in the field of agronomy, selection of grain and vegetable crops. Accounting and control procedures were carried out by a part-time manager and accountant, since the number of operations at the enterprise is small, except for seasonal peaks that are traditional for growing grain and vegetable crops. An important aspect of the work of this farm is the involvement of alternative technologies in the cultivation of vegetables: the absence of mineral fertilisers and the use of plant protection products of natural origin. It is this aspect that has led to the need for additional analytical tools and publication of the results of greening the company's activity.

Reformulating such a request within the framework of the proposed model, the goal of the strategy for improving the accounting and analytical support of a small agricultural enterprise was obtained: to additionally analyse activities using an indicator of economic potential and regularly publish the results of the analysis and features of activities in a publication similar to a management report. The manager does not want to draw up a full-fledged management report, since according to the law, his company does not have such an obligation, and accordingly, there is no need to spend resources on a full-fledged report. In addition, there is a need to create forms for analysing and monitoring the indicator of economic potential, which will be performed by the manager independently. The report on the ecological and economic features of production will be compiled by a full-time accountant. As a result, the following model for the small farm "ORKHIDEYA-2006" is obtained (Fig. 2).

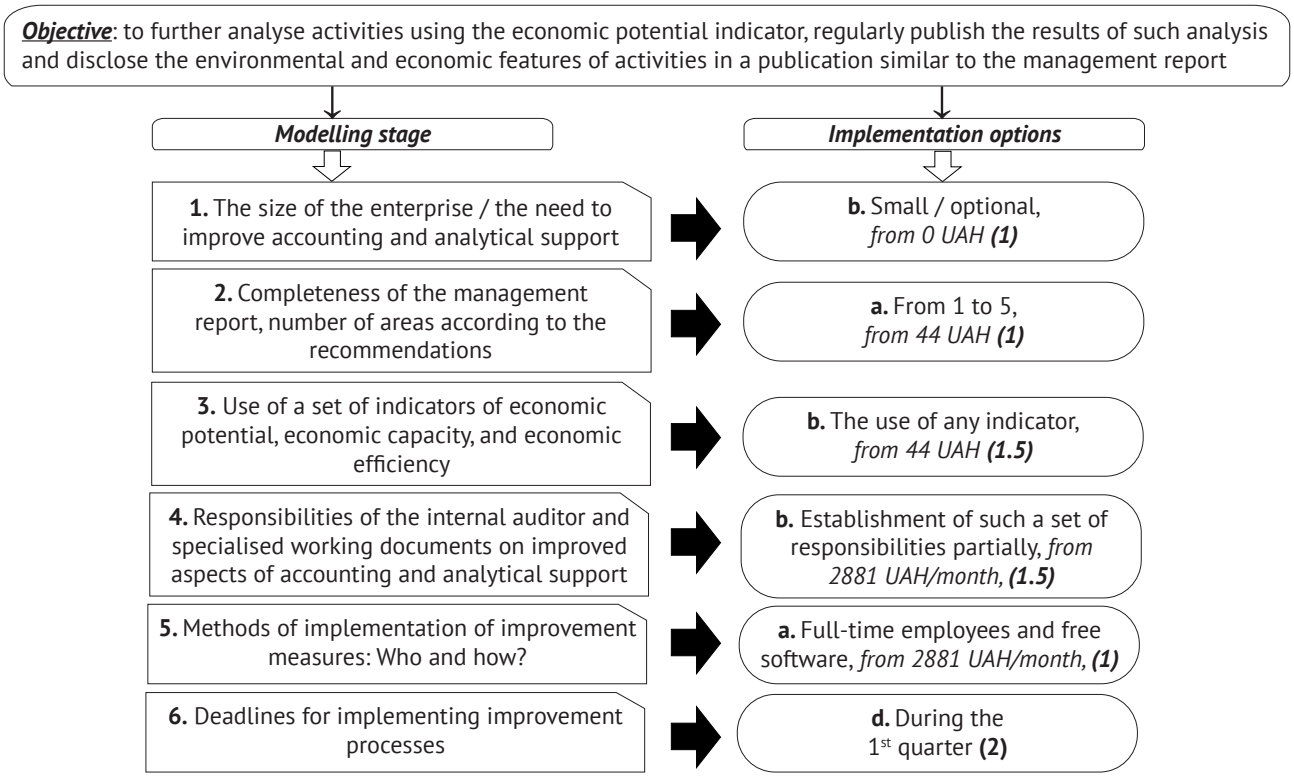

Figure 2. *Information model for improving accounting and analytical support for economic potential management with the involvement of the principles of sustainable development, developed by the author for small farm "ORKHIDEYA-2006"*

Source*: developed by the author of this study*

The combined strategy for improving accounting and analytical support for economic potential management with the involvement of the principles of sustainable development, developed for the small farm "ORKHIDEYA-2006" has the following form:

1b-2a-3b-4b-5a-6d,

and Index:

$I_p = 1 \times 1 \times 1.5 \times 1.5 \times 1 \times 2 = 4.5;$

which indicates a relatively small amount of resources attracted for the implementation of the planned improvement in accordance with model 2.

