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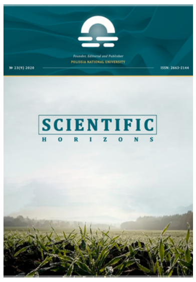

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Influence of the Value of Relascopic Coefficients on the Accuracy of Determining the Stand Basal Area

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Abstract. When conducting angle-count sampling in the forests of Ukraine, the most common is the use of factor gauge with a relascopic coefficient of 1. According to the standards, the recommended value of this coefficient depends on the approximate stocking and mean diameter of the stand and can be 0.5, 1, 2, 3, and 4. Proceeding from the fact that in Ukraine there are no tools for relascopic measurations that would allow making measurements using the 5 values of the relascopic coefficient provided for in the standards, the authors of this paper developed and tested an original model of the factor gauge "Crab". The purpose of this paper is to investigate the accuracy of determining the stand basal area of stands using relascopic coefficients of various values depending on the mean diameter and stand density. By comparing the data on fixed-area plots with a radius of 17.85 m with the data of angle-count sampling, it was discovered that no systematic errors were found that underestimated or overestimated the results of angle-count sampling. It is determined that deviations of the stand basal area from the true values slightly depend on the value of the relascopic coefficient, as well as on the stocking and mean diameter of the stand. According to the authors, the accuracy of the results of determining the stand basal area during angle-count sampling directly depends on the representation of the tree selection zone within the circular sample. This is completely random when using any relascopic coefficient. It is established that in mixed forest plantations, the greatest accuracy in determining the sum of cross-sectional areas of individual forest elements is provided by small coefficients (1, 0.5, and 2). In pure stands, it is advisable to use larger relascopic coefficients (2-4). This implies a corresponding increase in the number of measurements that can better cover stands and increase the accuracy of the results obtained

Keywords: angle-count sampling, fixed-area plots, factor gauge, mean diameter, stocking

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INTRODUCTION

Angle-count sampling is crucial in the system of selective forest inventory. This method, according to many scientists, is one of the greatest achievements of forest measurations [1; 2]. The main task in conducting angle-count sampling was primarily to determine the stand basal area of trees per unit area using protractor tools [3]. However, later, at the beginning of the second half of the 20th century, the possibility of using the method of relascopic samples to determine other tax indicators of the tree stand was proved [4]. At the same time, the basic principles of forming a sample depending on the biometric indicators of trees were described. This eventually led to the establishment of so-called relascopic coefficients (BAF), which directly depended on the diameter of the accounting trees. Based on the results of these studies in Ukraine, as in many countries, the corresponding standards were formed. The standards indicate the values of relascopic coefficients depending not only on the mean diameter, but also on the stand density [5; 6].

Like any sampling method, angle-count sampling gives a certain error in the results of measuring the stand basal area (SBA). In the publication of Finnish scientists [7] on combined plots with a maximum radius of 9 m, the use of angle-count sampling with BAF 1 was evaluated as a promising method for evaluating tax indicators. Technological methods of angle-count sampling, when adapted to the selection of appropriate laser scanning signals, are considered acceptable according to the conclusions of German scientists [8]. Comparison of the results of determining the sum of cross-sectional areas and density by Spanish scientists [9] did not reveal considerable differences in accuracy between inventory systems (relascopic and with a fixed value of the circular sample radius) for most of the stands and forest types under study. Indonesian scientists reached similar conclusions [10]. However, Brazilian scientists concluded that upon determining the SBA and wood stock per 1 ha, it is more expedient to use the angle-count sampling methods [11]. B. Zeide and J.K. Troxell [12] noted that small BAFs lead to a systematic underestimation of SBA. This is usually conditioned upon the presence of dense undergrowth, poor lighting conditions, hidden trees, and incorrect counting at high density [13]. Some Ukrainian scientists have investigated that upon using BAF 1, which is most frequently applied in Ukraine, there is also a systematic underestimation of SBA [14; 15]. However, another study of these scientists notes that the relascopic method with the same value of the relascopic coefficient makes provision for the highest accuracy in predicting tax indicators of forest stands based on the k-NN method [16].

