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Sensitivity Optimisation of a Main Marine Diesel Engine Electronic Speed Governor

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Abstract. Electronic speed governors have become widespread on marine diesel engines. In comparison with hydromechanical ones, they have an additional setting parameter – input signal sensitivity. This parameter allows changing the response of governors to high-frequency disturbances. In camshaft diesel engines, such disturbances are generated when the cams run over fuels pump push rods, while in ME (MAN Energy Solutions) or RT-flex (Wärtsilä) engines they result from the use of inductive sensors with a serrated tape on the diesel shaft for speed measurement. If the engine is used as a main engine on vessels, the governor's sensitivity additionally allows governors to vary the response to propeller shaft resistance moment fluctuations in sea waves conditions. In practice the value of sensitivity of electronic speed governors of main marine engines is selected intuitively. As a result, the adjustment of governors doesn't provide satisfactory stability of speed modes at the change of sea conditions. The study aims to develop a methodology for adjusting the sensitivity of main engines electronic speed governors with considering the stochasticity of the load on the diesel engine in sea waves state. The study was carried out using the systems of automatic speed control model, which is based on the assumption of relatively small deviations of diesel engine shaft rotation speed and load parameters at sea waves conditions. Considering the character and magnitude of change of load on diesel engine at sea waves conditions depend on many variables of external conditions (waves levels, course of a vessel in relation to wind-wave conditions, wind gusts, vessel's loading condition, given speed of a vessel), any set value of sensitivity of electronic speed governors appears to be optimum only for a particular case of vessel movement in sea waves state. The scientific novelty is defined by the fact that recommendations on the choice of governor sensitivity are determined with considering stochasticity of propeller shaft resistance moment fluctuations at sea waves conditions, that increased accuracy, and validity of recommendations. The practical significance of the research consist in the increase of stability of speed modes of the main engine with electronic speed governor at various sea waves conditions

Keywords: marine vessels, marine diesel engine, internal combustion reciprocating engine, automatic speed control system, electronic speed governor, speed control

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INTRODUCTION

Main marine diesel engines operate in sea waves conditions for a considerable part of the operational period, when propeller shaft resistance moment fluctuates in wide ranges of amplitude and fluctuations period. Based on statistical data of wind force values and waves height distribution repeatability of wind speeds (in Beaufort scale points) on lines of transport vessels, for example, of Black Sea Shipping Company in the third quarter of the year 1988 was: 0 ... 4 grade – 63.8%, 5 grade – 18.1%, 6 grade – 9.9%, and 10 or more grade – 0.2%. For propulsion systems of transport vessels, a wave of a 5 grade or more is considered to be tangible. That is why it can be approximately considered that propulsion systems work 1/3 of running time on unsteady modes, connected with sea waves state [1]. It means that systems of automatic speed control (ASCS) of main marine diesel engines should provide stability of speed mode at various amplitudes and periods of fluctuations of load on the diesel engine. At that, it is necessary to consider that amplitudes and periods of fluctuations of loading on main marine diesel engine at sea waves are random values depending on wave levels, course, and yaw of a vessel, gust of wind, and speed of a vessel. Therefore, if ASCS operation is optimised for specific deterministic rather than random disturbances, the stability of the diesel engine speed mode may deteriorate as the sailing conditions change. Electronic speed governors (ESG), in comparison with hydromechanical ones, has additional configuration parameters: the value of the reduced sensitivity range, which can usually vary from 0 to 5 ... 10%; the signal transfer coefficient in this range, which can be set from 0.1 to 1.0.

Decreasing the sensitivity increases the stability of the ASCS in the calm waving state but deteriorates the dynamics of the ESG in the rough sea especially with a small waving period. Normally, this parameter is selected intuitively, which does not provide optimum control under variable sailing conditions. One of the reserves for optimisation of diesel plants control in sea wave conditions is the consideration of stochastic characteristics of disturbing propeller action. The present study is devoted to this problem [2]. Merchant vessels often undertake lasting voyages in difficult operating conditions because of sea waves, where thermal stress values can reach extremes [3]. The rotation frequency of a main engines (ME) shaft at sea waves can be accompanied by mechanical overloads of details of the cranking mechanism [4], which leads to a decrease in efficiency and reliability of the work of the engine [5]. Besides, as a result of the decrease in excess air coefficient quality of fuel combustion processes worsens causing coking of a gas-air path and the increased wear of details of a cylinder-piston group. The problem of ensuring the quality of diesel engine speed control, taking into account the operational conditions of their work, remains relevant [6]. At the same time, electronic governors implementing proportional-integral-derivative (PID) control law provide the greatest opportunities for adaptation of ASCS operation to the working conditions [7]. Stabilisation of diesel engine shaft rotation speed, continuous monitoring, and automatic maintenance of the same load on all cylinders increase the reliability of engine operation as a whole and increase periods between inspections of cylinders and exhaust gas tract [8]. During the operation of an automated engine, it is also advisable to ensure systematic monitoring of its power utilisation and the effectiveness of the ESG configurations [9].

Quality and accuracy of engine rotation speed control are standardised by the international standard ISO 3046-4:2009 "Reciprocating internal combustion engines – Performance – Part 4: Speed governing" [10]. ESG not only provides stabilisation of speed mode of a diesel engine but also allows prevention of mechanical and thermal overload of a diesel engine on variable modes of operation [11], which also provides a decrease in the volume of harmful emissions with exhaust gases [12]. ESG using an electric motor as an actuator have a performance capability sufficient for engines of almost any capacity [13]. In sea waves conditions due to variable weather, it is often necessary to readjust the ESG to ensure the stability of the diesel engine speed mode [14]. However, the problem of ensuring maximum operational reliability, optimum control in conditions of sharply pronounced load dynamics, quality of operation of main marine diesel engines in sea waves conditions remains unsolved [15]. Unsatisfactory governor dynamics can cause increased fuming and thermal overloading of details of a cylinder-piston group [16], exchange power fluctuations between diesel engines working in parallel, and insufficient capacity of the unit. In the study S.I. Gorb [17], methods to improve the accuracy of simulation of ASCS dynamics are proposed to optimise the operation of governors under deterministic disturbances. These methods can be used for optimisation of hydromechanical governors or optimisation of ESG in S.I. Gorb and M.I. Budurov [18]. However, the proposed models for accounting for ASCS nonlinearities with refinement can also be used to optimise ASCS operation under stochastic variations in the main engine load under sea waves conditions.

The study aims to develop a methodology for adjusting the sensitivity of main engines ESG with considering the stochasticity of the load on the diesel engine in sea waves state. The realisation is aimed to improve the reliability of main engines, optimise vessel speeds and improve the energy efficiency of the fleet, being in line with the aims of resolution MEPC 77/6/2 as well as "related" resolutions MEPC 73/5/1, MEPC 74/5/5, and MEPC 75/6/2 [19].

MATERIALS AND METHODS

The study was carried out using the ASCS model [17], which is based on the assumption of relatively small deviations of diesel engine shaft rotation speed and load parameters at sea waves conditions. Under this assumption, the propeller characteristics are linearised, and the diesel speed characteristic is assumed horizontal (it is assumed that diesel shaft speed has no influence on fuel supply by high-pressure fuel pumps (HPFP) and on the diesel indicator efficiency, which is typical of modern types of diesel engines). To solve the optimisation problem the model allows analysing the influence of ESG configuration parameters on dynamic properties of ASCS diesel engine. This model provides consideration of delays in the channel of control action transfer from the governor to the diesel engine (due to fuel cycling and peculiarities of torque change in the cranking mechanism). The minimum instability of the regulated parameter was chosen as the criterion of optimality. This minimum must be achieved, first of all, at the most probable fluctuations of the disturbing influence. The study was conducted taking into account the results of S.I. Gorb [20], which substantiated the correctness of assumptions about stationarity and normality of disturbing influence on diesel system at sea waves, including the fact that the system under study contains linear inertial links, which normalise the law of distribution of random signals. Author borrowed from the work S.I. Gorb [20] quantitative dependencies of changes in the disturbance variance D_λ on the wind strength according to the Beaufort scale and the relationship of parameters α and β ($\alpha \approx 0.16\beta$), which characterise the correlation function of the disturbing effect.

The signal dispersions in the ASCS were determined through the spectral densities, which are related in different coordinates of the system by the square of the frequency transfer function modulus. The spectral density of the disturbing effect was set by Firsov's approximation formula, which reflects well the physical picture of the phenomenon, as it gives the lowest density at low frequencies in comparison with other formulas. The mathematical model didn't include the gas turbocharger dynamics, as the charge air pressure remains practically stable [21] in the dynamic modes of transport vessels' ME associated with sea waves state. The presence of non-linear links significantly complicates the calculation of system response to random disturbances because the transfer functions of the links depend on the parameters of random signals. To calculate the nonlinear transformation of random signals a method of statistical linearisation was used, the idea of which is based on the replacement of nonlinear links by linear ones that are equivalent concerning the response to a given random disturbance. As a result of this replacement, the system as a whole is linearised and the apparatus of linear theory can be applied for its investigation. The minimum expectation of the square of the difference between the random processes at the output of a nonlinear link and an equivalent linear link is chosen as the criterion of statistical linearisation for the system under study. This criterion combines satisfactory accuracy of statistical linearisation with the simplicity of calculation expressions for inertia-free links.

In statistical linearisation, each non-linear stage is replaced by two linear stages – one of which transforms the conditional expectation of the input signal and has a transfer ration of k^m and the other transforms the centered random component and has a transfer coefficient of k^D. To make these coefficients time-independent, the disturbing effect on the system under study must be stationary. If, in addition, the random signals in the system have a normal distribution law, the coefficients k^m and k^D are only functions of the conditional expectation and variance of the signals on links input. A closed-loop control system is calculated in the following sequence. First, some values of the coefficients are given k^m and k^D of all nonlinear links. Using transfer functions of the system author determine in first approximation conditional expectations and dispersions of signals at the input of non-linear links. Using the found values of conditional expectations and dispersions of signals author find the coefficients k^m and k^D. Then the cycle of expectation and variance calculations is repeated many times until the values obtained during the approximations coincide with the previous ones with sufficient accuracy. The object of investigation is the main diesel plant of HITACHI ZOSEN MAN – B&W type 6S60MC-6 of the large-capacity oil tanker "KORO SEA", which was built at Namura Ship Building Co. Ltd. in Japan and put into service 27.02.2008 (Table 1). The engine has a vertical cylinder arrangement, is crosshead, reversible, and runs with a direct transfer to a fixed-pitch four-bladed propeller, in increments of 4715 mm and 7300 mm in diameter. Gas turbine charging is provided by a MITSUBISHI HEAVY INDUSTRIES MET66SE series turbocharger.

The main technical data of the HITACHI ZOSEN – MAN B&W 6S60MC-6 engine is taken from the design documentation [22] and provided in Table 2.

***Table 1**. Main characteristics of the large-capacity tanker "KORO SEA"*

Gross register tonnage, tonnes	56355
Net register tonnage, tonnes	32524
Deadweight, t	105905
Displacement, t	121852
Draught, m	14.92
Length, m	241.03
Length between perpendiculars, m	232.0
Width, m	42.0
Submersible propeller draught, m	7.71

***Table 2**. Technical data of the HITACHI ZOSEN – MAN B&W 6S60MC-6 engine*

Number of cylinders	6
Cylinder diameter, mm	600
Piston stroke, mm	2292
Nominal power, kW	11770
Nominal speed, min.$^{-1}$	101.0
Average indicator pressure, kgf/cm^2	18.4
Maximum combustion pressure, kgf/cm^2	143
Average piston speed, m/s	7.72

The HITACHI ZOSEN – MAN B&W 6S60MC-6 engine is equipped with the Nabtesco electronic control system which does not contain hydraulic or pneumatic elements and consists of the M-800-III type automatic remote control system, the MG-800 type ESG and engine protection system. The Nabtesco MG-800 ESG [23] is based on a controller and is equipped with an electromechanical servo drive for fuel racks. The actuator with the maximum torque on the output shaft – 330 Nm is an AC electric motor with a planetary reduction gear whose output shaft is connected to the fuel rack. The controller provides PID control law. The ESG setting parameters can be changed according to a preset programme depending on the engine operating mode, allowing the control characteristics to change. For example, the basic setting of the governor ensures that the control law changes from PID to PI (proportional-integral) when the speed increases above 60 min^{-1} by zeroing out the differential time constant. The governor settings such as gain, integration time, and differentiation time are set independently of each other for five engine operating modes (depending on engine rotation speed or fuel supply). The governor is set to a reduced sensitivity zone (RSZ) ranging from 0 to 10 min^{-1} (for the diesel engine in question from 0 to 0.099 relative units).

The transfer coefficient in this zone is set within a range 0.5-1.0 (the sensitivity can be reduced by up to 50%). When the diesel shaft speed stabilises in the specified limits within the recommended time range of 10 ... 30 s, the zone value doubles. It is recommended that the signal transfer coefficient in the doubled zone is set in the range from 0.1 to 0.5 (it is recommended that the sensitivity is reduced by 50-90%). The control panel is equipped with a HIGH GAIN mode key, in which the PID configuration parameters are changed to a more "active" operation of the governor (the setting values in this mode can be changed). This mode is recommended if the governor does not provide the required speed stability in rough sea conditions, especially if a shaft generator is used. The engine speed is measured by an induction converter, whose circuit generates current pulses as the serrated tape mounted on the engine shaft. The pulse frequency is converted into a direct current with a voltage proportional to the engine shaft rotation speed.

RESULTS AND DISCUSSION

The structural scheme of the investigated ASCS is shown in Figure 1. Due to the fact that the modelling aims to improve the dynamics of the ESG under near-harmonic disturbances, the structural scheme did not consider the limitations of the permissible stroke of the actuator: as a function of the measured rotation speed; as a function of the charge air pressure and rigidly set on the control panel. In diesel engines, it is characteristic that the change in the relative torque of the diesel relative against the change in the relative stroke of the fuel pump racks $\overline{h}_r$ is delayed. This lag can be explained by the fact that the torque indicator does not reach its maximum value immediately after the fuel cut-off. The maximum torque value corresponds to the angle of rotation of the crank from the upper dead centre (UDC) 22 ... 32°. Smaller values are characteristic of partial fuel supply. When controlling the fuel supply by changing the end of the supply, the fuel cut-off torque depends on the value of $\overline{h}_r$ and usually varies from UDC to 18° of the crank turn. Considering the above, it can be assumed that with $\overline{h}_r$ close to 1, a delay of change of indicating torque of a diesel engine approximately corresponds to 10° of a turn of a crank, and at $\overline{h}_r$, close to zero, increases to 20°. Then the value of the delay:

$$\tau_{del} = \frac{20 - 10\overline{h}_r}{6n_{d0}\bar{\omega}_d} \quad (1)$$

where: n_{d0} – rotation speed of diesel engine shaft in nominal mode, min^{-1}; $\overline{\omega}_d$ – is a relative angular speed of the diesel shaft.

The study was carried out at an average engine load of 80% of nominal load, which corresponds to the main operating mode of the 93 min^{-1}.

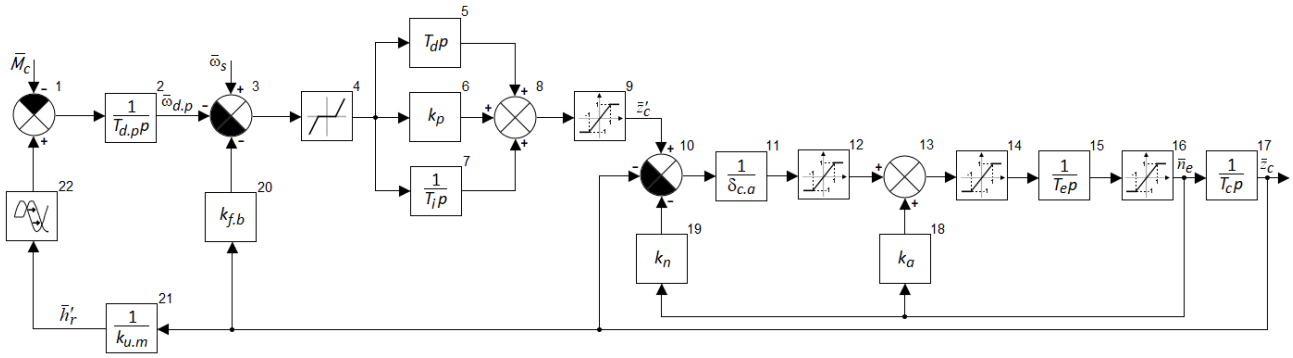

Figure 1. *Structural scheme of ASCS of marine diesel engine HITACHI ZOSEN – MAN B&W 6S60MC-6 with ESG Nabtesco MG-800*

***Note**: 1, 3, 8, 10, 13, 15 – adders; 2, 7, 15, 17 – integral links; 4 – functional converter, introducing a zone of low sensitivity; 5 – differentiating link; 6, 11, 18, 19, 20, 21 – proportional links; 9, 12, 14, 16 – nonlinear links, which consider signal saturation at level ± 1; 22 – nonlinear link, which consider transport delay* τ_{del}

The system is perturbed by the change in the relative torque on the diesel shaft $\bar{M}_c$ via the adder 1 (by the load channel). Nonlinear transformations of signals are carried out by a link 4 which introduces a zone of the decreased sensitivity of ESG to unbalance signals $\bar{\omega}_s$ and $\bar{\omega}_{d.p}$; links 9, 12, 14 and 16 which limit the signal at a level of relative unity; link 22 which realises a transport time delay of change of the diesel engine torque in relation to the index of fuel pumps. Elements 3-9 produce the required value of the actuator stroke $\bar{z}_c'$. This value is "worked out" by elements 10-20. The value $\bar{z}_c'$ is calculated directly from the signal for angular speed setting $\bar{\omega}_s$. If the signal $\bar{z}_c'$ does not provide the necessary fuel supply to the diesel engine (there is a difference between the set $\bar{\omega}_s$ and the measured $\bar{\omega}_{d.p}$ angular speeds), links 3-7 will generate correction signals to the adder 8. These correction signals allow the signal $\bar{z}_c'$ to be refined. Link 4 realises a zone of reduced sensitivity ε (from 0 to 0.099 relative units) to the input signal with transfer coefficient k_g (from 0.1 to 1 relative units). Links 5, 6 and 7 convert the signal according to the PID control law. With the normal ESG sensitivity set on the control panel, the proportional link gain coefficient k_p, integration time T_i, and the differentiation time T_d are adjustable within the limits of 0.1 ... 5 relative units, 0.5 ... 30 s and 0 ... 2 s respectively.

The actuator has two feedbacks: barrel nut position (output signal $\bar{z}_c$') and electric motor speed $\bar{n}_e$. In steady states $\bar{z}_c=\bar{z}_c'$ and $\bar{n}_e=0$. Therefore, the adder 10 output signal is zero. If an imbalance between the set and the exhausted signals occurs ($\bar{z}_c'$ and $\bar{z}_c$) the output signal of the adder 10 becomes non-zero. This signal is amplified by the control element 11, having the output signal limitation at the relative unity level. The occurrence of the signal at the output of element 11 causes the acceleration of the electric motor which in the circuit is represented by an integral link 15. The electric motor moves the barrel nut. The speed converter of the electric motor into the nut stroke is represented by an integral link 17 in the scheme. The barrel nut is moved until the signal $\bar{z}_c$ equals $\bar{z}_c'$. Rotation speed feedback of the motor ensures its quick acceleration and quick braking. Braking starts when the barrel nut approaches the desired position. The scheme explains it as follows. When the signal value $\bar{z}_c$ is approached to the value $\bar{z}_c'$ the output signal of element 19 on the adder 10 will become dominant. This will cause the signal at the output of element 11 to decrease sharply and be reversed. The maximum level of the output signal of element 18 is approximately equal 0.4. When the output signal of element 11 which has received the opposite sign exceeds this value in absolute value, the motor will start to decelerate. A reduction in the motor speed will reduce the signal at element 18 output, which will reduce the speed even more. When accelerating the motor, element 18 will only accelerate the process if the relative output signal of element 11 is less than unity. This is because the adder 13 output signal is also limited at the relative unity level. The signal is also limited to one $\bar{n}_e$.

Transfer coefficient k_n determines the level of signal unbalance $\bar{z}_c'$ and $\bar{z}_c$ at which the electric motor is braked (speed limitation – during acceleration). If k_n=0.08, braking begins at approximately the unbalance of the $\bar{z}_c'$ and $\bar{z}_c$, equal to 0.08 (at k_n<0.04 the electric motor may not have time to stop and overshoot occurs). Control element unbalance $\delta_{c.a}$ is several times lower than k_n. Link 20 feedback is used in the governor to ensure parallel operation of main engines. If a single main engine is used, its transfer coefficient $k_{f.b}$ can be zero. Link 21 takes into account the value of the stroke utilisation of the ESG during the transition from zero to nominal fuel supply, which is recommended in the design documentation [23] ($k_{u.m}$ – relative stroke utilisation). ASCS model of the HITACHI ZOSEN – MAN B&W 6S60MC-6 marine diesel engine with Nabtesco MG-800 electronic governor is shown in Figure 2.

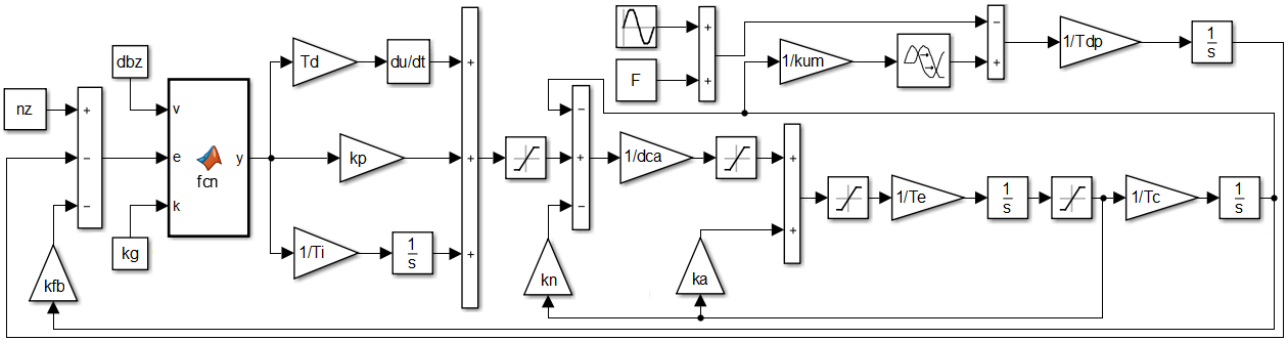

Figure 2. *Model of automatic speed control system for HITACHI ZOSEN – MAN B&W 6S60MC-6 marine diesel engine with Nabtesco MG-800 electronic governor*

The following values are used in the model: diesel acceleration time $T_{d.p}$=2.3 s; delay time τ_{del}=0.02 rel. un.; relative value of RSZ ε (*dbz*)=0.001 ... 0.099 rel. un.; coefficient of RSZ transfer k_g=0.1 ... 1 rel. un.; proportional link gain coefficient k_p=0.5 ... 5 rel. un.; integration link time T_i=0.5 ... 8 s; differential link time T_d=0 s; ESG actuator time T_c=0.4 s; inequality of control element of the actuator $\delta_{c.a}$=0.04 rel. un.; electric motor acceleration time T_e=0.03 s; transfer link coefficient for acceleration and deceleration of electric motor k_a=0.3 rel. un.; feedback transfer coefficient in electric motor speed k_n=0.06 rel. un.; governor stroke utilisation coefficient $k_{u.m}$=0.75 rel. un.; feedback coefficient $k_{f.b}$= 0 rel. un. Figure 3 shows the dependence of mean square deviation of the shaft rotation speed $\sqrt{D_n}$ and relative stroke of HPFP rack $\sqrt{D_{h_p}}$, on the value of RSZ (with fixed k_g=0.5 rel. un.) ESG (with configuration parameters k_p=2.2 rel. un.; T_i=2.0 s; T_d=0 s), defined by modelling. The results are obtained with three average fluctuation periods of perturbation T_0=3.3; 7.9 and 20.9 s, which practically cover the entire range of values encountered in operation.

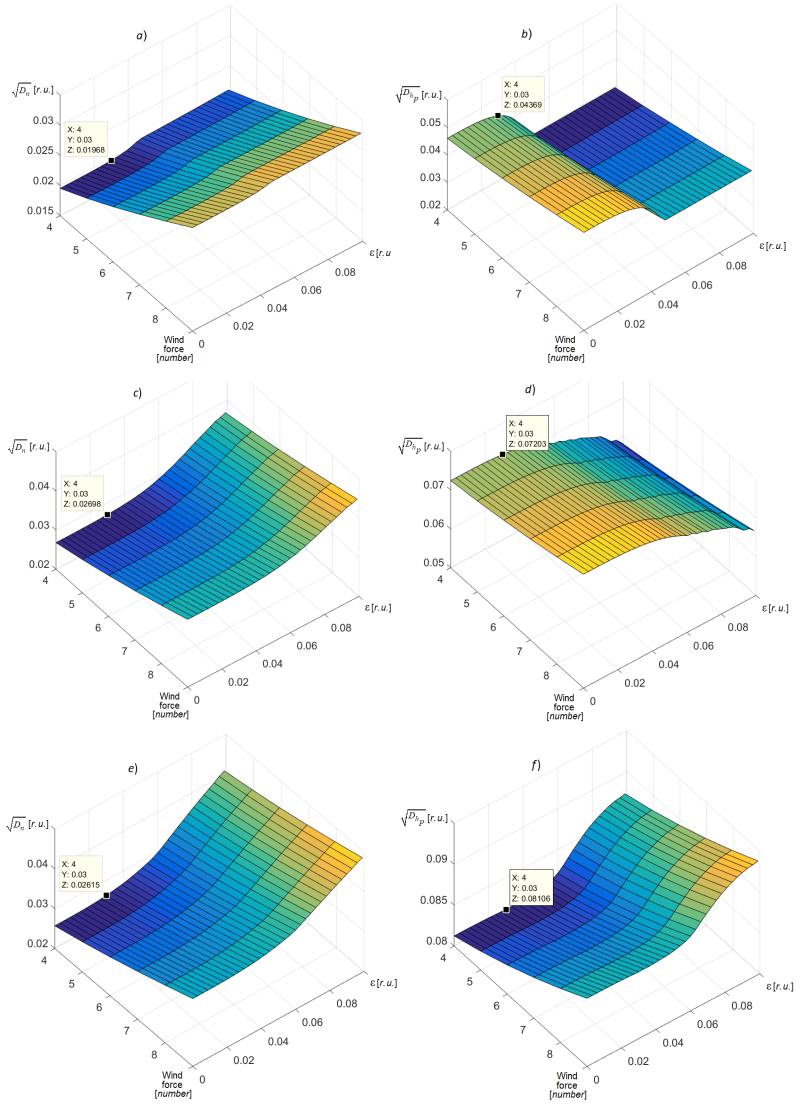

Figure 3. *Effect of sea waves levels on the mean square deviation of relative shaft rotation speed √D$_n$ and relative stroke of HPFP rack √D$_{hp}$ when changing the value of RSZ ESG – ε, rel. un. (transfer coefficient RSZ k_g=0.5 rel. un.)*
Note: *for wave condition with period: a, b –T_0=3.3 s; c, d –T_0=7.9 s; e, f –T_0=20.9 s*

Figure 3, *a* shows that for a period of fluctuations of the disturbing effect T_0=3.3 s, decrease of sensitivity in ESG from RSZ value of 0.099 to 0.03 rel. un. (with the ESG transfer coefficient of 0.5 rel. un.) increases stability of the speed mode of operation of the ME within the whole range of wind-wave conditions. For example, in a wave caused by 4-grade wind $\sqrt{D_n}$ has decreased from 0.0211 to 0.0197 rel. un. Decrease in RSZ value from 0.03 to 0.01 rel. un. practically does not lead to improvement of stability of the speed mode $\sqrt{D_n}$ does not change). The further reduction does not lead to the change of $\sqrt{D_n}$ in the whole range of the wind wave, it is not expedient to decrease the governor sensitivity at small deviations of the controlled parameter. Figure 3, *b* shows that at T_0=3.3 s throughout the entire range of wind-wave, a similar to speed mode tendency to stabilise the thermal regime is observed with a decrease in the sensitivity of the ESG. For example, in sea waves caused by 4-grade wind, $\sqrt{D_{hp}}$ is stabilised at the level of 0.0296 rel. un. The reason for this is that the ESG no more responds to low amplitude disturbances. If, however, the sensitivity of ESG is decreased in the range of values of RSZ from up 0.05 to 0.001 rel. un., there is a tendency of deterioration of stability of the ME thermal regime, for example, at a waves caused by the 4-grade wind, $\sqrt{D_{hp}}$ increased from 0.0296 to 0.0461 rel. un. This is explained by the fact that when the sensitivity decreases, the ESG moves the HPFP rail with a delay, but in spurts, which does not reduce the amplitude of its movements. Consequently, it can be concluded that since the increase in sensitivity of ESG is accompanied by an excessive increase in instability of speed mode (especially at rough seas), an increase in sensitivity of ESG cannot be recommended for stabilisation of thermal mode of diesel engine.

Figure 3, *c*, and *d* demonstrate that for the period of fluctuations of the disturbing effect T_0=7.9 s in ESG there is a similar tendency (as well as at T_0=3.3 s) to increase the stability of a speed mode and to decrease the stability of a thermal mode at the decrease of sensitivity of ESG. For example, in a waves caused by 4-grade wind, with a decrease in RSZ from 0.099 to 0.03 rel. un. (with RSZ transfer coefficient k_g=0.5 rel. un.) $\sqrt{D_n}$ decreases from 0.037 to 0.027 rel. un. and $\sqrt{D_{hp}}$ increases from 0.060 to 0.072 rel. un. Figure 3, *e*, and *f* show that at a period of fluctuations of disturbing effect T_0=20.9 s with the decrease of ESG sensitivity, improvement of both speed and thermal regimes of the ME is observed. For example, in the case of waves caused by 4-grade wind decrease and the decrease of RSZ from 0.099 to 0.03 rel. un. (with RSZ transfer coefficient of k_g=0.5 rel. un.) $\sqrt{D_n}$ decreases from 0.0410 to 0.0262 rel. un., and $\sqrt{D_{hp}}$ decreases from 0.0874 to 0.0811 rel. un. Further decrease in sensitivity of ESG practically does not lead to the change of stability of both speed and thermal modes of the ME.

By decreasing the ESG sensitivity at calm sea conditions in operational conditions, an increase in ASCS stability is observed while maintaining the stability of the engine thermal mode due to the fact that the ESG stops overreacting to load changes on the diesel engine. At rough sea conditions it is recommended to reduce a zone of sensitivity of ESG for it to more "actively" regulate shaft rotation speed, stabilising a diesel engine thermal mode. In this case, there is no gain in thermal mode stability (reduction of $\sqrt{D_{hp}}$, if sensitivity is reduced in a range of small values. This is explained by the fact that when the sensitivity is reduced, the ESG begins to move the HPFP rack with a delay, but in spurts, which does not reduce the amplitude of its movements. As a result of the investigation, it can be concluded for the ESG sensitivity reconfigurations it is recommended to decrease the setpoint unit of ESG sensitivity to the calculated average value of 0.015 … 0.03 rel. un. (with the RSZ transfer coefficient k_g=0.5 rel. un.) in the wave conditions, which causes intensive and large variations of shaft rotation speed (at a large dispersion of disturbing effect). In turn, the increase in sensitivity of ESG both at low (caused by 6-grade wind or less wind) and at rough seas (caused by 6-grade or more wind) worsens dynamics of ESG, as evidenced by the significant increase in the estimate of mean square deviation of the relative speed of a diesel engine shaft $\sqrt{D_n}$. Figure 4 demonstrates the specified by modelling dependence of mean square deviation of the shaft rotation speed and relative stroke of HPFP rack on the timing of the ESG integrating link at a RSZ value of 0.03 rel. un. with fixed k_g=0.5 rel. un. and ESG setting parameters k_p=2.2 rel. un. and T_d=0 s. Modelling has also been performed for three average fluctuation periods of the disturbance T_0=3.3; 7.9 and 20.9 s.

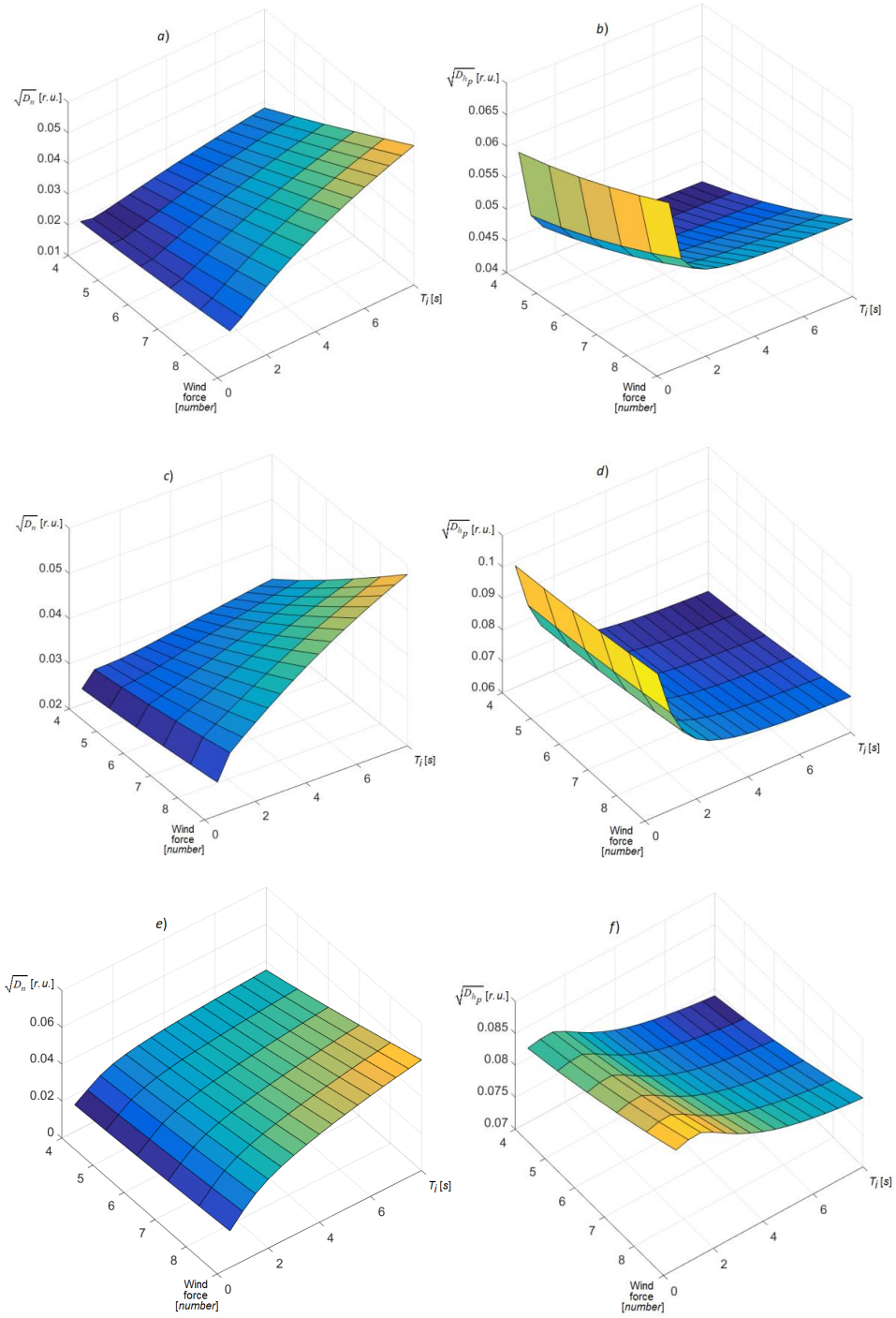

Figure 4. *Effect of wave levels on mean square deviation of relative shaft rotation speed $\sqrt{D_n}$ and relative stroke of HPFP rack $\sqrt{D_{h_p}}$ at ESG integrating link time variation – T_i, s (RSZ value ε=0.03 rel. un. and transfer coefficient of k_g = 0.5 rel. un.)*
Note: *for wave condition with period: a, b – T_0=3.3 s; c, d – T_0=7.9 s; e, f – T_0=20.9 s*

It follows from Figure 4, *a* and *b* that if the fluctuation period of the disturbing effect is T_0=3.3 s reducing the time of the integrating link increases the stability of the speed mode of the ME operation in the whole range of wind-wave conditions from 4 to 6-grade of Beaufort scale. However, a decrease of value T_i below 2 s leads to significant instability of the thermal mode of the ME operation. For example, in a wave caused by a 4-grade wind, the estimate $\sqrt{D_{hp}}$ increases from 0.0418 rel. un.: at T_i=8 s to 0.0437 rel. un.; at T_i=2 s and at T_i= 0.5 s to 0.0583 rel. un. Figure 4, *c*, and *d* show that if the period of fluctuation of the disturbance T_0=7.9 s over the entire range of variation T_i there is an increase in stability of the speed mode of the ME operation. For example, in case of a disturbance caused by 4-grade wind, when decreasing T_i from 8 to 0.5 s, estimate $\sqrt{D_n}$ decreased from 0.03240 to 0.02345 rel. un. The parameter T_i significantly affects the stability of diesel engine thermal conditions, and its influence is especially noticeable in the case of rough sea conditions. For example, at waves

caused by 7-grade wind, estimate $\sqrt{D_{hp}}$ increased from 0.068 rel. un.; at T_i=8 s to 0.076 rel. un.; at T_i = 2 s intermittently to 0.102 rel. un.

Figure 4, *e,* and *f* show that when the period of fluctuation of the disturbance T_0=20.9 s in the ESG there is an increase in stability of the speed mode of the ME, in case of sea waves conditions caused by the 4-grade wind, the estimation $\sqrt{D_n}$ has decreased from 0.035 to 0.015 rel. un. At the change of T_i from 8 to 0.5. At the same time, there is a tendency for the stability of the thermal regime of the ME to deteriorate over the entire range of wind waves, e.g., in sea waves conditions caused by 7-grade wind, the estimate $\sqrt{D_{h_p}}$ increased from 0.0775 to 0.0853 rel. un. while changing from T_i from 8 to 0.5 s. Figure 5 demonstrates the specified by modelling dependence of mean square deviation of the shaft rotation speed and relative stroke of HPFP rack on the ESG proportional link gain coefficient at a RSZ value of 0.03 rel. un. with fixed k_g=0.5 rel. un. and ESG configuration parameters k_p=2.2 rel. un. and T_d=0 s at three average fluctuation periods of the disturbance T_0=3.3; 7.9 and 20.9 s.

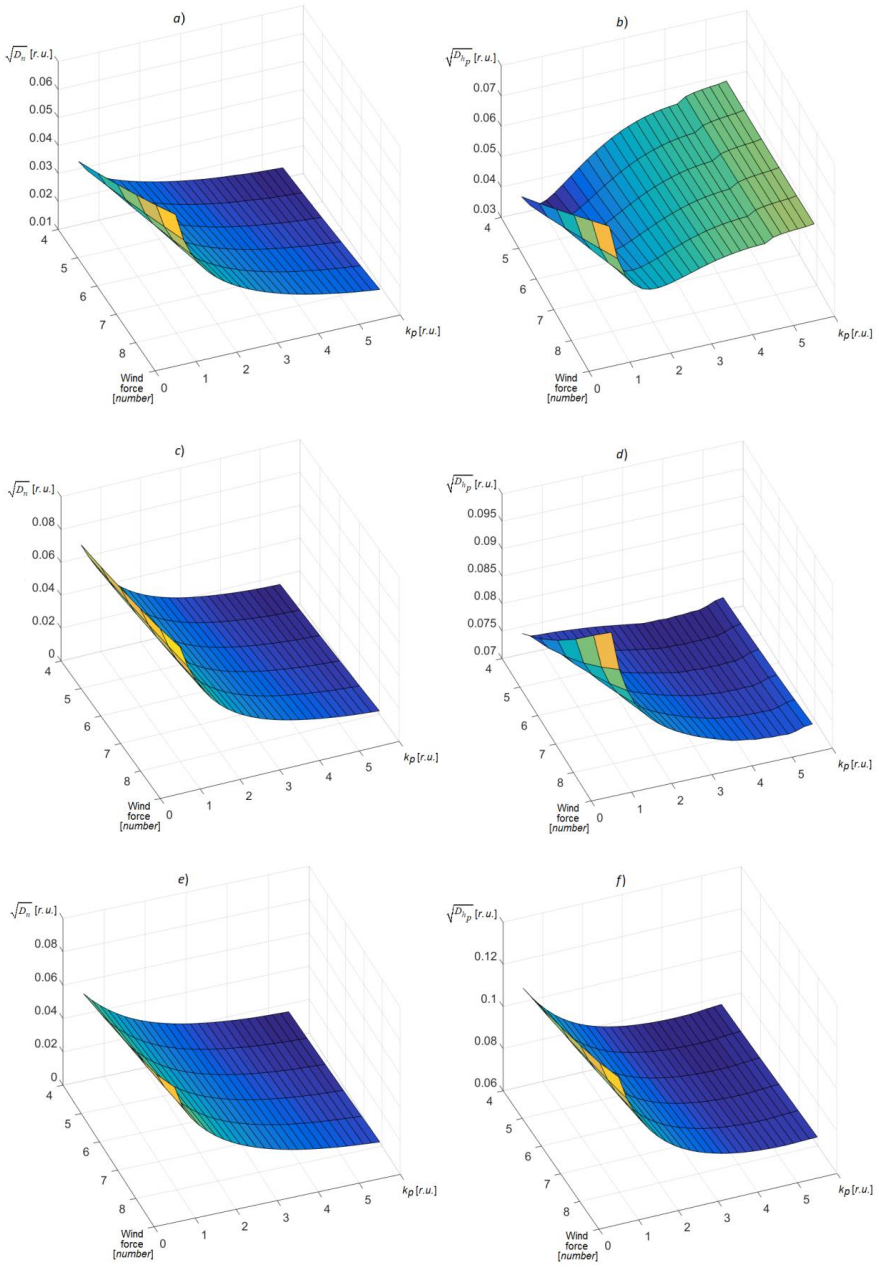

Figure 5. *Effect of wave levels on the mean square deviation of relative shaft rotation speed √D$_n$ and relative stroke of HPFP rack √D$_{hp}$ at ESG proportional link gain coefficient change k$_p$, rel. un. (RSZ value ε=0.03 rel. un. and transfer coefficient of k$_g$=0.5 rel. un.)*

Note: *for wave condition with period: a, b – T_0=3.3 s; c, d – T_0=7.9 s; e, f – T_0=20.9 s*

Figure 5, *a*, and *b* demonstrate that for a period of fluctuations of the disturbing effect T_0=3.3 s with a decrease of the proportional link gain coefficient leads to the appearance of self-fluctuating phenomena in the ASCS. It can be explained by the occurrence of reconfiguration in the ASCS (estimates of $\sqrt{D_n}$ and $\sqrt{D_{h_p}}$ increase simultaneously). Figure 5, *c*, and *d* show that when the period of fluctuations of the disturbance T_0=7.9 s there is a significant improvement in the stability of both the wind speed and the thermal modes of the ME. For example, if the disturbance is caused by 4-grade wind, by increasing k_p from 0.5 to 5 rel. un. the $\sqrt{D_n}$ estimate decreased from 0.068 to 0.015 rel. un. and the $\sqrt{D_{h_p}}$ estimate decreased from 0.0738 to 0.714 rel. un. Also, in the area of small values of k_p, the phenomenon of reconfiguration in ASCS is observed, especially in rough sea conditions. Figure 5, *e*, and *f* show that if the period of fluctuation of the disturbance T_0=20.9 s with increase of k_p there is a positive effect in stabilising the shaft rotation speed and thermal regime. For example, if the disturbance is caused by a 4-grade wind, by increasing k_p from 0.5 to 5 rel. un. the $\sqrt{D_n}$ estimate has decreased from 0.0523 to 0.0156 rel. un. and the $\sqrt{D_{h_p}}$ estimate decreased from 0.1065 to 0.0762 rel. un.