As for the costs of such an update, the main part of them will be spent on the accountant's salary, contributions to state funds, and utility costs, since the company already has accounting software suitable for the planned changes. According to preliminary estimates, such expenses amount to no more than UAH 175 per working day (or no more than UAH 3,500 per month, provided that there are 75-100 operations per month).

The results of such improvement, in accordance with its goal, should be to improve the image and identify reserves for strengthening the potential of the enterprise. Conclusions on the results of improvement will be drawn after the end of the production cycle of the enterprise, conducted with changes. It was decided to limit the implementation period of these changes to one quarter, since, according to the outlined plans, this time is sufficient to implement the planned improvement of accounting and analytical support.

Information model for improving accounting and analytical support for managing the economic potential of LLC "Podillya+"

The next enterprise that decided to apply the developed model was the medium-sized agricultural enterprise LLC "Podillya+". This company uses about 5 thousand hectares for growing such cereals and oilseeds as wheat, sunflower, barley, and rapeseed. In addition, the company is engaged in poultry farming. Taking into account the requirements of the law of Ukraine "On accounting and financial reporting in Ukraine", this company must prepare and publish a management report, which has already been done in 2020, but the process of forming such a report still has shortcomings.

The main goal of the policy of improving the accounting and analytical support of this enterprise is to develop a process for drawing up a management report. In addition, it was decided to adapt the proposed idea of expanding the report with the help of an analytical set of indicators of economic potential, economic capacity, and economic efficiency. This format of the management report will help not only to effectively present the company's work, but also to demonstrate the levels of potential and capacity of the agricultural enterprise (Fig. 3).

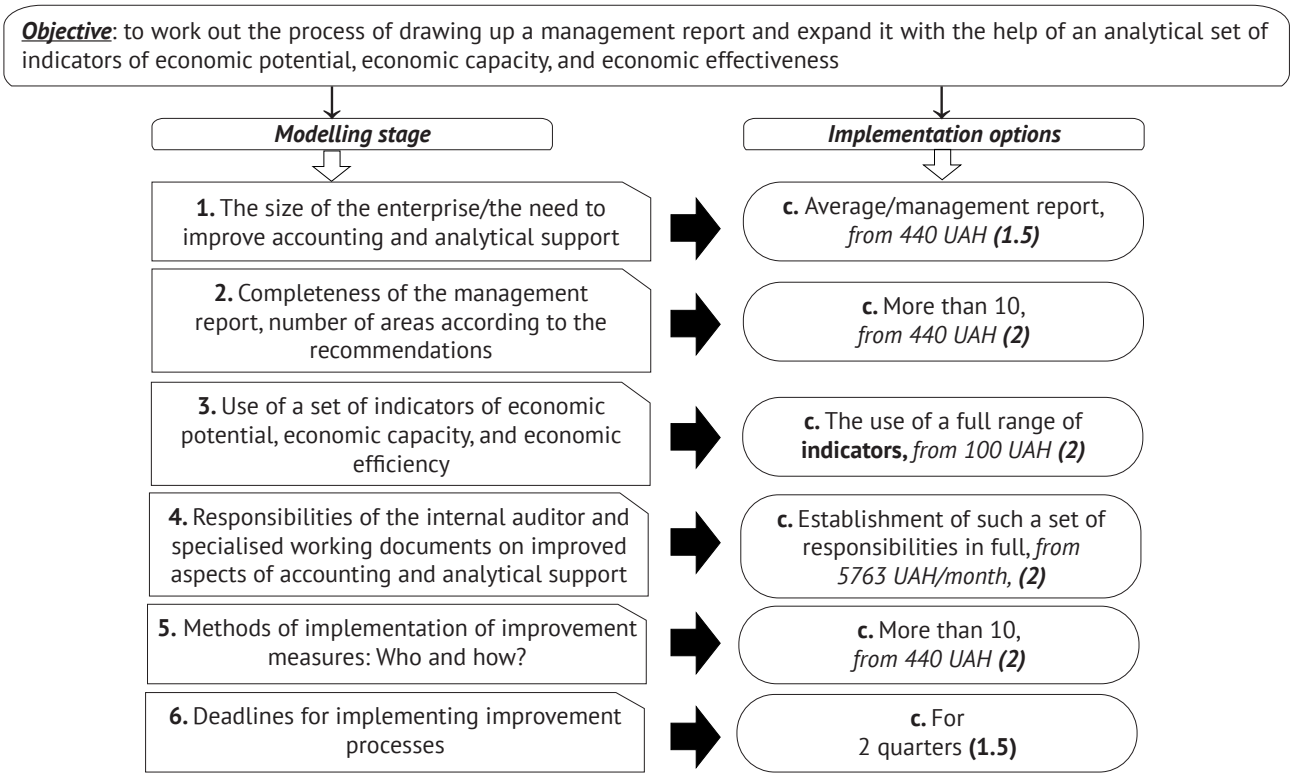

Figure 3. *IInformation model for improving accounting and analytical support for economic potential management with the involvement of a sustainable development reporting, developed by the author for a medium-sized agricultural enterprise LLC "Podillya+"*

Source*: developed by the author of this study*

The developed strategy for improving accounting and analytical support with the establishment of an updated management report within the model has the following form (the number is a step of the strategy, and the letter is a variant of its implementation):

1c-2c-3c-4c-5c-6c,

and the resource intensity index of this model:

$I_p = 1.5 \times 2 \times 2 \times 2 \times 2 \times 1.5 = 36;$

which indicates a high amount of resources required to implement the planned improvement in accordance with Model 3.