Another controversial issue is the use of the value of relascopic coefficients in inventory. It is quite common to use large BAF values in countries outside Ukraine [17]. In the Scandinavian countries, measurements are made with a relascopic coefficient from 1.5 to 4 [18]. This is explained by the fact that upon measuring in stands with high density, the use of a larger relascopic coefficient avoids cases of overlapping trees. These trees are located further to the centre of the angle-count sample plot. Therewith, it is also possible to reduce the probability of questionable trees getting into the sample [19; 20]. As early as 1955, it was determined that the mean SBA values increase with increasing BAF [21]. According to other scientists [22], large BAFs are effective in sampling, ensuring proper accuracy. Carlton Scott [23] noted that the use of lower BAF values implies lower standard error values and is appropriate in mixed plantations. But the advantage of using large relascopic coefficients is the speed of accounting, which is advisable in low-quality stands. Studies by other American scientists [24] also demonstrated an increase in coefficients of variation with an increase in BAF.

Regulatory reference books in Ukraine recommend using the BAF value depending on the mean diameter and stand density [4]. The forest Tax Reference Book [6], as well as the standards developed under the USSR [5] note that the use of large values of the relascopic coefficient to ensure the necessary accuracy causes a multiple increase (for BAF 0.5 decrease) in the number of measurements compared to BAF 1. However, the "All-Union standards" [3] indicate that due to the low dependence of the efficiency of angle-count sampling on the value of the relascopic coefficient, it is advisable to use optical squares with higher BAF values. To confirm or refute the recommended data on the feasibility of using the relascopic coefficient in stands of varying density and diameter, as well as data on the probable systematic underestimation of SBA in BAF 1, appropriate studies were conducted.

MATERIALS AND METHODS

This study was conducted in three stages. At the preparatory stage, a relascopic template "Crab" was developed and tested for the possibility of performing measurements using 5 BAF values: 0.5, 1, 2, 3, 4. At the stage of field work, SBA measurements were carried out on circular and angle-count sample plots using coefficients 0.5, 1, 2, 3, 4. During desk processing of the data, the accuracy of determining SBA in relascopic areas was analysed, depending on the mean diameter, density, composition, and uniformity of tree placement.

The primary task was to develop a relascopic template with the ability to perform measurements using BAF 0.5, 1, 2, 3, and 4. The main criteria for developing the relascopic template model were the versatility of measurements, ease of use, and the possibility of long-term operation. For the possibility of using the 5 BAF values provided for in the regulatory recommendations: 0.5, 1, 2, 3, 4 the width of the dioptres was calculated accordingly. For the convenience of using the relascopic template, options for fixing the tool using only one hand were provided. The estimated distance of the dioptre from the observer's eye was 50 cm. The accuracy of the scope width for each BAF was checked indoors using sheets of white paper on a dark background. For this, a sheet of paper was attached to a height of 1.3-1.6 m on a vertical dark surface at a distance of 10 m from eye level (the length was determined using a LDM-100 CEM laser tape measure) and sighting was performed through a sighting slot of the appropriate size. When calibrating BAF 0.5, a sheet with a width of 14.1 cm was used, BAF 1 – 20.0 cm, BAF 2 – 28.2 cm, BAF 3 – 34.6 cm, and BAF 4 – 40.0 cm. Upon applying the appropriate value of the relascopic coefficient, Sheets of the specified width had to fit exactly into the dioptre.

Field studies were conducted during the autumn-winter period of 2020-2021 on specially laid fixed-area plots (FAP) with a radius of 17.85 m, which corresponds to an area of 1,000 m^2. The size of the FAP is conditioned upon the purpose of conducting angle-count sampling using BAF 0.5 at the same sites, which involves sampling trees that are more distant from the centre of the sample (the diameter of the boundary trees is 25 cm). In total, 14 FAP were laid in the plantations of Levkivskyi and Tryhirskyi forest districts of the State Enterprise "Zhytomyr Forestry". Plots were selected in such a way that there was no under storey and large young growth. The age of plantations ranges from 20 to 120 years. The density of land plots according to forest management materials ranges from 0.5 to 0.9. According to the composition of stands, the experimental plots differed as follows: 10 FAP in pure stands (8 pine stands, 2 birch stands) and 4 FAP in mixed stands (2 pine stands, 1 birch stand, 1 oak stand). Mixed stands were selected to investigate the correctness of determining the composition of plantations using a factor gauge. Before carrying out angle-count sampling using a template with the conditional name of the model "Crab", a centre was fixed at each FAP and the territory was divided into four sectors using measuring tapes. This was done for the convenience of conducting a list of tree diameters, as well as for further determining the uniformity of their placement. Each tree was measured using a measuring fork with millimetre accuracy. The belonging of the extreme trees to the FAP was determined using a LDM-100 CEM laser rangefinder. The sum of cross-sectional areas was determined using Excel tools under desk conditions. The results of measurements at the CTA served as a control. From the centre of the FAP, each element of the forest was measured using the "Crab" template in 5 variants with the corresponding accuracy for each BAF (from 0.25 m^2 at BAF 0.5, 0.5 m^2 at BAF 1, 1 m^2 at BAF 2, 1.5 m^2 at BAF 3, and 2 m^2 at BAF 4). At FAP No. 5, 9, and 12, where the mean tree diameter was relatively small (8-12 cm), angle-count sampling was performed at three equidistant points in circular samples to ensure the adequacy of samples with BAF values of 2-4.