CONCLUSIONS

Considering the character and magnitude of change of load on diesel engine at sea wave conditions depend on many variables of external conditions (sea waves levels, course of a vessel in relation to windy conditions, wind gusts, vessel loading, given speed of a vessel), any set value of sensitivity of ESG appears to be optimum only for a particular case of vessel movement in rough sea conditions. At the same time, there is a possibility to optimise the operation of ESG at sea waves with the most probable intensity (for example, for wind waves up to 5-grade including) and fulfilment of the additional condition on tolerable instability of fuel supply to a diesel engine (instability of a thermal mode). For HITACHI ZOSEN – MAN B&W 6S60MC-6 marine diesel system it is recommended a RSZ ESG value of 0.03 rel. un. with a signal transfer coefficient in this zone of 0.5 rel. un. It allows to keep the speed mode stability in rough seas (caused by wind force of 6-grade and higher) and doesn't cause considerable disturbance of the thermal mode stability by changing external sailing conditions (change of course and vessel's speed in relation to the sea waves level).

If in very rough seas (wind force greater than 6-grade) the recommended configuration values do not provide the required stability of the speed mode, the sensitivity zone value can be reduced to 0.015 rel. un. while increasing the proportional gain to 3 rel. un. With a "heavy" propeller (including a fully laden vessel), speed stability can be improved by increasing the proportional link gain and reducing the integration time of the ESG. Further research is planned in the direction of automating the configuration parameters of the ESG, depending on the value of the actual stochastic indicators of changes in diesel engine speed and the ESG output signal.

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Оптимізація чутливості електронного регулятора частоти обертання головного суднового дизеля

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Анотація. Електронні регулятори частоти обертання набули широкого поширення на суднових дизелях і, порівняно з гідромеханічними, мають додатковий параметр налаштування чутливості до вхідного сигналу. Цей параметр дозволяє змінювати реакцію регуляторів на високочастотні збурення. У дизелях з розподільним валом такі збурення генеруються при набіганні кулачків на штовхачі паливних насосів, а в двигунах типу ME (MAN Energy Solutions) або RT-flex (Wärtsilä) вони виникають внаслідок використання індуктивних датчиків із зубчастою стрічкою на валу дизеля для вимірювання частоти обертання. Якщо двигун використовується як головний на суднах, то чутливість регулятора додатково дозволяє змінювати реакцію регуляторів на коливання моменту опору гребного валу при хвилюванні. Однак на практиці величина чутливості електронних регуляторів частоти обертання головних суднових дизелів вибирається інтуїтивно. Це призводить до того, що налаштування регуляторів не забезпечує задовільну стабільність швидкісних режимів при зміні морської обстановки. Метою дослідження є розробка методології налаштування чутливості електронних регуляторів частоти обертання головних двигунів з урахуванням стохастичності навантаження на дизельний двигун під час хитавиці на морі. Дослідження проведено з використанням моделі систем автоматичного регулювання швидкості, яка базується на припущенні відносно малих відхилень швидкості обертання валу дизеля та параметрів навантаження в умовах морських хвиль. Врахування характеру та величини зміни навантаження на дизельний двигун в умовах морських хвиль залежить від багатьох змінних зовнішніх умов (бальність моря, курсу судна щодо умов вітрових хвиль, поривів вітру, стану завантаження судна, заданої швидкості руху судна), будь-яке задане значення чутливості електронних регуляторів частоти обертання виявляється оптимальним лише для конкретного випадку руху судна під час хитавиці на морі. Наукова новизна визначається тим, що рекомендації щодо вибору чутливості регуляторів визначені з урахуванням стохастичності коливань моменту опору гребного валу при хвилюванні, що підвищило точність та обґрунтованість рекомендацій. Практична значущість дослідження полягає у підвищенні стабільності швидкісних режимів головного двигуна з електронними регуляторами частоти обертання за різного хвилювання

Ключові слова: морські судна, судновий дизельний двигун, поршневий двигун внутрішнього згоряння, система автоматичного регулювання частоти обертання, електронний регулятор частоти обертання, регулювання швидкості

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Phenology and Population of Strawberry Mites and Effectiveness of Using Strawberry Protection in the Conditions of the Right-Bank Forest-Steppe of Ukraine

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Abstract. Growing strawberries is a promising and profitable field of agriculture. However, there are a number of limiting factors that determine the productivity of the crop, in particular pests-phytophages. The study aims to determine the features of the phenological phases of strawberry mite (*Tarsonemus fragariae*) and to examine the effect of protection on the population of phytophagous mites, the impact on physiological and biochemical processes in strawberry plants Murano and Vivara. The study is based on generally accepted methods in entomology and ecology. The degree of damage to strawberry plants was determined on a five-point scale, which on average for 2016-2020 was estimated at 0-1 point. A phenological map of strawberry mite development was created, the dependence of phytophage phenophases on weather conditions was established. In the Murano strawberry plantations, the average population of strawberry mite eggs in 2016-2020 was in the range of 105.3-165.0 pcs/100 leaves, larvae – 37.0-61.3 pcs/100 leaves, imago – 20.8-96.3 pcs/100 leaves. In the Vivara strawberry plantations, the population of mite eggs was in the range of 90.8-180.0 pcs/100 leaves, larvae – 37.0–57.0 pcs/100 leaves, imago – 17.3-95.3 pcs/100 leaves. The effectiveness of the chemical plant protection systems under study (Masai® (0.4 kg/ha) + Biskaiia® (0.8 L/ha); Apollo® (0.5 l/ha) + Tsezar™ (0.2 L/ha) + Mavrik™ (0.6 l/ha)) against phytophage mites was almost at the same level. The exception was a direct ovicidal effect of the Masai and a mixture of Apollo + Tsezar; on the 3rd day after their introduction, the larvae in the eggs were unviable and the eggshells were mummified. The application of strawberry protection systems ensured berry yields of 33.4 t/ha in the Murano variety and 25.4-25.6 t/ha in the Vivara variety and a yield increase of 16.6-16.7 t/ha and 12.4-12.5 t/ha, respectively. The positive effect of plant protection systems against pests on the indicators of physiological and biochemical processes in the leaves of strawberries of both varieties was established. An increase in the content of chlorophyll by 33-58%, phenolic compounds – by 7-15%, sugars – by 6-10%, vitamin C – by 2-6% compared to the control was recorded in strawberry leaves. Given the high environmental safety requirements for berry growing technologies, the search for alternative biological products in the control of *Tarsonemus fragariae* is promising

Keywords: integrated plant protection system, phytophages, *Tarsonemus fragariae*, acaricides

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INTRODUCTION

Marketing research shows a constantly growing market for berry products worldwide [1]. The main factors determining the increase in berry production are the active development of modern trends related to healthy eating, vegetarianism and new storage and processing technologies in the food industry. Strawberries remain the most popular berry on the global market and about 70% of the global berry production is accounted for by this crop [2]. The chemical composition of strawberries is rich in pectin (1-2%), contains 8-10% sugar, 0.8-1.8% organic acids (dominated by citric, malic, oxalic, ascorbic, folic, salicylic, quinic). Berries contain trace elements such as potassium, phosphorus, calcium, magnesium, iron, and iodine. The special value of berries – is the high content of antioxidants and vitamins (A, C, PP, B, E, K). In terms of vitamins C and P, strawberries are second only to black currants [3].

Strawberries (*Fragaria x ananassa* Duch.) is a valuable berry crop with a high content of vitamins and antioxidants, which is grown in many countries of the world and is called the "Queen of Fruits" [3; 4]. The main countries producing this berry are the United States, Mexico, Turkey, Spain, Egypt, South Korea, Japan, Poland, Ukraine, and Germany. The average yield of strawberries in the world is 6.9 t/ha. According to official data [2], the global cultivation of strawberries in 2019 reached 4.5 million tonnes and is projected to grow in individual countries due to increased yields, the introduction of innovative methods of production and business organisation, and the expansion of berry plantations.

According to the State Statistics Service of Ukraine, the area of wild and garden strawberry plantations in the fruitful age in 2020 in Ukraine covered 8.1 thousand hectares, its gross annual harvest is 55.2 thousand tonnes, which is 20-30% more than other berry crops [5]. Considering the agroclimatic and resource potential of Ukraine, the cultivation of strawberries and the sale of berries in the EU countries is a promising and competitive area for national producers of fruit and berry products, the consumption of which is constantly growing worldwide [1].

A considerable reserve for improving the quality of crops and increasing the productivity of Berry plantations is to improve their protection against pests and pathogens. This can be achieved only with the complex application of agrotechnical, quarantine, mechanical, physical, and chemical measures [6].

Notably, berries are a product that is consumed mainly fresh, so there is an urgent issue of developing technologies for protecting berry crops, which allow minimising the ingress of pesticides on the organs of plants that are eaten [7; 8]. One of these measures is the use of resistant varieties, predecessors, biological products, etc. In addition, organic production is actively developing in the world with strict requirements for the use of chemicals in agricultural technologies and high-quality standards for grown products.

Ensuring optimal agroecological and technological conditions during the growing season contributes to obtaining stable berry yields. When greening agricultural production, new alternative approaches should be used, which consider the complete elimination or reduction of the use of chemical plant protection products and the introduction of biological methods in combination with adapted elements of cultivation technology. To prevent the spread of pests, a set of preventive and extermination measures is used, the implementation of which considerably reduces, and sometimes prevents, the development and spread of harmful organisms. It also corresponds to the ideology of integrated plant protection, the implementation of which is aimed at greening chemical plant protection, reducing the use of pesticides, choosing less toxic preparations, and preserving the natural environment. Now the scientific community is widely discussing the environmental hazards of modern agricultural technologies due to the use of chemical plant protection products and unpredictable results of biological control.

The purpose of the study is to examine the biological and ecological features of strawberry mite (*Tarsonemus fragariae*) in strawberry plantations of Murano and Vivara varieties in the Vinnytsia region and to determine the effectiveness of plant protection chemicals in controlling strawberry mite population and their impact on plants.

LITERATURE REVIEW

Experience shows that one of the important reserves for the fulfilment of the yield potential of strawberries is the prevention of losses through the use of effective protection of crops from pests [6; 8; 9]. More than 380 species of arthropods have been found in strawberry plantations located in the right-bank forest-steppe zone of Ukraine. Strawberries are damaged by 66 species of insects, mites, and nematodes, 19 of which are the most numerous and harmful. More than 100 species of invertebrates live in the biocenosis of strawberries, but their harmfulness is minor. The development of the species composition of pests on berry crops from the beginning of their planting occurs in different ways, with the age of plantations harmful fauna is increasingly diverse [8; 9].

The most common species in Ukraine are beetles, including June beetle (*Amphimallon solstitiale* L.), western May beetle (*Melolontha* L.), eastern May beetle (*M. Hippocastsni* Fabr.), marble beetle (*Polyphylla fullo* L.), hairy May beetle (*Anoxia pilosa* Fabr.), mole cricket (*Gryllotalpa grillotalpa* L.), blossom feeder (*Epicometes hirta* Poda.), field slug (*Agriolimax agrestis* L.), strawberry mite (*Tarsonemus fragariae*), spider mite (*Tetranychus urticae* Koch.), a strawberry-blossom weevil (*Anthonomus rubi* Hrbst.), small root strawberry aphid (*Aphis forbesi* Weed.), strawberry nematode (*Dytilenchus dipsaci* Filipjeu.), strawberry leaf beetle (*Pyrrhalta tenella* L.), curled rose

sawfly (Allantus cinctus L.) [9]. Among the numerous types of pests, *Tetranychus urticae* Koch is the most common and dangerous one [10; 11].

In the late 1950s, an integrated plant protection system was proposed, which provided a long-term containment of pests with means and measures that would ensure minimal negative consequences for the environment [12-14]. Since then, systems of integrated protection of crops from harmful organisms have been given a lot of definitions. Thus, Yu.N. Fadieiev and K.V. Novozhylov [15] established that the integrated system involves the use of available methods and measures in space and time, which give energy conservation, environmental impact, and are environmentally friendly.

An integrated plant protection system against pests is defined as one that provides for a rational combination of a number of tactical protection measures – agrotechnical, mechanical, biological, chemical, considering the economic thresholds of harmfulness and the presence of entomophages and acariphages in plantings under certain meteorological conditions [16]. Therewith, the pest population is kept below the economic level of harmfulness not only by applying pesticides. Not all methods can be suitable for a particular economic management system, so integrated protection systems should be developed separately for each region and culture.

Based on the above definitions, it should be noted that integrated plant protection systems should be based on a biocoenotic approach to the use of chemical pesticides [12; 17; 18]. It is known that the biocoenotic approach consists in investigating relationships in agrocenoses and based on this it is possible to model and regulate them. The rapid and effective action of chemical pesticides has helped to increase the pace of their production and use. However, uncontrolled use of pesticides has led to many negative consequences, from local to global. In particular, between 400,000 and 2 million cases of pesticide poisoning are reported worldwide each year.

The concept of plant protection, which is characterised by the transition from total destruction to the reduction of the population of pests at environmentally and economically efficient levels, is very important. Current "integrated" systems should be considered as more or less coordinated chemical protection programmes, which are the basis for their transformation into truly integrated ones [9; 13; 16]. This is especially relevant to growing strawberries [19].

MATERIALS AND METHODS

Field research was conducted during 2016-2020 in the Experimental Farm of Podolsk Horticulture Station (Vinnytsia region) on two varieties of remontant strawberries: Vivara and Murano. During the growing season, the phenological phases of strawberry mite development were determined using common entomological methods. During the examination period, plants, fallen leaves, and soil were inspected, and samples of soil and damaged plants were taken for detailed analysis in the laboratory. Due to the wide variety of pests on the experimental site, it was examined and accounted for several times during the growing season.

Assessment of the settlement of strawberry plantations of various varieties by strawberry mites is conducted from the II-III decade of April to the I decade of August – during the mass reproduction of the pest. Due to its very small size and hidden way of life (mainly in the folds of young unbroken leaves), strawberry mites were counted in the laboratory using a microscope on young leaves collected from registered plants (at least 100). To examine the dynamics of the population of strawberry mites, 50 young unopened strawberry leaves were periodically selected every 15 days during the growing season, on which the number was calculated in the laboratory using binoculars and the phases of pest development were determined.

The degree of damage to strawberry plants was determined on a five-point scale:

- 0 – no damage, leaf colour and plant development are normal;
- 1 – weak damage, the change in leaf colour is barely noticeable;
- 2 – medium, clear colour change on less than half of the leaves, green shades predominate, plant suppression is weakly expressed;
- 3 – strong, most of the leaves are yellowed, the leaves and berries are small, deformed, the growth and development of plants is very suppressed;
- 4 – very strong, all leaves turn yellow, the plant dies [20].

The effectiveness of systems for protecting strawberries from pests, which included chemical preparations was also examined:

1. Control, water treatment.
2. Etalon – Sanmait® (0.7 kg/ha) + Mospilan® (0.5 kg/ha).
3. Option I – Masai® (0.4 kg/ha) + Biskaiia® (0.8 l/ha).
4. Option II – Apollo® (0.5 l /ha) + Tsezar™ (0.2 L/ha) + Mavrik™ (0.6 l/ha).

The experiment is repeated three times, the area of the experimental site is 36 m^2 (18 m each^2 for each strawberry variety). Scheme of the planting of the crop in experiments: a strip with 2 rows of 30 cm between them, the distance between plants in a row is 25 cm, the distance between strips is 70 cm. According to this scheme, 84,204 plants are placed per 1 ha. There were 152 Murano bushes and 152 Vivara bushes at the experimental sites. The area without insecticides and acaricides was taken as the absolute control, the approved technology of garden strawberry protection on the production areas of the experimental farm was taken as the standard, and the options with insecticide and acaricide consumption rates were examined.

The effect of insecticides on strawberry plants was determined by the content of chlorophylls, sugars, phenolic compounds and their derivatives, and vitamin C. The content of vitamin C was determined by photocolorimetric method using Tillmans' paint, GOST 24556-89 [21]. The content of sugars in leaves and berries – according to Bertrand's method of DSTU 4954:2008 [22], phenolic compounds – using Folin-Denis' reagent, colourimetry (in leaves), and spectroscopy (in berries) [23]. The content of chlorophylls in strawberry leaves was determined by generally accepted methods [23]. Statistical processing of experimental data was performed by the method of variance analysis using Microsoft Excel.

RESULTS AND DISCUSSION

In the conditions of the experimental farm of the Podolsk horticultural station (Vinnytsia region) strawberry plantations are represented by a large number of high-yielding varieties. The complex of pests that live in the soil and on its surface causes great damage to strawberries. In years of mass development of such phytophages, especially after relatively warm winters, crop losses may exceed 10-15% [10; 24; 25]. During the period under study, the development of phenological phases of strawberry mites was observed. A close dependence of the phenological phases of strawberry mite development on the weather conditions of the year was established. The long autumn with high air temperatures (14.6°C) in October allowed a number of wintering pests to enter the winter diapause. In 2017, in the first decade of May, the air temperature was at +12.5°C and humidity at 61%, that is, the conditions were not favourable for the development of strawberry mites, so the development of various generations was somewhat prolonged. Weather conditions in 2018 and 2019 were characterised by a very high daytime air temperature of +18.2-24°C and humidity of 74-80%, so the development of the pest was very fast and its population grew rapidly (Table 1).

***Table 1**. Phenology of the development of Tarsonemus fragariae Zimm., T. pallidus Banks, 2016-2020*

Year	Months																				
	April			May			June			July			August			September			October		
	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
2016																*	*				
																ב	ב				
																		§	§	§	§
																א	א				
2017						*	*	*	*	*	*	*	*	*	*	*	*				
							ב	ב	ב	ב	ב	ב	ב	ב	ב	ב	ב				
	§	§	§	§	§	§	§	§										§	§	§	§
								א	א	א	א	א	א	א	א	א	א				
2018		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*				
		ב	ב	ב	ב	ב	ב	ב	ב	ב	ב	ב	ב	ב	ב	ב	ב				
	§	§	§															§	§	§	§
			א	א	א	א	א	א	א	א	א	א	א	א	א	א	א				
2019					*	*	*	*	*	*	*	*	*	*	*	*	*	*			
					ב	ב	ב	ב	ב	ב	ב	ב	ב	ב	ב	ב	ב	ב			
	§	§	§	§	§	§													§	§	§
						א	א	א	א	א	א	א	א	א	א	א	א	א			
2020							*	*	*	*	*	*	*	*	*						
							ב	ב	ב	ב	ב	ב	ב	ב	ב						
	§	§	§	§	§	§	§	§													
								א	א	א	א	א	א	א	א						

* – egg,	ב – larva,	§ – female imago (wintering stage)	א – imago of both sexes
Active stages		Mass appearance	Wintering stage

After almost five years under study, the degree of damage to plants by strawberry mites (*Tarsonemus fragariae* Zimm., *T. pallidus* Banks) in experiments using pesticides can be estimated at 0-1 on a five-point scale [20; 25]. In experiments where chemical means of protecting strawberries from strawberry mites were examined, the number of all stages of the pest was recorded after processing plantings for 10 days. Accounting for the strawberry mite population of Murano and Vivara strawberry using various protection systems is presented in Tables 2 and 3.

***Table 2**. Strawberry mite population of Murano strawberry using various protection systems, 2016-2020*

Option	Name of the preparation and application rate, l, kg/ha	2016	2017	2018	2019	2020	Average for 5 years
Egg, pcs /100 leaves							
Control	–	105.3	117.8	110.0	165.0	109.8	121.6
Etalon	Sanmait, 0.7	58.8	87.8	65.5	75.0	84.0	74.2
Option I	Masai, 0.4	0.0	0.0	0.0	0.0	0.0	0.0
Option II	Apollo, 0.5 + Tsezar, 0.2	0.0	0.0	0.0	0.0	0.0	0.0
Larva, pcs /100 leaves							
Control	–	61.3	37.0	57.0	48.8	40.8	49.0
Etalon	Sanmait, 0.7	8.8	30.5	2.5	0.5	1.3	8.7
Option I	Masai, 0.4	0.3	0	0	0.3	0	0.1
Option II	Apollo, 0.5 + Tsezar, 0.2	0.3	0	0.3	0	0	0.1
Imago pcs /100 leaves							
Control	–	20.8	52.5	96.3	54.8	48.8	54.6
Etalon	Sanmait, 0.7	0.5	1.0	0.5	0.8	1.0	0.8
Option I	Masai, 0.4	0.3	0.8	0.3	0.0	0.3	0.3
Option II	Apollo, 0.5 + Tsezar, 0.2	0.3	0	0.3	0	0	0.1

***Table 3**. Strawberry mite population of Vivara strawberry using various protection systems, 2016-2020*

Option	Name of the preparation and application rate, l, kg/ha	2016	2017	2018	2019	2020	Average for 5 years
Egg, pcs /100 leaves							
Control	–	101.5	115.8	90.8	180.0	122.0	122.0
Etalon	Sanmait, 0.7	64.0	89.0	68.5	86.0	79.5	77.4
Option I	Masai, 0.4	0	0	0	0	0	0
Option II	Apollo, 0.5 + Tsezar, 0.2	0	0	0	0	0	0
Larva, pcs /100 leaves							
Control	–	37.5	57.0	37.0	39.8	47.8	43.8
Etalon	Sanmait, 0.7	7.5	30.5	3.5	1.0	1.5	8.8
Option I	Masai, 0.4	1.0	0	0	0	0	0.2
Option II	Apollo, 0.5 + Tsezar, 0.2	0.3	0	0	0	0	0.1
Imago pcs /100 leaves							
Control	–	17.3	95.3	51.5	51.0	38.0	50.6
Etalon	Sanmait, 0.7	0.8	0	1.0	1.3	2.0	1.0
Option I	Masai, 0.4	0.5	1.8	0.3	0.3	0.3	0.6
Option II	Apollo, 0.5 + Tsezar, 0.2	0.3	0	0.3	0	0	0.1

It was established that the effectiveness of options I and II is almost the same. In addition, a direct ovicidal effect of Masai and a mixture of Apollo + Tsezar preparations was detected. On the 3rd day after the application of the Masai and Apollo + Tsezar mixture, the larvae in the eggs were non-viable and the eggshells were mummified. In contrast to the Sanmait (Etalon), where the effectiveness of ovicidal action over the years ranged from 23-55%. It is also necessary to note the resistance of the mixture of Apollo + Tsezar preparations to washing away by precipitation that fell 2 hours after spraying in 2018. According to the results obtained, precipitation did not reduce the effectiveness of the preparations. The use of pest control products also had some effect on the physiological and biochemical processes in the leaves of Murano and Vivara strawberries (Tables 4, 5).

***Table 4**. The content of chlorophyll, sugars, phenolic compounds and their derivatives, vitamins in the leaves of strawberries at the beginning of the growing season (Murano variety, average for 2016-2020)*

Experiment scheme	Name of the preparation and application rate, l, kg/ha	Content			
		Chlorophyll, mg/g of dry matter	Sugars, mg/g	Phenolic compounds, mg/g	Vitamin C, mg%
Control	–	1.4	11.0	31.6	101.2
Etalon	Sanmait, 0.7	1.6	11.0	32.0	103.0
Option I	Masai, 0.4	1.9	11.7	33.9	103.6
Option II	Apollo, 0.5 + Tsezar, 0.2	2.0	11.7	35.0	107.1
	NIR	0.80	0.56	0.81	0.19

***Table 5**. The content of chlorophyll, sugars, phenolic compounds, and vitamins in the leaves of strawberries at the beginning of vegetation recovery (Vivara variety, average for 2016-2020)*

Experiment scheme	Name of the preparation and application rate, l, kg/ha	Content			
		Chlorophyll, mg/g of dry matter	Sugars, mg/g	Phenolic compounds, mg/g	Vitamin C, mg%
Control	-	1.2	10.7	30.8	100.3
Etalon	Sanmait, 0.7	1.6	11.0	32.5	102.2
Option I	Masai, 0.4	1.6	11.6	33.3	104.1
Option II	Apollo, 0.5 + Tsezar, 0.2	1.9	11.8	35.4	105.7
	NIR	0.83	0.51	0.34	0.46

According to Tables 4 and 5, on average, Murano plants had the lowest chlorophyll value of 1.4 mg/g of dry matter in the control, the highest of 2.2 mg/g of dry matter in option II; the Vivara variety, respectively, 1.2 mg/g of dry matter in the control, 2 mg/g of dry matter in option II. Affecting the content of chlorophyll in the leaves, that is, indirectly, the activity of photosynthesis, pesticides positively influenced the sugar content in the leaves of strawberries at different stages of organogenesis. On average, over the years under study, the Murano variety had the lowest sugar values of 11 mg/g in the control, the highest values of 11.7 mg/g in plants of both varieties. The Vivara variety, respectively, 10.7 mg/g in the control, 11.7 in the I and 11.8 mg/g in the II option.

Chloroplasts are the site of the synthesis of water-soluble phenolic compounds and their derivatives. In plants, the role of phenolic compounds is associated with protein synthesis, enzyme activity, and photosynthesis of structural components. According to the data in Tables 4 and 5, an increase in the indicators of phenolic compounds and their derivatives occurred in all experimental options in relation to control when using pest control products at various stages of strawberry organogenesis. Therewith, the lowest rate of phenolic compounds at the beginning of the growing season of strawberries on the Murano variety was – 31.6 mg/g in the control. The highest rate is 35 mg/g in option II.

One of the factors of plant resistance to pest damage is the content of ascorbic acid in their organs, as A. Olkhovska-Burkova notes [26]. Increased solar activity and drought contribute to the strengthening of biochemical processes in plants at the cellular level and activate the antioxidant protection system [27-29]. The results have shown that the content of antioxidants: ascorbic acid (vitamin C), in the leaves depends on the phase of plant development. Notably, the ascorbic acid content is very sensitive to soil and air humidity – these indicators decrease during the dry period.

On average, over the years under study, the Murano variety had the lowest ascorbic acid index of 101.2 mg% in the control, the highest - 109.4 mg% in option II; the Vivara variety, respectively, 100.3 mg% in the control and 108.2 mg% in option II. All the processes that took place in strawberries also affected the yield of the crop in a certain way (Table 6).

***Table 6**. The yield of strawberries of Murano and Vivara varieties under various plant protection systems, the average for 2016-2020*

Experiment scheme	Name of the preparation and application rate, l, kg/ha	Murano variety		Vivara variety	
		t/ha	Crop growth, t/ha	t/ha	Crop growth, t/ha
Control	–	16.7	–	13.1	–
Etalon	Sanmait, 0.7	33.2	+16.5	25.1	+12.1
Option I	Masai, 0.4	33.4	+16.6	25.4	+12.4
Option II	Apollo, 0.5 + Tsezar, 0.2	33.4	+16.7	25.6	+12.5
	NIR	3.17	–	1.84	–

The yield of Murano and Vivara strawberries varied according to the experimental options. The average yield control (without the use of pesticides) was 16.7 t/ha for Murano and 13.1 t/ha for Vivara. The reference variant showed yields of 33.2 and 25.1 t/ha, respectively, by variety. The yield of strawberries in options I and II was at the same level of 33.4 t/ha for the Murano variety and 25.4-25.6 t/ha for the Vivara variety.

CONCLUSIONS

Based on the data obtained, the expediency of using a mixture of Apollo + Tsezar preparations and Masai acaricide as effective means to prevent an increase in the population of strawberry mites is confirmed. It is also necessary to note the resistance of the mixture of Apollo and Tsezar preparations to washing away by precipitation that fell 2 hours after spraying in 2018 and emphasise that this circumstance did not reduce the effectiveness of the preparations. The use of pesticides had a positive effect on the adaptation of plants to environmental conditions and the response to phytophage damage. Namely, the content of chlorophyll, phenolic compounds, and ascorbic acid in the leaves of strawberries grew.

The yield of strawberries in the use of pesticides notably exceeded both the control and reference options but was at the same level. The difference between the control and experimental options is confirmed by the results of statistical processing.

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Фенологія і чисельність кліща суничного та ефективність застосування засобів захисту суниці садової в умовах правобережного лісостепу України

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Анотація. Вирощування суниці садової – перспективний і прибутковий напрям у галузі сільського господарства. Однак існує низка лімітуючих чинників, які визначають продуктивність культури, зокрема шкідники-фітофаги. Метою роботи було визначення особливостей проходження фенологічних фаз розвитку кліща суничного (*Tarsonemus fragariae*) та вивчення ефективності застосування засобів захисту на чисельність кліща-фітофага, вплив на фізіолого-біохімічні процеси в рослинах суниці садової сортів Мурано і Вівара. Дослідження проводили згідно із загальноприйнятих у ентомології і екології методик. Ступінь пошкодженості рослин суниці садової встановлювали за п'ятибальною шкалою, який у середньому за 2016–2020 рр. було оцінено в 0–1 бал. Сформовано фенологічну карту розвитку кліща суничного, встановлено залежність фенофаз фітофага від погодних умов. У насадженнях суниці сорту Мурано у середньому за 2016–2020 рр. чисельність яєць кліща суничного була в межах 105,3–165,0 шт./100 листків, личинок – 37,0–61,3 шт./100 листків, імаго – 20,8–96,3 шт./100 листків. У насадженнях суниці сорту Вівара чисельність яєць кліща була в межах 90,8–180,0 шт./100 листків, личинок – 37,0–57,0 шт./100 листків, імаго – 17,3-95,3 шт./100 листків. Ефективність досліджуваних систем хімічного захисту рослин (Масаї® (0,4 кг/га) + Біскайя® (0,8 л/га); Аполло® (0,5 л/га) + Цезар™ (0,2 л/га) + Маврік™ (0,6 л/га)) від кліща-фітофага була майже на одному рівні. Винятком був варіант, де наявна пряма овіцидна дія препарату Масаї та суміші препаратів Аполло+Цезар, – уже на 3-тю добу після їх унесення личинки в яйцях були нежиттєздатні, а оболонки яєць муміфіковані. Застосування систем захисту суниці садової забезпечило отримання врожайності ягід на рівні 33,4 т/га у сорту Мурано та 25,4–25,6 т/га у сорту Вівара та приросту врожаю 16,6–16,7 т/га і 12,4–12,5 т/га відповідно. Встановлено позитивний вплив систем захисту рослин від шкідника на показники активності перебігу фізіолого-біохімічних процесів у листках суниці садової обох сортів. Фіксували у листках суниці підвищення вмісту хлорофілу на 33–58 %, фенольних сполук – на 7–15 %, цукрів – на 6–10 %, вітаміну С – на 2–6 % порівняно з контролем. Враховуючи високі вимоги екологічної безпеки до технологій вирощування ягідних культур у подальшому перспективним є пошук альтернативних біологічних препаратів у контролі *Tarsonemus fragariae*

Ключові слова: інтегрована система захисту рослин, фітофаги, *Tarsonemus fragariae*, акарициди

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Manifestation of Heterosis and Degree of Phenotypic Dominance by the Number of Grains from the Main Ear in the Hybridisation of Different Early-Maturing Varieties of Soft Winter Wheat

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Abstract. Winter wheat (*Triticum aestivum* L.) is the main food crop on a global scale, in the growth and stabilisation of yields, of which varietal resources are a significant factor. In practical breeding work, an essential role is played by a variety of thoroughly investigated source material. The purpose of this study was to determine hypothetical and true heterosis and establish the nature of inheritance of the number of grains from the main ear in hybrids of soft winter wheat. In 2018-2020, 45 combinations of cross-breeding of soft winter wheat varieties obtained from hybridisation of different growing season periods were investigated in the experimental field of the Research and Production Centre of the Belotserkovskyi National Agrarian University. Generally accepted methods were used to determine the hypothetical and true heterosis and the degree of phenotypic dominance by the number of grains in the main ear. Studies indicate that the number of grains in the ear of the main stem of the parent components of hybridisation is determined by genotype and considerably depends on the hydrothermal conditions of the year. The author of this paper established the influence of maternal cytoplasm on the manifestation of the trait under study. Thus, when used in hybridisation of early-maturing varieties with the mother form, the largest average number of grains in the main ear for hybrids (63.3 pcs.) was formed in 2019. At the same time, for the use of medium-early, medium maturing, and medium-late varieties in hybridisation, the maximum number of grains (64.8 pcs.) was marked in 2018. Therewith, all hybrids formed the minimum number of grains in 2020. The obtained experimental data indicate the influence of parental genotypes and year conditions on heterosis indicators and the degree of phenotypic dominance in first-generation hybrids. It is determined that the most common type of inheritance (85.6%) of the number of grains from the main ear is positive overdomination. Practical value for the selection of soft winter wheat are the selected cross-breeding combinations: Myronivska early / Zolotokolosa, Myronivska early / Cherniava, Bilotserkivska semi-dwarf / Cherniava, Bilotserkivska semi-dwarf / Antonivka, Kolchuha / Antonivka, Zolotokolosa / Charniava, Zolotokolosa / Yednist, Cherniava / Vidrada, Cherniava / Stolychna, Shchedra Nyva / Dobirna, Antonivka / Stolychna, Dobirna / Pyvna, which significantly exceeded the average number of grains from the main ear for F_1 in the changing fields under hydrothermal conditions the years of research

Keywords: parental components of cross-breeding, year conditions, inheritance, hybrids, true and hypothetical heterosis, degree of phenotypic dominance

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INTRODUCTION

Due to the rapid growth of the world's population [1; 2], Ukrainian crop producers, as one of the leading agricultural countries in the world, face an acute task of increasing production volumes and improving grain quality indicators that would meet the requirements of European standards [3-5]. An essential role in solving this issue belongs to winter wheat (*Triticum aestivum* L.), the leading world culture [6; 7], grain products of which form the basis of human nutrition [1; 2].

One of the most common ways to increase and stabilise yields is to create and introduce into production highly productive varieties and hybrids of soft winter wheat with high grain quality [8-10]. The genotype of the variety, as a means of production, should combine the maximum number of traits and properties contributing to a high level of yield. The potential of the variety is fulfilled when the genotype interacts with environmental conditions [11; 12]. Considering the transformation of environmental conditions [13], scientists are faced with the task of creating new varieties adapted to certain soil and climatic zones of cultivation [14; 15]. Improvement of varieties should be based on environmental stability, considering special interactions between the environment and the genotype, which will provide new approaches to the development of stable productivity [16; 17].

The main ear of soft winter wheat plays a critical role in increasing the productivity of the wheat plant [18]. Graininess of the ear constitutes an essential quantitative feature that is closely related to grain yield [19; 20] and is frequently used by scientists in practical breeding work.

One of the most common and effective methods in practical breeding work is hybridisation, wherein a new organism is born and formed from a zygote (fertilised egg), which is developed as a result of the fusion of female and male gametes. Hybridisation allows combining the necessary traits in one genotype, as well as due to genetic recombination and transgressive variability, obtaining qualitatively new source material [21] and information about the breeding and genetic features of parental forms involved in cross-breeding and their offspring [22]. It is also important to know how traits and properties are inherited by offspring under changing environmental conditions [23; 24].

The purpose of this study is to determine the effect of heterosis and the degree of phenotypic dominance in F_1 according to the number of grains in the main ear, when used in hybridisation of different early-maturing varieties of soft winter wheat.

MATERIALS AND METHODS

The experimental part of this study was carried out in 2018-2020 on the experimental field of the Research and Production Centre of the Bilotserkivskyi National Agrarian University. The research material involved 45 combinations of F_1. Hybridisation involved varieties of soft winter wheat that differed in the duration of the growing season, namely early-maturing: Myronivska early (Myr. early), Kolchuha, Bilotserkivska semi-dwarf (B. Ts. s-d); medium-early: Zolotokolosa, Cherniava, Shchedra Nyva; medium-maturing: Stolychna, Vidrada, Myronivska 61, Antonivka, Yednist; mid-late: Dobirna, Pyvna, and Vdala.

F_1 seeds were sown manually according to the scheme: mother form (♀), hybrid (F_1), male form (♂). The hybrid generation was handled using the pedigree method. During the growing season of wheat, phenological observations were made, and after the onset of full maturing of the grain, biometric analysis of the material under study was performed on an average sample of 75 plants [25; 26]. The predecessor of soft winter wheat was mustard. The soil of the experimental field is typical deep low-humus chernozem, coarse-sawn medium and light loamy chernozem. According to the 2016 agrochemical survey, the content of humus is 3.4-3.8%, alkaline hydrolysed nitrogen — 118-134 mg/kg of soil, mobile phosphorus — 180-208 mg/kg of soil, and exchange potassium — 73-91 mg/kg of soil. The reaction of the soil solution is slightly acidic and close to the neutral. Phosphorus-potassium fertilisers of 60 kg/ha in the form of superphosphate and potassium salt were added to the main fertiliser. During the resumption of spring vegetation, ammonium nitrate was added in the active substance of 60 kg/ha. Herbicides and irrigation were not used in the breeding nursery.

Hypothetical (Ht) and true (Htb) heterosis by the number of grains in the head ear in F_1 was determined according to the developments made by D.F. Matzinger [27] S. Fonseca, F. Patterson [28]:

$$Ht\,(\%)=(F_1 - MP)/MP\ x\ 100$$
$$Hbt\,(\%)=(F_1 - BP)/BP\ x\ 100$$

where: F_1 is the arithmetic mean of the hybrid; BP is the highest manifestation of the trait of one of the parents; MR is the arithmetic mean of the indicator of both parent forms.

Degree of phenotypic dominance (h_p) according to method of B. Griffing [29]:

$$hp=(F_1 - MP)/\,(BP - MP)$$

where: hp is the degree of dominance; F_1 is the arithmetic mean of the hybrid; BP is the arithmetic mean of the parent component with a stronger manifestation of the feature; MR is the arithmetic mean of the indicator of both parent forms.

The obtained data were grouped according to the classification by G.M. Beil, R.E. Atkins [30]: positive superdomination (heterosis) hp>+1; partial positive dominance +0.5<hp≤+1; intermediate inheritance -0.5≤hp≤+0.5; partial negative inheritance -1≤hp<-0.5; negative superdomination (depression) hp<-1.

The number of grains in an ear of wheat is developed from the exit into the tube of the main ear (30th micro-stage) to the formation of grain — 70th micro-stage according to the international BBCH scale.

At the time of sowing (October 1), meteorological conditions in 2017-2019 contributed to the simultaneous germination and growth and development of soft winter wheat in the autumn period. The amount of precipitation during this period exceeded (2017) or was at the level of long-term average indicators. Soft winter wheat stopped growing in the autumn period on 20.11. (2017), 12.11. (2018) and 21.11. (2019), which contributed to the successful hardening of plants. Precipitation in the winter period considerably exceeded the long-term average (112 mm) in the 2017/2018 and 2018/2019 growing seasons and was slightly inferior to 2019/2020. The temperature regime that developed in winter contributed to the successful overwintering of plants (Table 1).

***Table 1**. Meteorological conditions in 2018-2020 (according to the Bilotserkivska Meteorological Station)*

Month	Decade	Precipitation, mm					Air temperature, °C				
		2017	2018	2019	2020	Multi-year data	2017	2018	2019	2020	Multi-year data
September		53.2	47.9	19.2		35	16.1	16.2	15.3		13.8
October		50.4	22.0	66.1		33	8.0	9.9	10.6		7.9
November		36.4	23.1	23.4		41	3.2	-0.1	5.0		2.0
December		92.3	71.1	35.1		44	1.6	-2.0	2.5		-2.4
January			30.5	56.8	22.6	35		-2.7	-4.8	0.4	-5.9
February			34.6	21.4	38.4	33		-4.2	0.4	2.2	-4.4
March			74.0	23.4	17.2	30		-2.1	4.7	5.9	0.3
April	I		1.5	–	–	14		10.3	9.6	7.9	7.0
	II		1.3	14.2	5.5	17		13.8	7.3	8.0	7.8
	III		5.3	31.3	7.7	16		15.7	13.2	11.7	10.4
May	I		3.7	26.7	30.8	16		20.4	12.1	12.8	13.3
	II		19.1	15.3	17.6	12		15.9	18.3	13.2	15.3
	III		–	12.0	53.9	18		18.8	19.3	11.5	15.8
June	I		2.2	35.3	7.1	23		19.4	21.1	18.5	17.3
	II		23.3	–	50.4	27		21.9	23.6	23.2	17.4
	III		33.2	43.9	3.2	23		19.1	21.4	22.0	18.7

The temperature regime after the resumption of vegetation in 2018 (April 4) was described by elevated temperatures, which accelerated the growth and development of soft winter wheat. The average monthly temperature for April (15.5°C) was significantly higher than the long-term average (8.4°C), and the average air temperature for May and June was higher by 3.5 and 2.3°C, respectively. Therewith, the amount of precipitation in April and May was less than the long-term figures by 17.1 and 21.6 mm, respectively.

Vegetation of soft winter wheat from the time of recovery (02.03. – 2019, 28.02. – 2020) occurred during the month at low average monthly temperatures with a gradual increase in them. The amount of precipitation in March (23.4 mm) and the first two decades of April (14.2 mm) in 2019 was considerably lower than the long-term average. In March and April 2020, 46.6 mm less precipitation fell than the long-term average. Thus, meteorological conditions in the years of study were described by contrasting indicators, temperature regime and precipitation distribution, which significantly affected the development of the number of grains in the main ear.

RESULTS AND DISCUSSION

The obtained experimental data in 2018-2020 indicate that the number of grains in the main ear of the parent components of hybridisation was from 34.1 pcs. (Yednist in 2020) up to 59.0 pcs. (Chorniava 2019) (Table 2). The conducted studies indicate that the development of the number of grains in the main ear of soft winter wheat is influenced by the genotype, the conditions of the year and the interaction between the genotype and the conditions of the year.

Other studies [31] found that the greatest influence (53.96%) on the development of the number of grains in the main ear was the interaction between the genotype and the conditions of the year, wherein the genotype influence was at 31.02%, while the conditions of the year only at 7.90%.

Table 2. *Number of grains in the main ear of parent hybridisation components, pcs.*

Varieties	2018	2019	2020
Myronivska early	39.1	39.8	42.3
Bilotserkivska semi-dwarf	37.7	39.5	49.5
Kolchuha	41.8	38.4	38.3
Zolotokolosa	42.2	39.8	37.9
Chorniava	54.4	59.0	52.1
Shchedra Nyva	45.5	47.4	43.7
Stolychna	40.5	38.9	39.0
Vidrada	37.2	37.6	35.9
Myronivska 61	41.4	40.7	39.7
Antonivka	41.1	40.6	38.1
Yednist	40.8	44.1	34.1
Dobirna	40.7	43.8	47.7
Pyvna	41.2	38.4	53.5
Vdala	39.9	40.7	39.8
HIP_{05}	2.2	2.6	1.9

Note: *SSD_{05} is the slightest significant difference*

For F_1 hybrids obtained for the use of early-maturing varieties by the mother form, the number of grains in the main ear in the years of research had a consideable differentiation — 30.1-76.5 pcs. It is established that the variability of the number of grains in F_1, for 2018-2020 is conditioned upon both the components of hybridisation and the conditions of the year (Table 3).