Since the enterprise under study is medium-sized with several production areas, accounting and control is handled by a separate accounting service consisting of four employees.

Every year, the company orders an external audit of its financial statements and publishes an audit report. Since the management report is not part of such reporting, the auditors disclosed information about such a report very briefly in the "Other information" section of the report. When compiling the management report in 2020, it was decided to order auditors to check the results of accounting and control operations disclosed in it. That is, the oriented amount of expenses for the development and implementation of improvement measures in accordance with the accounting and analytical support model consists of the costs of analysing and monitoring a set of indicators, their involvement in the updated management report, as well as the costs of the audit. In addition, it is necessary to develop the concept of disclosing the necessary areas of the management report. Therefore, the following amount of work will be carried out: data analysis and control by an additional part-time accountant, which is about 7,500 UAH per month, as well as a range of services from the audit office in the amount of about 2,000 UAH in addition to the main fee for the annual audit. The structure of the management report will be finalised by an outsourcing company for UAH 3,600 (since the main body of work on developing the structure of such a report was already completed last year).

CONCLUSIONS

The developed information model of selective adaptation of accounting and analytical support for managing economic potential based on the principles of sustainable development reporting helps to reasonably form the approximate composition of expenses of an agricultural enterprise depending on the size, complications of its current business conditions and strategic priorities. If there are several options for implementing changes in business processes at the enterprise, managers need to assess the complexity of their implementation. Thus, an additional advantage of this approach is the ability to calculate the complexity index of transformation of accounting and analytical support for managing economic potential and economic capacity, taking into account the principles of sustainable development, which

shows the level of complexity of future modernisation of these aspects.

Therefore, it can be concluded that the proposed information model helps to form a strategy for the desired improvement of accounting and analytical support of the enterprise with an emphasis on sustainable development reporting, expanding it with an analytical set of indicators of the economic potential, capacity and effectiveness of an agricultural enterprise. A separate issue of improving the accounting and analytical support of enterprises using this information model is updating the paperwork on control and audit.

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ІНФОРМАЦІЙНА МОДЕЛЬ УДОСКОНАЛЕННЯ ОБЛІКОВО-АНАЛІТИЧНОГО ЗАБЕЗПЕЧЕННЯ УПРАВЛІННЯ ЕКОНОМІЧНИМ ПОТЕНЦІАЛОМ

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Анотація. Актуальність дослідження пов'язана з необхідністю посилення управлінської функції сільськогосподарського підприємства, яке орієнтується на принципи сталого розвитку і хоче модернізувати обліково-аналітичне забезпечення управління економічним потенціалом. Мета наукової роботи заключається в формуванні стратегії бажаного удосконалення обліково-аналітичного забезпечення підприємства з акцентом на звітність зі сталого розвитку, розширивши її аналітичний комплекс показників економічного потенціалу, потужності та результативності сільськогосподарського підприємства, а також удосконаливши обліково-аналітичне забезпечення підприємств за допомогою даної інформаційної моделі через оновлення документального оформлення контролю та аудиту. Теоретико-методологічну основу склали наукові методи, що базуються на діалектиці пізнання й об'єктивних законах розвитку економіки, природи і суспільства, економіко-математичне моделювання, метод систематизації та синтезу допомогли розробити стратегію з удосконалення обліково-аналітичного забезпечення управління економічним потенціалом сільськогосподарських підприємств з врахуванням принципів сталого розвитку. З'ясовано, що такий тип моделювання може допомогти ефективно модернізувати обліково-аналітичне забезпечення управління економічним потенціалом для сільськогосподарських підприємств. Розроблена інформаційна модель селективної адаптації допомагає управлінцям різних рівнів здійснювати контроль за реалізацією бізнес-процесів удосконалення обліково-аналітичного забезпечення управління економічним потенціалом, оцінювати ступінь досягнення пріоритетних цілей і дотримання принципів сталого розвитку. Запропоновано один із кроків перспективної модернізації обліково-аналітичного забезпечення аграрних формувань через запровадження звітності зі сталого розвитку, що має включати показники та документи з управління економічним потенціалом, економічною потужністю та результативністю сільськогосподарських підприємств. Перевагою даної інформаційної моделі є можливість розрахунку індексу складності трансформації обліково-аналітичного забезпечення управління економічним потенціалом із залученням принципів сталого розвитку, який показує рівень складності майбутньої модернізації зазначених аспектів

Ключові слова: економічна потужність, результативність, потенціал підприємства, сільськогосподарське виробництво, аграрні формування, аграрний сектор

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