RESULTS AND DISCUSSION

Proceeding from the results of a continuous list of trees at the FAP, accurate indicators of SBA, relative density and mean diameter were determined. The uniformity of tree placement in FAP can generally be considered uniform, as evidenced by the variability of SBA in sample sectors. Only FAP 7 contained an uneven arrangement of trees (Table 1).

***Table 1**. Results of SBA measurements at experimental sites*

No. sample plot	SBA on the FAP (control), m^2/ha	SBA on the angle-count sample plots, m^2/ha					Mean diameter, cm	Stand stocking	Variability of SBA in FAP sectors, %
		BAF 0.5	BAF 1	BAF 2	BAF 3	BAF 4			
1	33.4	39.5	32.0	34.0	39.0	36.0	23.8	1.14	14.3
2	53.7	50.5	57.0	58.0	60.0	60.0	30.1	1.10	16.5
3	14.7	18.0	19.0	16.0	15.0	16.0	17.2	0.52	17.1
4	27.8	31.5	30.0	22.0	25.5	28.0	30.0	0.86	13.4
5	17.3	20.3	20.8	21.6	19.5	18.8	7.9	0.55	17.8
6	50.6	41.5	52.0	58.0	66.0	64.0	33.8	1.00	8.5
7	29.0	24.5	34.0	31.0	37.5	36.0	30.0	0.67	33.7
8	35.5	35.5	39.5	43.0	45.0	36.0	30.5	0.75	14.7
9	19.3	20.8	18.8	19.0	20.3	22.0	12.3	0.63	13.6
10	38.8	39.0	35.0	40.0	39.0	34.0	35.9	0.79	18.9
11	35.1	30.0	29.5	26.0	25.5	26.0	28.9	0.96	7.7
12	14.8	19.0	18.0	18.0	19.5	22.0	8.9	0.63	11.6
13	23.6	27.5	22.0	24.0	24.0	20.0	17.8	0.88	16.4
14	39.0	41.0	47.0	39.0	39.0	30.0	24.2	0.82	13.4

In fact, in terms of density, 4 plots (sample plots 3, 5, 9, 12) were represented by low-density stands, as well as 4 plots (sample plots 7, 8, 10, 14) were medium-density and, respectively, 6 plots (sample plots 1, 2, 4, 6, 11, 13) were high-density stands. According to the recommendations [4], considering the density and mean diameter of stands in all experimental low-density stands, it would be necessary to perform measurements using BAF 0.5 and 1. BAF 2 and 3 are recommended in medium-density stands, while BAF 3 and 4 are recommended for high-density stands. However, as the calculations proved, the recommended relascopic coefficient in only one experimental site (No. 13) yielded the SBA value close to the control one.

Comparison of measurements of the sums of cross-sectional areas per 1 ha according to relascopic and list taxation data indicated corresponding discrepancies between the values both up and down (Table 2).

***Table 2**. Differences in the results of SBA measurements on the angle-count sample plot compared to the control (FAP)*