Table 3. *Number of grains in the head ear F_1 and parent forms for the use of early-maturing varieties by the mother form, pcs.*

Cross-breeding combinations	2018			2019			2020		
	♀	F_1	♂	♀	F_1	♂	♀	F_1	♂
♀ early maturing / ♂ early maturing									
Myr. early* / B. Ts. s-d**	39.1	63.5	37.7	39.8	61.8	39.5	42.3	53.1	49.5
Myr. early / Kolchuha	39.1	59.5	41.8	39.8	61.3	38.4	42.3	42.2	38.3
B. Ts. s-d / Kolchuha	37.7	55.6	41.8	39.5	67.8	38.4	49.5	51.0	38.3
♀ early maturing / ♂ mid-early									
Myr. early / Zolotokolosa	39.1	63.8	42.2	39.8	72.7	39.8	42.3	47.2	37.9
Myr. early / Chorniava	39.1	64.9	54.4	39.8	67.0	59.0	42.3	50.9	52.1
B. Ts. s-d / Zolotokolosa	37.7	60.2	42.2	39.5	59.2	39.8	49.5	51.4	37.9
B. Ts. s-d / Cherniava	37.7	76.5	54.4	39.5	60.2	59.0	49.5	53.6	52.1
Kolchuha / Chorniava	41.8	53.6	54.4	38.4	60.8	59.0	38.3	47.9	52.1
♀ early maturing / ♂ medium maturing									
Myr. early / Antonivka	39.1	53.6	41.1	39.8	65.7	40.6	42.3	30.1	38.1
Myr. early / Yednist	39.1	64.2	40.8	39.8	62.0	44.1	42.3	52.8	34.1
B. Ts. s-d / Antonivka	37.7	60.1	41.1	39.5	69.3	40.6	49.5	55.1	38.1
B. Ts. s-d / Yednist	37.7	69.0	40.8	39.5	58.3	44.1	49.5	44.1	34.1
B. Ts. s-d / Vidrada	37.7	55.4	37.2	39.5	63.7	37.6	49.5	44.9	35.9
Kolchuha / Antonivka	41.8	62.6	41.1	38.4	69.2	40.6	38.3	50.1	38.1
Kolchuha / Yednist	41.8	49.0	40.8	38.4	55.9	44.1	38.3	44.7	34.1
Kolchuha / Vidrada	41.8	51.0	37.2	38.4	53.0	37.6	38.3	38.0	35.9
Kolchuha / Stolychna	41.8	64.8	40.5	38.4	62.9	38.9	38.3	49.2	39.0
♀ early maturing / ♂ mid-late									
Myr. early / Vdala	39.1	69.1	39.9	39.8	67.5	40.7	42.3	37.6	39.8
Myr. early / Dobirna	39.1	63.1	40.7	39.8	69.1	43.8	42.3	48.8	47.7
B. Ts. s-d / Dobirna	37.7	58.2	40.7	39.5	64.9	43.8	49.5	45.0	47.7
HIP_{05}	2.4	2.1	2.3	3.8	2.0	2.8	2.1	2.4	2.2

Note: * *— Myronivska early,* ** *— Bilotserkivska semi-dwarf, ♀ — mother form, F_1 — hybrid, ♂ — male form, SSD_{05} — the slightest significant difference*

The largest average number of grains for hybrids (63.3 pcs.) in the main ear was formed in 2019. Slightly lower indicators (60.9 pcs.) were noted in 2018. Low number of grains (46.9 pcs.) was formed by hybrids in the conditions of 2020.

By average F_1 variability in the number of grains in the main ear (18.5 pcs.), in years of research, stable manifestation (8.8-12.9 pcs.) were established among the following: B. Ts. s-d / Zolotokolosa; Myr. early / B. Ts. s-d; Kolchuha / Yednist; Myr. early / Yednist; Kolchuha / Chorniava. Therewith, the number of grains higher than the average for hybrids for 2018-2020 (57.1 pcs.) was determined in Myr. early / Yednist (59.6 pcs.) and Myr. early / B. Ts. s-d (59.5 pcs.). A high amplitude of variability in the number of grains from the ear was established in hybrids Myr. early/ Antonivka (35.6 pcs.), Myr. early / Vdala (31.5 pcs.), Myr. early / Zolotokolosa (25.5 pcs.), B. Ts. s-d / Yednist (24.9 pcs.), B. Ts. s-d / Chorniava (22.9 pcs.).

In 2018-2020, the use of medium-early, medium-maturing, medium-late varieties for hybridisation yielded the number of grains in the main ear F_1 amounting to 38.6-87.8 pcs. The obtained experimental data indicate considerable variability depending on the selection of parent hybridisation pairs. In addition, most hybrids have a significant influence on the manifestation of the indicators of the year conditions (Table 4).

***Table 4**. Number of grains in the head ear F1 and parent forms for use in hybridisation of medium-early, medium-maturing and medium-late varieties, pcs.*

Cross-breeding combinations	2018			2019			2020		
	♀	F_1	♂	♀	F_1	♂	♀	F_1	♂
♀ mid-early / ♂ mid-early									
Zolotokolosa / Chorniava	42.2	62.2	54.4	39.8	64.1	59.0	37.9	61.6	52.1
Zolotokolosa/ Shchedra Nyva	42.2	62.2	45.5	39.8	58.8	47.4	37.9	53.9	43.7
Cherniava / Shchedra Nyva	54.4	63.9	45.5	59.0	53.3	47.4	52.1	46.2	43.7
♀ mid-early / ♂ medium maturing									
Zolotokolosa / Antonivka	42.2	53.3	41.1	39.8	62.5	40.6	37.9	54.3	38.1
Zolotokolosa / Yednist	42.2	70.5	40.8	39.8	73.3	44.1	37.9	48.5	34.1
Zolotokolosa / Vidrada	42.2	60.9	37.2	39.8	63.0	37.6	37.9	53.7	35.9
Zolotokolosa / Stolychna	42.2	57.2	40.5	39.8	64.6	38.9	37.9	61.2	39.0
Cherniava / Antonivka	54.4	70.3	41.1	59.0	41.0	40.6	52.1	43.7	38.1
Cherniava / Yednist	54.4	62.0	40.8	59.0	48.4	44.1	52.1	42.3	34.1
Cherniava / Vidrada	54.4	71.0	37.2	59.0	62.5	37.6	52.1	53.1	35.9
Cherniava / Stolychna	54.4	77.4	40.5	59.0	61.4	38.9	52.1	56.2	39.0
Shchedra Nyva / Antonivka	45.5	64.1	41.1	47.4	43.3	40.6	43.7	50.3	38.5
Shchedra Nyva / Stolychna	-	-	-	47.4	68.4	38.9	43.7	60.1	39.0
Shchedra Nyva / Vidrada	45.5	65.9	37.2	47.4	38.6	37.6	43.7	50.3	35.9
♀ mid-early / ♂ mid-late									
Shchedra Nyva / Dobirna	45.5	71.4	40.7	47.4	60.6	43.8	43.7	56.4	47.7
♀ medium maturing / ♂ medium maturing									
Antonivka / Yednist	41.1	52.0	40.8	40.6	61.3	44.1	38.1	51.4	34.1
Antonivka / Vidrada	41.1	65.0	37.2	40.6	48.5	37.6	38.1	50.5	35.9
Antonivka / Stolychna	41.1	68.2	40.5	40.6	60.2	38.9	38.1	55.9	39.0
Antonivka / Myronivska 61	-	-	-	40.6	69.2	40.7	38.1	56.4	39.7
Myronivska 61 / Yednist	41.4	62.7	40.8	40.7	66.1	44.1	39.7	42.5	34.1
Yednist / Vidrada	40.8	63.5	37.2	44.1	66.5	37.6	34.1	47.9	35.9
♀ medium maturity / ♂ mid-late									
Yednist / Dobirna	40.8	67.2	40.7	44.1	60.8	43.8	34.1	44.3	47.7
♀ mid-late / ♂ medium maturity									
Vdala / Stolychna	39.9	61.0	40.5	40.7	64.6	38.9	39.8	51.9	39.0
♀ mid-late / ♂ mid-late									
Vdala / Pyvna	-	-	-	40.7	87.8	38.4	39.8	62.3	53.5
Dobirna / Pyvna	40.7	74.5	41.2	43.8	80.5	38.4	47.7	50.8	53.5
HIP_{05}	1.5	1.7	2.3	2.7	1.5	2.1	1.6	1.2	2.2

***Note**: ♀ is the female form, F_1 is the hybrid, ♂ is the male form, SSD_{05} is the slightest significant difference*

The most favourable year for the formation of the average number of grains for F_1 in the main ear (64.8 pcs.) was established in 2018. In the conditions of 2019, the number of grains was considerably smaller – 61.2 pcs., and the minimum (52.2 pcs.) was formed by hybrids in 2020.

The average variability of the number of grains from the ear in these hybrids is determined at the level of 16.9 pcs. With a slight variation of the attribute (2.5-12.3 pcs. of grain), the hybrids Antonivka / Stolychna (64.1 pcs.), Zolotokolosa / Stolychna (61.0 pcs) were described by a consistently high reliable manifestation of the number of grains in 2018-2020.

High variability of the attribute was determined in the following hybrids: Dobirna / Pyvna (29.7 pcs.), Chorniava / Antonivka (29.3 pcs.), Shchedra Nyva / Vidrada (27.3 pcs.), Vdala / Pyvna (25.5 pcs.), Zolotokolosa / Yednist (24.8 pcs.), Myronivska 61 / Yednist (23.6 pcs.), Yednist / Dobirna (22.9 pcs.), Chorniava / Stolychna (21.2 pcs.), Shchedra Nyva / Antonivka (20.8 pcs.).

A special feature of hybrids of the first generation is the manifestation of the effect of heterosis in certain quantitative and qualitative characteristics, primarily due to the heterozygous state of the body [32; 33]. The manifestation of heterosis is explained by an increase in heterozygosity [34; 35], and its indicators F_1 vary widely.

In most F_1's the authors of this study determined a positive hypothetical heterosis from 0.2% (Chorniava / Shchedra Nyva) to 122.0% (Vdala / Pyvna). Therewith, the true heterosis varied from 0.2% (Shchedra Nyva / Dobirna) to 115.7% (Vdala / Pyvna). A considerable influence of hybridisation components and year conditions on the manifestation of the heterosis effect was established. Thus, depending on the selection of parent pairs for cross-breeding, the indicators of hypothetical and true heterosis in the years of research have substantial differences (Tables 5, 6).

Table 5. *Heterosis and degree of phenotypic dominance in F_1 according to the number of grains in the main ear, given the use of early maturing varieties with the mother form*

Cross-breeding combinations	2018			2019			2020		
	Heterosis, %		h_p	Heterosis, %		h_p	Heterosis, %		h_p
	Ht	Hbt		Ht	Hbt		Ht	Hbt	
♀ **early-maturing / ♂ early-maturing**									
Myr. early* / B. Ts. s-d**	65.4	62.4	35.9	55.9	55.3	147.7	15.7	7.3	2.0
Myr. early / Kolchuha	46.9	42.3	14.5	56.8	54.0	31.7	4.7	-0.2	0.9
B. Ts. s-d / Kolchuha	39.7	33.0	7.9	74.1	71.6	52.5	15.9	3.0	1.3
♀ **early maturing / ♂ mid-early**									
Myr. early / Zolotokolosa	56.8	51.2	15.4	82.6	82.6	1644.0	17.7	11.6	3.2
Myr. early / Chorniava	38.7	19.3	2.4	35.6	13.6	1.8	7.8	-2.3	3.1
B. Ts. s-d / Zolotokolosa	50.5	42.7	9.2	49.3	48.7	130.3	17.6	3.8	1.3
B. Ts. s-d / Cherniava	65.9	40.6	22.1	21.2	2.0	1.1	5.5	2.9	2.2
Kolchuha / Chorniava	11.43	-1.5	0.9	24.9	3.0	1.2	6.0	-8.1	0.4
♀ **early maturing / ♂ medium maturing**									
Myr. early / Antonivka	33.7	30.4	13.5	63.4	61.8	63.8	-2.5	-28.8	-4.8
Myr. early / Yednist	60.5	57.4	30.3	47.8	40.6	9.3	38.2	24.8	3.6
B. Ts. s-d / Antonivka	52.5	45.2	12.2	73.0	70.7	53.2	25.8	11.3	2.0
B. Ts. s-d / Yednist	75.6	69.1	19.8	39.5	32.2	7.2	5.5	-10.9	0.3
B. Ts. s-d / Vidrada	47.7	47.0	89.5	68.7	61.3	27.9	5.2	-9.3	0.3
Kolchuha / Antonivka	50.8	49.8	70.3	75.2	70.4	27.0	31.3	30.8	79.7
Kolchuha / Yednist	18.6	17.2	15.4	35.5	26.8	5.1	23.5	16.7	4.0
Kolchuha / Vidrada	29.1	22.0	5.0	65.8	38.0	62.5	2.4	-0.8	0.8
Kolchuha / Stolychna	57.3	55.0	39.3	62.7	61.7	97.0	27.3	26.2	30.1
♀ **early maturing / ♂ mid-late**									
Myr. early / Vdala	74.9	73.2	74.0	67.7	65.8	60.6	-8.4	-11.1	-2.8
Myr. early / Dobirna	58.1	55.0	29.0	65.3	57.8	13.6	8.4	2.3	1.4
B. Ts. s-d / Dobirna	48.5	43.0	12.7	55.8	48.2	10.8	-7.4	-9.1	-4.0

Note: * *— Myronivska early,* ** *— Bilotserkivska semi-dwarf, Ht — hypothetical heterosis, Htb — true heterosis, hp — degree of dominance,* ♀ *— maternal form,* ♂ *— male form*

***Table 6**. Heterosis and degree of phenotypic dominance in F_1 according to the number of grains in the main ear given the use of medium-early, medium-maturing and medium-late varieties for hybridisation*

Cross-breeding combinations	2018			2019			2020		
	Heterosis, %		h_p	Heterosis, %		h_p	Heterosis, %		h_p
	Ht	Hbt		Ht	Hbt		Ht	Hbt	
♀ mid-early / ♂ mid-early									
Zolotokolosa / Chorniava	28.5	14.3	2.3	29.8	8.64	1.5	36.9	18.2	2.3
Zolotokolosa/ Shchedra Nyva	41.4	36.7	12.1	34.9	24.1	4.0	32.1	23.3	4.5
Cherniava / Shchedra Nyva	27.8	17.5	3.2	0.2	-9.7	0.02	-3.5	-11.3	-0.4
♀ mid-early / ♂ medium maturing									
Zolotokolosa / Antonivka	27.8	26.3	23.2	55.5	53.9	55.8	42.9	42.5	163.0
Zolotokolosa / Yednist	69.9	67.1	41.4	74.7	66.2	14.6	34.7	28.0	6.6
Zolotokolosa / Vidrada	53.4	44.3	8.5	62.8	58.3	2.2	45.5	41.7	16.8
Zolotokolosa / Stolychna	38.2	35.5	19.8	64.2	62.3	56.1	59.2	56.9	41.4
Cherniava / Antonivka	47.1	29.2	3.41	-17.7	-30.5	-1.0	-3.1	-16.1	-0.2
Cherniava / Yednist	30.3	14.0	2.1	-6.1	-18.0	-0.4	-1.9	-18.8	-0.09
Cherniava / Vidrada	55.0	30.5	2.0	29.4	5.9	1.3	20.7	1.9	1.1
Cherniava / Stolychna	62.9	12.3	4.3	25.4	4.0	1.2	23.4	7.9	1.6
Shchedra Nyva / Antonivka	48.0	40.9	9.5	-1.6	-8.6	0.2	23.0	15.1	3.4
Shchedra Nyva / Stolychna	-	-	-	58.5	44.3	5.9	45.3	37.5	16.4
Shchedra Nyva / Vidrada	59.2	44.8	6.0	-9.2	-18.6	-0.8	26.4	15.1	2.7
♀ mid-early / ♂ mid-late									
Shchedra Nyva / Dobirna	65.7	56.9	11.8	32.9	27.6	8.3	23.4	0.2	5.4
♀ medium maturing / ♂ medium maturing									
Antonivka / Yednist	27.0	26.5	73.7	44.7	39.0	10.8	42.4	34.9	7.7
Antonivka / Vidrada	65.8	58.2	13.9	24.0	19.5	6.3	36.5	32.5	12.3
Antonivka / Stolychna	67.2	65.9	91.3	51.4	48.3	24.1	45.0	43.3	38.6
Antonivka / Myronivska 61	-	-	-	69.7	70.0	4.2	45.0	42.1	21.9
Myronivska 61 / Yednist	52.6	51.5	72.0	55.9	49.9	13.9	15.2	7.1	2.0
Yednist / Vidrada	62.8	55.6	13.6	62.8	50.8	7.9	36.9	33.4	14.3
♀ medium maturity / ♂ mid-late									
Yednist / Dobirna	64.9	64.7	529.0	38.3	37.9	112.3	8.3	-7.1	0.5
♀ mid-late / ♂ medium maturity									
Vdala / Stolychna	51.7	50.6	69.3	62.3	58.7	27.6	31.7	30.4	31.3
♀ mid-late / ♂ mid-late									
Vdala / Pyvna	–	–	–	122.0	115.7	42.0	33.5	16.4	2.3
Dobirna / Pyvna	81.9	80.8	134.2	62.3	83.3	14.6	0.4	-5.0	0.07

***Note**: Ht – hypothetical heterosis, Htb – true heterosis, hp – degree of dominance, ♀ – maternal form, ♂ – male form*

Stable high manifestation of hypothetical (27.0-75.2%) and true (26.2-70.4%) heterosis in the years of research was determined in Myr. early / Yednist, Kolchuha / Antonivka, Kolchuha / Stolychna, Zolotokolosa / Antonivka, Zolotokolosa / Yednist, Zolotokolosa / Vidrada, Zolotokolosa / Stolychna, Antonivka / Yednist, Antonivka / Stolychna, Yednist / Vidrada, Vdala / Stolychna. A certain level of heterosis does not always allow predicting the emergence of valuable forms in subsequent generations of splitting, since interallelic interactions may occur that are not passed on to descendants. Therefore, it is better to use heterosis with other performance characteristics that yield more efficient selection [36-38].

Analysis of the degree of phenotypic dominance in the years of research indicates that the inheritance of the number of grains from the main ear in most hybrids (85.6%) occurred with positive over-dominance. Intermediate inheritance is typical for 8.3% of cross-breeding combinations. For positive dominance and negative overdomination, inheritance of the trait occurred in the same amount – 4.6%. The least common type of inheritance is negative dominance – 1.5%.

In similar studies for crossing varieties of soft winter wheat of different origin inheritance of the number of grains from the ear in F_1 was followed by partial positive dominance, positive over-dominance, and intermediate Inheritance [39]. During hybridisation of various ecotypes of soft winter wheat under the conditions of the Bilotserkivska Experimental Station, the number of grains from the main ear in 9 out of 10 hybrids was determined by positive over-dominance [40].

The conducted studies demonstrate that the indicator of the degree of phenotypic dominance in F_1 depends on both the selection of hybridisation components and the year conditions. In 2018-2020, positive over-dominance was detected in 26 out of 42 cross-breeding combinations. As a result of the study, hybrids with positive overdomination were identified, which formed a high number of grains in the main ear (55.1-77.4 pcs.), namely: B. Ts. s-d / Antonivka, Zolotokolosa / Cherniava, Zolotokolosa / Stolychna, Cherniava / Stolychna, Shchedra Nyva / Dobirna, Antonivka / Stolychna.

The methods for determining indicators of heterosis and the degree of phenotypic dominance to assess F_1 used in this study are widely used by scientists in the breeding of winter wheat [4; 41], winter rye [42], winter triticale [43], spring barley [44], spring rapeseed [45]. Thus, by attracting to hybridisation, in the conditions of the forest-steppe of Ukraine, varieties of soft winter wheat that differ in precocity, the authors of this study managed to obtain hybrids of the first generation, which in comparison with the parent forms are described by a statistically significantly larger number of grains in the main ear. The analysis of the obtained experimental data allows predicting the influence of pairs selected for hybridisation and hydrothermal conditions of the year on the manifestation of the number of grains in the main ear F_1 and the nature of inheritance of the attribute under study.

CONCLUSIONS

1. The manifestation and variability of the number of grains in the main ear in hybrids of the first generation of soft winter wheat is considerably influenced by both the parent pairs of hybridisation and the year conditions.

2. A significant influence of the genotypes of the parent components of cross-breeding and the year conditions on the indicators of heterosis and the degree of phenotypic dominance in F_1 was established.

3. The most common type of inheritance (85.6%) of the number of grains in the main ear is positive over-dominance.

4. Cross-breeding combinations were singled out, which on average for three years statistically significantly exceeded the average number of grains from hybrids from the main ear: Myr. early / Zolotokolosa, Myr. early / Cherniava, B. Ts. s-d / Cherniava, B. Ts. s-d / Antonivka, Kolchuha / Antonivka, Zolotokolosa / Cherniava, Zolotokolosa / Yednist, Cherniava / Vidrada, Chernyava / Stolychna, Shchedra Nyva / Dobirna, Antonivka / Stolychna, Dobirna / Pyvna.

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Прояв гетерозису і ступеню фенотипового домінування за кількістю зерен з головного колосу при гібридизації різних за скоростиглістю сортів пшениці м'якої озимої

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Анотація. Пшениця (*Triticum aestivum* L.) озима є головною продовольчою культурою світового масштабу, в зростанні і стабілізації врожайності якої вагомим фактором є сортові ресурси. В практичній селекційній роботі важливу роль відіграє різноманітний досконало вивчений вихідний матеріал. Метою досліджень передбачалося визначення гіпотетичного та істинного гетерозису і встановлення характеру успадкування кількості зерен з головного колосу в гібридів пшениці м'якої озимої. У 2018–2020 рр. в умовах дослідного поля науково виробничого центру Білоцерківського НАУ досліджували 45 комбінацій схрещування отриманих від гібридизації різних за тривалістю вегетаційного періоду сортів пшениці м'якої озимої. Для визначення гіпотетичного та істинного гетерозису і ступеню фенотипового домінування за кількістю зерен у головному колосі використовували загальноприйняті методики. Проведені дослідження свідчать, що кількість зерен у колосі головного стебла батьківських компонентів гібридизації обумовлена генотипом та значно піддається впливу гідротермічних умов року. Встановлено вплив материнської цитоплазми на прояв досліджуваної ознаки. Так, за використання в гібридизації ранньостиглих сортів материнською формою найбільша середня по гібридах кількість зерен у головному колосі (63,3 шт.) формувалася у 2019 р. Водночас за використання в гібридизації середньоранніх, середньостиглих і середньопізніх сортів максимальна кількість зерен (64,8 шт.) відмічена в 2018 р. При цьому мінімальну кількість зерен усі гібриди формували у 2020 р. Отримані експериментальні дані свідчать про вплив батьківських генотипів і умов року на показники гетерозису і ступеню фенотипового домінування у гібридів першого покоління. Визначено, що найбільш поширеним типом успадкування (85,6 %) кількості зерен з головного колосу є позитивне наддомінування. Практичну цінність для селекції пшениці м'якої озимої становлять виділені нами комбінації схрещування: Миронівська рання / Золотоколоса, Миронівська рання / Чорнява, Білоцерківська напівкарликова / Чорнява, Білоцерківська напівкарликова / Антонівка, Кольчуга / Антонівка, Золотоколоса / Чорнява, Золотоколоса / Єдність, Чорнява / Відрада, Чорнява / Столична, Щедра нива / Добірна, Антонівка / Столична, Добірна / Пивна, які в мінливих за гідротермічними умовами роки досліджень достовірно перевищували середню по F_1 кількість зерен з головного колосу

Ключові слова: батьківські компоненти схрещування, умови року, успадкування, гібриди, істинний і гіпотетичний гетерозис, ступінь фенотипового домінування

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Formation of Seed Productivity and Sowing Qualities of Soft Winter Wheat Seeds Depending on the Levels of Mineral Nutrition of Plants in the Western Forest Steppe of Ukraine

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Abstract. Today, considerable attention is paid to the intensification of grain production, which depends on the accelerated introduction of highly productive varietal resources with the preservation of the properties of the variety in the process of further reproduction, the production of high-quality and competitive products for the sub-markets of pre-basic, basic, and certified seeds. Improved technologies for growing soft winter wheat should be based on the effective use of the soil and climatic conditions of the studied region, the biological, the genetic potential of varieties, technological innovations in agrotechnical methods of growing crops and the optimal use of material and technical resources. They should be effective for both the producer and the consumer of seed products. The purpose of the research was to determine the features of the formation of seed productivity and sowing qualities of soft winter wheat seeds, depending on the levels of mineral nutrition of plants in the Western Forest Steppe of Ukraine. The methodological basis consisted of general scientific and special research methods. Studies have established that with the low natural fertility of grey forest surface-gley soils of the Western Forest Steppe and considering climate change towards warming with a decrease in precipitation, the introduction of new more productive varieties of intensive type, complex forms of mineral fertilisers, microfertilisers, growth regulators into agricultural production, the questions of the nutrition system of soft winter wheat plants are insufficiently substantiated in this region. The research results presented in the article from 2019 to 2021 demonstrate the issues of the influence of the norm of application of mineral fertilisers with stage-by-stage feeding with nitrogen in different phases of organogenesis on the formation of indicators of seed productivity of varieties of the forest steppe ecological type of soft winter wheat. It was found that the rate of yield of conditioned seeds was the lowest in the control without fertilisers and grew by 16-20% for the application of mineral fertilisers. The seed yield varied from 1.58 t/ha in the control to 4.59 t/ha at the rate of $N_{220}P_{90}K_{160}S_{28}$, and the multiplication factor, respectively, from 6.3 to 19.8 units. According to this option, the total yield of the large and medium fractions was from 94.9 to 95.2%. A balanced complex of macroelements positively influenced the formation of indicators of sowing qualities of seeds, increasing the weight of 1000 seeds by 5.3-7.5 g, germination energy – from 4.8 to 8.4%, laboratory germination – from 13.6 to 14.4%

Keywords: variety, yield, multiplication factor, the yield of conditioned seeds, fractional composition

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INTRODUCTION

In the context of the functioning of new forms of market-type management in the agricultural sector, the scientifically based use of mineral fertilisers remains an effective factor in the guaranteed and efficient production of agricultural products [1-3]. Majority of scientists and specialists believe that the best conditions for seed formation occur when mother plants are fully supplied with nutrients [4-6]. Intensive technologies for growing soft winter wheat are based on the widespread use of mineral fertilisers and pesticides; therefore, their uncontrolled use is economically unjustified and environmentally hazardous [7-9]. According to scientific recommendations, the rate of application of nitrogen fertilisers for growing winter wheat in intensive technologies is 120 kg/ha a.b. [10-12]. However, an excess of nitrogen worsens the quality of seeds, since in the phases of milk and wax ripeness nitrate forms, toxic to the embryo, and accumulate in it. And also the supply of potassium, calcium, and magnesium to mother plants is delayed, which leads to the biological inferiority of seeds [13-15].

Phosphorus is an indispensable element for the complete development of plants. It promotes the assimilation of nutrients by the plant, thereby improving the sowing qualities and yielding properties of seeds, it actively participates in phosphorylation reactions; it is a part of organic compounds and largely determines the level of energy processes in the plant. Therefore, its presence in the seeds in sufficient quantities ensures the life of a young plant at a high energy level and determines the intensity of further biochemical transformations, plant development, and the final yield. In soil, phosphorus is mainly in a bound state, so the concentration of mobile forms in it is low [16-18]. The diffusion at soil temperatures above 14°C is the main method of its delivery to the root hairs; in lower plants, they suffer from its deficiency even at a high content in the soil [19].

Potassium serves as a regulatory and transport "agent" in a plant, promotes quality optimisation, increases plant resistance to diseases and pests, regulates water regime, improves root development, and prevents lodging of plants. Insufficient potassium supply to the soil leads to a delay in wheat growth, a sharp reaction of plants to soil temperature and moisture is observed, and the quality of seeds deteriorates [20; 21]. Sulfur is a key component of most proteins as it is found in the amino acids methionine and cysteine. In wheat, this microelement affects the increase in the content of proteins in seeds, grain for protein synthesis. A culture cannot assimilate nitrogen without a sufficient amount of sulfur, therefore the N:S ratio should not exceed 4-8:1 [22; 23].

In recent years, there has been a tendency in Ukraine to introduce higher norms of mineral fertilisers for wheat, but they remain significantly less than the standards adopted in the developed countries of the world. According to the FAO World Organisation, the increase in grain crop yields from the use of 1 kg of nitrogen in Germany is 20.3 kg, France – 21.2 kg, Great Britain – 24.3 kg, and in Ukraine it does not exceed 11-12 kg [24].

World experience in the use of mineral fertilisers convincingly confirms their 40-50% share in the formation of winter wheat yields, considering soil fertility, predecessors, and varietal characteristics [25-27]. According to the variety testing data in the Forest Steppe zone of Ukraine, on the production fields of Western Polissya, the Right-Bank and Left-Bank Forest Steppe, the average parameters of nutrient absorption by winter wheat of modern varieties are (kg/t): for grain N – 21.6; P_2O_5 – 6.5; K_2O – 4.6, for straw – 4.9; 1.1 and 17.5; trace elements (mg/kg): for grain – Zn – 19, Co – 0.51, Fe – 37, Mn – 30, Cu – 2.1, for straw – Zn – 1.8, Co – 0.52, Fe – 27, Mn – 12, Cu – 0.6 [28]. Studies conducted in the Eastern States of Australia confirm that when nitrogen fertilisers are applied up to 100 kg/ha active ingredient the yield of winter wheat increases significantly, but this effect strongly depends on environmental conditions (precipitation, temperature, and water-holding capacity of the soil) [29].

This problem is very important within the Western Forest Steppe zone, which is characterised by low natural fertility, leaching regime, high acidity, etc., which determines the physiological needs of varieties to obtain biologically valuable seeds.

The purpose of the study was to determine the features of the formation of seed productivity and sowing qualities of soft winter wheat seeds depending on the levels of mineral nutrition of plants in the Western Forest Steppe.

MATERIALS AND METHODS

Field experiments in the crop rotation were carried out in the laboratory of the Institute of Agriculture of the Carpathian Region of the National Academy of Agrarian Sciences, from 2018 to 2021. The total area of the experimental site was 60 m^2, the accounting area was 50 m^2. Placement of variants was systematic, repetition – threefold. The soil of the research plots was grey forest, superficially gleyed, light loamy, which was characterised by such indicators, as humus content (according to the Tyurins) – 1.7%, the number of absorbed bases – 13.7 mg-eq per 100 g of soil, puddle-hydrolysed nitrogen (according to Cornfield) – 89.6 mg/kg, mobile phosphorus and exchangeable potassium (according to the Kirsanovs) – 69.5 and 68.0 mg/kg, respectively. As for gradation, such a soil has a very low nitrogen, medium phosphorus, and low potassium supply. The reaction of the soil solution (pH sol – 5.4) is weakly acidic.

Agricultural technology for growing varieties of winter wheat is common for the crop in this area. The predecessor is winter rapeseed. Sowing time is from

09.25 to 01.10. Seeding rate – 5.5 million viable seeds/ha, application of mineral fertilisers (basic) – $N_{30}P_{70}K_{120}S_{21}$. Seed treatment – dressing agent Vitavax 200FF, 34% (water suspension concentrate, 3.0 l/t). Plant protection against weeds and diseases – herbicides: Roundup, 48% (4.0 l/ha); Granstar, 75% (water-soluble granules, 0.025 g/ha); Fungicide: Falcon (emulsion concentrate, 0.6 l/ha) [30].

The experimental scheme included 1 – control (without fertilisers), 2 – $N_{168}P_{66}K_{120}S_{21}$, 3 – $N_{224}P_{88}K_{160}S_{28}$, 4 – $N_{280}P_{110}K_{200}S_{35}$. Mineral fertilisers were applied in various forms, in particular: in all variants – phosphoric potash fertiliser – nitroammophoska $NPK_{8\text{-}19\text{-}29}$ (3S).

1 variant of experiment – $N_{90}P_{50}K_{90}S_{19}$ – nitroammophoska $NPK_{8\text{-}19\text{-}29}$ (3S) – 265 kg/ha for cultivation; BBCH 20-22 (permafrost soil) ammonium sulfate – 50 kg/ha; BBCH 30-32 (phase of plant emergence into the tube) ammonium nitrate – 90 kg/ha; BBCH 37-49 (heading phase) ammonium nitrate – 80 kg/ha.

2 variant of experiment – $N_{90}P_{50}K_{90}S_{19}$ – nitroammophoska $NPK_{8\text{-}19\text{-}29}$ (3S) – 370 kg/ha for cultivation; BBCH 20-22 (permafrost soil) ammonium sulfate – 50 kg/ha + ammonium nitrate – 150 kg/ha; BBCH 30-32 (phase of plant emergence into the tube) ammonium nitrate – 130 kg/ha; BBCH 37-49 (heading phase) ammonium nitrate – 93 kg/ha.

3 variant of experiment – $N_{90}P_{50}K_{90}S_{19}$ nitroammophosk $NPK_{8\text{-}19\text{-}29}$ (3S) – 450 kg/ha for cultivation; BBCH 20-22 (permafrost soil) ammonium sulfate – 60 kg/ha + ammonium nitrate – 190 kg/ha; BBCH 30-32 (phase of plant emergence into the tube) ammonium nitrate – 160 kg/ha; BBCH 37-49 (heading phase) ammonium nitrate – 150 kg/ha.

The studies were carried out according to generally accepted methods, such as phenological observations of the growth and development of plants, evaluation of crops in autumn and during the restoration of spring vegetation, the structure of plants in the phase of full grain ripeness – H.K. Fursova, D.I. Fursov, V.V. Serhyeyev, 2004 [31]; phytopathological assessment – according to V.P. Omelyuta, I.V. Hryhorovych, V.S. Chaban et al., 1986 [32]; leaf surface area and net productivity of photosynthesis were determined by N.V. Peterson, T.O. Chernomyrdina, Ye.K. Kurilyak, 1993 [33]. The yield was taken into consideration when determining the moisture at the time of harvesting and recalculating to a standard 14% moisture. The output of conditioned seeds was determined after bringing them to sowing conditions on the grain cleaning machine Petkus "Giant", multiplication factor – concerning the cleaned seeds to the sown ones. Processing and summarising the results of the study was carried out using Microsoft Excel programs. The obtained data were processed by the method of dispersion and correlation analysis by B.A. Dospekhov, 1985 [34].

RESULTS AND DISCUSSION

Seed technologies should be based on varietal agricultural technology, considering the reaction of the variety to certain growing conditions, including the nutritional system, under which the genetic potential laid down by selection can be used to the maximum. Yield is a complex feature that is formed from many structural elements, the value of each of which is determined by the impact on the effective value.

According to the grain yield formed by the varieties in 2019, the yield of conditioned seeds was the lowest in the control and amounted up to 65%. With an increase in the rates of application of mineral fertilisers, this indicator grew by 6-11%. Plants on the control (without fertilisers) created a shrivelled grain, therefore, the yield of conditioned seeds in 2020 was also low – 52%. The introduction of mineral fertilisers at different rates contributed to a better supply of plants with nutrients, which positively influenced the formation of full seeds. Under such conditions, the yield of conditioned seeds grew up to control simultaneously with an increase in the rate of fertilisation, according to the $N_{90}P_{50}K_{90}S_{19}$ option by 18%, $N_{168}P_{70}K_{120}S_{21}$ – by 21%. High rates of application of nitrogen fertilisers at rates of $N_{220}P_{90}K_{160}S_{28}$ somewhat reduced this indicator. In comparison with the control, its increase was significant, and with the norm $N_{168}P_{70}K_{120}S_{21}$ it was less by 3%. In 2021, the yield of conditioned seeds varied from 48% in the control (without fertilisers) to 76% with the application rate of mineral fertilisers $N_{220}P_{90}K_{160}S_{28}$. There are no differences between the norms $N_{168}P_{70}K_{120}S_{21}$ and $N_{220}P_{90}K_{160}S_{28}$ for this indicator. Over the years of research, the rate of yield of conditioned seeds was the lowest in the control (without fertilisers) (Table 1). With the introduction of mineral fertilisers, this indicator increased by 16-20%.

***Table 1**. Indicators of seed productivity of winter wheat varieties depending on the norms of mineral fertilisers application (from 2019 to 2021)*

Mineral fertilisers rate, active substance/ha	The yield of conditioned seeds		Seed yield		Seed multiplication factor	
	%	± *to control*	t/h*a*	± *to control*	units	± *to control*
Control (without fertilisers)	55	–	1.58	–	6.3	–
$N_{90}P_{50}K_{90}S_{19}$	71	16	3.14	1.56	12.6	6.3
$N_{168}P_{70}K_{120}S_{21}$	75	20	4.12	2.54	16.6	10.3
$N_{220}P_{90}K_{160}S_{28}$	73	18	4.95	3.37	19.8	13.5
$SSD_{0.05}$	2.1		0.47		2.8	

In 2019, under the influence of different rates of application of mineral fertilisers under control (without fertilisers), the average seed yield varied from 2.12 t/ha for the Gratsia Bilotserkivska variety to 2.37 t/ha for Trudivnytsa Myronivska and Vodograi Bilotserkivskiy. Depending on the yield of conditioned seeds in 2020, the yield under control was, respectively, 1.35 t/ha, and when the rate of mineral fertilisers $N_{90}P_{50}K_{90}S_{19}$ was applied, it increased to 3.37 t/ha. Under the weather conditions of 2021, the seed productivity of varieties varied from 1.11 t/ha in the control (without fertilisers) to 4.59 t/ha at the rate of application of mineral fertilisers $N_{220}P_{90}K_{160}S_{28}$. The average indicators over the years of research on the yield of seeds of soft winter wheat varieties varied from 1.58 t/ha for control to 4.95 t/ha for the option of applying mineral fertilisers at the rate of $N_{220}P_{90}K_{160}S_{28}$.

Depending on the yield of conditioned seeds in 2020, the yield under control was, respectively, 1.35 t/ha. When applying the rate of mineral fertilisers $N_{90}P_{50}K_{90}S_{19}$, it increased to 3.37 t/ha, or 2.02 t/ha. The highest was the application rate of $N_{220}P_{90}K_{160}S_{28}$ – 4.33 t/ha, or 2.98 t/ha in the control.

Under the weather conditions of 2021, the seed productivity of varieties ranged from 1.11 t/ha in the control (without fertilisers) to 4.59 t/ha at the rate of application of mineral fertilisers $N_{220}P_{90}K_{160}S_{28}$. An increase in the application rate of mineral fertilisers in $N_{168}P_{70}K_{120}S_{21}$ contributed to a significant increase to the lower rate by 1.0 t/ha and by 1.68 t/ha – to the $N_{220}P_{90}K_{160}S_{28}$ rate. The average indicators over the years of research on the yield of seeds of soft winter wheat varieties varied from 1.58 t/ha on the control to 4.59 t/ha according to the option of applying mineral fertilisers at the rate of $N_{220}P_{90}K_{160}S_{28}$.

The regulating factor for expanding the area under crops is to build up a sufficient number of pre-basic seeds of new varieties in the first years of their introduction after being included in the Register of plant varieties suitable for distribution in Ukraine. This is facilitated by obtaining a high rate of reproduction. In our experiments in 2019, compared with the control (without fertilisers), the seed multiplication factor increased from 9.2 to 23.8 units and was significantly higher than $SSD_{0.05}$ = 4 units. Depending on the obtained seed yield, the multiplication factor in 2020 increased with the rate of application of mineral fertilisers by 8.5-11.9 units in comparison with the control. With $SSD_{0.05}$ = 3.0, all the studied variants of the mineral nutrition of plants provided a significant increase in this indicator. In 2021, the seed multiplication factor grew from 4.4 units in the control to 18.4 units of the rate of application of mineral fertilisers $N_{220}P_{90}K_{160}S_{28}$. Over the years of research, the indicator of the seed multiplication factor in the control (without fertilisers) was -6.3 units and grew to 19.8 units of the application rate of mineral fertilisers $N_{220}P_{90}K_{160}S_{28}$.

Under the influence of weather and agro-technological factors, seeds with different weights were formed within the ear and on the plant as a whole, which determined its fractional composition when brought to sowing conditions and its assessment. Presented in Table 2 data allow us to assert that in the control (without fertilisers) the yield of the fine fraction of seeds was the highest – 28.0-29.9%, and the highest – 30.5-31.7%. When mineral fertilisers were applied at the rate of $N_{90}P_{50}K_{90}S_{19}$, the output of coarse (from 2.2 mm to 2.8 mm) and medium (from 2.2 mm to 2.5 mm) fractions increased: up to 41.6-42.0% and 44.6-45,0%, and small (from 2.0 mm to 2.2 mm) decreased to 12.4-13.8%. The same pattern was observed at the highest rate of mineral fertilisers $N_{168}P_{70}K_{120}S_{21}$, these indicators were, respectively: 52.2-53.4% (large), 36.7-37.8 (medium) and 9.9-10.0% (small). The highest total yield of coarse and medium fractions of 94.9-95.2% was provided by the rate of mineral fertilisers $N_{220}P_{90}K_{160}S_{28}$ with a phased application of nitrogen at the stages of organogenesis.

***Table 2**. Fractional warehouse of the population of winter wheat varieties fallow as normal application of mineral goodness (2019-2021), %*

Mineral fertilisers rate, active substance/ha	The output of seed fractions by years, mm									The average		
	2019			2020			2021					
	Large (2.2-2.8)	Medium (2.2-2.5)	Small (2.0-2.2)	Large (2.2-2.8)	Medium (2.2-2.5)	Small (2.0-2.2)	Large (2.2-2.8)	Medium (2.2-2.5)	Small (2.0-2.2)	Large (2.2-2.8)	Medium (2.2-2.5)	Small (2.0-2.2)
Control (without fertilisers)	30.5	39.6	29.9	31.7	40.3	28.0	31.0	40.0	29.0	–	–	–
$N_{90}P_{50}K_{90}S_{19}$	41.6	44.6	13.8	42.3	45.3	12.4	42.0	45.0	13.0	11.0	5.0	-16.0
$N_{168}P_{70}K_{120}S_{21}$	52.2	37.8	10.0	53.4	36.7	9.9	52.8	37.2	10.0	21.8	-2.8	-19.0
$N_{220}P_{90}K_{160}S_{28}$	60.7	34.2	5.1	61.2	34.0	4.8	61.0	34.0	5.0	30.0	-6.0	-24.0

The problem of increasing the sowing quality of seeds remains extremely important due to the influence of negative factors during its formation and maturation. One of the important indicators of the sowing properties

of seeds is the mass of 1000 seeds. The parameters of this indicator were genetically incorporated when creating a variety, however, the formation of biologically valuable seeds is provided primarily by the plant nutrition system. This issue acquires particular importance in cases where the cultivation technology does not correspond to the genetic capabilities of the variety to ensure a sufficient degree of reliability and protection of the genotype from the unfavourable influence of biotic and abiotic environmental factors.

In the conducted experiments, a balanced complex of macronutrients had a positive effect on the formation of the mass of 1000 seeds. The average given indicator over the years of research varied from 38.2 in the control to 45.7 g at the rates of application of mineral fertilisers $N_{220}P_{90}K_{160}S_{28}$ (Table 3).

The effect of fertilisers on the growth of this indicator was significant in all years of research. In 2019, in comparison with the control, this indicator grew by 4.2-5.6 g. In 2020, under the control (without fertilisers), the varieties formed a mass of 1000 seeds at the level of 36.3 (Gratsia belotserkivska) – 37.3 g (Kvitka poliv). It was higher by 5.8-8.4 g in the variants of applying mineral fertilisers. Compared to the control, the lowest rate of application of mineral fertilisers – $N_{90}P_{50}K_{90}S_{19}$ contributed to its growth by 5.8 g, and the highest $N_{220}P_{90}K_{160}S_{28}$ – by 8.4 g, with the smallest significant difference of 0.8 g between all rates of mineral fertilisers. Under the influence of weather conditions and levels of mineral nutrition of plants in 2021, the average weight of 1000 seeds by varieties was 35.9 g and higher by 6.1-8.7 g at the studied rates of mineral fertilisation.