No. sample plot	Mean diameter, cm	Stand stocking	BAF, $SBA_{control} - SBA_{angle\text{-}count}$, m²/ha				
			0.5	1	2	3	4
1	23.8	1.14	6.1	-1.4	0.6	5.6	2.6
2	30.1	1.10	-3.2	3.3	4.3	6.3	6.3
3	17.2	0.52	3.3	4.3	1.3	0.3	1.3
4	30.0	0.86	3.7	2.2	-5.8	-2.3	0.2
5	7.9	0.55	3	3.5	4.3	2.2	1.5
6	33.8	1.00	-9.1	1.4	7.4	15.4	13.4
7	30.0	0.67	-4.5	5.0	2	8.5	7.0
8	30.5	0.75	0.0	4.0	7.5	9.5	0.5
9	12.3	0.63	1.5	-0.5	-0.3	1.0	2.7
10	35.9	0.79	0.2	-3.8	1.2	0.2	-4.8
11	28.9	0.96	-5.1	-5.6	-9.1	-9.6	-9.1
12	8.9	0.63	4.2	3.2	3.2	4.7	7.2
13	17.8	0.88	3.9	-1.6	0.4	0.4	-3.6
14	24.2	0.82	2.0	8.0	0.0	0.0	-9.0

Analysis of the difference in SBA indicators during angle-count sampling and control generally indicated that the results of angle-count sampling measurements mostly overestimate the true (control) values upon using all BAF values. Based on the sum of the differences, it was determined that in general, the maximum overestimation of SBA values occurred when using BAF 3, the minimum – when using BAF 2. Underestimating $SBA_{angle\text{-}coun}$ values is mainly observed in high-density plantations, mainly upon using individual BAF values. These results refute the claims of some scientists regarding the systematic underestimation of the SBA values obtained during angle-count sampling [12-14], as well as the hypothesis of the previous studies of the authors of this paper upon using BAF 1 [15]. To compare the accuracy of determining SBA at relascopic sites using different BAF values, the relative deviation for each variant compared to the control was identified (Table 3).

***Table 3**. Results of SBA measurements at experimental sites*

No. sample plot	Mean diameter, cm	Stand stocking	BAF				
			0.5	1	2	3	4
1	23.8	1.14	18.3	4.2	1.8	16.8	7.8
2	30.1	1.10	6.0	6.1	8.0	11.7	11.7
3	17.2	0.52	22.4	29.3	8.8	2.0	8.8
4	30.0	0.86	13.3	7.9	20.9	8.3	0.7
5	7.9	0.55	17.1	19.9	24.9	12.7	8.7
6	33.8	1.00	18.0	2.8	14.6	30.4	26.5
7	30.0	0.67	15.5	17.2	6.9	29.3	24.1
8	30.5	0.75	0.0	11.3	21.1	26.8	1.4
9	12.3	0.63	7.5	2.6	1.6	4.9	14.0
10	35.9	0.79	0.5	9.8	3.1	0.5	12.4
11	28.9	0.96	14.5	16.0	25.9	27.4	25.9
12	8.9	0.63	28.4	21.6	21.6	31.8	48.6
13	17.8	0.88	16.5	6.8	1.7	1.7	15.3
14	24.2	0.82	5.1	20.5	0.0	0.0	23.1
	Mean deviation		13.1	12.6	11.5	14.6	16.4

Notably, the average values of relative deviations in angle-count sampling using 5 BAF values are quite close and do not give grounds to draw any reasonable conclusions. However, the data in Table 3 demonstrates that even with similar values of density and mean diameter, deviations within each BAF value can vary greatly.

Analysis of the dependence of the relative deviation of the SBA on the mean diameter revealed a significant relationship only upon measuring with BAF 0.5 – r=0.53 (Fig. 1). When performing SBA measurements using the BAF 1 value, the dependence of the relative deviation from the mean diameter is moderate – r=0.38 (Fig. 2).

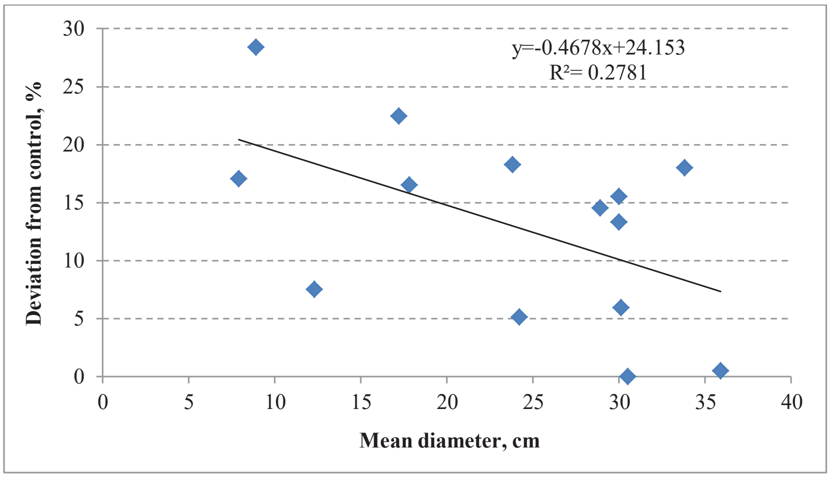

***Figure 1**. Dependence of the relative deviation of the SBA on the mean diameter for measurements with BAF 0.5*

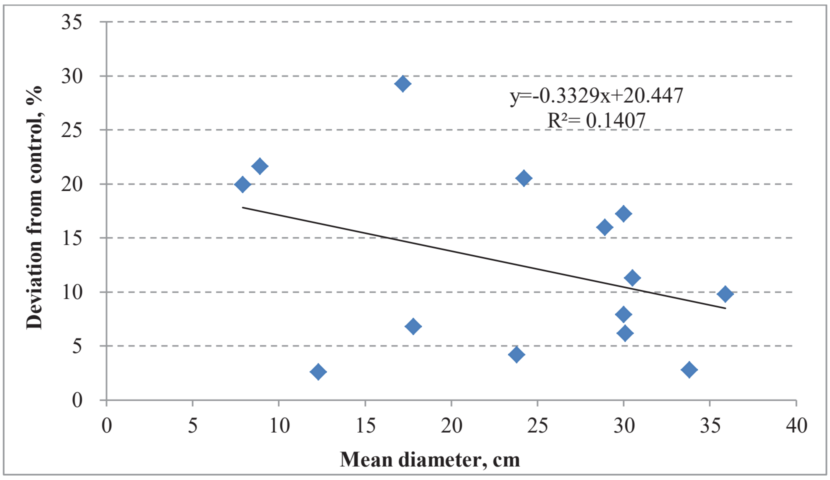

***Figure 2**. Dependence of the relative deviation of the SBA on the mean diameter for measurements with BAF 1*

At higher coefficients (BAF 2-4), no such relationship was detected. For a more thorough analysis, it was decided to group the data of experimental sites depending on their mean diameters and density, similar to the form of recommendations [5]. The first group included four test areas with the smallest mean tree diameter (Table 4). What is common for these sections is low density, which allows using the relascopic coefficient of 0.5 and 1 according to the recommendations. According to the data of relative deviations in these sections, it is noted that the BAF values of 3 and 2 yield slightly higher accuracy.

***Table 4**. Deviation of SBA from the angle-count sample plot control with the recommended BAFs 0.5-1, (%)*

No. sample plot	Mean diameter, cm	Stand stocking	BAF				
			0.5	1	2	3	4
3	17.2	0.52	22.4	29.3	8.8	2.0	8.8
5	7.9	0.55	17.1	19.9	24.9	12.7	8.7
9	12.3	0.63	7.5	2.6	1.6	4.9	14.0
12	8.9	0.63	28.4	21.6	21.6	31.8	48.6
	Mean deviation		18.8	18.4	14.2	12.9	20.0

The second group included test areas with medium-density stands (Table 5). Notably, the accuracy of angle-count sampling at the experimental sites of this group turned out to be better for all BAFs universally. However, the smallest deviations in the determination of SBA were noted for measurements using BAFs 0.5 and 2.

***Table 5**. SBA deviation from angle-count sample plot control with recommended BAFs 2-3, (%)*

No. sample plot	Mean diameter, cm	Stand stocking	BAF				
			0.5	1	2	3	4
7	30.0	0.67	15.5	17.2	6.9	29.3	24.1
8	30.5	0.75	0.0	11.3	21.1	26.8	1.4
10	35.9	0.79	0.5	9.8	3.1	0.5	12.4
14	24.2	0.82	5.1	20.5	0.0	0.0	23.1
Mean deviation			5.3	14.7	7.8	14.1	15.2

The third group included test areas laid in high-density stands, wherein, depending on the mean diameter, it is recommended to measure relascopic areas using BAFs 3 and 4 (Table 6).

***Table 6**. SBA deviation from angle-count sample plot control with recommended BAFs 3-4, (%)*

No. sample plot	Mean diameter, cm	Stand stocking	BAF				
			0.5	1	2	3	4
1	23.8	1.14	18.3	4.2	1.8	16.8	7.8
2	30.1	1.10	6.0	6.1	8.0	11.7	11.7
4	30.0	0.86	13.3	7.9	20.9	8.3	0.7
6	33.8	1.00	18.0	2.8	14.6	30.4	26.5
11	28.9	0.96	14.5	16.0	25.9	27.4	25.9
13	17.8	0.88	16.5	6.8	1.7	1.7	15.3
Mean deviation			14.4	7.3	12.2	16.0	14.6

According to the results of the values of average deviations, the most accurate accounting was found in high-density stands using the BAF 1 coefficient. The remaining BAF values indicate generally similar deviation rates.