Seeds with a higher mass of 1000 seeds provided a high percentage of germination energy (from 73.1% to 76.7%) and laboratory germination (from 92.8% to 93.6%). With a high rate of mineral fertilisers $N_{220}P_{90}K_{160}S_{28}$ compared to the rate of $N_{168}P_{70}K_{120}S_{21}$, the difference in seed germination energy and laboratory germination was within the error limits of 2.1 and 0.5% ($SSD_{0,05}$ = 2.5 and 1.1).

***Table 3**. Sowing qualities of seeds of winter wheat varieties depending on the application rates of mineral fertilisers (average for varieties and years 2019-2021)*

Mineral fertilisers rate, active substance/ha	Weight 1000 seeds		Seed germination energy		Laboratory germination of seeds	
	g	± to control	%	± to control	%	± to control
Control (without fertilisers)	38.2	–	68.3	–	79.2	–
$N_{90}P_{50}K_{90}S_{19}$	43.5	5.3	73.1	4.8	92.8	13.6
$N_{168}P_{70}K_{120}S_{21}$	44.7	6.5	76.7	8.4	93.6	14.4
$N_{220}P_{90}K_{160}S_{28}$	45.7	7.5	74.6	6.3	93.1	13.9
$SSD_{0.05}$	0.6		2.5		1.1	

CONCLUSIONS

In the zone of the Western Forest Steppe of Ukraine, on low in natural fertility grey forest surface gleyed soils, obtaining a high yield and quality of seeds depends on the provision of soft winter wheat plants with an optimal level of mineral nutrition.

1. At the rate of application of complex mineral fertilisers at the rate of $N_{90}P_{50}K_{90}S_{19}$ (nitroammophoska $NPK_{8\text{-}19\text{-}29}$ 3S) – 450 kg/ha for cultivation and feeding in BBCH 20-22 (frozen ground) with ammonium sulfate – 60 kg/ha + ammonium nitrate – 190 kg/ha + BBCH 30-32 (phase of plant emergence into the tube) ammonium nitrate – 160 kg/ha + BBCH 37-49 (heading phase) ammonium nitrate – 150 kg/ha, varieties provided a higher (before control without fertilisers) 18% yield of conditioned seeds, 3.37 t/ha yield and 13.5 units of multiplication factor.

2. With an increase in the rates of application of mineral fertilisers, the yield of large (from 2.2 to 2.8 mm) and medium (from 2.2 to 2.5 mm) seed fractions increased. At the rate of $N_{220}P_{90}K_{160}S_{28}$ with staged nitrogen addition by stages of organogenesis, the total yield of these fractions was from 94.9% to 95.2%.

3. Mineral fertilisers at different application rates contributed to an increase in the mass of 1000 seeds by 5.3-7.5 g, which increased the seed germination energy by 4.8-8.4% and laboratory germination by 13.6-14.4 g.

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Формування насіннєвої продуктивності та посівних якостей насіння пшениці м'якої озимої залежно від рівнів мінерального живлення рослин у Західному Лісостепу України

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Анотація. Сьогодні значна увага приділяється інтенсифікації виробництва зернових культур, яка залежить від прискореного впровадження високопродуктивних сортових ресурсів із збереженням властивостей сорту в процесі подальшого його розмноження, виробництва високоякісної та конкурентоспроможної продукції для субринків добазового, базового та сертифікованого насіння. Удосконалені технології вирощування пшениці м'якої озимої повинні базуватися на ефективному використанні ґрунтово-кліматичних умов досліджуваного регіону, біологічному й генетичному потенціалі сортів, технологічних інноваціях в агротехнічних прийомах вирощування культури та оптимальному застосуванні матеріально-технічних ресурсів, бути ефективними як для виробника, так і споживача насіннєвої продукції. Мета наших досліджень полягала у визначенні особливостей формування насіннєвої продуктивності та посівних якостей насіння пшениці м'якої озимої залежно від рівнів мінерального живлення рослин в Західного Лісостепу України. Методологічну основу становили загальнонаукові та спеціальні методи досліджень. Дослідженнями встановлено, що за низької природньої родючості сірих лісових поверхнево-оглеєних грунтів Західного Лісостепу та з урахуванням змін клімату в сторону потепління і зменшення кількості опадів, впровадженням у сільськогосподарське виробництво нових більш продуктивних сортів інтенсивного типу, складних форм мінеральних добрив, мікродобрив, регуляторів росту, недостатньо обґрунтованими в даному регіоні є питання системи живлення рослин пшениці м'якої озимої. Подані в статті результати досліджень за 2019–2021 рр. висвітлюють питання впливу норм внесення мінеральних добрив з поетапним підживленням азотом у різні фази органогенезу на формування показників насіннєвої продуктивності сортів лісостепового екологічного типу пшениці м'якої озимої. Встановлено, що показник виходу кондиційного насіння найнижчим був на контролі без добрив) і зростав на 16–20 % за внесення мінеральних добрив. Урожайність насіння варіювала від 1,58 т/га на контролі до 4,59 т/га за норми $N_{220}P_{90}K_{160}S_{28}$, а коефіцієнт розмноження, відповідно від 6,3 до 19,8 одиниць. За даного варіанту сумарний вихід крупної і середньої фракції становив 94,9–95,2 %. Збалансований комплекс макроелементів позитивно впливав на формування показників посівних якостей насіння підвищуючи масу 1000 насінин на 5,3–7,5 г, енергію проростання – на 4,8–8,4 %, лабораторну схожість – на 13,6–14,4 %

Ключові слова: сорт, урожайність, коефіцієнт розмноження, вихід кондиційного насіння, фракційний склад

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Control of *Heracleum Sosnowskyi* Plant Numbers in Agricultural and Forestry Phytocenoses of Ukraine

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Abstract. As of today, *Heracleum Sosnowskyi* have expanded from transformed habitats and small areas into natural conditions, where they occupy stable positions and is characterised by high phytocenotic activity, often being dominant or co-dominant. Considering that there are no clearly developed methods of control of this invasive species, there still is an urgent need to develop the methods of control of both annual and perennial plants under conditions of Ukraine. The aim of the study was to determine the effectiveness of different methods of control of *Heracleum Sosnowskyi*. A field experiment was carried out during 2015-2020 on typical medium loam black soil. Four experiments were conducted: 1 – mechanical measures; 2 – screening; 3 – hot steam; 4 – use of herbicides. A randomised experimental design with four repetitions was used. It was found that an effective approach is the removal of the weeds with the root to a depth of at least 10-15 cm. Complete shading of the plants to the stage of four leaves within 30 days ensured their complete disappearance. The rate of *Heracleum Sosnowskyi plants* mortality by hot steam ranged from 100% (cotyledon stage) to 85% (6 leaves stage). The most sensitive to herbicides were the shoots in the cotyledon stage, from 97.3% to 100%. The most susceptible to herbicides in the phase of cotyledon was from 97.3% to 100%. To the phase of 6 leaves sensitivity decreased from 43.2 to 60.7%. The most effective herbicides were: TaskExtra 66.5 WG (rimsulfuron – 23 g·kg^{-1}, nicosulfuron – 92 g·kg^{-1}, dicamba – 550 g·kg^{-1}) + Trend-90 at a consumtpion rate of 385 g·ha^{-1} + 0.2 l·ha^{-1} and MaisTer Power OD (foramsulfuron, 31.5 g·l^{-1} + iodosulfuron, 1.0 g·l^{-1} + tincarbazone-methyl, 10 g·l^{-1} + cyprosulfamide (antidote), 15 g·l^{-1}) at a consumption rate of 1.5 l·ha^{-1}). *Heracleum Sosnowskyi* the following herbicides proved to be efficient: Elumis 105 OD, MD (mesotrion 75 g·l^{-1}, nikosulfuron, 30 g·l^{-1}) at a consumption rate of 2.0 l·ha^{-1} and the following tank compositions: Elumis 105 OD, MD + Roundup Max v.r. (glyphosate potassium salt, 551 g·l^{-1}) at a consumption rate of 2.0+6.0 l·ha^{-1}. In further study of this issue, it is advised to increase the efficiency of controlling the number of *Heracleum Sosnowskyi* plants and reducing the chemical effect on the environment

Keywords: weeds, mechanical measures, screening, hot steam, herbicides

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INTRODUCTION

Heracleum Sosnowskyi Mandenova is significantly widespread in Ukraine. It is dangerous so it must be controlled. Since these plants are characterised by high biological productivity, competitiveness and vitality, they form a seed bank, that can grow under natural conditions during up to 5 years of conservation, it is difficult to effectively control their presence in residential areas and on agricultural land [1; 2].

Heracleum Sosnowskyi occupies a specific place among the weeds in the crops and the environment in general. The species, being at one time a promising fodder crop, has turned into an aggressive invasive and adventitious object, which poses a threat both for natural phytocoenoses and humans. The genus *Heracleum* L. belongs to the botanical family *Apiaceae*. The family includes some 300 genera and 3,990 species spread throughout the world. Central Asia and the Caucasus are considered to be the centre of the species diversity of the family [1]. The renowned Swedish taxonomist Carl Linnaeus described the genus *Heracleum* L. in 1735, which the Roman botanist Pliny named after the hero of Greek mythology Heracles, for its ability to rapidly increase its vegetative mass, large size, and its very stout appearance. The genus *Heracleum* L. is widely distributed in the world flora and includes 69 species, growing mainly in the temperate climatic zone of Eurasia [2; 3].

In Eurasia, the north border of the range of the genus stretches from the Scandinavian Peninsula to Kamchatka, and in North America from Alaska to Labrador and Newfoundland, the southern – covers North Africa, West and North Asia, in West America stretching from California and eastern Mexico to North Carolina. There are several major centres: East Asia, the mountainous regions of southern Europe and the Caucasus. Accordingly, the active expansion of giant *Heracleum Sosnowskyi* as an invasive species started approximately in the mid-1980s, almost simultaneously in different parts of Ukraine as well as in Europe, Russia and the Baltic states. *Heracleum Sosnowskyi* as an invasive species is also present in Germany, Hungary, Denmark and Poland [4; 5].

After successful acclimatisation, these plants due to their extremely high reproductive capacity (the main mass of *Heracleum Sosnowskyi* seeds crumbles right near the mother plant (up to 75,000-80,000 seeds per 1 plant) and are spread by wind, water currents, road and rail transport over long distances); their adaptability to habitat conditions is widespread [6]. At the beginning of its expansion, *Heracleum Sosnowskyi* was detected only in heavily anthropic disturbed ecotopes – along the roadsides, on the outskirts of settlements, in waste grounds, trash, near farms, in pits. At the second stage, they considerably increase the number and area of population and growth, some of them merge into large, solid groups. At the third stage, *Heracleum Sosnowskyi* plants successfully expand into natural ecotopes, croplands, and forests [7-10].

In the Baltic States since the 1980s, *Heracleum Sosnowskyi* has been considered a malignant and dangerous weed. In 1986 in Latvia and 1987 in Estonia, it was declared an aggressive weed, primarily due to the negative impact on the flavour of the meat and milk of the animals that ate it and partly because of health risks for humans and animals [11; 12]. In Belarus, according to recent data, every year the number of *Heracleum Sosnowskyi* growth increases by 30%, and the area of existing populations – by 20-25%. Analysis of the distribution of *Heracleum Sosnowskyi* growth areas by land categories showed that more than a half (49%) of populations of this species is centred on the lands of industry, transport, communications, energy, defence and other purposes, and primarily – on the roads. A significant proportion of the populations were found on lands of agricultural and farming purposes (23%), and lands of settlements, gardening associations, dacha cooperatives (26%) [13].

In Ukraine, *Heracleum Sosnowskyi* gradually invades new territories. It grows particularly fast in unkempt fields and other places with disturbed natural vegetation. Due to its large size, fast accumulation of biomass, and a high degree of plasticity, *Heracleum Sosnowskyi* is able in a short time to reduce the size of populations of a large number of local plants species, especially those growing in meadows and near-river areas, until they are completely displaced [14].

The purpose of this study was to investigate the control methods for both annual and perennial *Heracleum Sosnowskyi* plants within the Ukrainian environment.

LITERATURE REVIEW

According to the researchers, only 15-20 species of mostly weed-ruderal plants can survive in the synusia with *Heracleum Sosnowskyi*. From the structure of flood plain phytocenoses, this species pushes back the species of fodder and medicinal plants. As a consequence, there is a fall-out from the grass of rhizomatous plants with the replacement for *Heracleum Sosnowskyi* with a rod root system, which is not capable of forming a dense turf and holding the soil layer, leading to soil erosion [14; 15]. The life cycle of *Heracleum Sosnowskyi* plants can proceed in two variants: in the first one the plant develops as a biennial plant: in the first year it forms a large, ramified, and strong root system with a rosette of leaves, and in the next year – a sprout with inflorescences, that produce a significant amount of seed. In another variant, the species develop as a biennial plant and can blossom and bear fruit at the age of 3-7 years. The *Heracleum Sosnowskyi* is a cold-resistant plant and can live at – 4-7°C during its first year of life; from the second year onwards it can bear up to -25°C and even to -45°C when under the layer of snow. At the same time, the plants are light-demanding, poorly tolerant of shade and cover crops, and require moist soil [16; 17].

Human activity contributes to the spread of giant *Heracleum Sosnowskyi* plants: they often grow in roadside ditches and on roadside verges and other ecotopes of a ruderal character. *Heracleum Sosnowskyi* from transformed habitats move into natural, where they occupy a rather stable position and are characterised by high phytocoenotic activity, often acting as a dominant or co-dominant species. It is known that *Heracleum Sosnowskyi* increases the area occupied by its plants by 10% per year, but there is also information about its more intensive growth [18; 19]. Control of invasive *Heracleum Sosnowskyi* species requires the use of a wide variety of techniques. Phytosanitary control of roads and railways, settlements, green areas, roadside and field protective plantations needs to be strengthened. In order to choose optimal control methods it is necessary to consider environmental and coenotic needs of such species and peculiarities of agricultural activities in the region [20].

Mowing is one of the mechanical methods of controlling *Heracleum Sosnowskyi*. If to mow weed after seeds are created, it is not possible to prevent fresh seed from entering the soil. After pollination and fertilisation, the seedlings will be fully emerged after 10-12 days and will be able to fully develop into new full-grown plants. The efficient method is the cutting of flowers during the period of budding and the beginning of flowering and burning of plants during the period of seed development. It is effective to cut plants of any age to a depth of at least 10-15 cm from the soil surface, resulting in their complete death. However, this can be done in small areas. In addition, such an operation is potentially dangerous for staff, as it is easy to get juice and strong dermatoses on different parts of the body [21-24].

It is difficult to control the number of *Heracleum Sosnowskyi* due to the specifics of their biology, the potential risk posed by the plants themselves, the high level of plant productivity and the formation of a seed bank. Therefore, the chemical area is one of the tensions of control. Among systemic herbicides, specialists recommend using a product based on such active substances as glyphosate, sulphometuron-methyl and other sulphonylureas, imazapyr, or their tank compositions. The optimum phases of the treatment are from the beginning of the growing season in spring to the beginning of flowering. Herbicide application during the later stages of organogenesis is less effective [25; 26].

According to the data of both European and Ukrainian studies, the fastest results are obtained by the use of the active substance gliphosate (N-(phosphonomethyl)-glucine, $C_3H_8NO_5P$) in the form of ammonium, isopropylamine and calamine salt [18; 27]. Up to date, in Ukraine, chemical methods of *Heracleum Sosnowskyi* control have not been investigated sufficiently. Due to the latest data [18], the control of *Heracleum Sosnowskyi* plants use Roundup with the rate of consumption – 6.0 l·ha^{-1}, or its analogues 6-8 l·ha^{-1} for the formation of vegetation height of 30-50 cm (the end of April – the first half of May). The available method is to mow the plants twice a year during the period of the flowering of the main (central) and repeatedly during the regeneration of the weed plants.

The heating effect of *Heracleum Sosnowskyi* plants (thermal method) is promising for agricultural areas where the use of herbicides is limited. Traditionally, plants are heated by a flare of fire or hot gases – products of the combustion of natural gas or petroleum products. High temperatures lead to denaturation of protein-enzymes and loss of their catalytic properties. As a result of this disorganisation of metabolic processes, the plants subsequently die [28-30].

MATERIALS AND METHODS

The research was carried out during 2015-2020 at the Herbology Department of the Institute of Bioenergy Crops and Sugar Beet of the NAAS (IBCBSBN) and the Bila Tserkva Experiment Breeding Station (BCEBS), located in the Central Forest Steppe of Ukraine, in the unstable hydration zone. Climate is temperate continental. Station area is located on the Prydniprovsk plateau of the Right Bank Highland. Relief terrain is flat. Forest is the main soil-forming agent. The depth of forest cover varies from 4 to 18 m. The prevailing soil is of the black soil type, surface, medium depth low-humus and different degrees of leaching, with a pronounced natural structure and good provisioning with nutrition elements. The soil of the investigated field is a typical leached black soil, of a medium loam mechanical composition, with humus horizon depth from 100 to 120 cm and humus part in the arable layer (0-30 cm) – 3.9%, which is characteristic for low humus black soil. It is also characterised by the following agrochemical indicators: the depth of the humus horizon – 50-60 cm, Ca and Mg carbonates occur at a depth of 50-65 cm. Hydrolytic acidity is 1.5-1.8 mg-eq·100 g^{-1} of soil. The amount of alkaline-hydrolysed nitrogen (according to Kornfield) is from 120 to 140 mg·kg^{-1} , nitrate is 14.2-19.6 mg·kg^{-1}; mobile phosphorus and exchangeable potassium (according to Chirikov) are from 180 to 240 and from 90 to 120 mg·kg^{-1} of soil. The acidity of the soil is neutral or close to neutral.

The main source of soil humidity is rainfall. Precipitation is variable throughout the year, most of it occurring during the warm period, especially in the middle of the summer (July) in the form of rain. In some years there is a period without rain in summer, which negatively affects the growth and development of crops. According to the Bila Tserkva meteorological station sum of effective temperatures (the sum of temperatures above 10°C during the growing season) is from 2,500 to 2,800°C, the amount of precipitation per year is 521 mm. The average air temperature is +7.4°C (a summary of the results of the last 25 years). In the years of research, weather conditions showed some deviations from the average

perennial indicators, but in general, they were favourable for the growth and development of most species of crops, weeds and *Heracleum Sosnowskyi*.

The evaluation of the efficiency of different control methods *Heracleum Sosnowskyi* plants required a field study:

1. Mechanical influences on weed plants. The research included planting the seeds of *Heracleum Sosnowskyi* and their vegetation during one year. The following year, in the spring, experiments were carried out on the plots. At each site, 20 *Heracleum Sosnowskyi* plants were selected. The experiment was set in 4-time repetition. That is, 80 plants of weeds were used in each variant. The experiment plan included the following options: 1. Control. Plants grow without mechanical damage. 2. Cut into the ground at a depth of 5 cm. 3. Cut into the ground at a depth of 10 cm. 4. Cut off on the ground surface. 5. Cut off at a height of 5 cm above the ground. 6. Cut off at a height of 10 cm above the ground. 7. Cut off at a height of 15 cm above the ground. Mechanical damage to *Heracleum Sosnowskyi* plants is done when reaching the shoot height of 20 cm.

2. Control of Heracleum Sosnowskyi plants by the method of screening (monitoring of energy nutrition). *Heracleum Sosnowskyi* plants of the first (grown from seed) and the second year of growing were used for field experiments. The plot was planted with 20 plants in four repetitions. Accordingly, each variant had 80 *Heracleum Sosnowskyi* plants. The first plant cut was carried out during the formation of 20 cm high shoots. Experiment plan for plants of the first year of growing included: 1) shading during the phase of formation of 2 leaves for a period of 15 days; 2) cutting during the phase of 2 leaves + shading 15 days; 3) in the phase of the formation of 6 leaves + shading 15 days; 4) in the phase of 6 leaves + shading 30 days. For perennial plants: 1) cutting and shading during 15 days; 2) during 30 days; 3) during 45 days; 4) during 60 days; 5) during 30 days + second shading for 30 days.

3. Control of Heracleum Sosnowskyi plants by the heating method. The research was field-based. The area of the seeding plot is 3.0 m^2, the experimental plot is 2.0 m^2. The experiment is carried out 7 times. Plots location is regular. A portable steam generator was used to heat the *Heracleum Sosnowskyi* plants during their vegetation. The plants were heated with hot steam using a non-contact laser thermometer. To obtain plants with different phases of their development during the hot steam treatment, spring planting was carried out at an interval of 5 days. *Heracleum Sosnowskyi* plants were subjected to hot water vapour treatment during the following growth phases: 1. fruiting, 2. 2 leaves, 3. 4 leaves, 5. 6 leaves, 6. 8 leaves. The estimation of the efficiency level of hot steam heating of *Heracleum Sosnowskyi* plants to different temperatures was carried out according to the scheme: 1. Control – without induced heat stress of the plants. 2. Induced heat stress with a steam temperature of 800°C. 3. Heat-stress with steam at 850°C. 4. Heat stress with a steam temperature of 900°C. 5. Heat stress by steam at 950°C. 6. Thermal stress with steam at a temperature of 1,000°C. On each m^2 of the experimental plot, the density of 50 *Heracleum Sosnowskyi* plants was formed after the emergence of shoots. Accordingly, 700 plants were used for each variant of the study. Plants were always treated with hot steam in the experiments on all variants and repetitions on the same day. The efficiency level of hot steam was evaluated 7 days after the treatment.

4. Control of Heracleum Sosnowskyi plants using chemical protection agents. The size of the tested plots was 25 m^2. The experiment was carried out on a 4-times repeated basis. The agents were applied by a special laboratory gas sprayer on wheels with a reducer, rod, and a constant working pressure of 2.1 atm. The working fluid consumption rate was from 200 to 210 $l \cdot ha^{-1}$. The screening was carried out at a temperature of 18ºC, and in sunny weather with a wind speed of up to 4 $m \cdot sec^{-1}$. The working liquid was prepared without any intermediary before applying. In the process of changing herbicides, the applicator was necessarily washed with water, a part of the water was passed through a rod and sprayers. The evaluation of the herbicidal effect on *Heracleum Sosnowskyi* plants was carried out during the following growth phases of the weed plants: cotyledon, 2 leaves, 4 leaves, 6 leaves, 8 leaves.

Experiment plan with annual *Heracleum Sosnowskyi* plants:

1. Control, plots with no use of herbicides;
2. Betanal Max Pro 209 OD (phenmedipham 60 $g \cdot l^{-1}$ + desmedipham 47 $g \cdot l^{-1}$ + ethofumesate, 75 $g \cdot l^{-1}$ + lenacil (activator) 27 $g \cdot l^{-1}$) at a cost of 1.0 $l \cdot ha^{-1}$;
3. Gezagard 500 FW (promethrin 500 $g \cdot l^{-1}$) at an expanse rate of 3.0 $l \cdot ha^{-1}$;
4. Granstar Gold 75 (tribenuron-methyl 562.5 $g \cdot kg^{-1}$, tifensulphuron-methyl 187.5 $g \cdot kg^{-1}$) at an expanse rate of 35 $g \cdot ha^{-1}$;
5. Esterone 600 EC (905 $g \cdot l^{-1}$ 2-ethylhexyl ether; 2.4-dichlorophenoxyacetic acid, in acid equivalent 600 $g \cdot l^{-1}$), at a rate of 0.8 $l \cdot ha^{-1}$;
6. Tasc Ekstra 66.5 WG (rimsulfuron 23 $g \cdot kg^{-1}$, nicosulfuron 92 $g \cdot kg^{-1}$, dicamba 550 $g \cdot kg^{-1}$) + Trend-90 at a rate of 385 $g \cdot ha^{-1}$ + 0.2 $l \cdot ha^{-1}$;
7. MaisTer Power OD (foramsulfuron 31.5 $g \cdot l^{-1}$ + iodosulfuron 1.0 $g \cdot l^{-1}$ + thiencarbazone-methyl 10 $g \cdot l^{-1}$ + cyprosulfamide (antidote), 15 $g \cdot l^{-1}$) at a rate of 1.5 $l \cdot ha^{-1}$.

Plan of experiment into the perennial *Heracleum Sosnowskyi* plants:

1. Control, plots without the use of herbicides.
2. Roundup Max WG (Glifosatu potassium salt 551 $g \cdot l^{-1}$) at a consumption rate of 6.0 $l \cdot ha^{-1}$.
3. Banvel 4S, 480 SL (dicamba 480 $g \cdot l^{-1}$) at a consumption rate of 0.8 $l \cdot ha^{-1}$.
4. Elumis 105 OD (mesotrion 75 $g \cdot l^{-1}$, nikosulfuron 30 $g \cdot l^{-1}$) at a rate of 2.0 $l \cdot ha^{-1}$.
5. Banvel 4S, 480 SL at a consumption rate of 0.8 $l \cdot ha^{-1}$ + Roundup Max WG at a consumption rate of 6.0 $l \cdot ha^{-1}$.
6. Elumis 105 OD at a consumption rate of 2.0 $l \cdot ha^{-1}$ + Roundup Max WG at a consumption rate of 6.0 $l \cdot ha^{-1}$.

RESULTS AND DISCUSSION

Mechanical impact on Heracleum Sosnowskyi plants

The study was carried out with *Heracleum Sosnowskyi* plants of the second year of the growing season. In spring, after the beginning of active growing of weed plants which successfully survived winter and reached a height of 20 cm, they were cut mechanically according to the scheme given in the methodology. The results of this mechanical influence on *Heracleum Sosnowskyi* plants are presented in Table 1.

Table 1. *Regeneration capacity of Heracleum Sosnowskyi plants after mechanical damage, 2013-2015*

No.	Schematic diagram of the design	Shoots growth, cm	Raw plant mass, g·m^2	Leaf area, cm^2·plant^{-1}
1	Control (no cuts)	273	4,241	15,734
2	5 cm lower than the soil surface	74	327	811
3	10 cm lower than the soil surface	-	-	-
4	0 cm from the soil surface	139	412	913
5	5 cm above the surface of the soil	147	421	927
6	10 cm above the surface of the soil	153	425	1,010
7	15 cm above the surface of the soil	157	432	1,017
	$LSD_{0.05}$	9.3	32.4	68.3

The following growth of the weed plants was successful in most of the experiment variants. In the control plots, variant 1, where no cuts were carried out, the plants underwent successive stages of organogenesis. At the generative stage of organogenesis (flowering) the height of *Heracleum Sosnowskyi* plants reached an average of 2.73 m with the leaves area of 15,734 cm^2·plant^{-1}. The mechanical cuts of the plants on the soil level required the renewal of the lost above-ground parts and the re-forming of the stems and leaves. The new stems heights averaged 1.39 metres, or 49.1% less than the control variant plants (var. 1). In addition to a decrease in the ability to form the height of the shoots, the possibility of forming the above-ground mass in the previously cut plants also decreased. On average it was 412 g·(m^2)$^{-1}$ or a 90.3% decrease compared to plants of variant 1. The leaf area of *Heracleum Sosnowskyi* at the time of flowering was 913 cm^2 per plant or 94.2% less than in the plants of variant 1.

There was a tendency to a decrease in the height of the shoots, which growth was less pronounced, of weed plants with an increase in the height of their mechanical cut (5, 10, 15 cm from the soil surface). Part of the above-soil mass of such plants, and primarily, their leafy apparatus, was preserved and continued to function successfully. The plants did not need to completely renew it. As a result, the height of the plants' shoots was between 147 cm and 157 cm after growth. The total volume of formation of a raw mass of above-soil parts of *Heracleum Sosnowskyi* after cut and subsequent growth also decreased, but the value of the decrease was in the range of 89.8-90.1% of the total volume of a raw mass of plants of the weed plants of variant 1. A similar trend was noted in the value of the formation of the leaves area of weed plants. The cutting of the above-ground parts of *Heracleum Sosnowskyi* plants significantly decreased their biological productivity, but they successfully continued their growth and passed the next stages of their organogenesis.

The mechanic cutting of the weed plants below the soil surface was based on the morphological peculiarities of the upper buds on the underground parts of the plants in the soil (cryptophytes). Mechanical cutting of the plants at a depth of 5 cm from the surface of the soil significantly reduced their regenerative capacity to renew lost above-ground parts and buds. The most developed apical buds in the plants were lost as a result of such mechanical damage. After the application of such mechanical undercuts, only those adventitious buds which remained undamaged on the underground parts of *Heracleum Sosnowskyi* plants ensured regrowth. By the end of the growth period, the new bud of weed plants had an average height of 74 cm or a decrease of 72.9% compared to the plants of variant 1 was 72.9%. The plants formed an average of 327 g·(m^2)$^{-1}$ mass of above-ground parts or the decrease compared to the level of plants on the control plots was 92.3%.

The use of such a technique significantly reduced the biological potential of *Heracleum Sosnowskyi* plants, but showed a significant disadvantage: it did not ensure the complete elimination of the weed plants. During the following growth periods, the plants were able to gradually regain their high competitiveness. The research scheme included (var. 3) cutting of the weed plants 10 cm below the soil surface. This depth of mechanical damage involved damaging almost all the buds of the growth regeneration that plants form at the top of the overgrown root. This mechanical approach deprived the weed plant of its ability to regenerate. The underground parts, which had a well-developed root system and a reserve of plastic substances, lost their connection with the buds of the growth recovery as the result. The upper part buds were not linked with plastic substances and the root system. Consequently, both parts of the plants have since been non-viable and have gradually died out. Similar results were obtained by researchers in Lithuania [27], Poland [24], and Russia [22].

Control of Heracleum Sosnowskyi plants with the method of screening (monitoring of energy consumption)

For successful photosynthetic processes, the essential prerequisite for green plants is the availability of access to the flow of light energy, first and foremost PAR energy (photosynthetically active radiation of the light wavelengths between 380 nm and 710 nm), which is supplied to their above-ground parts. To achieve attenuation or complete deprivation of the energy (light) life of weed plants, including *Heracleum Sosnowskyi*, thus blocking the photosynthesis processes in them is the easiest way to screen with the optically non-isolated screen [16; 17]. The study evaluated the reaction of *Heracleum Sosnowskyi* plants of the first year growth (from seed) on the duration of the period of their shading and their ability to bear mechanical damage.

On the plots of variant 1, the young weed plants grew without mechanical damage or screening. In the plots of variant 1, the young plants grew without mechanical damage or scarring. On the plots of var. 2 after the formation of 2 true leaves, the plants were covered with black film for a period of 15 days. After the shading period was over, the plants were in severe energy distress, but they gradually resumed photosynthetic processes and continued their successful growth. On the plots of variant 3 *Heracleum Sosnowskyi* plants, after the formation of 2 leaves, were cut and covered with black film for 15 days. The plants were 100% dead before the shading period was over.

The plants from the plots of var. 4 successfully grew after the emergence of shoots. They were cut during the formation phase of 6 leaves and then covered with black film for 15 days. After the shading period, 6.2 units of plants or 7.7% continued growing. The main part of the *Heracleum Sosnowskyi* died out. On the plots of variant 5 bushes were cut in the phase of 6 leaves and covered with black film for 30 days. By the end of the shading period, all the test plants were dead. The ability of *Heracleum Sosnowskyi* plants of the first year of growth to survive primarily depended on the presence and size of plastic substances reserves and the duration of the shading period.

In order to evaluate the possibilities of control of perennial *Heracleum Sosnowskyi* plants (of the second year of growth) through screening, field studies were carried out. On the plot, 20 units of plants were grown in four replications. Accordingly, each variant was represented by 80 *Heracleum Sosnowskyi plants*. The change of conditions of energy (light) supply to the plants at the initial growth period (from the appearance of buds on the roots) manifested unequal influence on the course of the following stages of their organogenesis. The most important was the change in the intensity of the PAR energy flux, which reached the surface of leaves of young plants and the possibility of its absorption by their above-ground parts. In *Heracleum Sosnowskyi* plants of the second-year growth, at the initial stage of ontogenesis under conditions of almost complete absence of (light) provision, the energy distress occurred, which manifested itself in loss of the ability of plants to form new organic substances.

The reserves of plastic substances of the previous growth period in the underground (perennial) parts of the plants are used for the formation of repeated annual shoots and leaves since the previous ones were lost as a result of their first cut. According to the growth conditions of Variant 2, where *Heracleum Sosnowskyi* plants were cut above the soil surface and then shaded for the next 15 days, the formation of raw mass amounted to 4,702 g per m^2 during the following growth period. The plants tolerated the increased duration of the shading period up to 30, 45 and 60 days, but in such conditions of photosynthetic processes absence, the plants decreased their ability to produce above-surface weight during the next growth period by 8.5, 20.2, and 63.3% (Table 2).

***Table 2**. The capacity of Heracleum Sosnowskyi plants to form above-surface weight, (g per 1 m^2) after cutting and the period of screening, 2015-2020*

Experiment variants	Period of shading, days			
	15	30	45	60
1	Control without cutting (all plants grow successfully)			
2	4,702	4,333	3,910	2,880
3	4,705	4,544	1,638	793
4	4,755	4,386	1,480	–
5	4,597	4,491	1,585	–
$LSD_{0.05}$	126.2			

Variants 6 and 7 of the research scheme included two subsequent cuttings of *Heracleum Sosnowskyi* plants (the second growth of above-surface parts after 30 days of shading after the first) and the following shading for another 30 days (variant 7 for 45 days) resulted in partial (variant 6) mortality (67.5% or 54 plants out of 80 in this variant) The weed plants bourbon from variant 7, where the duration of re-shading after the second cutting was 45 days, died completely.

Identification of the sensitivity of Heracleum Sosnowskyi plants to water vapour during different phases of their development

According to a range of scholars herbologists [28-30], the heating of juvenile *Heracleum Sosnowskyi* plants may contribute to significant control of their numbers. Investigation of the reaction of weed plants to induced thermal distress was carried out using a portable steam generator. *Heracleum Sosnowskyi* plants were treated with 100°C steam at the nozzle outlet at a distance of 10-12 cm. The velocity of the steam flow is 5 m·sec^{-1}. The power of the flow of steam on the emerged plants lasted from 0.5 to 0.8 sec. The investigations were model field-based.

The results of the research are summarised in Figure 1. *Heracleum Sosnowskyi* plants' treatment with hot steam resulted in complete disorganisation of metabolism processes in cells of young plant tissues. The thickness of tissue descents in the phase of cotyledon in the above-surface parts of plants is insignificant and they were quickly heated to a temperature close to 100°C. The transfer of heat from the plant surface into the soil was well handled by the tissues themselves since they are very watered during this period of organogenesis. Traditionally, the water part in cells of *Heracleum Sosnowskyi* plants tissues is from 80 to 94% of their total mass.

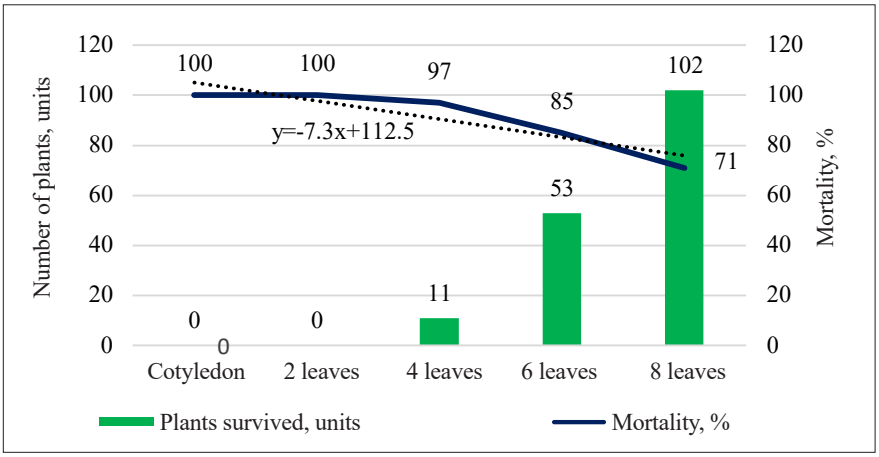

Figure 1. *Changes in phase sensitivity of Heracleum Sosnowskyi plants to water vapour heating*

The weed growth phases build-up (formation of 2 true leaves) increased the area of their contact with the flow of hot steam, but the mass of the plants grew steadily and their ability to resist the rapid heating of tissues in the depths increased. The *Heracleum Sosnowskyi* plants died completely. At the phase of formation of 4 leaves in the different species of weed plants, their sensitivity to the influence of high temperatures compared to the previous phases of growth tended to decrease. *Heracleum Sosnowskyi plants*, which were used in the study in this phase of growth, died out by 97%, or 339 units in the study variant. However, 11 plants or 3% of the total number in the variant survived and continued to grow.

The hot steam treatment of the emerged *Heracleum Sosnowskyi* plants during the formation of 6 leaves showed a significant increase in their resistance to heating. This effect can be explained by the accumulation by the above-surface parts of young *Heracleum Sosnowskyi* plants of a greater mass, which requires a greater amount of heat energy to heat as well as the complicated process of heating the plant tissues in their midst, especially the heating of meristem tissues at the growth points both apical and collateral on the stems. Consequently, the rate of mortality of the *Heracleum Sosnowskyi* plants was lower than that of the previous plants. The plants were dying by 65% during the phase of formation of 6 leaves.

The hot steam treatment of *Heracleum Sosnowskyi* plants was less effective in the phase of formation of 8 leaves compared with the previous stages of their growth. The weed plants died by 80% as a result of temperature stress by means of hot steam, i.e., 62 plants out of 350 in the study variant continued to grow.

Identification of the sensitivity of Heracleum Sosnowskyi plants to water vapour at different temperatures

In the process of research of peculiarities of sensitivity of *Heracleum Sosnowskyi* plants to hot steam, a certain specificity of indicators of plants sensitivity and phases of development on the level of their mortality from heat stress was determined. However, the level of plant vulnerability to heat is influenced by the parameters of hot vapour flow temperature, i.e., the level of heating of the emerged plants themselves and their ability to survive in the next period. The temperature of hot steam flow that was in contact with the plants in the experiments had different temperatures: from 80 to 100°C with intervals between variants of 5°C. The growth phase of *Heracleum Sosnowskyi* plants in the studies was the same – 4 true leaves. The temperature of plants heating with hot steam was controlled by a special non-contact laser thermometer.

The treatment of the above-surface parts of plants by a stream of water vapour at 80°C had a significant

effect on their ability to continue their growth. The *Heracleum Sosnowskyi* plants which were heated to a temperature of 80°C received thermal stress which resulted in the mortality of 53% of the total number of plants that were in the variant. At the same time, 164 plants or 47% of the total number survived (Fig. 2). The rise in the temperature of *Heracleum Sosnowskyi* plants by water vapour to 85°C provided them with more severe thermal stress and accordingly tended to increase the number of plants which could not counteract such negative influences. The result was that the mortality rate was 64%, or an average of 126 plants survived out of 350 emerged ones in the variant. Application of higher heat up to 90°C for *Heracleum Sosnowskyi* plants increased the mortality rate of plants due to thermal stress. As a result of heat treatment, 78% of the plants that were used in the study variant died.

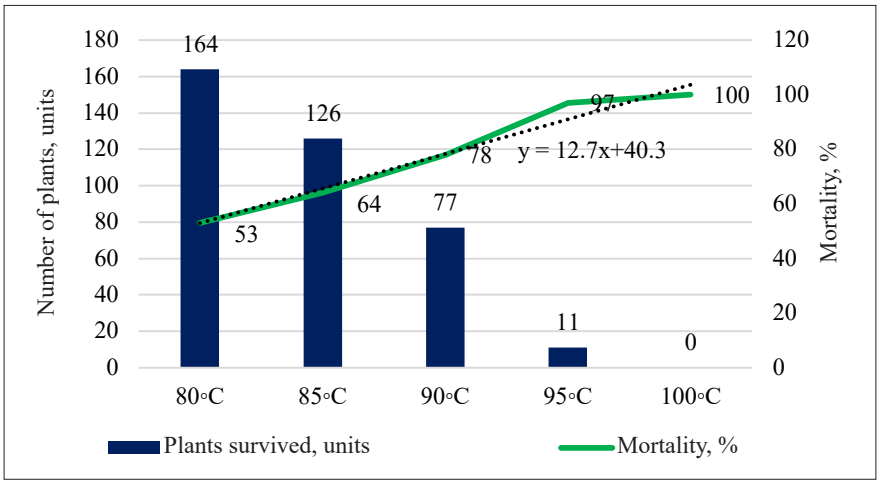

***Figure 2**. Sensitivity of Heracleum Sosnowskyi plants during the 4 leaves phase to water vapour heating*

Heating the *Heracleum Sosnowskyi* plants to 95°C resulted in 97% mortality of all in the variant. Only 11 plants out of the 350 used in the study survived. Thus, the level of efficiency in the protective effect of hot steam flow on the emerged *Heracleum Sosnowskyi* plants was at a level that can provide a highly effective herbicide. The increase of *Heracleum Sosnowskyi* plants (phase of forming of 4 leaves) heating temperature up to 100°C led to complete death, that is 100% of weed plants stopped their growth.

Summarising the results of the efficiency of water vapour effect on the emerged *Heracleum Sosnowskyi* plants with the temperature of plant heating to 80°C it can be stated that the applied thermal stresses can influence the young plants significantly. Increasing the heating temperature of the emerged *Heracleum Sosnowskyi* plants to 90°C resulted in greater heat stress in the plants. As a result some of them gradually died out, the other part after a long period of depression (from 7 to 20 days) survived and continued their growth. An increase in water vapour temperature and heating level of the emerged *Heracleum Sosnowskyi* plants, according to the research plan requirements, up to 95°C, ensured an increase of thermal stress in young plants and correspondingly high level of their next death.

The general level of reduction in a number of the emerged *Heracleum Sosnowskyi* plants as a result of heating of plants during the phase of formation of 4 leaves at 95°C reached an average of 96.3%.

Effectiveness of herbicides on Heracleum Sosnowskyi plants

The study was carried out on *Heracleum Sosnowskyi* plants of the first year of growth, that emerged from seed. Herbicides were applied by means of application during different growth phases of the weed plants. The research showed that such agents as TaskExtra 66.5 WG (385 g·ha^{-1}) and MaisTer Power OD (1.5 l·ha^{-1}) can effectively control *Heracleum Sosnowskyi* plants during the cotyledon phase. The effectiveness of their action reaches – 100%. In the growth and development build-up phase of *Heracleum Sosnowskyi*, the efficiency of these agents decreased and reached accordingly in the phase of formation of 2 leaves – from 99.7% to 99.4%, in the phase of 4 leaves – from 85.7% to 84.2%, in the phase of 6 leaves – from 63.2% to 60.7%. The effect of the growth of phase resistance of plants to herbicides appeared. Other herbicides, which were used in the research plan, showed a lower rate of the efficiency level of control of emerged weed plants (Table 3).

***Table 3**. Level of efficiency of herbicides on Heracleum Sosnowskyi plants during the first growth period in different phases of their development, (% mortality) 2015-2020*

Herbicides and their consumption rates	Phases of development of *Heracleum Sosnowskyi* plants				
	cotyledon	2 leaves	4 leaves	6 leaves	8 leaves
Control, without the use of herbicides	0	0	0	0	0
Betanal Max Pro 209 OD – 1.0 l·ha^{-1}	97.3	85.4	62.1	43.2	23.3
Gezagard 500 FW s.c. – 3.0 l·ha^{-1}	80.1	73.2	61.1	38.4	21.4
Granstar Gold 75, w.g. – 35 g·ha^{-1}	87.3	79.4	61.3	39.7	22.6
Esteron 600 EC e.c. – 0.8 l·ha^{-1}	87.2	77.9	62.2	40.1	24.5
TaskExtra 66.5 WG + Trend – 385 g·ha^{-1} + 0.2 l·ha^{-1}	100	99.7	85.7	63.2	38.7
MaisTer Power OD, o.d. – 1.5 kg·ha^{-1}	100	99.4	84.2	60.7	43.2

Effect of herbicides on Heracleum Sosnowskyi plants

Heracleum Sosnowskyi plants change their level of sensitivity to herbicides in the process of ontogenesis. While in the cotyledon phase the mortality rate of the emerged plants reached 100%, in the phase of 6 leaves the level of sensitivity decreased to an average of 40-60%. The treatment of the plants during the next phases of growth (8 leaves) was less effective. One of the prerequisites for successful control of *Heracleum Sosnowskyi* plants in crops is to carry out the immediate treatment when the plants are in the cotyledon phase of 2 leaves.