Before fieldwork, the working hypothesis was that the accuracy of angle-count sampling at FAP with a radius of 17.85 m using various BAFs would primarily depend on the mean diameter of the trees on the sample. The selection area at BAF 0.5 and 1 is the largest, and at diameters greater than 20 cm will approach the FAP. Therefore, higher accuracy seemed most probable upon using these values of relascopic coefficients. However, behavioural analysis indicated that there was no relationship between the accuracy of different BAF levels and the mean diameter. Only upon conducting studies in four mixed plantations was some connection found. The greatest accuracy in determining SBA in the context of forest elements is provided by small BAFs 1, 0.5, and 2 (Table 7).

***Table 7**. Results of SBA measurements at experimental sites in mixed stands, m^2/ha*

No. sample plot	Stand composition	SBA on the FAP (control) m^2/ha	BAF, SBA on the angle-count sample plots, m^2/ha				
			0.5	1	2	3	4
1	5Cb	15.4	22.5	15	12	12	16
	4Qr	15.1	17	14	20	24	20
	1Ap	3.5	1.5	3	2	3	0
5	8Ps	14.6	16	15.25	17	13.5	12
	2Bp	2.8	4.25	5.5	4.6	6	6.8
9	7Ps	12.9	12.75	11.25	12.5	13.5	14
	3Bp	6.4	8	7.5	6.5	6.75	8
12	7Bp	9.9	13.25	13.5	14	15	16
	2Ps	3.4	2.5	1.75	2	1.5	2
	1Pt	1.5	3.25	2.75	2	3	4

***Notes**: Cb is the Common hornbeam (Carpinus betulus L.), Qr is the Common oak (Quercus robur L.), Ap is the Norway maple (Acer platanoides L.), Ps is the Scots pine (Pinus sylvestris L.), Bp is the Silver birch (Betula pendula Roth.), Pt is the Common aspen (Populus tremula L.)*

However, it is very probable that a corresponding increase in measurements using relascopic coefficients BAF 3 and 4 can also yield sufficient accuracy. In general, the results of the conducted studies confirm the data of foreign scientists regarding the feasibility of using large values of relascopic coefficients [17-20]. The use of small relascopic coefficients is justified only in mixed plantations, which is consistent with the data of Carlton Scott [23]. Along with this, the authors of this paper can refute the statement regarding an increase in SBA values with an increase in the BAF value [21].

CONCLUSIONS

The specially developed model of the factor gauge "Crab" has proven itself quite well upon determining the SBA using 5 normatively prescribed BAF values. In comparison with the results of SBA measurements at the FAP, which served as a control, no systematic errors were detected during relascopic pattern measurements that would unilaterally distort the results of angle-count sampling. Data on possible systematic underestimation of SBA values in relascopic sites both at the value of BAF 1 and at other relascopic coefficients based on the results of the study can be refuted.

When conducting angle-count sampling in mixed stands, it turned out that the greatest accuracy in determining SBA in the context of forest elements is provided by the use of small BAFs 1, 0.5, and 2. Upon determining the total SBA in low-density young stands, the smallest deviations from the control were noted at BAF 2 and 3, in older medium-density middle-aged stands – at BAF 0.5 and 2, in high-density maturing and mature stands – at BAF 1.

There is reason to assert that deviations from the true values of the SBA slightly depend on the value of the relascopic coefficient, as well as on the density and mean diameter of the stand. Most essentially, according to the authors of this paper, the accuracy of the results of determining SBA in angle-count sampling depends on how well the trees in the selection zone of a certain BAF value represent the entire selection area of FAP, which is completely random in nature. Since larger BAF 2-4 values make provision for a corresponding increase in the number of measurements that can better cover plantings, there are prerequisites to recommend these relascopic coefficients, also considering the ease of accounting.