It is more difficult to control the *Heracleum Sosnowskyi* plants of the second and subsequent years of growth with herbicides than those annual plants. To assess the level of efficiency of herbicides application on plants of the second year of growth after the beginning of regrowth and the formation of 3 true leaves, the field studies were carried out. Evaluation of the efficiency of various herbicidal tank combinations on *Heracleum Sosnowskyi* plants was carried out in 30 days after the treatment in accordance with the research plan showed the following results (Table 4).

***Table 4**. Effectiveness of various herbicides, (mortality, %) on Heracleum Sosnowskyi plants (2013-2015)*

No. var.	Herbicides and consumption rates, l·ha^{-1}	Effectiveness of herbicides, %	Weed plant mass, g·plant^{-1}	
			30 days after herbicide application	60 days after herbicide application
1	Control, without the use of herbicides	–	3,124	3,251
2	Roundup Max WG at a rate of 6.0 l·ha^{-1}	87.0	–	322
3	Banvel 4S, 480 SL at a rate of 0.8 l·ha^{-1}	54.0	2,731	3,010
4	Elumis 105 MD at a rate of 2.0 l·ha^{-1}	100	0	0
5	Banvel 4S s.c. at a rate of 0.8 l·ha^{-1} + Roundup Max WG at a rate of 6.0 l·ha^{-1}	100	0	0
6	Elumis 105MD at a rate of 2.0 l·ha^{-1} + Roundup WG at a rate of 6.0 l·ha^{-1}	100	0	0

The *Heracleum Sosnowskyi* plants successfully passed the stages of their ontogenesis and started flowering on the plots of the variant 1 (Control without herbicides). In the plots of var. 2 as a result of herbicide Roundup, a.s. (6.0 l·ha^{-1}) the above-surface part of the plants completely died out (100%). However, some of the plants still continued to grow and formed above-surface mass. The results of research carried out in Lithuania also indicate the low efficiency of different rates of glyphosate application, because after 4-6 months the plants emerged again. A mixture of gliphosate and triasulphuron was more effective [27].

On the plots of variant 3 the result of herbicide Banvel 4S 480 SL (0.8 l·ha^{-1}) the *Heracleum Sosnowskyi* plants had a downtrodden appearance, the leaves were twisted. However, the above-surface parts of the plants remained alive and continued their growth. In the plots of variant 4 as a result of herbicide Elumis 105 OD MD (2.0 l·ha^{-1}) was noted complete destruction of weed plants. On plots of variant 5 as a result of tank herbicidal compositions Banvel 4S 480 SL + Roundup WG at a rate consumption of 0.8+6.0 l·ha^{-1} *Heracleum Sosnowskyi* plants were completely dead. In the plots of Variant 6 as a result of exposure to herbicides Elumis 105 OD, MD + Roundup WG at a rate of 2.0+6.0 l·ha^{-1} the *Heracleum Sosnowskyi* plants both above- and below-surface parts died out completely (Table 4). Such tank herbicide compositions for control of perennial *Heracleum Sosnowskyi*

plants are suitable for use on arable lands after harvesting of cultivated plants.

According to foreign researchers [24], the complete struggle against this weed is achieved by cutting the roots of plants up to 5 years old to the depth of 15 cm or by continuous (5 years) application of three times during the growth period with the use of a tank mixture of Gliphosate and Flazasulphuron. (1,260 g of glyphosate per 1 ha + 50 g of flazasulphuron on 1 ha). It is also noted that a high effect on *Heracleum Sosnowskyi* plants is caused by a mixture of Fluroxipyr + Metsulphuron-Methyl [27].

A prerequisite for successful control of annual *Heracleum Sosnowskyi* plants in crops is a regular test of crops and identification of species composition of weeds in cotyledon phase to detect in time the presence of such species of weeds and implement preventive measures.

CONCLUSIONS

1. Mechanical control methods. *Heracleum Sosnowskyi* plants are characterised by a high level of biological productivity and can easily regenerate the lost above-surface parts. The regeneration process only reduces the ability of plants to form above ground mass by 89.8-90.3%. The maintenance of the perennial plants is advisable to be carried out in the soil at a depth of more than 10 cm, which ensures the effective control of *Heracleum Sosnowskyi* and eliminates the effect of their subsequent regrew.

2. Screening techniques. Annual *Heracleum Sosnowskyi* plants are quite sensitive to their screening (total shading), especially in the early stages of organogenesis: from 2 to 4 leaves. Efficient shading of juvenile annual plants for more than 30 days ensured their death. Screening of *Heracleum Sosnowskyi* plants at the next stages of their organogenesis proved to be less effective. For a significant decrease in biologic productivity of annual weed plants before their death after their formation of 6-10 leaves the minimum period of shading should be at least 60 days. In perennial *Heracleum Sosnowskyi* plants, supplementing shading with two consecutive cuttings of the shaded above-ground parts accelerated depletion of their plastic substances and dying during 45-60 days of the next treatment.

3. Thermal control method. The sensitivity of *Heracleum Sosnowskyi* plants to hot steam decreases with growth build-up phases of plants. The level of mortality was from 100% (cotyledon phase) to 85% in the phase of the formation of the 6-leaf plant. The efficiency of thermal control of *Heracleum Sosnowskyi* plants (4 leaves) also depended on the indicators of heat-carrier – hot steam. At a hot steam temperature of 80°C, 53% of the weed plants died. An increase in steam temperature to 95°C led to the mortality of plants at 96.3%, which means that they did not concede the level of herbicides. The thermal method of *Heracleum Sosnowskyi* control is sufficiently effective and environmental-friendly. It can be successfully used for *Heracleum Sosnowskyi* control in rural areas where the use of herbicides is restricted.

4. Chemical control method. The sensitivity of weed plants to herbicides varied with the growth build-up phases of plants. *Heracleum Sosnowskyi* plants were the most sensitive to herbicides in the phase of cotyledon: the level of efficiency was from 97.3 to 100%. Up to the phase of 6 leaves, the sensitivity of the emerged weeds decreased from 43.2 to 60.7%. Among the agents, the highest level of efficiency on *Heracleum Sosnowskyi* plants was recorded in the plots with the use of herbicides Task Ekstra 66.5 WG + Trend-90 at a consumption rate of 385 $g \cdot ha^{-1}$ + 0.2 $l \cdot ha^{-1}$ and MaisTer Power OD at a rate of 1.5 $l \cdot ha^{-1}$. The study of the level of efficiency of herbicides effect on perennial *Heracleum Sosnowskyi* plants showed that the most powerful was the effect of herbicides Elumis 105 OD, at a rate of 2.0 $l \cdot ha^{-1}$ and a tank composition of Elumis 105 OD, MD + Roundup Max WG at a rate of 2.0+6.0 $l \cdot ha^{-1}$ and Banvel 4S s.c. at a rate of 0.8 $l \cdot ha^{-1}$ + Roundup Max WG at a rate of 6.0 $l \cdot ha^{-1}$.

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Контроль численності рослин *Heracleum Sosnowski* в сільськогосподарських і лісогосподарських фітоценозах України

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Анотація. На сьогодні борщівник Сосновського із трансформованих місцезростань чи невеликих осередків поширився у природні умови, де займає стабільні позиції й характеризується високою фітоценотичною активністю, часто виступає домінантом або співдомінантом. Враховуючи те, що немає чітко розроблених методів контролю рослин цього інвазійного виду, актуальним залишається розробка прийомів контролювання як однорічних, так і багаторічних його рослин в умовах України. Метою дослідження було визначення ефективності різних методів боротьби з рослинами *Heracleum Sosnowskyi*. Польовий експеримент проводився протягом 2015–2020 років на типовому середньосуглинковому чорноземі. Було створено чотири експерименти: 1 – механічні заходи; 2 – екранування; 3 – гаряча пара; 4 – застосування гербіцидів. Використовували рандомізований експериментальний план із чотирма повтореннями. Встановлено, що ефективним заходом є видалення бур'янів з корінням на глибину не менше 10–15 см. Повне затінення рослин до стадії чотирьох листків протягом 30 днів забезпечило їх повне зникнення. Відсоток вимирання H. sosnowskyi від гарячої пари коливався від 100 % (стадія сім'ядолі) до 85 % (стадія шести листків). Найбільш чутливі до гербіцидів сходи бур'янів у стадії сім'ядолей – від 97,3 до 100 %. Найбільш чутливі сходи бур›яну до дії гербіцидів у фазу сім›ядоль: відмирання від 97,3 до 100 %. До фази 6-ти листків чутливість знижувалась від 43,2 до 60,7 %. Найбільш ефективними були гербіциди: Таск екстра 66,5 в.г. (римсульфурон – 23 г·кг$^{-1}$, нікосульфурон – 92 г·кг$^{-1}$, дикамба – 550 г·кг$^{-1}$) + Тренд-90 у нормі втрати 385 г·га$^{-1}$ + 0,2 л·га$^{-1}$ та МайсТер Пауер ОД (форамсульфурон, 31,5 г·л$^{-1}$ + йодосульфурон, 1,0 г·л$^{-1}$ + тієнкарбазон-метил, 10 г·л$^{-1}$ + ципросульфамід (антидот), 15 г·л$^{-1}$) у нормі витрати 1,5 л·га$^{-1}$). На багаторічні рослин борщівника Сосновського ефективно діяли гербіциди: Елюміс 105 OD, МД (мезотріон, 75 г·л$^{-1}$, нікосульфурон, 30 г·л$^{-1}$) у нормі витрати 2,0 л·га$^{-1}$ та бакової композиції: Елюміс 105 OD, МД + Раундап Макс, в.р. (гліфосату калійна сіль, 551 г·л$^{-1}$) у нормі витрати 2,0+6,0 л·га$^{-1}$. У подальшому дослідження цієї проблеми доцільно проводити в напрямі підвищення ефективності заходів контролювання чисельності рослин борщівника Сосновського та зменшення при цьому хімічного пресу на довкілля

Ключові слова: бур'яни, механічні заходи, екранування, гаряча пара, гербіциди

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Infertile and Less Infertile Forest Types in the Ukrainian Carpathians: Classification and Complementation

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Abstract. Forest typology is yet to get sufficiently integrated into related ecological and geographical sciences. The succession of plant phytocenoses necessitates constant adjustments to forest types. The discussed studies have been conducted to improve the classification of forest types in the Ukrainian Carpathians and bring the description closer to the actual distribution of vegetation within the studied area. The paper provides a detailed analysis of forest typology research for the Ukrainian Carpathians area during late 20th and early 21st century. The forest fund areas of the Carpathian region, which are subordinated to the State Agency of Forest Resources of Ukraine, have been classified by forest vegetation types. Total area of subor and coniferous forest types is 1,493.1 ha and 28,910.2 ha, respectively. The study involved establishing of permanent sample plots on the territory of nature protection institutions and forest management enterprises. According to the findings, it is proposed to complement the classification of subor and coniferous forest type as defined by Z.Yu. Herushynskyi on the territory of the Ukrainian Carpathians with the following types: fresh pine subor forest type, wet pine subor forest type, and wet pine coniferous type. The paper defines the main diagnostic features of the suggested forest types. These subor and coniferous forest types can be clearly distinguished from other forest types by soil and hydrological conditions, and can be used to describe the corresponding forest vegetation types. The correctness of definition of new forest types is confirmed with a set of plant indicator species that have been identified within the relevant areas. The findings provide a better understanding of forest ecology and make a significant contribution to forest typology studies on the territory of the Ukrainian Carpathians. Another step towards researching the patterns of the establishment of plant complexes in the Ukrainian Carpathians has been taken. Forest formations of the Carpathians are presented in more detail in forest typological science

Keywords: forest typology, forest vegetation type, diagnostic features, indicator plants, forest type index, typological profile, ecological figure

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INTRODUCTION

The need to increase productivity and integrated use of wood and non-wood forest resources forces foresters to manage forests on a typological basis differentiated depending on various economic and forestry conditions [1]. Scientific works of a number of Ukrainian researchers are devoted to forest typological studies in the Ukrainian Carpathians [2-4]. At the present stage of development of typological science in Ukraine, researchers are trying to create a detailed typological scheme of forests, which would consider not only edaphic, but also climatic and coenotic factors. At the same time, the forest typology has a significant practical application, as it solves the problem of classification of forest areas that are homogeneous in soil, hydrological, climatic, and forest site conditions. This results in the possibility to develop uniform requirements for forestry management.

The constant development of main conditions of the forest and ecological method of forest type diagnosis, the development of quantitative approaches to the assessment of edatops, and the expansion of possible areas of application makes it universally applicable in both industry and research. The forest typology is the basis for close to nature forestry, the methods of which are most relevant in forestry and environmental management in the context of climate change.

Forest typology is yet to get sufficiently integrated into related ecological and geographical sciences. The succession of plant phytocenoses forces to make constant adjustments of forest types. One of the reasons behind such a state is the lack of quantitative determination of edatope.

A number of researchers have been introducing adjustments to the existing model to improve the existing classification system. In particular, A. Shvydenko suggested to introduce additional trophotopes and hyhrotopes [5]. At the same time, O. Migunova argued about the need to combine the existing edaphic grid with the predominant soil rocks and the content of certain chemical compounds (phosphate anhydride and potassium oxide) [6], and assumed the possibility of applying the principles of the forest ecological classification system for the classification of nature as a whole. The study involved the analysis of subor and coniferous forest types aiming to improve the forest topology, establishment of permanent sample plots within the tree stands that did not meet the existing diagnostic features aiming to detect and diagnose new forest types.

Considering the global climate change on our planet that leads to drying of spruce forests, Scots pine deserves the attention of foresters as an indigenous, reclamation, forest forming tree species, and not only as a relict species that is in a need of careful protection. Proper diagnosis of forest types would allow carrying out all necessary forestry and environmental measures correctly to form the forthcoming tree stand composition, living ground cover, undergrowth, and other forest elements as close to the natural forest habitat as possible. In particular, natural stands of Scots pine should be used for both protective and forest breeding purposes. To solve these problems, foremost, it is necessary to study relevant issues related to forestry and ecological features of the formation of these stands, along with their spatial and morphological structure. This knowledge will help to properly carry out further research, especially in forestry, geobotany, dendrology, soil science, geology, etc.

MATERIALS AND METHODS

Objects of the study have been determined within the Ukrainian Carpathians using own experimental research based on the materials from forest management expedition databases, state forest inventory data, and additional information obtained during communication with forest workers on the territory of the study area.

The choice of areas for establishing the set of sample plots was based on the previous inventory and a route method of inspection of the studied objects. Field research included establishment of sample plots according to the standard of organisation of Ukraine 02.02-37-476:2006 [7] and processing of the obtained data according to the generally accepted methods in forestry and inventory research [2; 3; 8; 9]

The work within the permanent sample plots involved the following:

1. Complete enumeration of trees with simultaneous measurement of DBH. Tree numbering was performed using white paint on the same side of the trunk that is relative to the sample plot.

2. Height measurement was performed using a laser altimeter TruPulse 360B with an accuracy of 0.1 m according to the method of using the device.

3. Assigning individual coordinates to each tree by using a pre-established relative grid of coordinates within the sample plot area [10; 11].

4. Assessment of the sanitary condition of trees and their categorisation in accordance with the "Sanitary rules in the forests of Ukraine".

5. Counting the undergrowth within the sample plot area separately for each species. Simultaneously, undergrowth has been distributed into one-, two-, five-, seven-, and ten-year age groups. Coordinates of the undergrowth location have been recorded as well.

6. Identification of all types of grass cover and determination of dominant and co-dominant species, along with identification of indicator plant species that are relevant to forest vegetation conditions.

7. Recording the outline of the living above ground cover distribution using a coordinate grid to determine the percentage and nature of its spatial scattering.

8. Excavation of soil profile and determination of soil horizons within the sample plots where the soil was well-formed.

9. Taking photos of work stages, types of living above

ground cover, creators of mycorrhiza, pathogens, and pests for further illustration of the research.

10. Collection of cones and needles, sampling of wood, fruiting bodies of fungi, and soil of all horizons for further laboratory research.

Typological analysis of subor and coniferous forest types in the territory of the Ukrainian Carpathians was carried out using own research, the conclusions of other researchers along with the forest inventory data. Determination of forest types and distribution of tree stands within natural and successive categories was made in accordance with the generally accepted forestry methods and on the basis of the Pohrebniak & Vorobiov forest typology grid, and using practical recommendations suggested by Herushynskyi [3].

The obtained results of measurements and observations were processed using standard methods of statistical analysis as developed by the Department of Forest Inventory and Forest Management of the Ukrainian National Forestry University. All photos and tables in the paper represent own research results.

RESULTS AND DISCUSSION

Initial data. Forest fund areas of the Carpathian region have been divided based on the materials from forest management expedition databases by types of forest vegetation conditions. According to the findings, the majority of subor forest areas are located on the territory of Ivano-Frankivsk region (fresh subor conditions – 118.8 ha (8.0%), humid subor conditions – 1,230.6 ha (82.4%), moist subor conditions – 1.6 ha (0.1%), wet subor conditions – 132.2 ha (8.9%). As of the Lviv region, subor areas are located on the territory of the Sambir State Forest Management Enterprise (dry subor conditions – 0.5 ha (0.03%), fresh subor conditions – 9.4 ha (6.3%). The total area of subor forests on the territory of the Ukrainian Carpathians is 1,493.1 ha. The total area of coniferous forests on the territory of the Ukrainian Carpathians is 28,190.2 ha. The vast majority of coniferous forest conditions are managed by the Ivano-Frankivsk Regional Forest and Hunting Management Enterprise – 79.58% (dry coniferous forest conditions – 3 ha, fresh coniferous forest conditions – 333.5 ha (1.15%), humid coniferous forest conditions – 21,954.9 ha (75.94%), wet coniferous forest conditions – 716.2 ha (2.48%). As of the Lviv Regional Forest and Hunting Management Enterprise, coniferous forest conditions are present on the area of 2,633.3 ha (9.11%), while Chernivtsi and Zakarpattia Regional Forest and Hunting Management Enterprises manage 1,374.3 ha (4.75%) and 1,895.0 ha (6.55%) of coniferous forest areas.

Research of predecessors. Herushynskyi has established 5 permanent sample plots in the areas of fresh subor forest types and 10 permanent sample plots in the areas of humid subor forest types during his studies of forest typological features of the Carpathian forests [10]. Based on the carried-out researches, Herushynskyi considers the types of Scots pine forest to be interregional for the Pokuty-Marmorosh part of the Ukrainian Carpathians. As a result of his typological study, Herushynskyi described all forest types he discovered on the territory of the Ukrainian Carpathians, including subor and coniferous ones [3]. This work is the basis for determining forest types for scientific and practical purposes. It identifies the main indicator plants for the proposed forest types.

However, R. Yatsyk [12] cites the most common forest types of *Pinus sylvestris* L. of relict origin in the Ukrainian Carpathians based on his own research. The author notes such less common forest types as moist spruce-pine Carpathian coniferous forest type, moist spruce-pine Carpathian coniferous forest type, and wet pine coniferous forest type. The forest types have not been identified earlier by Herushynskyi.

Shevchenko suggests the division of pine forests and their types depending on the ecological conditions. In particular, into coniferous forest types with the dominance of *Pinus sylvestris* L. but sufficient admixture of *Picea abies* (L.) Karsten, *Betula pendula* Roth, and *Abies alba* Mill. in trophotopes from B_2 to B_5. Trophotope B_3 is predominant among all relict pine forests [10].

Milkina (1987) provides a detailed description of cenoses which have *Pinus sylvestris* L. in tree species composition on the territory of the Ukrainian Carpathians [12]. The author divides pine forests, in particular in coniferous forest types, into three main sub-formations. These sub-formations, in their turn, are divided into associations and sub-associations.

Sub-formation *Pineta sylvestris* consists of the following monodominant pine cenoses (associations): *Pinetum vaccinioso-hylocomiosum* and *Pinetum myrtilloso-hylocomiosum* (those are formed within the forest type B_4-Ps individually in the geographical tracts "Sokil", "Bredulets", "Pichne"); *Pinetum empetroso-hylocomiosum*; *Pinetum sphagnosum* as divided into 4 sub-associations: (a) *Pinetum myrtilloso-sphagnosum* (forest type B_4-Ps, individual trees of spruce can be found in the second storey and has class V^a bonitet); (b) *Pinetum eriophoroso-sphagnosum* (pure tree stands with slightly higher productivity in forest type B_5-Ps with the climatic admixture of *Betula pubescens* Ehrh. of less than 500 trees per ha of undergrowth).

Sub-formation *Piceeto-Pinetum* represents spruce-pine cenoses, which mostly grow within coniferous forest conditions and represent a transitional form of cenoses between pure pine stands and spruce stands. It is represented by such associations as *Piceeto-Pinetum myrtilloso-hylocomiosum* (forest type – B_2-paPs, B_3-paPs); *Piceeto-Pinetum myrtilloso-sphagnosum typicum* (forest type – B_4-paPs, and can be found in the geographical tracts "Liutoshary"). Sub-formation *Abieto-Piceeto-Pineta* is represented by the association *Abieto-Piceeto-Pineta myrtilloso-hylocomiosum* (forest type – B_3-paPs).

Practical review and analysis of previous research. A visual inspection has been carried out for tree stands,

which had corresponded to the previously described forest types. Observations have been used for visual comparison with stands that have distinctive features. The following forest types have been distinguished within subor forest vegetation types:

Forest type – humid spruce and pine subor type (A_3-paPs) is common in the upper belt of the Ukrainian Carpathians (Pokuty Carpathians, Gorgany) within the heights of 900-1,450 m above sea level, on slopes with a steepness of 15-30°, and on fine soils in micro-depressions and crevices of rock placers. The composition of the stand is dominated by *Pinus sylvestris* L. and *Picea abies* (L.) Karsten (class IV bonitet mostly) (Fig. 1) with an admixture of *Betula pendula* Roth. *Sorbus aucuparia* L. is present as a part of a sparse undergrowth. *Vaccinium myrtillus* L., *Calluna vulgaris* (L.) Hull, *Empetrum nigrum* L. and mosses, less herbaceous species, predominate in the layer of above-ground cover.

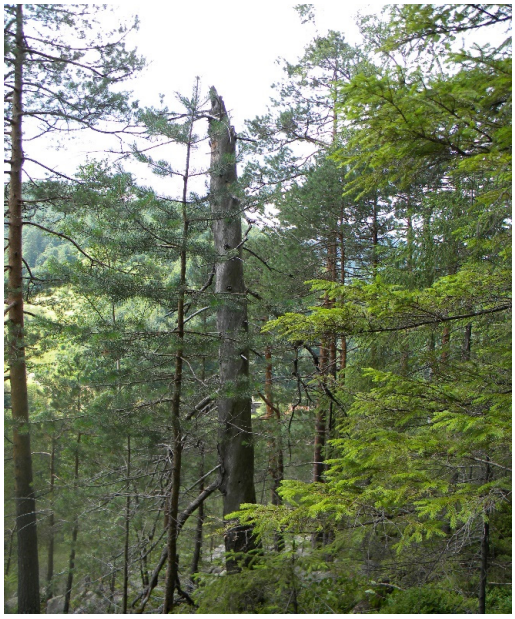


Figure 1. *Humid spruce and pine subor forest type (A_3-paPs)*

Forest type – humid mugo pine subor type (A_3-Pm) can be found in the high mountain belt of the Carpathians within the altitudes of 1,400-1,750 m above sea level on the territory of Chornohora, Chyvchyny, Gorgany, Grynyava mountain massifs. Soils are underdeveloped, low-strength with a small layer of fine soil (up to 25 cm). Tree stand layer is represented by the continuous thickets of *Pinus mugo* Turra with the height of up to 2 m (Fig. 2). *Sorbus aucuparia* L., *Salix caprea* L., *Salix silesiaca* Willd., *Juniperus sibirica* Burgsd. form the layer of a sparse undergrowth. *Vaccinium myrtillus* L., *Vaccinium vitis-idaea* L. and a large variety of herbaceous species can be found within the layer of above-ground cover.

Figure 2. *Humid mugo pine subor forest type (A_3-Pm)*

Forest type – humid stone pine and spruce subor type (A_3-pcPa). This type is common on mountain tops and their slopes within altitudes of 1,250-1,550 m above sea level in Gorgany and Chornohora massifs. Soils are underdeveloped, low-strength with a small layer of fine soil (up to 30 cm), stony. Tree stand is dominated by *Picea abies* (L.) Karsten with an admixture of *Pinus cembrae* L. (class IV bonitet mostly) and *Betula pendula* Roth. (Fig. 3). *Sorbus aucuparia* L., *Salix caprea* L., *Salix silesiaca* Willd., *Juniperus sibirica* Burgsd. represent the layer of undergrowth, while *Vaccinium myrtillus* L. and mosses can be found as above-ground cover. These forests are one of the many virgin areas of the subalpine belt of the Carpathians [14].

Figure 3. *Humid stone pine and spruce subor forest type (A_3-pcPa)*

Forest type – moist mugo pine subor type (A_4-Pm) is common in the highlands of the Carpathians (Chornohora, Gorgany, Chyvchyny, and Grynyava massifs) on flat locations or concave slopes up to 15° peat-podzol soils within altitudes of 1,300-1,800 m above sea level (Fig. 4). Undergrowth and underbrush are absent in *Pinus mugo* Turra thickets of up to 1.2 m tall. Mosses are commonly present in the above-ground cover, while *Vaccinium myrtillus* L., *Ledum palustre* L., *Oxycoccus microcarpus* Pers., *Empetrum nigrum* L., are represented much less. Similarly to the previously mentioned moist mugo pine subor type, forests of A_4-Pm may have areas of virgin vegetation within the subalpine belt [14].

Figure 4. *Moist mugo pine subor forest type (A_4-Pm)*

Herushynskyi (1996) has identified and described 16 coniferous forest types, which are composed by almost all forest-forming tree species of the Carpathians. *Fagus sylvatica* L. is a forest-forming species for such forest types as:

– fresh beech coniferous forest type (B_2-Fs) is rather uncommon, but can still be found on the slopes of the Southern exposure in the Pokut Carpathians and Gorgany massif in the altitude range from 500 to 1,200 m above sea level. A stand has low bonitet value and consists of the trees of vegetative origin with low market value (Fig. 5a). Soils are gravelly with the release of the parent rock to the surface [15].

– humid beech coniferous forest type (B_3-Fs) is formed

in similar forest vegetation conditions as B_2-Fs does. However, it is mostly located on the slopes of Northern exposure (Fig. 5b).

Picea abies (L.) Karsten is a forest-forming species for such forest types as:

– humid spruce coniferous forest type (B_3-Pa) is exclusive to the highlands of the Carpathians in the altitude range of 1,000-1,500 m above sea level. regardless of the slope exposure with a slope of 20-30°. Soils do not have a great thickness (only 20-40 cm thick) on rock placers and rubble (Fig. 6a).

– moist spruce coniferous forest type (B_4-Pa) can be found in the highlands of the Carpathians in the lower slopes of the northern exposure. This forest type features peat soils with excessive moisture level. Tree stand have low productivity values and rarely exceed class IV bonitet (Fig. 6b). The vast majority of these forests belong to the virgin areas of the Carpathians [16; 17].

a) fresh beech coniferous forest type (B_2-Fs)

b) humid beech coniferous forest type (B_3-Fs)

***Figure 5**. Coniferous forest types of Fagus sylvatica L.*

a) humid spruce coniferous forest type (B_3-Pa)

b) moist spruce coniferous forest type (B_4-Pa)

***Figure 6**. Pure spruce coniferous forest types*

– humid fir and spruce coniferous type (B_3-aaPa) is formed everywhere in the Carpathians at altitudes of 650-1,300 m above sea level with western and northern exposure of the slopes. Tree stand has an average productivity. Trees of *Abies alba* Mill. have much lower growth rates compared to *Picea abies* (L.) Karsten (Fig. 7a).

– humid stone pine and spruce coniferous forest type (B_3-pcPa) is common mainly for Gorgany massif in the upper part of the forest cover at absolute altitudes of 1,300-1,500 m above sea level. However, it can be found on small area within Chornohora and Pokyty massifs of Carpathians as well. Tree stand has an average productivity and class II or III of bonitet. *Pinus cembrae* L. is mainly present in the overstory (Fig. 7b). These forests on the territory of the Ukrainian Carpathians have been disturbed severely or destroyed because of the valuable qualities of *Pinus cembrae* L. timber [18].

– humid larch, stone pine and spruce coniferous forest type (B_3-ldpcPa) is exclusive to Gorgany on the slopes of the southern exposure in the altitude range of 1,000-1,300 m above sea level. Soils are poorly developed, very stony. Tree stands have class II or III of bonitet.

– moist stone pine and spruce coniferous forest type (B_4-pcPa) is common for heights of 1,100-1,400 m above sea level in the same conditions as B_3-pcPa, except for the slope steepness. It is lower for B_4-pcPa compared to B_3-pcPa and helps to retain moisture better. Soils are underdeveloped and include peat (Fig. 7c).

a) humid fir and spruce coniferous forest type (B_3-aaPa)

b) humid stone pine and spruce coniferous forest type (B_3-pcPa)

c) moist stone pine and spruce coniferous forest type (B_4-pcPa)

***Figure 7**. Spruce subor forest types*

Quercus petraeae Liebl. acts as a forest-forming species for a single forest type – fresh sessile oak coniferous forest type (B_2-Qp). It is limited to Zakarpattia and Prykarpattia geographical regions on the southern exposures of slopes with absolute heights of 150-550 m above sea level. Tree stands of sessile oak have low density and low bonitet values (Fig. 8).

***Figure 8**. Fresh sessile oak coniferous forest type (B_2-Qp)*

Similarly, to *Quercus petraeae* Liebl., *Alnus viridis* (Chaix.) D.C. can be found within one forest type only – humid green alder coniferous forest type (B_3-Av). It is common in the highlands of the Carpathians in the subalpine zone. Mostly, this forest type is confined to the places of formation of high mountain streams (Fig. 9).

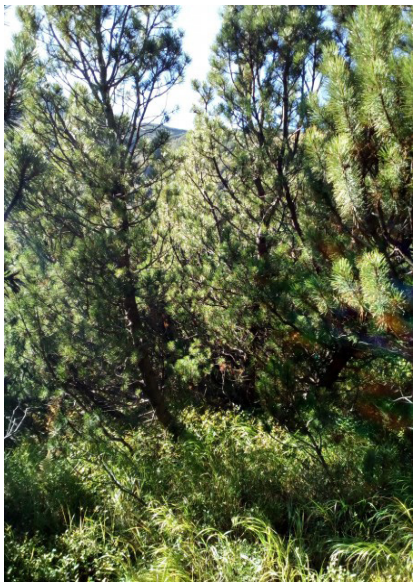
***Figure 9**. Humid green alder coniferous forest type (B_3-Av)*

Pinus mugo Turra is a forest-forming tree species for such three forest types as:

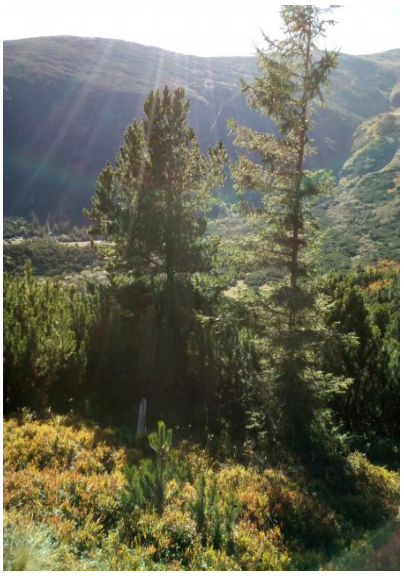
– humid mugo pine coniferous forest type (B_3-Pm) can be found everywhere in the Carpathians at altitudes of 1,450-1,750 m above sea level. This is one of the most common forest types for *Pinus mugo* Turra. Tree stand is represented by continuous thickets over 2 m high (Fig. 10a).

– humid stone pine and mugo pine coniferous forest type (B_3-pcPm) can be found in Gorgany and Chornohora massifs of the Ukrainian Carpathians. A special feature of this forest type is the presence of isolated *Pinus cembrae* L. trees (see Fig. 10b).

– moist mugo pine coniferous forest type (B_4-Pm) is common for the altitude range of 1,250-1,550 m above sea level, on gentle slopes with a slope of not more than 35° with peat soils (Fig. 10c).



a) humid mugo pine coniferous forest type (B_3-Pm)



b) humid stone pine and mugo pine coniferous forest type (B_3-pcPm)

c) moist mugo pine coniferous forest type (B_4-Pm)

***Figure 10**. Mugo pine coniferous forest types*

Pinus sylvestris L. is a forest-forming species for such three forest types as:

– fresh spruce and pine coniferous forest type (B_2-paPs) can be found on the southern exposures of the slopes with rocky placers of Yamne sandstone of III-IV category in the altitude range of 500-900 m above sea level. *Pinus sylvestris* L. is the primary forest-forming species here, while *Picea abies* (L.) Karsten is usually present as an admixture and second storey of the tree stand. Relative density of the tree stand does not exceed 0.7 (Fig. 11a). Tree stand has a grouped spatial distribution and is concentrated in places of accumulation of organic matter;

– humid spruce pine coniferous forest type (B_3-paPs) is the most common type of relict forest of *Pinus sylvestris* L. in the Carpathians, which is common on rocky placers of Yamne sandstone. It occurs on the southern, southwestern and north-eastern exposures of slopes with an altitude range of 600-1,100 m above sea level [10]. The rocky outcrops of Yamne sandstone within this forest type are categorised into III-IV categories depending on the slope and height above sea level (Fig. 11b). *Pinus sylvestris* L. is the primary forest-forming species here as well. *Picea abies* (L.) Karsten is present as a 30-40% admixture within the tree stand;

– moist spruce pine coniferous forest type (B_4-paPs) occurs quite rarely on the rocky outcrops of Yamne sandstone of III-V categories and is quite common in peat bogs of river terraces of mountain rivers. The process of formation of this type of forest is similar to the one of A_4-paPs on rock placers with the only difference related to the thickness and fertility, which are higher for B_4-paPs. This forest type is concentrated on the edges of swamps with small micro-elevations. The primary forest-forming species is *Pinus sylvestris* L. *Picea abies* (L.) Karsten can be found as an admixture, but not more than 20% of the tree stand composition (Fig. 11c).

a) fresh spruce and pine coniferous forest type (B_2-paPs)

b) humid spruce pine coniferous forest type (B_3-paPs)

c) moist spruce pine coniferous forest type (B_4-paPs)

***Figure 11**. Pine coniferous forest types*

Study results. After a detailed analysis of previous scientific and research work [2; 3; 9; 12; 13] and forest management expedition databases, it has been found that there is a significant share of forests, which have *Pinus sylvestris* L. within their composition. Such forests are studied insufficiently, or not described at all. The practice of forest typological study had been continued in subor (Table 1) and coniferous (Table 2) forest types of *Pinus sylvestris* L. within the Ukrainian Carpathians and established numerous sample plots on the territory of forest management enterprises and nature protection institutions.

***Table 1**. Characteristics of permanent sample plots on the territory of coniferous areas of the Ukrainian Carpathians*

INDICATORS		Sample plot (SP)									
		1	2	3	4	5	6	7	8	9	10
Enterprise		Carpathian State Special Forestry Enterprise of Agro-Industrial Complex			Bolekhiv State Forest Management Enterprise	Carpathian National Nature Park	Nadvirna State Forest Management Enterprise		Mizhhiria State Forest Management Enterprise	Vyhoda State Forest Management Enterprise	
Forest district		Roztokivske			Solotvynske	Yamnenske	Zelenske		Izkivske	Mizunske	
Population		Bukovynska			Bubnynska	Mykulychynska	Zelenske		Holiatynska	Mizunske	
Geographical tract		Protiati Kaminnia			Skeli Dovbusha	Pohary	Bredulets		Holiatyn	Shyrkovets	
Status		Geological natural monument of local importance			Natural monument of state importance	–	Natural monument of state importance		Natural monument of state importance	Hydrological natural monument of state importance	
Compartment		12	12	12	9	12	5	5	9	13	13
Section		22	23	22	1	21	10	10	47	18	18
Coordinates	Longitude	48° 09’ 55.9”	48° 10’ 00.2”	48° 09’ 48.9”	49° 02’ 35.0”	48° 25’ 30.8”	–	–	48° 39’ 03.8”	48° 54’ 22.3”	48° 54’ 27.0”
	Latitude	25° 09’ 90”	25° 09’ 17”	25° 09’ 56”	23° 40’ 57”	24° 36’ 36.9”	–	–	23° 26’ 45.8”	23° 50’ 48.9”	23° 50’ 50.4”
Altitude, m		726	670	750	650	660	726	720	777	490	489
Slope exposure		S-W	S-W	S-W	S-W	S	S-W	S-W	S-W	–	–
Slope steepness, degrees		8-50	8-50	8-50	8-50	18	5-15	2-3	15-30	–	–
SP area, ha		0.25	0.22	0.04	0.35	0.2	0.045	0.045	0.48	0.21	0.2

Table 1, Continued

INDICATORS		Sample plot (SP) 1	2	3	4	5	6	7	8	9	10
Enterprise		Carpathian State Special Forestry Enterprise of Agro-Industrial Complex			Bolekhiv State Forest Management Enterprise	Carpathian National Nature Park	Nadvirna State Forest Management Enterprise		Mizhhiria State Forest Management Enterprise	Vyhoda State Forest Management Enterprise	
Forest vegetation type		A_2	A_2	A_2	A_2	A_2	A_3	A_4	A_2	A_5	A_5
Forest type index		A_2-Ps	A_2-Ps	A_2-Ps	A_2-Ps	A_2-Ps	A_3-Ps	A_4-Ps	A_2-Ps	A_5-Ps	A_5-Ps
Stand composition		80%Ps15%Pa 5%Bp	50%Ps 45%Pa5%Bp	90%Ps 5%Bp5%Pa	90%Ps5%Bp 5%Fs	90%Ps10%Bp	100%Ps	100%Ps	80%Ps 20%Pa	80%Ps 10%Pa10%Ai	90%Ps 5%Bp5%Pa
Absolute basal area	m^2/plot	3.33	1.3	0.7	2.28	6.66	0.22	0.59	12.59	6.2	4.18
	m^2/ha	13.3	5.9	17.4	6.5	33.3	5.0	13.01	26.2	29.5	20.9
Volume	m^3/plot	21.53	7.73	4.31	12.97	52.88	0.52	2.60	101.8	44.18	15.24
	m^3/ha	86.1	35.1	107.8	337.1	264.4	11.6	58.0	212.1	210.4	76.2
Relative density		0.4	0.3	0.4	0.3	0.6	0.4	0.5	0.5	0.3-0.7	0.6
Bonitet		V	V	V	V	IV	V^b	V^a	III-IV	IV-V^a	V^a

Note: *Aa – Abies alba Mill.; Ai – Alnus incana (L.) Moench); Bp – Betula pendula Roth.; Bpb – Betula pubescens Ehrh.; Fs – Fagus sylvatica L.; Ps – Pinus sylvestris L.; Pa – Picea abies (L.) Karsten*

Table 2. *Characteristics of permanent sample plots on the territory of coniferous areas of the Ukrainian Carpathians*

INDICATORS		Sample plot (SP) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Enterprise		Carpathian State Special Forestry Enterprise of Agro-Industrial Complex		Carpathian National Nature Park			Osmoloda State Forest Management Enterprise												
Forest district		Roztokivske	Tatarivske		Pidlisnivske	Zhenetske	Yamnenske	Anhelivske	Krasnianske									Osmolodske	
Population		Bukovynska	Tatarivske			Palianytska	Mykulychynska	Anhelivske	Krasnianske									Osmolodske	
Geographical tract		Protiati Kaminnia	Bredulets			Popovychivske	Pohary	Sokil	Turova dacha									Liutoshary	
Status		Geological natural monument of state importance	Natural monument of state importance			Protected area of the park			Botanical natural monument of state importance	Natural monument of state importance								Natural monument of local importance	
Compartment		12	12	1	1	8	5	22	13	25	26	14	14	14	14	14	14	14	6
Section		22	22	1	3	3	21	20	21	9	1	5	28	18	37	20	23	31	19
Coordinates	Longitude	48° 09' 55.7"	48° 09' 56.4"	48° 22' 12.1"	48° 22' 06.5"	48° 22' 13.8"	48° 22' 16.7"	48° 20' 48.9"	48° 25' 13.8"	48° 41' 56.7"	48° 41' 59.1"	48° 51' 16.1"	48° 51' 16.1"	48° 51' 11.1"	48° 51' 03.5"	48° 50' 51.4"	48° 56' 21.7"	48° 51' 12.1"	48° 39' 33.9"
	Latitude	25° 09' 35"	25° 09' 27"	24° 33' 16"	24° 33' 19.5"	24° 33' 17.8"	24° 33' 04"	24° 29' 29.8"	24° 36' 36.9"	24° 05' 05.9"	24° 05' 05.9"	24° 14' 33.5"	24° 14' 56.2"	24° 14' 56.2"	24° 23' 24.4"	24° 14' 23.6"	24° 14' 56.2"	24° 14' 24.6"	24° 01' 50.1"
Altitude, m		699	684	730	750	730	720	863	670	970	980	444	453	453	454	454	450	452	707
Slope exposure		S-W	S-W	S-W	S-W	N-E	S-W	S-W	S	S-W	S-W	–	–	–	–	–	–	–	–
Slope steepness, degrees		8-50	8-50	16	15	16	45	20	10	17	14	–	–	–	–	–	–	–	–
SP area, ha		0.13	0.13	0.2	0.2	0.21	0.21	0.21	0.21	0.21	0.21	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.2

Table 2, Continued

INDICATORS	Sample plot (SP)																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Enterprise	Carpathian State Special Forestry Enterprise of Agro-Industrial Complex		Carpathian National Nature Park						Osmoloda State Forest Management Enterprise									
Forest type index	B_2-paPs	B_2-paPs	B_3-paPs	B_3-paPs	B_3-paPs	B_3-paPs	B_2-paPs	B_2-paPs	B_3-paPs	B_3-paPs	B_4-paPs	B_4-paPs	B_4-paPs	B_5-Ps	B_5-Ps	B_5-Ps	B_4-paPs	B_5-Ps
Stand composition	70%Ps20%Pa5%Bp5%Fs	80Fs16%Ps2%Pa2%Bp	90%Ps5%Pa5%Bp	96%Ps2%Pa2%Bp 50%Pa30%Ps20%Bp	80%Ps10%Pa10%Aa 60%Pa20%Aa10%Ps10%Fs	50%Ps20Aa20%Bp10%Pa 40%Pa30%Ps20%Bp10%Aa	90%Ps10%Pa 70%Pa20%Ps10%Bp	90%Ps6%Pa2%Aa2%Bp	100%Ps 60%Ps30%Bp10%Pa	90%Ps5%Bp5%Pa 80%Pa10%Ps5%Bp5%Aa	100%Ps 80%Pa10%Bpb10%Ps	90%Ps5%Pa5%Bpb	90%Ps5%Pa5%Bpb	100%Ps 60%Ps30%Bpb10%Pa	95%Ps35%Bp 80%Ps10%Pa10%Bpb	96%Ps2%Pa2%Bpb	90%Ps5%Pa5%Bpb	95%Ps5%Pa
Basal area, m^2/plot	1.08	2.28	5.3	9.4	9.82	11.33	6.78	11.09	8.35	10.41	8.44	9.12	12	7.87	5.68	8.26	9.11	5.22
Basal area, m^2/ha	8.3	17.5	26.7	47	46.8	53.9	32.3	52.8	39.8	49.6	42.2	43.4	39.9	39.3	28.4	41.3	45.6	26.1
Volume, m^3/plot	6.18	15.11	32.82	79.01	83.24	80.23	60.12	109.2	72.01	90.15	87.9	90.1	145	65.32	46.33	77.9	91.21	30.27
Volume, m^3/ha	47.5	116.2	164.1	395	396.4	382.1	286.3	520.1	342.9	429.3	439.5	429	483	326.6	231.7	389	456.1	151.4
Relative density	0.3	0.5	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.7	0.7	0.8	0.6	0.7	0.6	0.7	0.9	0.7
Bonitet	V	V	IV	III	III	III	III	III	III	III	II	III	II	III	IV	III	II	V

***Note**: Aa – Abies alba Mill; Ai – Alnus incana (L.) Moench); Bp – Betula pendula Roth.; Bpb – Betula pubescens Ehrh; Fs – Fagus sylvatica L.; Ps – Pinus sylvestris L.; Pa – Picea abies (L.) Karsten*

Detailed analysis of the results of the forest typological study and characteristics of diagnostic features of the studied pine forest types allow to complement existing classification of subor and coniferous pine forest types of Herushynskyi (1996) for the Ukrainian Carpathians with the following three forest types: fresh pine subor forest type (A_2-Ps), wet pine subor forest type (A_5-Ps), and wet pine coniferous forest type (B_5-Ps) [10; 11; 19] (Table 3).

***Table 3**. Suggested complementation of pine forest types for the territory of the Ukrainian Carpathians**

Forest vegetation type	Characteristic admixture	Forest type name	Forest type index	Natural stand composition
A_2	–	*Fresh pine subor forest type*	*A_2-Ps*	*100%Ps*
A_3	Spruce	Humid spruce and pine subor forest type	A_3-paPs	80%Ps20%Pa
A_4	Spruce	Moist spruce and pine subor forest type	A_4- paPs	80%Ps20%Pa
A_5	–	*Wet pine subor forest type*	*A_5- Ps*	*100%Ps*
B_2	Spruce	Fresh spruce and pine coniferous forest type	B_2- paPs	80%Ps20%Pa
B_3	Spruce	Humid spruce and pine coniferous forest type	B_3- paPs	60%Ps40%Pa
B_4	Spruce	Moist spruce and pine coniferous forest type	B_4- paPs	70%Ps30%Pa
B_5	–	*Wet pine coniferous forest type*	*B_5- Ps*	*100%Ps*

***Note**: *In italics – suggested complementation for topological structure of subor and coniferous pine forest types in the Ukrainian Carpathians according to Herushynskyi (1996)*

Fresh pine subor forest type (A_2-Ps) can be found on rocks and rock placers of Yamne sandstone of the category V, which are concentrated on the southern slope exposures with the steepness of 25° or more, and within the altitude ranges of 500-1,100 m above sea level. *Pinus sylvestris* L. is the primary forest forming tree species, while *Betula pendula* Roth can be spotted as an admixture. Tree stand is one-storey and has a grouped spatial distribution. Relict stands of *Pinus sylvestris* L. have low productivity and can be categorised to classes V-V[a]

of bonitet. Such stands are concentrated in cracks and depressions of rocks and rock placers, where organic matter has much higher chance to accumulate and moisture to get retained (Fig. 12). Undergrowth is almost absent. Yet some seldom trees of *Sorbus aucuparia* L. can still be found. Natural regeneration is rather weak. Understory is present in the quantity of around 1,000-1,500 trees/ha and mostly consists of *Pinus sylvestris* L. with scarce presence of *Betula pendula* Roth. The above-ground cover is rather poor. It has grouped spatial distribution and is concentrated in the same spots as trees. The above-ground cover consists of *Vaccinium vitis-idaea* L. (mostly), *Vaccinium myrtillus* L., *Sedum acre* L., *Festuca ovina* L., *Polytrichum commune Hedw.* and other mosses can be found as well.

Figure 12. *Fresh pine subor forest type (A_2-Ps)*

Wet pine subor forest type (A_5-Ps) is common for peat bogs of river terraces with a high coefficient of humidity. In particular, geographical tracts "Shyrkovets" or "Turova dacha". This forest type is formed by pure pine stands with low productivity values (V^a-V^b classes of bonitet). Tree stands are one-storied and have a grouped spatial distribution (Fig. 13). A large number of pine trees have twisted stem, with poorly developed crown, and in some places, they take the form of a bush because of the high humidity. Undergrowth is absent, and the quantity of understory does not get higher than 2,000-2,500 trees/ha. The latter consists of *Pinus sylvestris* L. only. Undergrowth can only be spotted on micro-elevations with thinned above-ground cover. The above-ground cover itself is well developed and takes around 90-100% of area coverage. It consists of *Vaccinium myrtillus* L., *Vaccinium vitis-idaea* L., *Ledum palustre* L., *Oxycoccus palustris* Pers, *Vaccinium uliginosum* L., *Empetrum nigrum* L. and other species. Mosses are represented by *Sphagnum sp.* with some groups of *Polytrichum commune Hedw.*

Figure 13. *Wet pine subor forest type (A_5-Ps)*

Wet pine coniferous forest type (B_5-Ps) can be found on peat bogs of river terraces within the territory of geographical tracts "Liutoshary", "Turova dacha", and "Shyrkovets". It differs from A_5-C with a better soil fertility that is caused by slightly lower humidity. The primary forest-forming species is *Pinus sylvestris* L., which grows in one- or two-layered stands. Such species as *Betula pendula* Roth., *Betula pubescens* Ehrh. and *Picea abies* (L.) Karsten can be found as an admixture within the main stand or understory. Single-storied stands are formed in relatively mono-aged plantations up to 140 years old. Older stands are affected by the processes of natural

decay and mortality. As a result, the second storey of the stand gets formed within windows of previously decayed and fallen trees. The productivity of such stands is low. Most stands belong to classes IV-V of bonitet (Fig. 14). Understory is rather poor and is spatially present in groups. Natural regeneration is slow because of the well-spread above-ground vegetation. The latter takes 100% of area coverage. *Pinus sylvestris* L. dominates the undergrowth along with admixture of *Betula pendula* Roth., *Betula pubescens* Ehrh., and *Picea abies* (L.) Karsten. The quantity of undergrowth does not exceed 1,000 trees/ha. The above-ground cover is represented by *Vaccinium myrtillus* L., *Vaccinium vitis-idaea* L., *Ledum palustre* L., *Oxycoccus palustris* Pers, *Vaccinium uliginosum* L., *Empetrum nigrum* L., and *Carex sp.* The mosses cover is dominated by *Sphagnum sp.*

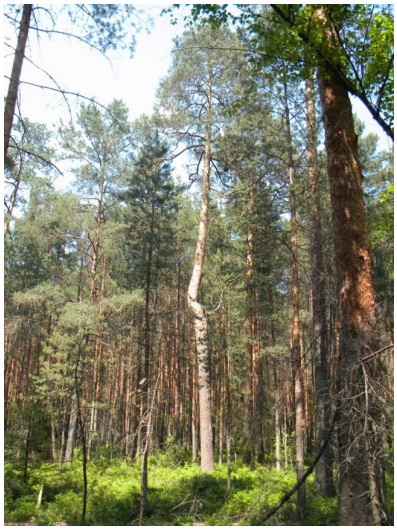


***Figure 14**. Wet pine coniferous forest type (B_5-Ps)*

Practical importance. The distinguishing of new forest types is considered logical and correct given that similar complementation has been adopted on the basis of research and monitoring of the forest typological profile plot of A. Piasetskyi [8; 19]. The complemented forest types have also been understudied for the corresponding study region.

Taking into account the methodological suggestions of Herushynskyi (1996), a set of diagnostic features is proposed for the defined subor and coniferous forest types on the territory of the Ukrainian Carpathians (Table 4). The given diagnostic features differ from the others by a number of characteristics and describe the relevant soil, hydrological, and forest vegetation conditions. The correctness of their determination is confirmed with a set of plant indicator species in the relevant areas.

***Table 4**. Diagnostic features of the defined subor and coniferous pine forest types*

Forest vegetation type	Forest type (name and index)	Geographical distribution of the forest	Soil conditions	Forest elements			
				Tree stand		Understory	Above-ground cover
				Natural	Successive		
A_2	Fresh pine subor forest type (A_2-Ps)	On the territory of Pokyty Carpathians and Gorgany. The range of altitudes 500-1,100 m. Based on the rocky outcrops and rocks of Yamne sandstone. Usually, on the southern slope exposures with the slope steepness more than 25°	Soil profile is absent. Fine soil is concentrated exclusively in cracks and depressions of rocks, and their placers of the V category	*Pinus sylvestris* L. is the dominant species (classes V^a-V^b of bonitet). Climatic admixture of *Betula pendula* Roth. Tree stand has grouped spatial distribution. Groups are confined to areas of fine soils	Tree stand of *Betula pendula* Roth.	It is represented by a thinned storey that consists of *Sorbus aucuparia* L. and *Picea abies* (L.) Karsten	It is distributed in the same areas as tree stands. However, above-ground cover can generate larger groups. It is represented by oligotrophic xero- and mesophytes, e.g., *Calluna vulgaris* (L.) Hill., *Vaccinium myrtillus* L., *Vaccinium vitis-idaea* L., *Saxifraga stellaris*, *Sedum acre* L., *Festuca ovina* L., *Polytrichum commune*, *Pleurozium schreberi*, *Hylocomium splendens*, *Cladonia rangiferina* and other

Table 4, Continued

Forest vegetation type	Forest type (name and index)	Geographical distribution of the forest	Soil conditions	Forest elements			
				Tree stand		Understory	Above-ground cover
				Natural	Successive		
B_5	Wet pine coniferous forest type (B_5-Ps)	On the river terraces of the lowlands of the Gorgany massif rivers within the altitude of 450-800 m	Soil profile is represented by a large share of peat deposit of brown peat, which was formed by the constant extinction of sphagnum moss biomass. The occurrence of groundwater is 20-30 cm lower, hence there is no boggy areas and higher share of oxygen in the soil	*Pinus sylvestris* L. (classes IV-V of bonitet) dominates the composition with the admixture of *Betula pubescens* Ehrh. and *Betula pendula* Roth. Tree stands can be one- or two-storied	Tree stand of *Betula pubescens* Ehrh.	It is represented by sparse groups of *Sorbus aucuparia* L., *Salix aurita* L., and *Betula pubescens* Ehrh.	Forms a continuous cover and is represented by the same species as A_5-C with addition of *Carex leporina, Carex nigra, Geum rivale*, and other

CONCLUSIONS

Additional forest types for Scots pine have been suggested for the Ukrainian Carpathians – two in subor and one in coniferous forest conditions. These types differ by the environmental factors from each other and from other forest types. Most importantly, they fully meet the characteristics of the relevant forest vegetation types and conditions. The correctness of their definition and diagnostics is confirmed by the identified indicator plants within the permanent sample plots. The background behind the existence of such forest types can be the subject of future study. The findings elucidate dynamic nature of forest types, provide a better understanding of forest ecology, and make a significant contribution to the forest topology research on the territory of the Ukrainian Carpathians. Another step has been taken towards understanding the patterns of vegetation formation and distribution within the Ukrainian Carpathians. This knowledge will help to carry out further study, especially in forestry, geobotany, dendrology, soil science, geology, etc., in the future.

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Борові та суборові типи лісу в Українських Карпатах: класифікація та доповнення

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Анотація. На сьогодні лісова типологія ще недостатньо інтегрована у суміжні науки екологічного та географічного спрямування, а сукцесії рослинних фітоценозів змушують здійснювати постійне коригування типів лісу. Дані наукові дослідження здійснені з метою удосконалення класифікації типів лісу Українських Карпат та наближення її до дійсного поширення рослинності в регіоні досліджень. Здійснено детальний аналіз лісотипологічних досліджень в Українських Карпатах з часів другої половини XX – початку XXI ст. Виконано розподіл площ лісового фонду Карпатського регіону, що перебувають у підпорядкуванні Державного агентства лісових ресурсів України, за типами лісорослинних умов. Загальна площа борів і суборів Карпатського регіону становить відповідно 1493,1 та 28910,2 га. Закладено низку постійних пробних площ на території природоохоронних установ та лісогосподарських підприємств регіону. На підставі отриманих результатів та їх аналізу запропоновано доповнити класифікацію борових і суборових типів лісу З.Ю. Герушинського (1996) в Українських Карпатах такими типами: свіжий сосновий бір, мокрий сосновий бір і мокрий сосновий субір. У статті наведено основні діагностичні особливості нових типів лісу. Описані борові та суборові типи лісу в Українських Карпатах чітко різняться ґрунтово-гідрологічними умовами від інших типів лісу і характеризують відповідні лісорослинні умови. Правильність їх визначення додатково підтверджується виявленими рослинами-індикаторами на відповідних ділянках. Результати наших досліджень з вивчення біологічної різноманітності рослинності в Українських Карпатах дають змогу краще зрозуміти екологію лісу та додають значний внесок у лісову типологію. Зроблено ще один крок до пізнання закономірностей формування рослинних комплексів в Українських Карпатах та детальніше представлено лісові формації Карпат у лісовій типологічній науці

Ключові слова: лісова типологія, тип лісорослинних умов, діагностичні ознаки, рослини-індикатори, індекс типу лісу, типологічний профіль, екологічна фігура

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Applying Machine Learning Approach to Start-up Success Prediction

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Abstract. Predicting the success of a new venture has always been a topical issue for both investors and researchers. Nowadays, it has become even more relevant concerning start-ups-young innovative and technology enterprises aimed at scaling their businesses. The purpose of this study is to create a model for predicting start-ups' success based on their descriptive characteristics. A model that connects such start-up features as the period from foundation to the first financing, the area of activity, type, and amount of the first financing round, business model, and applied technologies, with the start-up investment success, which refers to re-investment, has been developed using data from the Dealroom platform on statistics of start-ups activity and their description. The final sample included 123 start-ups that are founded or operate in Ukraine. Three machine learning algorithms are compared: Logistic Regression, Decision Tree, and Random Forest. Acceptable results were obtained in terms of Accuracy, Sensitivity, and F-score, despite the limited data. The best model concerning start-up success prediction is determined by a Decision Tree, with an average effectiveness of 61%, 55%, and 52%, respectively. The AUC level for the Decision Tree achieved 58%, which is lower than the Logistic Regression and Random Forest scores (65%). But the last models had done so well by better predicting start-up failures, while more practical is the ability to predict their success. All models showed an acceptable level of AUC to confirm with confidence their effectiveness. The decision support system for the investment object can be helpful for entrepreneurs, venture analysts, or politicians who can use the built models to predict the success of a start-up. This forecast, in turn, can be used to drive better investment decisions and develop relevant economic policies to improve the overall start-up ecosystem

Keywords: start-up ecosystem, start-up, innovation, decision support system, classification, data modelling, predicting the success of a start-up

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INTRODUCTION

Start-ups, which according to the European Association of Start-ups are recognised as "an independent organisation, which is younger than five years and aimed at creating, improving, and expanding a scalable, innovative, technology-enabled product with high and rapid growth" [1], are the driving force of rapid and innovative change in present-day business environment. According to the World Economic Forum, the global start-up economy was estimated at 2.8 billion dollars in 2019, and its development is about three to four times faster than the growth of economies in many countries [2]. Their high growth rates and the flexibility in deploying innovative business models make them an increasingly visible element of the global economy, as creators of economic value and destroyers of existing industries, as a source of employment generation, and a place for talent development, as a way to commercialise science and research and development (R&D).

Summarising the studies available, several research groups can be distinguished, depending on the research object. The first group of researchers based their models on quantitative methods for assessing the key factors of start-up success. For example, in [3], using statistical tests, researchers try to evaluate which business model brings the highest success rates. By success, they mean the level of profitability, the level of profit growth, the start-up valuation, and the amount of investment. Another example of this type of research is the study that determines the impact of indicators such as the level of innovation, education of founders and employees, the level of investment, and the start-up size on the growth of a start-up's business performance. As the criterion for success, researchers consider the level of income per employee [4]. A similar approach was applied in [5], but its authors consider the fact of continuing to carry out start-ups activities as a criterion of success.

The second group of researchers focused on identifying the qualitative internal factors of start-up success. In particular, in [6], based on a survey of 25 experts, the authors summarise the answers to the question "What are the key factors for the success of a start-up?" Using the AHP method, eight main factors of start-up success were identified as follows: product uniqueness, product characteristics, customer demand, marketing promotion, distribution channels, after-sales service, new product development, and financial support. In [7], researchers assessed the influence of the digital activity of the founders and their affiliation with venture investors on the business performance of a start-up by constructing multiple regression. The researchers consider the asset turnover ratio to be the criterion for the success of a start-up.

The third group of researchers sets themselves the task of identifying external factors that increase the probability of start-up success, at a country level in particular. Thus, in [8], the application of the principal component analysis allowed identifying five main factors, the presence of which contributes to the development of a start-up ecosystem in the country: 1) access to human capital; 2) the quality and results of the institutions' activities; 3) focus on market conditions; 4) business environment; 5) development potential.

The methodology of start-up success prediction, which is used in research on this issue, is very diverse. However, most frequently, researchers use machine learning methods. The level of complexity of research using this technique is also very different: from simple works [9; 10], where one method is used – a logistic model, to complex (from a methodological standpoint) research using 9 algorithms, including Random Forest, Bayesian network, Decision tree, their comparison and selection of the best [11]. In most studies, 2-3 algorithms are used, followed by the selection of the best one based on the level of forecasting accuracy.

Considering the complexity of information support of this study (initial data), researchers choose different approaches to defining the success of a start-up, which leads to different accuracy of the developed models:

- in [12], the success of a start-up is defined by conducting an IPO, selling a start-up, or receiving re-financing in an amount exceeding the previous maximum. In [10], this is the fact that a start-up has a profitability of more than 20 percent, new patent applications, and participation in the innovation subsidy programme is considered a success;
- in [13] argues the expediency of changing the criterion of "obtaining re-financing" to the criterion of "reaching the round". Researchers applied 3 algorithms (logistic regression, support vector machine, gradient boosting), obtaining F-score accuracy rates of 57%, 34%, 43%, respectively;
- in [14], the random forest and gradient boosting methods were used in combination with the success definition "the start-up is still functioning" (the researchers predicted that the start-up would fail, not succeed). The maximum performance of the study was set at 94.5% in terms of accuracy, and 92.91% in terms of AUC (Area Under the Curve);
- a higher forecasting accuracy was obtained by studying the correlation between a start-up's digital activity and its chances of surviving for more than 5 years [15]. The researchers managed to predict the start-up survival probability with 91% accuracy, using random forest and gradient boosting methods.

Thus, there are two types of problems that have not been adequately addressed in previous studies so far: 1) what start-up should be considered as a success, what factors determine it; 2) what techniques, having a relatively small amount of public data on the start-up activities, are used to evaluate the prospects for its success.

That is why the actual scientific task is to further investigate the essence, manifestations, and varieties of the concept of "start-up success", to identify the relationships between indicators of start-up activity, and their

impact on the achievement of various types of success. The limited information field of the research determines the interest in improving the input data preparation methods, setting up machine learning models, and evaluating their quality.

Critically comprehending the available approaches to determining and predicting the success of a start-up, this study yielded the following conclusion: various events that meet the interests of the start-up in terms of implementing a development strategy or the interests of its founders can be considered the success of a start-up. Understanding this polyvariety allows distinguishing between different types of success as follows:

- investment success – getting additional financing;
- customer success – achieving the target volume or increase in the number of users (consumers) of a start-up product;
- market success – achieving target sales of a start-up's product or achieving target market share;
- adaptive success – continued existence for a certain period (more than 5 years), which allows identifying the transition from the status of a young new to an ordinary enterprise;
- financial success – IPO (Initial Public Offering) or selling a start-up, which allows its founders and primary investors to exit the start-up and monetise their investments. Financial success is in line with the "classic understanding" of start-up success [12].

The purpose of this study is to develop a methodology for predicting the success of a start-up using machine learning methods based on its activity data from open sources. The results of this study will considerably facilitate the decision-making process of choosing objects and areas of investment (start-up specialisation) for entrepreneurs, potential co-founders of start-ups, and venture capitalists.

To achieve the said purpose, *the following tasks* were identified:

– to prepare the available public data on the activities and funding of start-ups for the features of the application of machine learning algorithms and determine the criterion indicating the success of a start-up;

– to systematise the model building methodology for the start-up success prediction: choosing algorithms and adjusting their hyperparameters, setting up cross-validation, selecting indicators of forecasting accuracy;

– according to the developed methodology, to implement three different algorithms for predicting the investment success of a start-up;

– to conduct an in-depth comparative quality analysis of the constructed model and, on this basis, to substantiate the best methodology for predicting the investment success of a start-up in terms of accuracy.

MATERIALS AND METHODS

Data pre-processing

The study uses open data from the Ukrainian version of the Dealroom resource [16]. Dealroom.co is a leading provider of data on start-ups and technology ecosystems in Europe and all around the world. The Ukrainian version allows analysing data on start-ups that are based or operate in Ukraine with ease. Due to limited resources, information about only 566 start-ups related to Ukraine could be accessed.

The generated data set contains 98 start-up characteristics fields. A list of all fields is presented in Figure 1.

NAME	TAGS	FACEBOOK LIKES	FOUNDERS UNIVERSITES
PROFILE URL	B2B/B2C	TWITTER FOLLOWERS	FOUNDERS COMPANY EXPERIENCE
WEBSITE	REVENUE MODEL	TWITTER TWEETS	FOUNDERS FIRST DEGREE
TAGLINE	LAUNCH DATE	TWITTER FAVORITES	FOUNDERS FIRST DEGREE YEAR
ADDRESS	CLOSING DATE	SW TRAFFIC 6 MONTHS	FOUNDERS LINKEDIN
HQ REGION	INDUSTRIES	SW TRAFFIC 12 MONTHS	FOUNDERS FOUNDED COMPANIES TOTAL FUNDING
HQ COUNTRY	SUB INDUSTRIES	ANGELLIST	LISTS
HQ CITY	DELIVERY METHOD	FACEBOOK	COMPANY STATUS
LATITUDE	GROWTH STAGE	TWITTER	APP DOWNLOADS LATEST (IOS)
LONGITUDE	DEALROOM TAG	LINKEDIN	APP DOWNLOADS 6 MONTHS (IOS)
LOCATIONS	YEARLY GROWTH (SIMILARWEB)	GOOGLE PLAY LINK	APP DOWNLOADS 12 MONTHS (IOS)
FOUNDING LOCATION	ALEXA GROWTH (ALL TIME)	ITUNES LINK	APP DOWNLOADS LATEST (ANDROID)
TEAM (DEALROOM)	EMPLOYEES	EACH ROUND TYPE	APP DOWNLOADS 6 MONTHS (ANDROID)
TEAM (EDITORIAL)	EMPLOYEES (2016, 2017, 2018, 2019, 2020, 2021)	EACH ROUND AMOUNT	APP DOWNLOADS 12 MONTHS (ANDROID)
INVESTORS	EMPLOYEES IN HQ country (2016, 2017, 2018, 2019, 2020)	EACH ROUND CURRENCY	TRAFFIC COUNTRIES
EACH INVESTOR TYPES	LAST KPI DATE	EACH ROUND DATE	TRAFFIC SOURCES
LEAD INVESTORS	PROFIT (2016, 2017, 2018, 2019)	TOTAL ROUNDS NUMBER	SIMILARWEB RANK 3/6/12 MONTHS
TOTAL FUNDING (EUR M)	EBITDA (2016, 2017, 2018, 2019)	EACH ROUND INVESTORS	EMPLOYEE RANK 3/6/12 MONTHS
LAST ROUND	REVENUE (2016, 2017, 2018, 2019)	LOGO	APP RANK 3/6/12 MONTHS
LAST FUNDING	FINANCIALS CURRENCY	FOUNDERS	NUMBER OF ALUMNI EUROPEAN FOUNDERS THAT RAISED > 10M
LAST FUNDING DATE	VALUATION	FOUNDERS STATUSES	TECHNOLOGIES
FIRST FUNDING DATE	VALUATION CURRENCY	FOUNDERS GENDERS	INCOME STREAMS
SEED YEAR	VALUATION (EUR)	FOUNDERS IS SERIAL	TECH STACK DATA (BY PREDICTLEADS)
OWNERSHIPS	VALUATION DATE	FOUNDERS BACKGROUNDS	TRADE REGISTER NUMBER
SDGS	CORE SIDE VALUE		

***Figure 1**. List of all fields in the start-up data set*

Evidently, many fields are not acceptable for usage in modelling. For example, PROFILE URL (link to the start-up site), FOUNDERS (names of the founders), or LOGO (link to download the start-up logo). Accordingly, the first step will be to clean up the redundant fields from the data. The rest of the factors are presented in Figure 2.

NAME	B2B/B2C	FACEBOOK LIKES	TWITTER FOLLOWERS
REVENUE MODEL	TWITTER TWEETS	LAUNCH DATE	TWITTER FAVORITES
SW TRAFFIC 6 MONTHS	SW TRAFFIC 12 MONTHS	EACH ROUND TYPE	APP DOWNLOADS LATEST (IOS)
HQ REGION	INDUSTRIES	EACH ROUND AMOUNT	APP DOWNLOADS 6 MONTHS (IOS)
HQ COUNTRY	SUB INDUSTRIES	EACH ROUND CURRENCY	APP DOWNLOADS 12 MONTHS (IOS)
HQ CITY	DELIVERY METHOD	EACH ROUND DATE	APP DOWNLOADS LATEST (ANDROID)
TOTAL FUNDING (EUR M)	GROWTH STAGE	TOTAL ROUNDS NUMBER	APP DOWNLOADS 6 MONTHS (ANDROID)
LAST ROUND	YEARLY GROWTH (SIMILARWEB)	PROFIT (2016, 2017, 2018, 2019)	APP DOWNLOADS 12 MONTHS (ANDROID)
LAST FUNDING	ALEXA GROWTH (ALL TIME)	EBITDA (2016, 2017, 2018, 2019)	SIMILARWEB RANK 3/6/12 MONTHS
LAST FUNDING DATE	EMPLOYEES	REVENUE (2016, 2017, 2018, 2019)	APP RANK 3/6/12 MONTHS
FIRST FUNDING DATE	EMPLOYEES (2016, 2017, 2018, 2019, 2020, 2021)	VALUATION	TECHNOLOGIES
SEED YEAR	EMPLOYEES IN HQ country (2016, 2017, 2018, 2019, 2020)	VALUATION CURRENCY	INCOME STREAMS

***Figure 2**. Available fields after data clearing*

Another problem with this dataset is that it lacks a criterion for whether a start-up made an attempt to get funding. Accordingly, there is no reliable information that a start-up that has not attracted external investment is unsuccessful. It is probable that the start-up did not require financial support from investors (Fig. 3), developing based on its own financing sources.

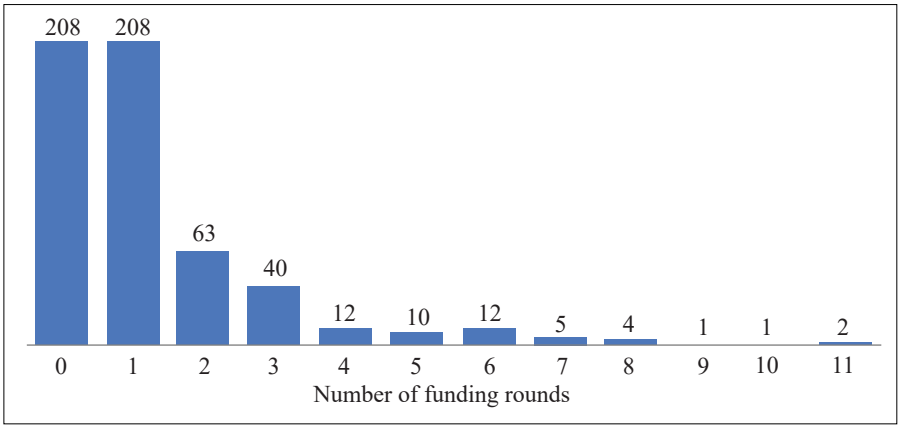

***Figure 3**. Distribution of start-ups according to the number of funding rounds*

Therefore, to avoid inaccuracies, start-ups for which information on funding was not reflected were removed from the data set. Thus, 358 start-ups were left in the data array.

The next problem is that data on Internet activity (SW TRAFFIC 12 MONTHS, APP DOWNLOADS 12 MONTHS (IOS), and TWITTER FAVORITES) are available either for the current date or for the last year. Accordingly, it is impossible to apply these factors for enterprises that had the last round before 2019 (except for the situation that it was a single round of funding). For the reliability of the conclusions, the sample was limited to start-ups that had the first funding in 2017-2019. After these manipulations, only 149 start-ups were left. The distribution by type of the last round of funding is presented in Table 1.

***Table 1**. Distribution of start-ups by type of last funding*

Type of last round	Number of start-ups
SEED	82
ANGEL	18
ACQUISITION	13
EARLY VC	10
GRANT	10
SERIES A	5
ICO	4
SERIES C	2
LATE VC	2
CONVERTIBLE	1
DEBT	1
GROWTH EQUITY	1

In Table 1, only 14 start-ups fit the classic definition of a successful start-up – ACQUISITION or GROWTH EQUITY, which is insufficient for building a model. Taking this into account, it was decided to limit the study solely to investment success, the criterion of which was recognised as obtaining repeated funding. Since part of the agreements on attracting investments in a start-up is confidential information and not all start-ups know the amount of preliminary investments raised, an increase in funding cannot be used as a success criterion (as suggested in [12]). A factor that can also affect the reliability of the obtained results is the presence of start-ups that received A+ funding or made an exit already in the first round. It is unknown what influenced the decision of investors in this situation, so the data on such start-ups were also removed from the data set.

As a result, 123 start-ups were left, which were transformed according to the binary method (1 – a successful start-up (fact of repeated investment), 0 – unsuccessful (there is no fact of repeated financing). The number and ratio of successful and unsuccessful start-ups is presented in Figure 4.

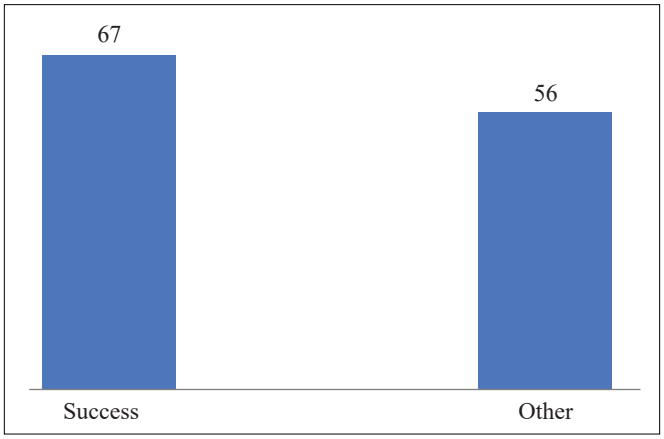

***Figure 4**. Number of successful and unsuccessful start-ups in the dataset*

The next step was to create new variables from the available ones. Thus, for example, a new variable was created by subtracting LAUNCH DATE and the year of the first investment in the EACH ROUND DATE field (Time_to_first_funding). To create First_round_type variable, the first value was taken from the EACH ROUND TYPE. From the EACH ROUND AMOUNT field, the amount of the first investment was allocated – First_round_amount.

For an integrated assessment of the volume of traffic to the site (SW_traffic), the value SW TRAFFIC 12 MONTHS was taken as a basis. To estimate the number of downloads (APP_downloads) – the sum of APP DOWNLOADS 12 MONTHS (IOS) and APP DOWNLOADS 12 MONTHS (ANDROID).

The presence of a start-up in the top ratings of Similar Web was evaluated by creating a new variable TOP_Rank_SW, where the presence in the chart of any rating SIMILAR WEB RANK 3/6/12 MONTHS or APP RANK 3/6/12 MONTHS was indicated under the "TOP" value.

The next step is to verify factors gaps. If a field value is missing for most start-ups – it is removed. If only a part is missing – the value was supplemented manually. Qualitative information was received from the start-up website and open sources, and quantitative information was filled in by the mean method to replace the missing values. For the missing values, based on the filled ones, was assigned the average for each ratio B2B_B2C, INDUSTRIES, First_round_type, INCOME STREAMS, REVENUE_MODEL, and TECHNOLOGIES. Since the algorithm for developing a machine learning model assumes dividing the data into a test and training set (25%/75%), and training set is divided into 5 equal groups for cross-verification, the quantity of each of the qualitative values must be greater than 6 (5 per each cross-verification and one per training set). Therefore, it is necessary to group the values of the model parameters according to the given threshold value.

The grouping results are as follows:

– HQ_COUNTRY – turned into a binary variable. Characterises the presence of Head office in Ukraine or another country.

– Time_to_first_funding – now characterises the time to the first investment in the context of three groups: receiving funding in the year of opening, for the next year, for over 1 year.

– First_round_type – the variable is grouped into two categories SEED_EARLY_VC and ANGEL_GRANT.

– INDUSTRIES – divided into 4 categories: Heals_Food_Education, Enterprise_Software_Manufacturing, Creative_Services, Home_Travel_Hobbies.

– TECHNOLOGIES – grouped into 4 categories: App_programs_development, New_product_development, Online_services, and VR_AR_ML_AI.

As a result, there were 14 fields that characterise a start-up. The description of fields is presented in Table 2.

***Table 2**. Characteristics of model variables*

Variable name	Description
Success	Dependent variable characterising the factor of start-up success (Yes/No)
HQ_COUNTRY	Country of the head office location
Time_to_first_funding	Time to the first investment
B2B_B2C	Client type (business or individual)
INDUSTRIES	Area of activity
YEARLY_GROWTH_SIMILARWEB	The annual increase in digital activity in the SW rating
SW_TRAFFIC	The number of visits to the site on average per year
First_round_type	Type of the first funding round
First_ROUND_AMOUNT	The first funding round amount
APP_DOWNLOADS	The average number of app downloads over the last year
TOP_Rank_SW	Presence in the top ranking by digital activity in their area of activity
INCOME_STREAMS	Income channel
REVENUE_MODEL	Revenue model
TECHNOLOGIES	What technologies/innovations have been proposed

This means that if there is an x number of factor levels, x-1 dummy variables will be created and all but the first-factor level are converted to new columns. All numerical factors have been normalised. To perform this operation, the R programming language and the Rstudio IDE were used. Tidymodels package was chosen as the main software package for tuning machine learning algorithms.

Methodology and technology of start-up success prediction

During the study, 3 classification models will be applied – decision tree, random forest, and logistic regression. A decision tree develops solutions using a tree model. The algorithm splits the sample into two or more homogeneous sets (branches) based on the most significant differentiators of the input variables. To select a differentiator (predictor), the algorithm takes into account all the features and produces a binary partition. Then it chooses that option with the least cost (i.e., high precision) and repeats recursively until the data is successfully split across all branches (or reaches the maximum depth).

A random forest is an ensemble model that builds multiple trees and classifies features based on a "vote". The object belongs to the class that has the majority of votes from all trees. The algorithm trains several decision trees on different datasets and uses the mean to improve the forecasting accuracy of the model. Logistic regression is a technique for modelling the probability of an event. Like linear regression, it helps understand the relationship between one or more variables and a target variable, except that in this case, the target variable is binary: its value is 0 or 1.

These machine learning methods were chosen proceeding from the results of the analysis of existing studies and because of their ease in development and interpretation.

The modelling procedure requires the division of our sample into training and test. The distribution takes place in the proportion of 75% – training, 25% – test. The first set was used to tune the parameters of the model. The second was to test the algorithm against previously unseen values.

The next step is to set up the cross-verification procedure. Cross-verification is a statistical technique used to evaluate the predictive capabilities of machine learning models. It is commonly used in applied learning to compare and select models for a specific predictive modelling problem.

The general methodology is as follows:

1. The dataset in the training sample is shuffled randomly.
2. The sample is divided into k groups.
3. Each group is divided into two samples for training and testing.
4. A test sample is taken from one group, and all the rest serve as a training sample. This is done k-times.
5. The model learns on the training set and evaluated on the test.
6. The results of constructing k-models are averaged.

Usually, 10-fold cross-validation is used. But due to the limited data, a 5-fold check was used. Each algorithm is cross-validated, and the best model was chosen as the basis for prediction.

In machine learning, measuring accuracy is an important task. Therefore, when it comes to classification, can be relied upon the AUC (Area Under the Curve) – ROC (Receiver Operating Characteristics) curve. It is one of the most important metrics for testing the effectiveness of any classification model. The AUC-ROC curve is a performance measurement for classification tasks at various threshold settings. ROC is the probability curve and AUC is the degree or measure of the distribution.

It describes how the model can distinguish between classes. The higher the AUC, the better the model predicts 0 as 0 and 1 as 1.

The ROC curve is plotted with TPR (True Positive Rate) to FPR (False Positive Rate), where TPR is on the Y-axis and FPR is on the X-axis.

TPR (True Positive Rate)/Recall/Sensitivity – the share of correctly distributed positive values among all positive values is determined as follows:

$$TPR = \frac{TP}{TP + FN} \quad (1)$$

where TP is the true positive classification, FN is the false negative classification.

Specificity – the proportion of correctly distributed negative values to all negative values is calculated according to the formula:

$$Spec = \frac{TN}{TN + FP} \quad (2)$$

where TN is the true negative classification, FP is the false positive classification.

FPR (False Positive Rate) – the proportion of incorrectly distributed negative values to all negative values is calculated according to the formula:

$$FPR = 1 - Spec = \frac{FP}{TN + FP} \quad (3)$$

where TN is the true negative classification, FP is the false positive classification.

An excellent model has an AUC close to 1, which means that it divides classes well. A bad model has an AUC close to 0, which means the worst allocation score. This effectively means that the algorithm matches the reverse values. It predicts 0 as 1 and 1 as 0. And when the AUC is 0.5, it means the model has no class separation ability at all.

Another classical method for evaluating the quality of a classification model is Accuracy, which is calculated according to the formula:

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \quad (4)$$

where TN is the true negative classification, FP is the false positive classification, TP is the true positive classification, FN is the false negative classification.

The last metric in our study will be the weighted accuracy estimation (F-score), which is calculated according to the formula:

$$F = \frac{TP}{TP + \frac{1}{2}(FP + FN)} \quad (5)$$

where FP is the false positive classification, TP is the true positive classification, FN is the false negative classification.

A feature of the machine learning algorithm is that they are based on numerous hyperparameters. These hyperparameters have their default values, which are applied if no adjustments are made. Obviously, they do not always provide the most accurate forecasts. Therefore, the optimal hyperparameters were selected for each model. And for each hyperparameter, a 5-fold cross-verification is done to find their most optimal ratio.

– Decision Tree model hyperparameters:

cost_complexity: The complexity of the model

tree_depth: The maximum depth of the tree

min_n: The minimum number of points in a node that the node will require for further separation.

– Random Forest model hyperparameters:

mtry: The number of variables (predictors) that will be randomly selected at each division when creating models.

trees: The number of trees contained in the ensemble.

min_n: The minimum number of points in a node that the node will require for further separation.

– Logistic regression model hyperparameters

penalty: The total amount of regularisation in the model.

mixture: A mixture of different types of regularisation.

The method of random search of parameters was used to select the hyperparameters. Since there are an infinite number of variants of parameter compounds, a simpler method of parameter determination is required. One option is a random search. Where the "n" is a number of randomly selected values of compounds of hyperparameters. Next, a model is studied for each compound and 5-fold cross-verification is performed. In this study, 25 random parameter compounds for each model will be calculated.

RESULTS AND DISCUSSION

As already noted, the first stage, common to all models, is the division of the initial sample into test and training samples. 93 start-ups were included in the training sample, 30 in the test sample.

Decision tree implementation

After the implementation of the Decision Tree algorithm, Accuracy was set at 0.633, Roc_Auc – 0.665. The evaluation was based on a test sample.

But one iteration of the evaluation is not enough to assert with complete confidence the effectiveness of the model. Therefore, to finalise the results, it was necessary to cross-validate the model's performance. The cross-verification results are presented in Table 3.

***Table 3**. Decision Tree cross-verification results*

Metric	Min	Median	Mean	Max
Roc_Auc	0.444	0.581	0.550	0.644
Accuracy	0.444	0.632	0.590	0.722
Sensitivity	0.333	0.625	0.572	0.778
Specificity	0.3	0.5	0.602	0.909
F-score	0.462	0.5	0.553	0.667

To improve the forecasting efficiency, the model hyperparameters tuning procedure was carried out. Table 4 shows the hyperparameters that will provide the model with the largest minimum values for Roc_Auc and Accuracy. Table 5 demonstrates the forecasting results with the new hyperparameters considered. Figure 5 demonstrates the Roc curve.

***Table 4**. Optimal hyperparameter values*

Hyperparameter	Default value	Optimal value
cost_complexity	0.01	9.45078958391999e-08
tree_depth	30	14
min_n	20	33

***Table 5**. Decision Tree cross-verification results after customisation*

Metric	Min	Median	Mean	Max
Roc_Auc	0.512	0.581	0.576	0.644
Accuracy	0.5	0.632	0.612	0.722
Sensitivity	0.125	0.625	0.547	0.875
Specificity	0.3	0.8	0.662	0.909
F-score	0.182	0.636	0.523	0.667

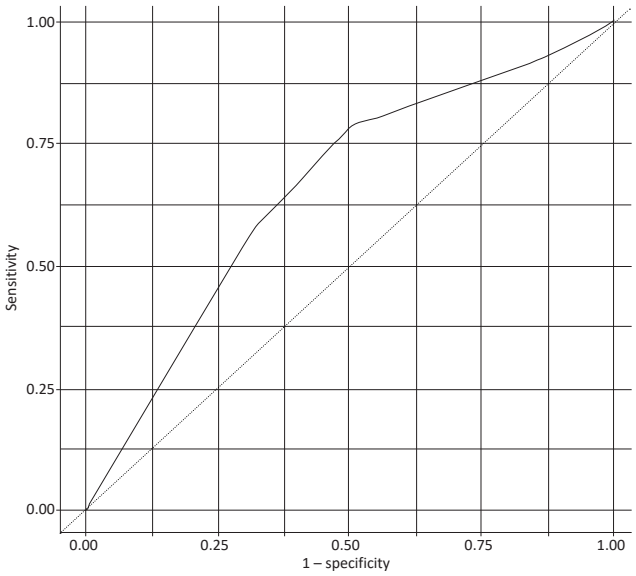

***Figure 5**. Roc curve for decision tree*

Logistic regression implementation

After the implementation of the Logistic Regression algorithm, Accuracy was set at 0.467, Roc_Auc – 0.473. The evaluation was based on a test sample. Logistic Regression cross-verification results are presented in Table 6.

***Table 6**. Logistic Regression cross-validation results*

Metric	Min	Median	Mean	Max
Roc_Auc	0.462	0.495	0.544	0.689
Accuracy	0.389	0.55	0.504	0.579
Sensitivity	0.333	0.375	0.45	0.667
Specificity	0.3	0.5	0.545	0.727
F-score	0.375	0.421	0.445	0.6

Table 7 demonstrates the hyperparameters that provide the model with the largest minimum values for Roc_Auc and Accuracy. Table 8 shows the forecasting results with the new hyperparameters considered. Figure 6 shows the Roc curve.