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Вплив величини реласкопічних коефіцієнтів на точність визначення суми площ поперечних перетинів

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Анотація. При проведенні реласкопічної таксації в лісах України найбільш поширеним є використанням кутових шаблонів із величиною реласкопічного коефіцієнта 1. Рекомендована величина даного коефіцієнта відповідно до нормативів залежить від орієнтовної повноти та середнього діаметру деревостану і може становити 0,5, 1, 2, 3 і 4. Виходячи з того, що в Україні відсутні засоби для реласкопічної таксації, які б давали змогу проводити заміри з використанням 5-х передбачених у нормативах значень реласкопічного коефіцієнта, було розроблено власну модель реласкопічного шаблону «Краб» та проведено його апробацію. Метою даної роботи є дослідження точності визначення сум площ поперечних перетинів насаджень при використанні реласкопічних коефіцієнтів різної величини залежно від середнього діаметру та повноти деревостанів. Шляхом порівняння даних на кругових пробних площах радіусом 17,85 м із даними реласкопічної таксації встановлено, що систематичних помилок, які б занижували чи завищували результати реласкопічної таксації виявлено не було. Визначено, що відхилення суми площ поперечних перетинів від істинних значень незначною мірою залежать від величини реласкопічного коефіцієнта, а також від повноти і середнього діаметру деревостану. На думку авторів, точність результатів визначення суми площ поперечних перетинів при реласкопічній таксації залежить напряму від репрезентації зони відбору дерев в межах кругової проби. Це має цілком випадковий характер при використанні будь-якого реласкопічного коефіцієнта. Встановлено, що у мішаних насадженнях найбільшу точність визначення суми площ поперечних перетинів окремих елементів лісу забезпечує саме використання невеликих коефіцієнтів (1, 0,5 і 2). У чистих насадженнях доцільним є застосування більш великих реласкопічних коефіцієнтів (2–4). Це передбачає відповідне збільшення кількості замірів, які можуть краще охопити насадження і збільшити точність отриманих результатів

Ключові слова: реласкопічна таксація, кругові пробні площі, реласкопічний шаблон, середній діаметр, повнота насадження

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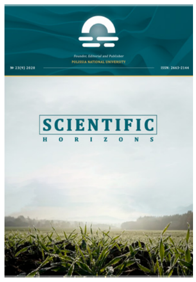

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Determination of the Nutritional Properties of Snail Meat and Its Comparative Analysis with Other Animal Species

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Abstract. In Ukraine, in today's conditions, snails, which are widely used for food in a number of European countries, are of increased interest. Over the past few years, this type of shellfish has been intensively harvested for processing and exporting abroad. However, there is not much data on the nutritional properties of snail meat, and there is practically no such information in Ukraine. The aim of this study is to determine the chemical composition (wet, dry matter, and energy value) of raw and cooked snail meat *Helix aspersa maxima*, *Helix aspersa muller*, *Helix pomatia* and conducting their comparative analysis among themselves with other types of meat. Indicators of nutritional properties were determined according to the following methods. The moisture and fat content was determined according to DSTU ISO 1442:2005; DSTU ISO 1443:2005, respectively. The mass fraction of dry matter, protein, ash, and caloric content of meat was determined by the methods described by P.V. Zhitenko and others. Comparative analysis of snail meat with other animal species was carried out based on literature sources. In the study, the authors found that on average in snails of the following species: *Helix aspersa maxima*, *Helix aspersa muller*, *Helix pomatia* it contains moisture – 72.03±0.29% and dry matter – 27.97±0.29%, of which: protein – 22.83±0.3%, fat – 0.23±0.03%, carbohydrates – 2.07±0.17%. It was determined that the indicators of moisture, dry matter, protein, fat, carbohydrates, ash and energy value in snails of all three species taken in the experiment did not differ significantly from each other. At the same time a sample of boiled snail meat *Helix pomatia* it has a higher chemical composition compared to the other two types of snails, namely: dry matter (28.5%), protein (23.4%), fat (0.3%) and energy value (103.9 kcal/100 g). Comparing the obtained data on the study of the chemical composition of raw and boiled meat of the same snail species, it was found that boiled meat is 14.2% more energetically valuable than raw, both in kCal/100 g and in kJ/100 g. We consider determining changes in organs at the cellular level, that is, conducting histological studies, taking into account different periods: hibernation, after hibernation and during the active period of their vital activity, to be a promising area of further research

Keywords: chemical composition, snail *Helix aspersa maxima*, snail *Helix aspersa muller*, snail *Helix pomatia*, heat treatment, caloric content

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INTRODUCTION

The nutritional value of food products is determined by the content of proteins, fats, carbohydrates, vitamins, minerals, as well as biologically active compounds. Protein is the most valuable component of food, involved in the most important functions of the body. Their main importance lies in their indispensability with other food substances. The need to determine the amount of demand for animal protein, as the most complete and best absorbed, is not in doubt [1; 2].