***Table 7**. Optimal hyperparameter values*

Hyperparameter	Default value	Optimal value
penalty	0.1	0.0621016941891562
mixture	1	1

***Table 8**. Logistic Regression cross-verification results after customisation*

Metric	Min	Median	Mean	Max
Roc_Auc	0.575	0.606	0.645	0.733
Accuracy	0.5	0.611	0.600	0.684
Sensitivity	0.125	0.5	0.45	0.625
Specificity	0.5	0.8	0.724	0.818
F-score	0.182	0.533	0.486	0.625

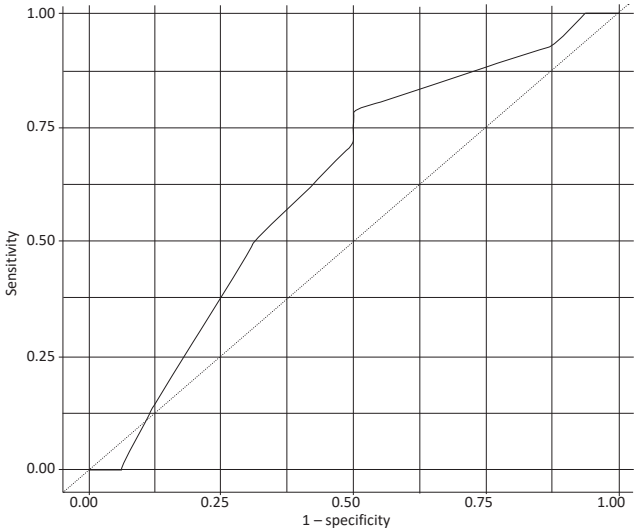

***Figure 6**. Roc curve for logistic regression*

Random forest implementation

After the implementation of the Random Forest algorithm, Accuracy was set at 0.467, Roc_Auc – 0.5. The evaluation was based on a test sample. Random Forest cross-verification results are presented in Table 9.

The hyperparameter optimisation process did not give significant results, so conclusions were based on their default values. Figure 7 shows the Roc curve.

Comparison of models

To compare the models, the average values of the characteristics of forecasting efficiency were calculated (Table 10).

***Table 9**. Random Forest cross-verification results*

Metric	Min	Median	Mean	Max
Roc_Auc	0.562	0.626	0.645	0.8
Accuracy	0.5	0.556	0.570	0.684
Sensitivity	0.111	0.5	0.358	0.556
Specificity	0.5	0.8	0.744	0.9
F-score	0.167	0.471	0.399	0.625

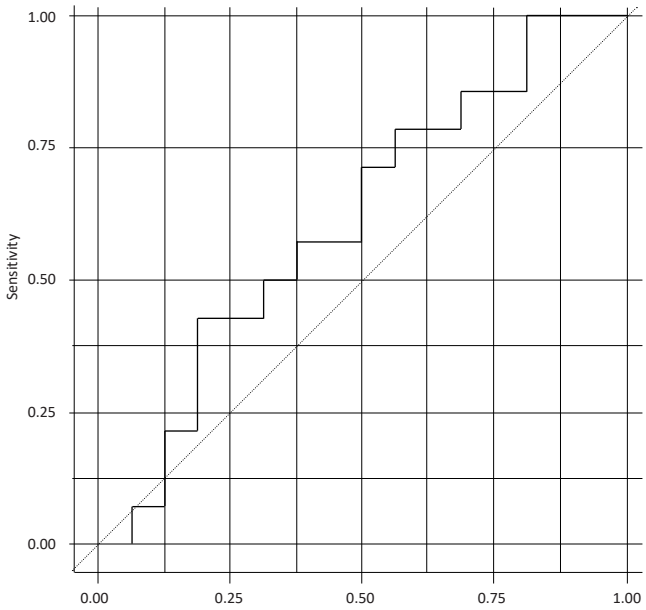

***Figure 7**. Roc curve for random forest*

***Table 10**. Comparative table of the model's effectiveness*

Metric	Decision tree	Logistic regression	Random forest
Roc_Auc	0.576	0.645	0.645
Accuracy	0.612	0.600	0.570
Sensitivity	0.547	0.45	0.358
Specificity	0.662	0.724	0.744
F-score	0.523	0.486	0.399

Discussion of machine learning modelling results

This study provides a complete guide to implementing a start-up success prediction model. In the beginning, 566 start-ups were presented in the data set, which were characterised by 98 variables. Since this is an open-access database, it contains certain inaccuracies, redundant and contradictory information (Fig. 1). All parameters that, according to the authors, do not characterise a start-up, but are only technical fields were ignored (Fig. 2).

One of the main tasks was to define a clear concept of "start-up success". After doing an exploratory analysis of the data, it was concluded that, based on the sample under study, the object of research could be a financial success – successful start-ups are those that made Acquisition, while GROWTH EQUITY or investment success are start-ups with more than one round of funding (Table 1). The first criterion was rejected due to the extremely small number of start-ups that meet it. The model was further tuned for start-ups that had at least one round of funding for the current period (Fig. 3). The final sample included 123 start-ups (Fig. 4).

Since the algorithm for developing a machine learning model assumes dividing the data set into a test and training set, and the training set into 5 equal groups for cross-verification, the quantity of each of the qualitative values must be greater than 6 (5 for each cross-check and one for the training sample). Therefore, it was necessary to group the values of the model parameters according to the given threshold value. If a field value was missing for most start-ups – it was removed. If only a part was missing – the value was manually supplemented. Qualitative information was taken from the start-up website and open sources, and quantitative information was filled in by the mean method of missing values replacement. As a result, 14 fields characterising a start-up were formed (Table 2). In the final, for better operation of machine learning algorithms, all qualitative variables, except for the dependent one, were converted to binary form.

All stages of the implementation of the start-up success prediction model were carried out, namely:

- selection of machine learning algorithms;
- the division of the sample into test and training samples;
- tuning model hyperparameters;
- selection of metrics for evaluating the model quality;
- implementation of algorithms;
- cross-verification of all forecasting accuracy metrics;
- comparative analysis of forecasting efficiency.

Thus, according to the developed methodology and the proposed algorithm, three models for predicting

the success of a start-up were implemented: Decision Tree, Logistic Regression, and a Random Forest.

During studying the results of forecasting by the Decision Tree method the calculated results according to the ROC-AUC metric were set at 66.5%. This level means that the model allows to predict the success of a start-up more likely than it would be done randomly. After cross-validation, lower model performance results were obtained. The minimum values for Roc_Auc and Accuracy are of particular concern. They are less than the threshold value for the effective model – 0.5 (Table 3). To improve the forecasting accuracy, the model hyperparameters were adjusted (Table 4). This allowed increasing the minimum values of the forecasting accuracy using the Roc_Auc and Accuracy metrics to 0.512 and 0.5, respectively (Table 5). In Figure 5 the ROC curve is above the dashed line, which means that model is more efficient than random distribution into classes.

As Table 6 demonstrates, the logistic regression model yielded unacceptable results to claim that this model is effective – it did not pass the 0.5 thresholds. The next step was to improve the prediction results by adjusting the model hyperparameters. Table 7 demonstrates the model hyperparameters that gave us the highest minimum values for Roc_Auc and Accuracy. Table 8 presents the forecasting results considering the new hyperparameters: Roc_Auc – 0.575 and Accuracy – 0.5. Figure 6 the ROC curve is above the dashed line, which means that the model presented in this study is more efficient than random distribution into classes.

Evidently, the minimum values of the Roc_Auc and Accuracy parameters after cross-verification of the random forest model were established at the level of more than 0.5, which indicates the acceptability of the model for decision-making. The average values were established at the level of 0.645 and 0.57, respectively (Table 9). The hyperparameter optimisation process did not give significant results, so conclusions were made based on their default values. In Figure 7, the ROC curve is above the dotted line, which means that model is more efficient than random distribution into classes.

To compare the models, the average values of the characteristics of forecasting efficiency were calculated (Table 10). Since, for all models, the highest accuracy rates are observed in terms of Specificity, which means that models are better at recognising start-up failure than its success. The most descriptive indicators are Sensitivity and Accuracy because they are focused on measuring the accuracy of predicting the success of start-ups. Therefore, even if the weighted accuracy indicator Roc_Auc in the logistic regression (0.645) and random forest (0.645) is higher, but due to a more accurate prediction of negative factors, the decision tree will be considered as the most effective model (Sensitivity – 0.547, Accuracy – 0.612).

As a result of the work performed, the key factors influencing various manifestations of a start-up success are defined. In addition, the study revealed a methodology for cleaning and preparing data for modelling using machine learning methods. For the first time, this paper describes an algorithm for working with missing data by manually adding information from open sources and according to the method of mean missing values replacement.

The efficiency of the method proposed can be confirmed by the effectiveness of forecasting based on generally accepted assessment metrics and performance thresholds. To make the research more practical, it relied on publicly available data. This is a considerable advantage over the studies [4], [5] due to the simplicity of implementation and the possibility of repeating the modelling processes. Achievement of high-quality results of predicting success, based on a much smaller list of start-ups and their characteristics, makes the study more universal for application in emerging markets than studies [14] and [15], which were based on start-ups from all over the world, mainly from the USA and Europe.

In this study, much more attention is paid to methods of improving forecasting efficiency than in similar studies [9; 10]. The process of tuning the model hyperparameters was implemented, conducted multiple cross-validations against five different metrics for evaluating the quality of the models. This allowed investigating the model from different angles of its efficiency as opposed to only one – the number of positively predicted observations, as in the study [11].

Upon critically evaluating the obtained results, it is advisable to pay attention to certain limitations that are inherent in them as follows:

1. The results of the practical implementation of the models are very strongly influenced by the country's economic environment. In some countries with a better investment climate, start-ups can achieve better results even with worse characteristics than in the models provided in this study. While in countries with the worst estimates of the investment climate, even promising start-ups can fail due to the lack of infrastructure to support their development.

2. The disadvantage of the proposed methodology is that the success of a start-up is highly dependent on the field of start-ups activity (specialisation). Since every day new trends are formed, new technologies appear, new inventions are commercialised, some start-ups and areas that are relevant and promising now, over time, will no longer be of interest to investors.

3. The proposed algorithms are incapable of predicting the success of a start-up in the early stages. To forecast success, one needs to wait for at least some results of activity, and only then predict. For many real-life investors, this may be too long.

CONCLUSIONS

Predicting start-up success is a challenging task that is critical for many stakeholders making decisions about their start-up investments. The decision support system for the investment object can be useful for entrepreneurs, venture analysts, or politicians who can use the built models to predict the success of a start-up, using such start-up characteristics as the economic sector and business model, basic technologies, and indicators of digital activity, time to first funding and its amount. This forecast, in turn, can be used to drive better investment decisions and develop relevant economic policies to improve the overall start-up ecosystem.

The machine learning algorithms used are based on data on the receipt of investments by these start-ups in 2017-2021. Given the limited number of start-ups, it was decided to accept the fact of re-investment (investment success) as a start-up's success. 3 machine learning models, that allow predicting the probability of success of start-ups, were built: Decision Tree, Logistic Regression, and a Random Forest. Evaluation of the accuracy of the developed models was a key task of the work. The effectiveness of the algorithms was tested according to five indicators: Accuracy, AUC, Sensitivity, Specificity, and F-score. Compared to the initial experiments, the accuracy of start-up success prediction has been successfully improved by adjusting the model hyperparameters. The built models are qualitative without signs of overfitting, which can be seen by evaluating the results of cross-verification.

The results were cross-verified using metrics such as AUC (Area Under the Curve), Sensitivity (True Positive Rate), Specificity (True Negative Rate), Accuracy, Recall, Precision, etc. The value of these metrics allows asserting that predictions made based on developed models are better than based on our judgments or randomness. The decision tree model demonstrated the highest Accuracy, Sensitivity, and F-scores for the tested algorithms, averaging 61%, 55%, and 52%, respectively. This allows recommending the use of a decision tree algorithm to predict the start-up success. The AUC score for the decision tree settled at 58%, which is lower than the logistic regression and random forest result (65%). That is, the last two models allow for better prediction of the start-up's failure which is also extremely useful proceeding from the interests of practical usage. All models have an acceptable level of AUC classification accuracy to confidently confirm their efficiency.

Further research may lie in scaling the proposed approaches to other markets or groups of regions at the same stage of economic development. It is necessary to continue the search for other algorithms that would allow for a better understanding of the correlation between different types of start-up activity and different manifestations (types) of its success.

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Застосування методів машинного навчання для прогнозування успіху стартапу

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Анотація. Прогнозування успіху новоствореного підприємства завжди було актуальною задачею як для інвесторів, так і для дослідників. У теперішній час вона набула ще більшою актуальності стосовно стартапів – молодих інноваційних технологічних підприємств, спрямованих на масштабування свого бізнесу. Дане дослідження спрямоване на створення моделі прогнозування успіху стартапу на основі його описових характеристик. Використовуючи дані платформи Dealroom стосовно статистики фінансування стартапів та їх опису, розроблена модель, яка пов'язує такі характеристики стартапу як: період від заснування до отримання першого фінансування, сфера діяльності, тип і сума першого раунду фінансування, бізнес-модель і застосовані технології із інвестиційним успіхом стартапу, під яким розуміється отримання повторного фінансування. У фінальну вибірку увійшло 123 стартапи, які засновані або ведуть свою діяльність в Україні. Порівняно три алгоритми машинного навчання – логістичну регресію, дерево рішень і випадковий ліс. Незважаючи на обмеженість доступних даних, отримані прийнятні результати з точки зору Accuracy, Sensitivity та F-score. Найкращою моделлю з точки зору передбачення успіху стартапу визначено – дерево рішень, із показниками середньої точності 61 %, 55 %, і 52 % відповідно. Оцінка AUC для дерева рішень встановилася на рівні 58 %, що нижче показників логістичної регресії та випадкового лісу (65 %), але останні моделі досягли таких високих результатів за рахунок кращого передбачення провалів стартапів, у той час коли ж більш практично-значущим є можливість передбачення їх успіху. Всі моделі показали прийнятний рівень точності класифікації AUC, що з впевненістю дозволяє стверджувати про їх ефективність. Система підтримки прийняття рішень стосовно об'єкту інвестування може бути корисною для підприємців, венчурних аналітиків або політиків, які можуть використати побудовані моделі для прогнозування успіху стартапу. Цей прогноз, зі свого боку, може використовуватися для прийняття більш ефективних інвестиційних рішень і розробки релевантної економічної політики, спрямованої на поліпшення загальної екосистеми стартапів

Ключові слова: стартап-екосистема, стартап, інновації, система підтримки прийняття рішень, класифікація, моделювання даних, передбачення успіху стартапу

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Sustainable Development: Strengthening of Food Security in EU Countries

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Abstract. The issue of food security is relevant for all countries, but it does not have a universal solution. In particular, this is confirmed by the countries of the European Union, which, despite a common food policy, demonstrate different levels of food security. Using their example, this study aims to develop recommendations for improving food security in the context of sustainable development. The study is based on quantitative approaches and analyses the main food security indicators of the Czech Republic, Germany, the Netherlands, and Norway, based on data from the Food and Agriculture Organisation of the United Nations. This study proves the need for more detailed development of individual development strategies in the field of food security in the context of sustainable development. The main differences between the food systems of the Czech Republic, Germany, the Netherlands, and Norway in terms of average food energy needs, GDP per capita, the number of obese adults and food security per capita were identified. There have also been changes in the food security systems of the Netherlands and Norway, which have reduced the volatility of food supply per capita in 2010-2020. EU countries need to stabilise volatility to increase food security. EU Member States' attempts to implement new food security policies must consider the local specificities of food systems. Despite the common problems of waste, nutrition of different social groups, obesity, equal access to food, sustainable production, implementation of research and development of the food security programme, the degree of these challenges varies. The practical value of the study lies in the empirical assessment of the state of food security on the example of the Czech Republic, Germany, the Netherlands, and Norway in 2000-2020, which proves the need for differentiation in the common food security policy

Keywords: Common Agricultural Policy (CAP), sustainable development, sustainable food system, diets, agriculture

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INTRODUCTION

Food security enhancement is a principal issue for countries with different socio-economic development. In developed countries, the main problem is healthy food, environmental friendliness, and the organic market products development. In developing countries, the main problem is food safety, accessibility, especially for citizens with low income. In this context, sustainable development of the agricultural sector plays a strategic role in improving food safety, access, quality, environmental friendliness [1]. Food security is a global challenge even in the most developed countries. The dynamic food system globalisation is accompanied by the increasing complexity of trade links, climate change, transformational processes of production, determination of the availability of food for different countries [2].

Food security is a difficult problem to solve because it is not limited geographically or socially within a single demographic, educational, income group of people. Approximately 690 million people (381 million in Asia and 250 million in Africa), representing 8.9% of the world's population, suffer from hunger while having sufficient food. One in ten people on the planet is food insecure, and 2 billion people do not have regular access to ample, safe, and nutritious food [3]. This paradox of abundant but unequal access to food for different population segments makes food security an urgent issue. Governments must be guided towards balance through sustainable food security strategies that address growing food insecurity due to multiple wastes in some countries and ever-increasing inaccessibility, food scarcity in others. Current projections imply a 70% increase in global food production by 2050 with overexploited, limited infrastructure [4].

EU food security policy has been implemented since the late 1960s. Common Agricultural Policy (CAP), EU bioenergy policy, trade policy, development aid and assistance policy, fisheries policy, macroeconomic policy, and immigration policy are closely linked as components of EU food security [5]. Experts and international organisations have criticised the lack of coherence of these components of EU policy and the inconsistency of their impact on developing countries. For example, the EU's stabilisation of domestic agricultural markets through high tariffs and export subsidies has harmed developing countries. The increase in taxes has led to the dumping of surplus production of the agrarian sector, lower market prices, and destabilisation of global markets.

Local production in developing countries began to decline. It points to the other side of CAP policies that exploded EU development policy, the goal of which was to create local food supply chains. EU policies on renewable energy (biofuels) and trade (tariffs, restrictive import standards) have also been criticised due to incoherence with EU measures to combat nutrition and food security problems. Therewith, EU food security policies are constantly changing, responding to global challenges regarding sustainable development. Food aid policies, for example, have transformed significantly in recent decades.

The EU provides the most poverty-stricken countries with development-oriented trade preferences (e.g., the Everything but Arms initiative), the purpose of which is to help producers in developing countries. CAP policies have also changed dramatically since the early 1990s. In addition, the "food crisis" of the late 2000s confirmed that the impact of food prices on food security is complex: the consequences are often opposite for consumers and producers in poverty-stricken countries. The new challenge for EU food security policy is the development of the non-tariff barrier to trade through the EU food standards' implementation. It restricts small farmers' access to markets in developed countries, worsening their food security.

The purpose of this paper is to develop recommendations to improve food security under sustainable development, using EU countries as an example.

LITERATURE REVIEW

The first phase of the food security policy development covers the period between 1958 and 1992. Its primary goal was to ensure food safety, increase production and create "European agricultural prosperity" by protecting farmers and consumers in a market economy. Regulated prices and the elimination of domestic trade barriers were defined as the main results of the policy. Food security was viewed as food availability [6]. The regulatory regime focused on creating a single market for agricultural products, and policy measures focused on the agricultural modernisation paradigm to increase productivity. The environmental component was not considered in this policy [7].

The second phase (1992-2000) was characterised by the European agriculture identification within the free trade framework. Environmental concerns about food quality were integrated into agricultural policy. Policy measures were aimed at encouraging farmers to use environmentally friendly production methods. Meanwhile, EU policy has been an opponent of trade liberalisation for face beef and genetically modified organisms (GMOs) [8]. EU's local products were protected by a regulatory framework.

The third phase (2000-2013) emphasised on high food quality standards, safety, sustainable agriculture, and EU rural development. The 1999 CAP reform was enshrined in the European Commission's "Agenda 2000'5" strategy document, which outlines rural development policies, defines subsidies and policy instruments, and recognises the multiple functions of agriculture [9; 10]. The UN embodies the broad concept of sustainable development [11].

Since 1999, food security policy has been characterised by two contradictory directions: the first, aimed at solving problems of competitiveness in the market, the second — the development of rural areas of the

multifunctional role of agriculture. The latter included the involvement of regional governments and dynamic funding under the EU cohesion policy. Integration with other policies in various areas involved the implementation of the "cross-compliance" principle [12], according to which farmers are eligible for CAP financial support if they comply with social welfare, environmental, and food safety regulations of animal origin.

Subsequent phases of EU food security policy development (2013-2019) suggested CAP reforms in 2013 under the impact of the 2007-2008 food crisis when global food prices began to rise sharply. Accordingly, food price volatility as a component of food security has been actively discussed in the academic literature [13].

However, food security is mainly interpreted as a problem of food availability, maintaining high levels of production, and supporting farmers [14; 15]. The need to align food production with sustainability has given rise to the concept of sustainable intensification [16]. EU policies, therefore, include greening and the introduction of environmental measures, namely payments for clean food production methods [17].

The new phase of food security policy is characterised by political problems within Europe, Brexit, the awakening of nationalism, inequality problems, unequal access to food, social problems, and migration. In the last decade, attention has shifted evenly from sustainable agriculture to the broader food system. New food security policies are paying more attention to social issues under sustainable development context, as prescribed in the New European Consensus on development of the European Council in particular, which has given rise to new discussions on policy integration [18; 19].

These discussions cover malnutrition, waste, nutrition of different social groups, obesity, equal access to natural resources, ensuring sustainable management of production processes, implementation of food security research and development programs [1; 20; 21]. McCarthy et al. [4] identified 5 weaknesses in food system governance that affect food security: mismanaged cross-scale, geopolitical, and sectoral interdependencies, unequal food rights, power imbalances, and conflicting values. As J.J. Candel and R. Biesbroek [6] note, at the European Union (EU) level, awareness of various food security issues has led to an awareness of the need for integrated approaches to food security governance.

The political integration of food security strands, according to different concerns, has been slow and gradual, including its new dimensions (food safety, food availability). Therewith, there are differences between policies across the EU, and efforts to integrate these policies seem to have stopped in recent years [6]. J.C. Bureau and J. Swinnen [22] argue for the complex impact of EU countries' reformed policies on agriculture, food and food standards, bioenergy, and trade on global food security.

The FOOD2030 Policy Framework for Research and Innovation suggests four priority areas for research and innovation: "nutrition for sustainable and healthy diets; climate-smart and environmentally sustainable food systems; circularity and resource efficiency of food systems; and innovation and empowerment of communities" [5]. However, significant changes in food security policy are currently lacking.

The European Commission's Common Agricultural Policy (CAP) proposal for the post-2020 period provides opportunities for greater sustainability. However, it also allows Member States to choose how to implement their security policies [23].

Thus, EU food security includes aspects of healthy diets, food safety, availability, affordability, sustainable use, and sustainability of production. These aspects of secure food systems are not only compatible in the context of outcomes and important sustainability goals for food systems but should theoretically complement each other in terms of synergy and impact on achieving high bone of population living [24].

MATERIALS AND METHODS

This research is based on a quantitative methodology of the principal food security indicators' analysis of the Czech Republic, Germany, the Netherlands, and Norway as countries of different EU regions and different indicators of socio-economic development. The source database is the Food and Agriculture Organisation of the United Nations Database [25], which allows real-time selection of security indicators, namely:

1. Average dietary energy requirement (kcal/cap/day).
2. Gross domestic product per capita, PPP, dissemination (constant 2011 international $).
3. Number of obese adults (18 years and older) (million).
4. Per capita food production variability (constant 2004-2006 thousand int$ per capita).
5. Per capita food supply variability (kcal/cap/day).

They were selected based on their availability in the 2000-2020 database for all countries. The selection of indicators revealed a lack of disaggregated data on the availability, safety, and quality of food, health indicators, particularly in different age groups. It means that the sustainability state of food security cannot be assessed for all EU countries, which is a considerable limitation for this study. The lack of detailed data renders the analysis of the actual food security issues impossible.

RESULTS AND DISCUSSION

Under the sustainable development context, the food security goals to be achieved by 2030 are defined as follows:

1) to provide all of the world's population with safe and sufficient food by 2030, to completely mitigate famine;

2) to fully eliminate all forms of malnutrition by 2030, including malnutrition in children under the age of five, to meet the needs of pregnant women, adolescents, lactating women, and the elderly;

3) to double agricultural productivity, the income of small agricultural producers (fishers, pastoralists, farmers) through equal access to land, inputs, financial services, knowledge and information, markets for surplus-value, increased employment of non-agricultural production sector;

4) to ensure the sustainability of the food production system, implementation of sustainable agricultural production methods to maintain ecosystems, strengthening adaptation, climate change, drought, extreme weather conditions, gradual improvement of soil quality;

5) to support genetic diversity in seeds, cultivated plants, farm animals, especially through well managed and diversified seed and plant banks at different levels (international, national, regional), promoting equitable access and benefit-sharing of genetic resources and associated knowledge;

6) to increase investments through enhanced international cooperation mechanisms in rural infrastructure, agricultural research and service delivery, technology development, and plant and livestock gene banks to raise levels of agricultural production in developing countries, specifically in least developed countries;

7) to introduce measures for ensuring the proper functioning of markets for food products and derivatives, facilitating timely access to market information, including food stocks, to limit excessive food price volatility.

Food security indicator analysis demonstrates approximately average energy requirement for food in different EU countries: the Czech Republic had 2,530.5 kcal/cap/day, Germany had 2,543.0 kcal/cap/day, the Netherlands had 2,576.83 kcal/cap/day, Norway had 2,549.5 kcal/cap/day (Tables 1-4). Gross domestic product per capita at purchasing power parity (PPP) was highest in Norway at $63,753 per capita, compared with $54,801 per capita in the Netherlands, $5,210 per capita in Germany, and $384 per capita in the Czech Republic. Therewith, the Czech Republic had the highest growth rate, averaging 2.2% annually from 2000 to 2020, while Germany had 0.9% annually, the Netherlands — 0.69% annually, and Norway — 0.55% each year. It means an income sustainability issue, which is ensured in the Czech Republic due to the economic growth potential and exists to some extent in the most developed countries with a high level of prosperity (Table 1). For the Czech Republic, this trend means improving the population's quality of life and, thereby, food security.

Table 1. *Food security indicators in the Czech Republic, 2000-2020*

Indicator of food security	Average			Standard deviation
	2000-2010	2010-2015	2015-2020	2000-2020
Average dietary energy requirement (kcal/cap/day)	2,566.91	2,542.33	2,530.50	17.89
Gross domestic product per capita, PPP, dissemination (constant 2011 international $)	30,038.26	34,231.67	38,492.82	4601.56
Number of obese adults (18 years and older) (million)	1.87	2.15	2.25	0.19
Per capita food production variability (constant 2004-2006 thousand $ per capita)	16.58	14.62	15.17	4.67
Per capita food supply variability (kcal/cap/day)	69.09	17.00	59.40	36.29

Source: *Food and Agriculture Organisation of United Nations Database [25]*

The number of obese adults (18 years and older) is a crucial problem in Germany, where the rate was 15.2 million on average for 2015-2020, with an annual standard deviation of 1.38 million (Table 2). Overall, this rate increased substantially from 12.22 million in 2000-2010 to 15.2 million in 2015-2020. By comparison, in the Czech Republic, the rate was 2.25 million, up from 1.87 million in 2000-2010; in the Netherlands, the average obesity rate was 2.75 million in 2015-2020; in Norway, it was less — 0.9 million on average in 2015-2020.

Table 2. *Food security indicators in Germany, 2000-2020*

Indicator of food security	Average			Standard deviation
	2000-2010	2010-2015	2015-2020	2000-2020
Average dietary energy requirement (kcal/cap/day)	2,548.18	2,553.00	2,543.00	5.93
Gross domestic product per capita, PPP, dissemination (constant 2011 international $)	44,755.02	49,691.45	52,310.85	3,759.08
Number of obese adults (18 years and older) (million)	12.22	14.15	15.20	1.38
Per capita food production variability (constant 2004-2006 thousand $ per capita)	12.18	6.75	8.13	3.41
Per capita food supply variability (kcal/cap/day)	33.27	27.67	26.00	10.25

Source: *Food and Agriculture Organisation of United Nations Database [25]*

The change in food production per capita (constant $2004-2006 thousand per capita) fluctuated significantly in the Czech Republic, averaging $16.58 thousand per capita in 2000-2010, $14 thousand per capita in 2010-2015, and $15.17 thousand per capita in 2015-2020. In Germany, the figure was $12.18 thousand per person, $6.75 thousand per person, and $8.13 thousand per person, respectively, declining significantly from 2000-2010.

In the Netherlands, the figure was $21.42 thousand per person, $20.23 thousand per person, and $18.3 thousand per person, according to a significant fluctuation from 2000 to 2020 and a non-significant decrease. In Norway, the figure was $4.41 thousand per person, $4.87 thousand per person, $4.37 thousand per person, in line with a slight fluctuation of $1.57 thousand over twenty years (Table 3).

***Table 3**. Food security indicators in Netherlands, 2000-2020*

Indicator of food security	Average			Standard deviation
	2000-2010	2010-2015	2015-2020	2000-2020
Average dietary energy requirement (kcal/cap/day)	2,571.73	2,574.67	2,576.83	2.62
Gross domestic product per capita, PPP, dissemination (constant 2011 international $)	50,081.69	52,214.75	54,801.68	2,732.84
Number of obese adults (18 years and older) (million)	1.96	2.50	2.75	0.36
Per capita food production variability (constant 2004-2006 thousand $ per capita)	21.42	20.23	18.30	5.29
Per capita food supply variability (kcal/cap/day)	39.45	8.50	7.80	18.03

***Source**: Food and Agriculture Organisation of United Nations Database [25]*

Food reserve change per capita increased significantly in the Czech Republic during 2015-2020 compared to 2010-2015, ranging from 59.4 kcal/cap/day and 14.62 kcal/cap/day, respectively. In Germany, the rate averaged 26 kcal/cap/day in 2015-2020, with a fluctuation of 10.25 kcal/cap/day over the twenty years. In the Netherlands, the value decreased considerably between 2010 and 2020, compared to 39.45 kcal/cap/day during 2000-2010. In Norway, the figure had also seriously dropped to an average of 10.4 kcal/cap/day in 2015-2020 compared to 30.18 kcal/cap/day in 2000-2010.

***Table 4**. Food security indicators in Norway, 2000-2020*

Indicator of Food Security	Average			Standard deviation
	2000-2010	2010-2015	2015-2020	2000-2020
Average dietary energy requirement (kcal/cap/day)	2,533.27	2,542.00	2,549.50	7.97
Gross domestic product per capita, PPP, dissemination (constant 2011 international $)	60,773.43	61,959.65	63,753.73	2,151.91
Number of obese adults (18 years and older) (million)	0.65	0.85	0.90	0.13
Per capita food production variability (constant 2004-2006 thousand $ per capita)	4.41	4.87	4.37	1.57
Per capita food supply variability (kcal/cap/day)	30.18	11.17	10.40	12.54

***Source**: Food and Agriculture Organisation of United Nations Database [25]*

Thus, the food security indicators analysis demonstrates differences in various EU countries regarding its level, which indicates the unification of particular sustainable development goals in the accessibility, safety, and food quality context. At an elevated level of prosperity, the EU countries are characterised by different challenges in the food security field. For the Czech Republic, the biggest challenge is fluctuations in food production. For all countries, the main challenge can be seen as providing incentives for citizens to address obesity, which has worsened over the past twenty years, especially in Germany, the Czech Republic, and the Netherlands, where a dynamically growing trend is observed.

This study proves the need for individual sustainable development strategies in the food security field. Similar to the findings of K. Pawlak and M. Kołodziejczak [1] regarding the differences in the level of food system security between regions, this paper identifies differences in the food systems of the Czech Republic, Germany, the Netherlands, and Norway. The need for stimulating investment in the infrastructure of the agricultural sector and investing in extension services for food buyers and

consumers are highlighted by K. Pawlak and M. Kołodziejczak [1] as key measures. This study focuses on the government information campaigns development for national citizens to spread awareness of the obesity problem. The availability of food in European countries due to high-income levels, steadily increasing between 2000 and 2020 in all countries, has exacerbated the problem of adult obesity. The latter has increased in all EU countries under study, with some differences in numbers.

The study also proves changes in food security in the Netherlands and Norway, which managed to achieve a reduction in per capita food supply volatility between 2010 and 2020 (by 31.65 and 19.78, respectively). In comparison, the Czech food system was characterised by an increase in supply volatility from 2015-2020, and the German food system achieved a reduction of 7.27 per capita volatility from 2010-2020 compared to 2000-2010. Thus, EU countries should stabilise the volatility to improve food security, as Norway has achieved, where volatility in food production and supply is stable. Over the past twenty years, the Norwegian food system has been characterised by stability in key security indicators: stable energy requirements for food, fixed GDP growth per capita, no significant increase in the number of obese people, a small-scale variation in food production, reduced volatility in per capita stocks. Despite various food security issues and policies to address them, some studies argue that no single policy solution should ensure sustainability in the future [4]. This study proves that more developed countries can better influence food challenges, while less developed countries (the Czech Republic) are less sustainable.

CONCLUSIONS

The efforts of EU Member States' governments to integrate food security policies must consider the regional characteristics of food systems. Despite the common problems related to waste, nutrition of different social groups, obesity, equal access to food, ensuring sustainable management of production processes, implementation of research and development programmes in the food security field, the scale of these challenges is different. Furthermore, in times of economic crisis, food systems are characterised by various levels of resilience and volatility. While the Czech Republic has a higher level of volatility, Norway has a prominent level of food system sustainability. The food security policy should be aimed at individual challenges, depending on the regional social, economic, and environmental country development.

Notably, the goals for the proper provision of the planet's population with food and eradication of various malnutrition forms are slightly optimistic in view of the slow pace of solving food security problems. Therefore, these goals should be adjusted proceeding from regional statistics on these issues. It is advisable to define the purpose of creating an effective food distribution chain, considering regional characteristics of supply, accessibility to the food of different segments of the population, their actual needs per the state of health.

The achievement of the most sustainable global food security will require a holistic systems approach built on a combination of policy and technology reform that leverages existing systems combined with modern technology, methods, and best practices.

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Посилення продовольчої безпеки у країнах ЄС в умовах сталого розвитку

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Анотація. Питання продовольчої безпеки актуальне для усіх країн, утім воно не має універсального рішення. Зокрема, це підтверджують країни Європейського Союзу, які, попри спільну політику щодо продовольства, демонструють різний рівень продовольчої безпеки. Використовуючи їхній приклад, стаття має на меті розробити рекомендації задля покращення продовольчої безпеки за умов сталого розвитку. Дослідження базується на кількісних підходах й аналізує головні індикатори продовольчої безпеки Чеської республіки, Німеччини, Нідерландів та Норвегії, базуючись на даних Продовольчої та Сільськогосподарської Організації ООН. Це дослідження доводить необхідність більш детальної розробки окремих стратегій розвитку у питанні продовольчої безпеки в умовах сталого розвитку. Були встановлені основні відмінності між продовольчими системами Чеської республіки, Німеччини, Нідерландів та Норвегії у питаннях середньої харчової потреби в енергії, ВВП на душу населення, кількості дорослих з ожирінням і забезпеченості їжею на душу населення. Також були доведені зміни у системах продовольчої безпеки Нідерландів і Норвегії, які дозволили зменшити волатильність забезпечення продовольством на душу населення у 2010–2020 рр. Країни ЄС мають стабілізувати волатильність задля підвищення рівню продовольчої безпеки. Спроби країн-членів ЄС впровадити нові політики продовольчої безпеки мають враховувати локальні особливості продовольчих систем. Незважаючи на спільні проблеми щодо відходів, харчування різних соціальних груп, ожиріння, рівного доступу до їжі, забезпечення сталого виробництва, імплементації досліджень і розвитку програму сфері харчової безпеки, ступінь цих викликів є різною. Практична цінність дослідження полягає в емпіричній оцінці стану продовольчої безпеки на прикладі Чеської республіки, Німеччини, Нідерландів та Норвегії у 2000–2020 рр., яка доводить необхідність диференціації у спільній політиці продовольчої безпеки

Ключові слова: Спільна сільськогосподарська політика, сталий розвиток, стала продовольча система, дієти, сільське господарство

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Developing a Marketing Strategy to Improve the Market Activities of Agricultural and Processing Enterprises, Using the Policy of "Goodvalley" as an Example

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Abstract. In the national economies of many countries, especially developing ones, agriculture represents a significant share of GDP. The relevance of the issue stated in the study is due to the fact that the marketing strategy of agricultural enterprises is the most important element of their management system, which contributes to the sustainable development of agriculture and provision of the population with better quality food products. The need to increase the competitiveness of agricultural enterprises among similar ones also contributes to the development of agricultural technologies for obtaining high quality and environmentally friendly products. The purpose of this study is to investigate the nature of a modern agricultural company's marketing strategy. The leading method for investigating this issue is the empirical method, namely examining the practice of marketing strategy in agriculture. As a result of the study, it has been established that a marketing strategy in the agricultural sector should make an enterprise stand out from its competitors through non-price methods. This is primarily due to the peculiarity of agricultural products – they are quite homogeneous, standardised and subject to state regulation not only in terms of safety, but also in terms of conformity with their name. It has been revealed that due to current trends in modern society regarding the need for environmentally friendly production and healthy lifestyles, it is desirable to include these elements in an agricultural company's marketing strategy. Serious work needs to be done to improve the brand image and the image of the producer. These marketing techniques enable an agricultural company to stand out from its competitors and keep prices and demand at the required level. The results of this marketing strategy make it possible to turn a standardised, uniform product from an agricultural producer into an exclusive, special, high-end product

Keywords: agricultural marketing, marketing strategy, agricultural production, agri-marketing, agricultural business

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INTRODUCTION

In many developing countries, more than half of the economically active population is engaged in agriculture. Meanwhile, agriculture is a major supplier to trade and a supplier of raw materials to industry. Hence, it can be concluded that agriculture is the main source of economic growth for many developing countries. Half of the average person's income from a developing country is spent on agricultural products – food. To put this in perspective, in a developed country like the US, people spend only about twelve percent of their income on food, while in Western Europe they spend about sixteen – nineteen percent. In developed countries the standard of living is quite high and the percentage of poor people is small, which is why the government has no difficulty in creating social programmes to provide food to the poor, which also supports agriculture. Poverty levels are very high in developing countries, which requires the use of marketing tools for the development of agricultural enterprises [1].

Modern global economic trends aimed at the development of the agricultural sector require a careful approach to developing effective marketing strategies, which are primarily based on an in-depth analysis of the market environment. Under the current economic conditions, it is only possible to increase the volume of demand for agricultural products, and consequently their sales volumes, by applying an effective marketing strategy [2].

Agricultural marketing (agri-marketing) is the activity in the agricultural sector that involves the full cycle of organisation and management of agricultural production in order to meet the needs of the following entities: households; industry; society. Agricultural marketing can be carried out by the economic entities of the following activities: suppliers of raw materials, materials, equipment for agriculture; agricultural producers; market infrastructure enterprises; trade and trade mediation enterprises of wholesale and retail trade; specialised marketers in the field of agriculture and others [3].

The marketing strategy for the development of an agricultural enterprise is a set of directions for its activities on the market and decision-making focused on individual marketing activities, to the fullest possible implementation of the enterprise's main strategy. Global experience shows that marketing is a means for further development of agricultural enterprises. The development of an enterprise's marketing strategy is therefore a process of creating and putting into practice an overall action programme for the enterprise. Its purpose relates to the efficient allocation of resources to reach the target market [4].

The purpose of the study is to examine the best practices for developing and implementing a marketing strategy for agricultural and processing enterprises. In order to fulfil this objective, the tasks to be carried out include a study of the characteristics of agricultural marketing and a study of the branding of agricultural enterprises.

The external environment of modern agricultural enterprises is characterised by a high level of competition, complexity and uncertainty, which necessitates the use of various marketing tools in order to strengthen their competitive position, both in the national and international markets. A marketing strategy is an essential tool for achieving a high level of competitiveness in an agricultural enterprise. It should be based on a strategic analysis of the strengths and weaknesses of the enterprise, prospective goals and long-term development programmes, and have a tactical action plan [5]. Thus, under current conditions, the development of a marketing strategy for agricultural enterprises has become a prerequisite for their activities, both in national and international markets.

MATERIALS AND METHODS

Today's economy requires innovative solutions when developing a marketing strategy to improve the market activity of agricultural and processing enterprises. Agricultural products, on a global scale, are quite homogeneous; it is this feature of agricultural commodities that has made it possible to sell them on agricultural commodity exchanges. However, in such a case, when the price is formed solely under the influence of supply and demand and the factors associated with them, the agricultural producer faces a high risk of non-return of the invested funds, losses. The marketing strategy of an agricultural enterprise can help to avoid such risks by transforming homogeneous standard products into special, exclusive ones. As practice shows, an agricultural producer should pay great attention to creating a positive image of his or her brands and his or her production. This approach enables the agricultural enterprise to create its own circle of consumers committed to that particular agricultural brand. In the modern market model, economic entities that position themselves as companies with a high level of social responsibility to society have a better chance of increasing their sales without lowering the price. The following research methods were used in the course of the study:

– theoretical (analysis, synthesis, concretisation, generalisation, comparison);

– empirical (study of the marketing strategy of an operating international agricultural company; the individual elements of its marketing strategy; the positive effects that this strategy produces; the use of brand image and producer image improvement techniques in marketing strategy; the role of brand image and producer image in agricultural enterprises).

The study is based on the practical experience of a real agricultural company and on research by scientists and practitioners on the issues of agricultural marketing.

The study of the issue was carried out in three stages:

1. The first stage involved identifying the essence of agricultural marketing, its role in the activities of agricultural companies and the specifics of the marketing strategy. The elements and stages of marketing strategy development and its application in agricultural production are studied. The importance of a marketing strategy for an agricultural company under today's complex, rapidly changing market conditions is explored.

2. The second stage analysed the marketing strategy of the international agricultural company Goodvalley, which has its own production and market outlets in Eastern European countries: Ukraine, Poland and Russia. An assessment of the state of the company is given in order to ascertain its condition. The tools and techniques of a company's marketing strategy are examined. The basic principle of marketing strategy is studied. It has been established that the main efforts of an agricultural company's marketing strategy are aimed at positioning it as a socially responsible enterprise that cares about the environment and produces high quality premium products. Thanks to this kind of marketing strategy, the company was able to make its products more exclusive and set higher prices. This strategy also reduces the company's dependence on market fluctuations, as it operates in a more stable segment – the premium segment.

3. The third stage involved refining the theoretical and practical conclusions, as well as summarising and systematising the findings.

RESULTS AND DISCUSSION

Agricultural marketing is an activity that accompanies the entire cycle of agricultural production, starting with the decision to create a product and ending with its sale to the final consumer, and sometimes also with the after-sales service. It is based on the results of technical and economic analysis and should take into account market, functional and institutional aspects [6]. The marketing strategy of any enterprise should be developed in a comprehensive way. When one element of the marketing strategy is changed, the possible impact on the other elements must be taken into account. Sometimes it seems that the solution to a particular marketing problem may lie in one specific element of the marketing mix. But a deeper analysis will reveal that the problem has a different cause. Thus, it is important to integrate all elements of a marketing strategy.

Firstly, the marketing mix cannot be static. The marketing mix is a dynamic entity. An enterprise cannot stop marketing activities once it has assembled and implemented its marketing mix. At the same time, a company cannot afford to constantly change its marketing strategy every other day. In fact, strategy should be understood and used as the opposite of "special reaction" to changes in the environment, competition, consumer tastes and technologies. Basically, a company's marketing decisions are strategic decisions with long-term objectives and a long-term framework. Nevertheless, they need to be modified and manipulated based on short-term requirements. After all, quite often short-term events do represent vital changes from a marketing perspective, and these changes must be taken into account by appropriate changes in marketing strategy if the enterprise is to achieve its goals on the market. Since the main task of marketing is to successfully anticipate and respond to the changes on the market, the marketing strategy should be flexible and dynamic. In other words, the marketing mix has both long-term and short-term implications. The overall strategy usually remains unchanged over time, but within this framework adjustments and tactical manoeuvres will occur continuously [7].

Secondly, the company's resources are an important factor when deciding on a marketing strategy. It is also clear that decisions about marketing strategy depend largely on the resources available to the company and the resources allocated to a particular business unit. Mere ambition or desire will not lead to the creation of an effective marketing strategy, only resources in the form of money, materials and people can do this. Thus, the form that a marketing strategy will take and the intensity with which each of its elements can be engaged will depend on the resources, the resources of the whole corporation and the resources allocated to each of its business units.

Thirdly, decisions regarding marketing strategy are becoming increasingly complex in multi-business companies. In a multi-business company, although a separate marketing mix is usually developed for each brand / product, it does not work in isolation. After all, the strategy underlying a specific marketing mix for a particular brand plays a much larger role. The strategy as a whole works at four different levels: corporate level, business unit level, product line level and brand level. This link exists not only because of the interrelated nature of resource allocation, but also because of the interconnected nature of the objectives of the enterprise and its constituent business units. Although individual marketing strategy decisions are made by marketers responsible for individual brands/product lines, each comprehensive marketing decision is ultimately aimed at achieving the company's overall business goals. Furthermore, in the case of a multi-industry corporation, the influence of resources on the marketing strategy decision is also of additional importance, since a multi-industry corporation needs to carefully decide how to reallocate its resources to its business, products and markets.

Fourthly, improving competitiveness is the goal and essence of marketing strategy. The main objective of a marketing strategy is to cope with competition. Undoubtedly, it is competition that requires strategy, or, more precisely, fighting competition is the main goal of strategy. Similarly, in a marketing environment devoid of competition, the scale and need for marketing strategies will be much smaller. It is the presence of competition that

makes the marketing task strategic in the first place. In a competitive market alone, a company should definitely study its competitors and promote its policies, people and products in action, i.e. in a strategic way. Strategic actions will help the company gain a clear competitive consciousness. A marketing strategy is basically a competitive position of a company on the market [8]. The following stages of marketing strategy development can be distinguished [9]:

1. Defining business goals and budget.
2. Analysing the external environment of the enterprise.
3. Identifying the target audience.
4. Defining the marketing objectives.
5. Positioning the brand, the products.
6. Drawing up an action plan.
7. Implementation and monitoring of the strategy.

The marketing strategy of an agricultural enterprise, based on the example of Goodvalley, a major international company in Eastern Europe, will be examined. The company Goodvalley positions itself as a manufacturer of quality products and a company that cares about the environment. The company's founder, the Danish Tom Axelgaard, questioned the efficiency and environmental impact of agriculture back in 1980. He began to develop an idea that has evolved into a proven model for sustainable farming. The date of the company's foundation is considered 1994, when Tom Axelgaard bought the first farm in Poland, with the infrastructure concentrated in the middle of a large maize field to minimise the transportation of fodder. This corresponds to his vision that all major areas of activity should be brought together in one place in order to increase sustainability and minimise the impact on the environment. The company has been operating in Ukraine since 2004 and in Russia since 2013. He company is registered in Denmark. Goodvalley specialises in pork production. The company emphasises that it has a full cycle of safe production. The distribution of business revenues by country in 2020 is as follows [10]:

– Poland – 59%;
– Ukraine – 32%;
– Russia – 9%.

The structure of Goodvalley is vertically integrated. Its core activity is the production of pork. The products are produced under its own brand. The basic principle of the company's organisation is to organise sustainable, zero-carbon agricultural production. The company has facilities in three countries: Ukraine, Poland and Russia, and uses Danish technology. The main activities of the company's enterprises [10]:

– crop production;
– production of mixed fodder (own factories);
– pig breeding;
– slaughtering of animals (own slaughterhouse);
– selling live pigs to external slaughterhouses;
– meat processing, production of pork products;
– biogas production.

The company Goodvalley positions its products as premium, made from meat from pigs raised without antibiotics, also positioning its production as environmentally friendly. The company's key performance indicators are presented in Table 1. Figure 1 illustrates the dynamics of the company's assets.

Table 1. *Random Forest cross-verification results*

Indicator	Value
Number of staff	2304 people
Amount of land in use	42,000 hectares
Number of farms	35 units
Number of branded products	15 units

Source: *[10]*

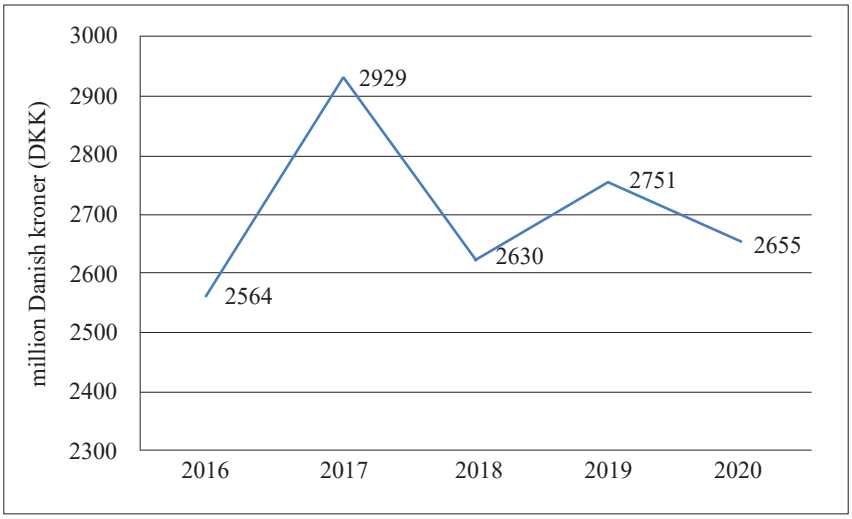

Figure 1. *Dynamics of Goodvalley's revenue and gross profit*

Source: *created on the basis of [10]*

Thus, as for an agricultural company, the enterprise is quite large. Figure 2 presents the dynamics of the company's revenue and gross profit.

As can be seen from Figure 2, the enterprise is highly successful and generates significant profits. However, the company reports that COVID-19 has severely impacted markets in 2020 and Goodvalley's business has also been affected. Market participants reacted sharply and governments enforced quarantine and closed hotels, restaurants and cafes, causing a drop in demand from slaughterhouses [10]. The key features of Goodvalley's marketing strategy are discussed below.

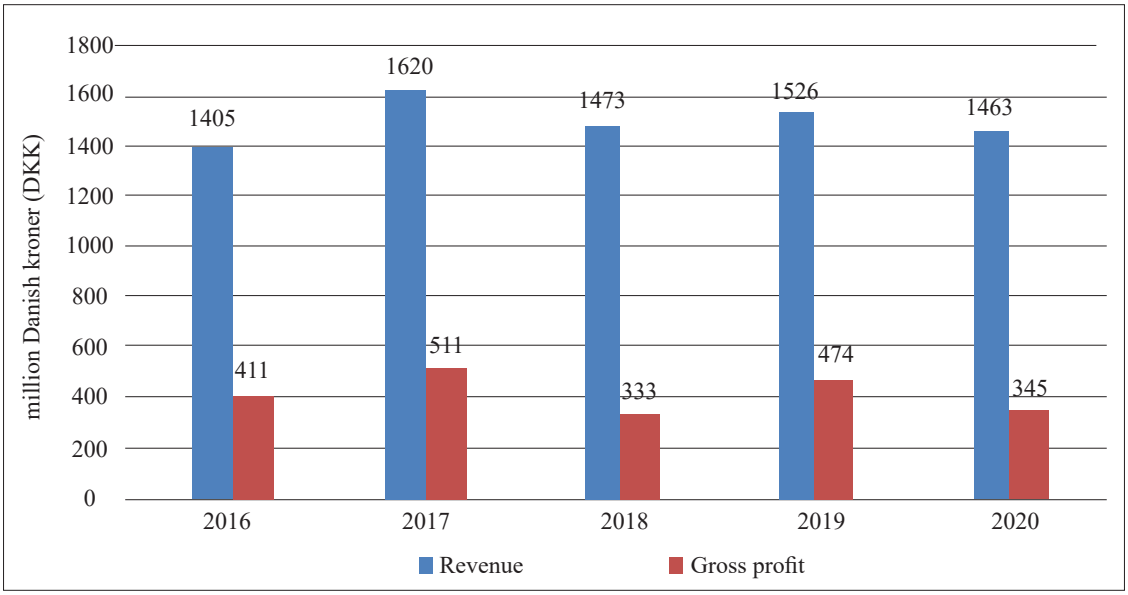

***Figure 2**. Dynamics of Goodvalley's revenue and gross profit*

***Source**: created on the basis of [10]*

Firstly, the company is spreading the idea of caring for the climate. In 2005, the company began using its first biogas plant in Poland, which is positioned in line with the company's ambition to create an integrated, fully sustainable model of farming. The company reports that with this proprietary biogas plant integrated into their production, the company's facilities can now produce environmentally friendly energy from manure and crop waste. This has enabled Goodvalley to get even closer to its goal of being a zero-carbon company. In 2011, the company had already created a full cycle of environmentally friendly production in Poland, and is transferring its unique farming model to other Eastern European countries. In 2011, Goodvalley integrates its first biogas plant into its Ukrainian division. Goodvalley opens a division in Russia in 2013 and introduces its sustainable way of farming there in 2014. The same year, the company is awarded the Transformational Business Award by The Financial Times and the World Bank for being a pioneer in environmentally friendly, carbon-neutral manufacturing. In 2018, the company received a carbon-neutral company certificate for the entire enterprise. In 2019, the company switches to a recycled and recyclable plastic for its products [10].

All of these activities create an image of the company as environmentally conscious and highly socially responsible. Public announcements of this kind on the company's website, in the media, constitute prestige (image) advertising, that is, advertising aimed at creating a positive image of the company, which will give it a competitive advantage over other similar businesses. It is absolutely clear that the company is positioning its brand as "green", concerned with ecology and the environment. Indeed, the modern consumer is more likely to buy the products of a socially responsible business that cares about the environment than a company that does not follow environmental regulations. The products of a company that violates environmental regulations and does not care about the environment in the production of its products may be deliberately ignored by today's consumers.

The company can be said to be using a marketing strategy of greening agricultural production. This type of strategy links the agricultural enterprise, the market and society, and promotes a positive image of the company [11]. The objective of prestige advertising is to create a consumer image of a commercial organisation that is not just positive, but as necessary. In this case, consumer behaviour can be programmed. Tasks to be undertaken to create the necessary image:

– increasing brand awareness;
– creating consumer attitudes;
– an aura of public usefulness for the company;
– product is associated with the brand;
– brand evocative events.

Image advertising affects the emotional level of the consumer, as it is emotion that motivates people to buy the most. Emotional attachment to a brand is created through associations that come from the values a person has formed.

Secondly, the company Goodvalley positions its products as being of high quality and safe for consumption.

Thus, for example, in 2016, the company delivered the first pork products from pigs raised without antibiotics to its markets of presence. Since 2021, the company is also placing QR codes on its products in Poland within the framework of its sustainability philosophy, so that consumers can scan each of them and see its specific path from the field to the customer's table [10]. If people can see how much labour has been put into producing agricultural products, under what conditions the products have been produced, they trust that agricultural enterprise more [12].

A healthy lifestyle and the use of high-quality food products are extremely popular these days. Companies that emphasise the health and safety of their products are able through this trend to increase sales volumes while keeping their prices relatively high. In other words, positioning a product as beneficial and safe for health becomes a significant positive competitive factor. Consumers want to know the origin of the food they have on their table, as this increases their confidence in the quality and safety of the products. The use of QR codes, which provide information on the movement of raw materials and their transformation into finished products, is a good example of addressing this problem.

After the crisis year of 2020, the company updated its marketing strategy. In its accounts for 2020, the company reports a positive trend for its premium branded products in the 2020 crisis year. Due to this market signal, it was decided to strengthen Goodvalley's own brand promotion strategy in Poland. On top of this, the challenge is to sustainably improve efficiency in the main markets where the company operates. It has been found that pork consumption is stable in Western European markets, while it is increasing in Eastern European markets. The reasons for the growth of the market are an increase in the number and income of the population. The company expects the global pork market to grow at a prospective annual rate of 1%, with higher growth rates in its markets of operation. Society, nowadays, pays a great deal of attention to the impact of human activity on the environment, including agricultural production and meat production in particular. The company continues to position itself as environmentally friendly. It will also continue to operate in the premium segment. Certain consumer groups wish to use only higher-quality products in their diet, including premium meat. According to the company, producing high-quality products aimed at these consumers will be a great competitive advantage over traditional manufacturers [10].

The company's next strategic objective is to optimise operations and improve competitiveness, in the current complex and volatile external environment, in order to achieve growth in financial and operational performance through increased volumes of selling both live pigs and processed products. Optimisation work is carried out in the following strategic directions: continuous training of ordinary employees and managers; exchange of experience between the enterprises in the company's three markets of operation; continuous performance monitoring; benchmarking between the company's enterprises; benchmarking between the company's enterprises and the best enterprises in Denmark [10].

Strengthening the company's own brand of premium food products is another crucial area of strategic marketing for the company. The advantage for the company here is the high added value of such products. High quality for the consumer is also determined by product characteristics such as adaptation to the local market and consideration of consumer preferences. Brand name products, widely distributed in retail chains on the Polish market, are characterised by the following, brand characteristics that provide competitive advantages: food security; animal protection; environmentally friendly production. All this enables the company to apply its own sustainable business model to an expensive and growing market segment. Through a diversification strategy, a stable market for premium products enables the company to reduce its dependence on fluctuations in the live pig market and wholesale pork markets [10].

The company is constantly working to optimise production. The company's production capacity is constantly being increased across all stages of production, which contributes to making it more fully utilised. At the same time, territorially, the capacity is built up as close to the markets as possible, which also enables premium products to be produced. As can be seen from the above, the company is constantly improving its brand image. The image of a business organisation represents people's perceptions of it, arising for a variety of reasons. Image affects, and is a significant factor in, others' assessment of a subject's actions. A positive image is essential for a commercial organisation, otherwise it will be very difficult to operate and find contractors and qualified staff. A brand's image has a direct impact on its value.

The objectives of building a commercial organisation's image are as follows: to gain people's trust in the commercial organisation and its products; to create an aura of high quality around the products; to convince the public that the enterprise is unique; and to create a cohesive team of employees. Brand image represents people's perception of the brand, or what they think of the brand. The brand image in people's minds is formed over a period of time. The brand image among people is shaped by their interaction and experience with the brand's products, as well as by the manufacturer itself. Meanwhile, interactions may not necessarily involve purchase and use, but can also take place in a variety of forms [13]. A brand is an intangible asset of a company, and its value is manifested in an indicator such as goodwill. Goodwill is an intangible asset and is measured as the amount that exceeds the net fair value

of all assets and liabilities of the company. Causes of goodwill [14]:

– the value of a brand (trademark) linked to its positive image;

– large number of customers;

– consumer loyalty to the brand;

– company reputation as a good employer;

– availability of intellectual property rights.

Figure 3 illustrates Goodvalley's goodwill data over time.

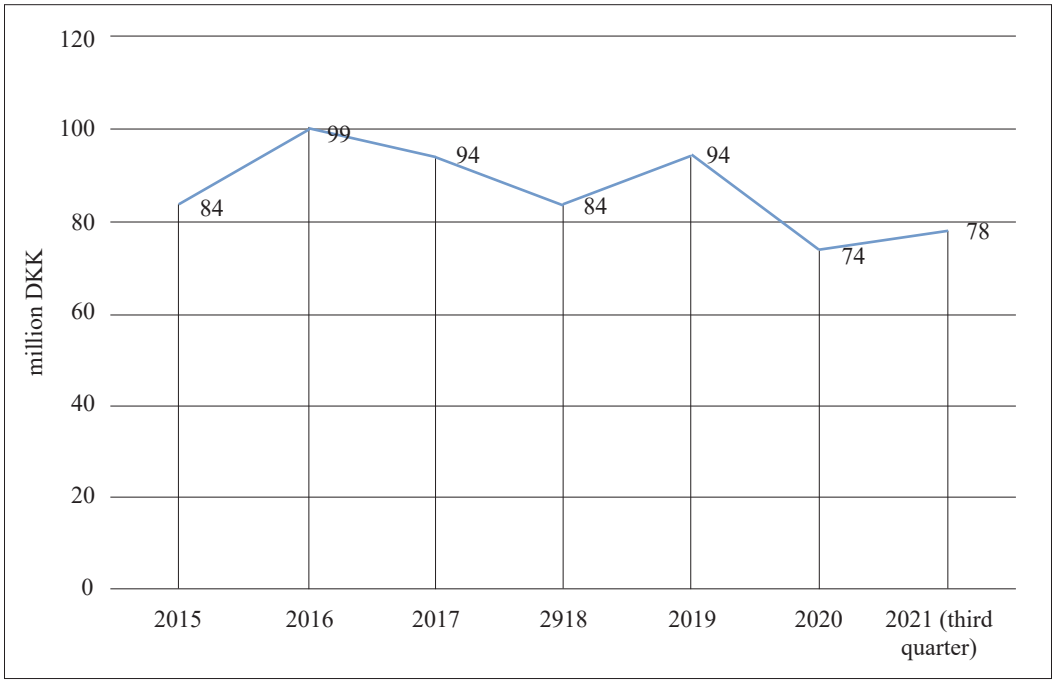

***Figure 3**. Goodvalley's goodwill*

***Source**: created on the basis of [10; 15; 16]*

As can be seen in Figure 3, the company's goodwill is at a relatively high level, despite falling in the 2020 crisis year, then starting to grow in 2021. Thus, it is obvious that the value of a company's intangible assets increases its market value.

The brand is an important factor for consumers when buying goods. This guarantees the quality of the product and allows consumers to experience the added value of the product. Therefore, when consumers buy products, they usually choose to buy from companies with a good brand image. A brand is built through a company's marketing strategy, through repeated promotion, implementation and improvement, as well as consumer feedback. Furthermore, brand improvement is influenced by whether the company implements a marketing strategy for the product. When a company implements marketing strategies, consumer satisfaction depends largely on the company's brand image [17].

The most important principle for a brand to succeed is to consistently and continuously provide consumers with appealing, distinctive offers from its competitors [18]. Thus, Goodvalley's marketing strategy aims to create a highly positive image of a brand that produces quality products while taking care of the environment. This approach gives the company the advantage of competing on non-price factors and selling its goods at higher prices as premium products.

CONCLUSIONS

Agricultural marketing plays an important role in the market activities of modern enterprises in the agricultural sector. The marketing strategy of an agricultural company is essentially the principle of its market activity according to which it promotes its products and acquires consumers. The marketing strategy of agricultural and processing enterprises needs to be original if the enterprise wishes to stand out from the competition. This is primarily due to the characteristics of agricultural products, which for the most part are standardised. Therefore, for the most part, agricultural producers' products may differ only in quality level and brand. As practice shows, consumers are often willing to pay extra for these two components. Product packaging, appearance – all of these play an important role in promotion.

Building a brand image is a complex, time-consuming process that involves not only positioning products as high quality or premium, but also shaping a company's image in the public perception. Nowadays, the concept of the social responsibility of business, which implies that business, among other things, takes care of the environment, has become widespread. An agricultural enterprise the marketing strategy of which involves improving its brand image as environmentally friendly has a much better chance of success than an enterprise that does not do so.

Also popular in modern society is the trend towards a healthy lifestyle, where the choice of quality food products is of utmost importance. Agricultural producers can also exploit this tendency in their marketing strategy by offering higher quality products and positioning them as such. Using these two elements of product and company positioning in a marketing strategy enables it to increase sales while setting relatively high prices for its products. The factors mentioned transform agricultural products from typical, standardised goods into exclusive products that encourage certain groups of consumers to purchase that particular brand and that particular producer.

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Розробка маркетингової стратегії щодо вдосконалення ринкової діяльності сільськогосподарських та переробних підприємств на прикладі політики компанії «Goodvalley»

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Анотація. У національному господарстві багатьох країн, особливо тих, що розвиваються, сільське господарство становить суттєву частку ВВП. Актуальність заявленої у статті проблеми зумовлена тим, що маркетингова стратегія сільськогосподарських підприємств є одним з найважливіших елементів їхньої системи управління, яка сприяє сталому розвитку сільського господарства та забезпеченню населення більш якісними продуктами харчування. Необхідність підвищення конкурентоспроможності сільськогосподарських підприємств серед подібних сприяє також розвитку сільськогосподарських технологій для отримання продукції високої якості та з відсутністю шкоди для екології. Мета статті полягає у дослідженні сутності маркетингової стратегії сучасної сільськогосподарської компанії. Провідним методом для дослідження даної проблеми є емпіричний метод, а саме вивчення практики застосування маркетингової стратегії в сільському господарстві. В результаті дослідження встановлено, що маркетингова стратегія в аграрному секторі має виділяти підприємство серед конкурентів у вигляді нецінових методів. Це пов›язано насамперед із особливістю сільськогосподарської продукції – вона досить однорідна, стандартизована і підлягає державному регулюванню не лише з безпеки, а й відповідно до найменування. Виявлено, що у зв›язку з існуючими в суспільстві тенденціями необхідності екологічно безпечного виробництва та здорового способу життя, дані елементи бажано включати до маркетингової стратегії сільськогосподарської компанії. Необхідно здійснювати серйозну роботу з покращення іміджу бренду та іміджу виробника. Вказані маркетингові прийоми дозволяють виділятися сільськогосподарській компанії серед конкурентів і тримати ціни та обсяг попиту на необхідному рівні. Результати застосування такої маркетингової стратегії дозволяють зробити із стандартизованої, однакової продукції сільськогосподарського виробника – ексклюзивну, особливу продукцію високого класу

Ключові слова: сільськогосподарський маркетинг, маркетингова стратегія, сільськогосподарське виробництво, агромаркетинг, сільськогосподарський бізнес

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Legal Issues of Agricultural Land Use by Owners and Workers

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Abstract. The study investigates the problems of compliance with the legislative requirements in the use of agricultural land in Ukraine, depending on who directly extracts useful properties from such land plots: employees of agricultural enterprises, or the owners of these lands – farmers, members of agricultural cooperatives, citizens who engaging in agricultural production activities individually. The article provides examples of the impact of the activities of workers and the labour of agricultural landowners on the state of land use, compliance with environmental safety requirements, deterioration, and improvement of the quality of land plots. Research of legal issues of targeted, rational, and efficient use of land plots, ensuring the requirements for the preservation of the natural environment, biological diversity and ecosystems contained in the study, provide an opportunity to draw certain conclusions, the essence of which comes down to the fact that the current state of legal relations concerning the use of land plots by employees and landowners needs to be reformed. This is conditioned upon the fact that employees are not motivated to improve the quality of land and its soils, comply with environmental safety requirements, and preserve biological diversity in ecosystems that include the corresponding land plots. Since the main motivation is to obtain a certain benefit, and sanctions for non-compliance with the requirements of legislation in the field of land protection are inefficient, the use of hired labour in agriculture is often described as a negligent and mindless attitude towards land use and ensuring environmental safety. But the owner or user of a land plot that uses it as a farmer, cooperative member, entrepreneur, etc., is motivated not only to make a profit at a given time, but also to improve its quality characteristics, ensure environmental safety, and preserve ecosystem biological diversity, since this is a factor in the stability of obtaining profits from agricultural activities performed on a certain site and in the future

Keywords: environmental safety, biological diversity, ecosystems, soil quality, right to use land plots, agricultural activities, land legislation

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INTRODUCTION

The functioning of the agro-industrial complex is characterised by the establishment of land relations, which are based on the use of agricultural land. Modern conditions of land market reform, particularly the removal of restrictions on the sale of agricultural land, qualitatively and quantitatively change the principles of their use, according to which the need to establish a correspondence between the agricultural sector activities and land law becomes relevant. At the same time, since land is both a natural base of the economic sector of the state and a means of agricultural production, it is important to consider it in the context of rational and efficient use, which determines the relevance of the research topic.

It should be noted that the issue of agricultural land use has been repeatedly studied by a number of Ukrainian and foreign scholars. Thus, K. Sosiedko and M. Palmieri focused on the analysis of the legislative component of the land market in accordance with the land reform in Ukraine [1]. R. Stupen, M. Stupen, Z. Ryzhok, and O. Stupen in their study searched for key issues in the functioning of the agricultural land market, based on which they proposed their method of determining the market value of land plots [2]. V. Kurylo, P. Pantaliienko, and others considered a separate aspect of agricultural land use, in particular, "fragmentation in different agro-climatic zones of Ukraine" [3]. Based on empirical research, scholars have concluded that the issue of land fragmentation is complicated by improper legal regulation. At the same time, according to agro-climatic zones, researchers have established the peculiarities of fragmentation in the mountain area of Ukraine [3]. The scientific works of I.O. Kostyashkin, N.I. Chudyk-Bilousova and others are of particular importance for the current study [4]. The authors conducted a comparative analysis of the functioning and legal regulation of the land market in Ukraine and European countries. Thus, scientists have found that in the context of the full implementation of land relations, it is advisable to consider the factor of land lease. Turning to the experience of legal regulation of land relations in European countries, it is important to emphasise such aspects as "establishing restrictions on the size of the land plot, control of changes in its intended purpose or the establishment of a ban on such activities, as well as restrictions on the right to purchase land by foreigners" [4]. At the same time, in the process of establishing a correlation between Ukrainian and European experience in the legal regulation of land use, it is impossible not to mention the prevalence of farmland tenure in European practices. I.O. Kostyashkin and N.I. Chudyk-Bilousova think that in this way the land fulfills its social role [4]. In the end, the topic of rational and efficient land use is revealed by such authors as O. Zaiets, Yu. Vlasenko and others [5]. Scholars emphasise the importance of environmental friendliness in the process of land reform. In this context, it is a question of legal regulation of land melioration and the use of pesticides and agrochemicals during land use.

Therefore, according to the above, it can be argued that the study of the legal nature of labor in the farm is relevant, given the uniqueness of the very form of land use [6; 7]. Researchers note that this uniqueness is due to the fact that it is created by uniting individuals on the basis of membership in a certain production and social group, the purpose of which is to make a profit through the production of agricultural products [8; 9]. This association is based on the fact that the citizen decides to acquire the status of a member of the farm, thereby assuming certain responsibilities due to the need to transfer his land for use to the specified entity, as well as mandatory labor participation in the activities of the farm itself.

Given the above, *the purpose of the study* is to determine the range of problematic issues of agricultural land use in accordance with the subjects of land relations, owners, and employees in particular.

FACTORS INFLUENCING MOTIVATION FOR TARGETED, RATIONAL, AND EFFICIENT LAND USE

It is worth starting with the fact that in Ukraine, relations arising over labour in the agricultural sector are formed under the influence of several factors that are closely related to each other. The first of these factors is the legal form of the economic entity that directly uses the land plot. The legislation that governs the use of land for the needs of agricultural production defines the list of entities that can carry it out. These include citizens, farms, agricultural enterprises and cooperatives, other legal entities whose main purpose is not to produce agricultural products, religious organisations, educational and academic institutions [10].

The analysis of the impact of the role of agricultural workers on the state of land use and protection should begin with farms, since today this is the most common and, ultimately, the most numerous forms of land use. Thus, according to the State Statistics Service of Ukraine, as of 2020, there are 47.6 thousand farms [11]. They process approximately 15.9 million hectares of agricultural land. Therewith, the number of farms is constantly increasing, as is the amount of land that these entities process (Fig. 1).

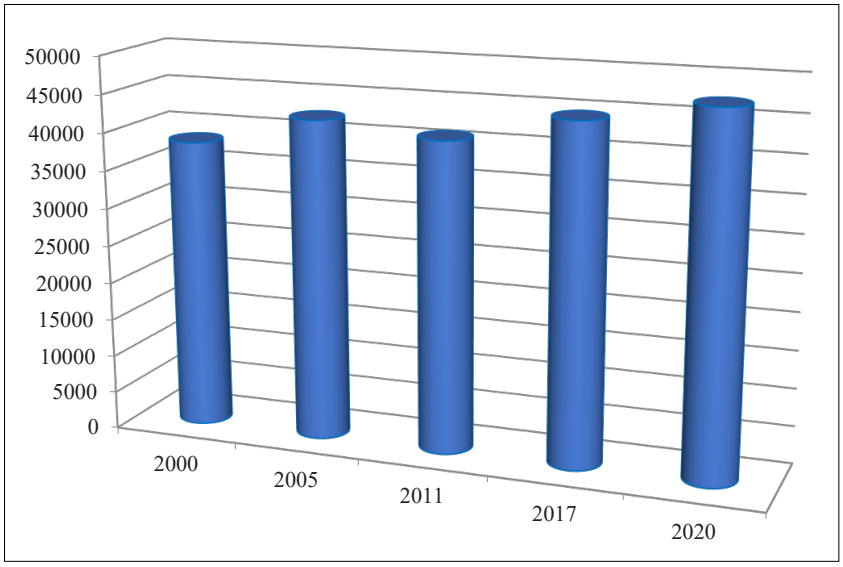

Figure 1. *Statistics of changes in the number of farms on the territory of Ukraine for 2000-2020*

Therefore, since the legislation governing the activities of farms determines the main division of labor into two types, in particular the work of members of the farm and the work of employees, it is advisable to consider the motivation for targeted, rational, and efficient land use in the context of the activities of each individual entity and in accordance with certain factors [12; 13]. Firstly, a farm member is not deprived of ownership of the land plot for the duration of performing certain legislatively prescribed types of labour, the need for which is caused by the status of a farm member. Ensuring the intended use of a land plot, taking measures to protect it, restore and reproduce it, and increase its fertility are the main responsibilities of the land plot owner. Consequently, a farm member who takes a personal labour part in the activities of this family and labour association is directly interested in having the land plots belonging to it used based on the provisions of Article 13 of the Law of Ukraine "On Farming" [8] and Article 32 of the Land Code of Ukraine [7] were restored, reproduced, and protected properly, and the extraction of useful properties from them took place pursuant to their intended purpose.

In case of labour of a farm member, upon performing any functions related to the implementation of agricultural land use, several factors can be traced to ensure the ownership and legality of the use of land plots [14; 15]. First of all, this is the right of ownership of a land plot, which did not cease after the transfer of the right to use it to a farm. Remaining the owner of the land and performing their labour function on it, a farm member is more interested than anyone else in ensuring that this land plot is not depleted, that the necessary fertilisers are applied in a timely manner to at least maintain the suitability of its condition and the possibility of further effective agricultural use, as a maximum – to increase fertility. A farm member, as the land plot owner, is personally interested in ensuring that actions on its agricultural cultivation do not have an adverse impact on the overall condition.

To this end, the landowner will not allow excessive adoption of measures for the introduction of pesticides and agrochemicals, violations of crop rotation rules, and other violations of land or land protection legislation. To ensure such prevention, the legislation on the activities of farms gives the farm member the right to vote in making decisions concerning the nature and procedure for the use of land plots. It is essential that the control of a farm member over agricultural land use activities, preventing them from excessive application of pesticides and agrochemicals to the land plot, and ensuring environmental requirements also has a positive effect on the state of environmental safety.

The second factor influencing the behaviour of a farm member, which causes a positive attitude towards compliance with the requirements of the legislation in the process of extracting useful properties from a land plot, preventing its depletion, improving the condition and increasing fertility, is the common goal of uniting citizens in a farm. In this case, this refers to making a profit. There is no doubt regarding the statement that a large profit from crop-growing agricultural activities will be obtained with the correct use of the land plot, when the subjects of such use comply with all the necessary, scientifically sound requirements. The direct link between the profit and condition of the land plot acts as a fundamental factor in the farm member's labour, which directly affects his or her motivation for targeted, rational, efficient use of land, improving its condition, taking land protection measures, etc.

The situation with the second type of labour used in the activities of farms is somewhat different. This refers to the work of employees. The law establishes absolute differentiation between farm members and employees.

Thus, members of a farm cannot be persons who work in it under an employment agreement. In fact, the legislation does not allow persons in the status of an employee to be farm members. Such a prohibition directly affects the legal status of these entities. If the legal regulation of the work of members of a farm mainly uses acts of land, civil, and economic legislation, then the legal regulation of the work of a subject that performs its activities based on an employment agreement uses only labour legislation. This strongly affects both the characterisation of legal relations arising between an employee and a farm, and the motivation for targeted, rational, and efficient land use.

It is necessary to analyse the differences in the legal status of farm members and its employees, and based on this analysis, draw conclusions on the impact of such differences on the state of land use.

ANALYSIS OF DIFFERENCES IN THE LEGAL STATUS OF FARM MEMBERS AND ITS EMPLOYEES

Taking the previously obtained results of the study of the motivation of a farm member to target, rational, effective use of the land plot as a basis, they can be defined as a combination of factors, including the presence of a land plot in the ownership of a farm member, the possibility of influencing the decision-making of the farm in the field of land use and protection, personal interest in the most efficient use of the land plot to profit from agricultural activities, the desire to preserve the useful properties of the land plot and increase its fertility because the right of membership can be terminated, and the land plot will return from someone else's use.

All these factors are absolutely atypical of the employee's activities. Below, the study considers each of them separately. Thus, an employee does not act as the owner of a land plot that is used by a farm. In other words, the employee has no personal interest in proper and conscientious compliance with the requirements of the legislation on targeted, rational, and efficient land use. Their motivation here will be reduced only to formal compliance with the requirements of the relevant legislation in order not to impose personal sanctions for committing an offence in this area. Such motivation can hardly be considered appropriate to ensure the use of land as the main national wealth. The employee takes absolutely no part in the decision-making process of the farm in the field of determining the procedure for using and protecting land plots in the process of agricultural land use. Admittedly, it is possible to consider their opinion if they perform special functions in the farm related to their high qualifications, but the final decision is still up to the farm members.

In addition, it is unnecessary to include in the list of factors influencing the behaviour of workers and personal interest in the most efficient use of the land plot to profit from agricultural activities. As remuneration for their activities, a worker receives a salary, the amount of which, if it depends on the profit of an agricultural enterprise, then only indirectly, while according to the requirements of labour legislation, it can in no way be reduced if the volume of profit of the enterprise decreases. Only the material aspect, expressed in the form of wages and the need to comply with the requirements of legislation in the field of land use and protection, act as motivation for employees to engage in their professional activities in the agricultural sector. There is doubt concerning the sufficiency of such motivation in comparison with farms members.

However, the situation is more critical when using land by corporate agricultural enterprises. There is a certain tendency for private, temporary interest to prevail here, which is associated with obtaining instant benefits from using a land plot for agricultural production, over public interest. The public interest in this case is to implement the constitutional provisions regarding the definition of land as the main national wealth, ensuring its use for its intended purpose, efficiently and rationally. Large agricultural producers are least interested in the long-term prospect of efficient land use, since the vast majority of their land is leased. The agricultural land market is just starting to form, and legal entities are factually deprived of the opportunity to be owners of such land. These entities use only hired labour in their activities, while this applies not only to the factual performers of work on the production of agricultural products, but also to the management of all links. It is logical that this management is the least focused on preserving the state of land, increasing its fertility, and improving its quality characteristics in the long term. The main purpose is to make a profit, while the performance of the duties of a land user prescribed by land legislation has signs of formality [16].

Profit-motivated agricultural producers resort to excessive use of plant protection products. This leads to a systematic deterioration in soil quality. Economic activity carried out on agricultural land is necessarily accompanied by changes in the quality characteristics of the soil layer, namely a violation of the balance of chemical elements and organic substances in the soil. To predict the results of agricultural activities, it is necessary to conduct periodic agrochemical surveys of soils on agricultural land. Such soil surveys in Ukraine have been conducted since 1966 with a frequency of once every 5 years. During this period, 10 full-fledged rounds of surveys were conducted to determine the quality indicators of soil condition, monitor their changes, and plan measures for the protection and rational use of agricultural land [17].

The authority to conduct agrochemical surveys of soils is currently assigned to the State Institution "Institute of Soil Protection of Ukraine" ("Derzhgruntokhorona"), formed in 2013 by reorganising the State Institution "State Scientific and Technological Centre for Soil Fertility Protection" ("Tsentrderzhrodiuchist") and regional

centres Krymderzhrodiuchist and Oblderzhrodiuchist. The results of surveys conducted by the State Institution "Derzhgruntokhorona" are published in National and periodic reports on the state of the natural environment, on the state of soils on agricultural land and in scientific reports of the National Academy of Sciences of Ukraine. Thus, by referring to the above-mentioned official sources, it is possible to track changes in the qualitative state of soils that occur in the process of economic use of agricultural land.

Among the main factors affecting the state of soil fertility, experts name the main chemical elements necessary for plant nutrition (nitrogen, phosphorus, potassium), as well as organic matter (humus), which ensures optimal air and heat conditions of the soil and improves its structure. It is by these indicators of soil fertility that it is possible to investigate changes in the physical and chemical properties of Ukrainian soils.

According to the results of 5, 6, and 7 rounds of agrochemical certification of agricultural land, over 1986-2000, the humus content in the soils of Ukraine decreased by 0.16% (from 3.35% as of 1986 to 3.19% as of 2000) [18]. Experts assess such scales of dehumification as considerable and associate them with many factors, namely with a decrease in the volume of organic and mineral fertilisers applied; a high degree of ploughing of agricultural land; violation of the rules of crop rotation and structure of sown areas; high intensity of agricultural tillage.

Over the past two decades, the humus content in the soils of Ukraine has somewhat stabilised. Its percentage in the soil ranges between 3.14-3.16% [19]. The slowdown in the rate of dehumification between 2001 and 2021 was achieved thanks to the technology of embedding nutrient residues of agricultural crops in the soil, which are a source of humus reproduction in soils. According to the information presented in the National Report on the State of the Natural Environment in 2019, in some regions of Ukraine (Vinnytska, Zhytomyrska, Zakarpatska, Lvivska, Poltavska, Rivnenska, Ternopilska, and Chernihivska Oblasts), there is a positive balance of humus in the soil, which is ensured by an increase in the volume of ploughing plant residues (straw, green manure, etc.), as well as the cultivation of green mass with its subsequent ploughing [20].

Unlike the organic component of the soil, the nutrient chemical elements in its composition cannot be retained solely by wrapping plant residues. To maintain the balance of nitrogen, phosphorus, and potassium, it is necessary to apply mineral fertilisers to the soil. Consequently, for decades, the dynamics of the content of nutrient chemical elements in the soil composition has changed depending on the intensity of implementation of chemical land reclamation measures. Thus, thanks to intensive measures of chemical land reclamation during the 1970s-1980s, the level of soil supply with chemical elements necessary for plant nutrition systematically increased, as a result of which the first half of the 1990s brought a maximum increase in the content of chemical elements in the soils of Ukraine. On average, this figure reached 112-114 mg of nutrient chemical elements per 1 kg of soil [13].

Since 1991, land reclamation programmes have been almost completely discontinued at the state level. As a result, since 1996, there has been a steady tendency to reduce the content of nutrient chemical elements in the composition of Ukrainian soils. A considerable part of agricultural products of plant origin was produced due to the loss of natural soil fertility. As a result, during 2005-2011, the State Institution "Tsentrderzhrodiuchist" recorded the lowest indicators of nitrogen, potassium, and phosphorus content, which at their minimum level amounted to 107 mg per 1 kg of soil [21]. Since 2012, the downward trend in the concentration of chemical elements in the soils of Ukraine has not changed, but the dynamics of reducing their content has considerably slowed down compared to previous years. If in 2008 the losses amounted to 130 kg per 1 ha of the surveyed land area, in 2009 – 129 kg/ha, in 2010 and 2011 – about 110 kg/ha. From 2012 to the current year, the loss rates of mobile compounds of nutrients and chemical elements on average in the country range between 70-72 kg/ha [21]. This is explained by an increase in the introduction of mineral fertilisers into the soil at the expense of agricultural enterprises and at the expense of local budgets, as well as changes in climatic conditions (warming), which affected the metabolism of nutrients in the soil. According to the State Statistics Service of Ukraine, the total number of agriculture workers is annually decreasing. Thus, in 2010, 738.5 thousand people were employed at agricultural enterprises, in 2015 – 581.8 thousand people, in 2017 – 574.2 thousand people, in 2018 – 559.6 thousand people, in 2019 – 541.9 thousand people [11; 22].

However, according to official data, over the past 10 years, the number of agricultural employees working on hired labour terms for individuals-entrepreneurs has increased (from 1.9 thousand people in 2010 to 3.4 thousand people in 2019) [11]. Such a direct correlation between the number of employees in the agricultural sector and the deterioration of the state of land use proves the need to reform these legal relations by adopting appropriate changes in legislation that would be aimed at prioritising the provision of agricultural land to those entities that perform a labour function as its owners or users, and not as hired workers.

CONCLUSIONS

Thus, it can be concluded that entities that use hired labour are not focused on preserving the state of agricultural land, improving the quality characteristics of such land, ensuring its most rational and efficient use, which is conditioned upon their status of not owners, but users of land plots, lack of personal interest in the long-term sustainable use of land. On the contrary, the

use of land by its owners and enterprises with personal labour participation of members is focused on environmentally balanced land use, increasing soil fertility, and improving the quality characteristics of land plots.

In this regard, when adopting appropriate norms aimed at reforming land relations, it is necessary to provide more preferences to farms, private farms, agricultural cooperatives, and citizens who produce agricultural products on their land plots individually. However, subjects where the main focus is on the use of hired labour should be particularly monitored for compliance with legislation in the field of land protection, as well as compliance with environmental requirements in their activities.

At first glance, it may seem that the problem of motivating persons who factually cultivate agricultural land and managers of agricultural enterprises to rational, efficient, and environmentally balanced land use, the use of hired labour and the labour of members of farms, agricultural cooperatives and private farms lies exclusively in the plane of corporate and labour law. However, this statement is erroneous, since unsuccessful approaches to the process of agricultural production directly affect the state of the natural environment.

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Правові проблеми використання сільськогосподарських земель власниками та найманими працівниками

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Анотація. Стаття присвячена дослідженню проблем додержання вимог законодавства при використанні сільськогосподарських земель в Україні залежно від того, хто безпосередньо здійснює вилучення корисних властивостей із таких ділянок: наймані працівники сільськогосподарських підприємств, або власники цих земель – фермери, члени сільськогосподарських кооперативів, громадяни, що одноосібно провадять агровиробничу діяльність. У статті наводяться приклади впливу діяльності найманих працівників та праці власників сільськогосподарських земель на стан землекористування, додержання вимог екологічної безпеки, погіршення та покращення якості земельних ділянок. Дослідження правових проблем цільового, раціонального та ефективного використання земельних ділянок, забезпечення вимог до збереження навколишнього природного середовища, біологічного різноманіття та екосистем, що розкриті у статті, надають можливість зробити висновки про те, що сучасний стан розвитку правовідносин щодо використання земельних ділянок найманими працівниками та власниками землі потребує реформування. Це обумовлено тим, що наймані працівники не вмотивовані до покращення якості земель та їх ґрунтів, додержання вимог екологічної безпеки, збереження біологічного різноманіття у екосистемах, куди входять відповідні земельні ділянки. Оскільки головна мотивація полягає у отриманні певної вигоди, а санкції за недодержання вимог законодавства у сфері охорони земель неефективні, використання найманої праці у сільському господарстві досить часто характеризується як недбале та халатне ставлення до використання земель і забезпечення екологічної безпеки. Натомість, власник або користувач земельної ділянки, що використовує її як фермер, член кооперативу, підприємець тощо, вмотивований не тільки на отримання прибутку у даний момент часу, а й покращення її якісних характеристик, забезпечення екологічної безпеки, збереження екосистемного біологічного різноманіття, оскільки це виступає фактором стабільності отриманні прибутків від сільськогосподарської діяльності, що здійснюється на певній ділянці й в майбутньому

Ключові слова: екологічна безпека, біологічне різноманіття, екосистеми, якість ґрунтів, право користування земельними ділянками, сільськогосподарська діяльність, земельне законодавство

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