The usefulness of food products is characterised by nutritional, energy, biological, physiological and organoleptic value, as well as biological efficiency, digestibility and safety. Nutritional value characterises the fullness of the useful properties of the product and its taste preferences, which are conditioned upon the nutrients contained in it. Depending on the energy value, animal meat can be divided into three groups: high-, medium- and low-calorie [3; 4].

The energy value is determined by the proportion of energy that is released from the product during biological oxidation and provides physiological functions of the body and is measured in kCal or kJ. According to modern concepts, the concept of "nutritional value" reflects the full significance of the useful properties of a product, including such more precise definitions as "biological value" (protein quality), "energy value" (the amount of energy released in the body from a food product) [5].

The value of the nutritional value of meat can be defined as the percentage of provision of each of the most important nutrients, the average values of human needs for nutrients and energy [6]. In addition, the nutritional value of a product depends on important factors: the use of individual food substances (biotransformation), the degree of grinding, heat treatment, storage conditions, and other technological factors for processing raw materials [7].

Meat of agricultural and exotic animals and poultry is a combination of muscle, connective, bone, and adipose tissues in their natural ratio. These tissues have different nutritional value, and therefore their ratio affects the nutritional properties of meat. The specific weight of tissues depends on the type, breed of animals, gender, age, fatness and part of the carcass [1; 8]. Notably, meat productivity and the qualitative composition of meat of farm animals and poultry have been studied by many scientists, but the study of these indicators of snail meat in the scientific literature is not sufficiently covered. Most publications in foreign literature in the field of productive snail farming, as a branch of Agriculture, relate to the issues of proper cultivation of shellfish and the useful properties of their meat [2; 6].

Among the traditional types of meat available on the Ukrainian market, such as pork, beef, poultry meat, non-traditional ones also appear. Non-traditional types of meat include snail meat. Snail meat gained popularity abroad at the end of the last century, as one of the products of delicatessen food. Now farms are being created to grow snails as a source of protein substances. Snail meat is considered only muscle, connective and adipose tissue. The edible part of the snail is its "leg" with which it moves. It is the most important and valuable muscle tissue and is used to make various dishes [9].

Based on the results of the analysis of literature sources, it was found that there are no publications on the nutritional value of snail meat. In particular, there is no information on the chemical composition of food snail meat in terms of moisture, dry matter and energy value, and these indicators after its cooking. Since in the modern world the use of snails in the restaurant industry is mostly gaining momentum, and there are no data on the chemical composition of frozen and boiled meat of these shellfish, the need to determine these indicators is not in doubt.

Purpose of the study it consists in determining the chemical composition: moisture, dry matter and energy value of raw and boiled meat of food snails *Helix aspersa maxima*, *Helix aspersa muller*, *Helix pomatia*, comparative analysis of them among themselves and with other types of meat.

MATERIALS AND METHODS

At the beginning of the experiment, average samples of snail meat of each species were formed, which were selected in early summer – 100 shellfish. To prevent the meat from spoiling, it was frozen for delivery to the laboratory in proper condition. At the second stage of research, an average sample of snail meat of each species was formed – 200 shellfish (based on the boiling coefficient). It was boiled for 90 minutes. Snails were selected during their active use (in mid-summer). At the third stage, an average sample of snail meat of each species was taken, which was taken at the end of the season of their use (in autumn) – 100 shellfish. The research was conducted based on a testing laboratory accredited according to the international standard during 2017-2018.

Before forming an average sample of snail meat, attention was paid primarily to their condition: behaviour, reaction to external stimuli, mobility, that is, only live ones were selected. For research, snails were taken that moved in a calm state, and in a stressful state they hid in a shell. Snails were removed from the shell using a spiral-shaped dental probe (Fig. 1) and only the "leg" of the snail was selected. At the same time, the snail was held in the left hand, and the snail's leg was hooked on the right side of the mouth with the right hand. The shell was placed at an angle of 90 degrees and with a sharp movement of the right hand, the snail was completely removed. Further, only the "leg" of the snail was separated.

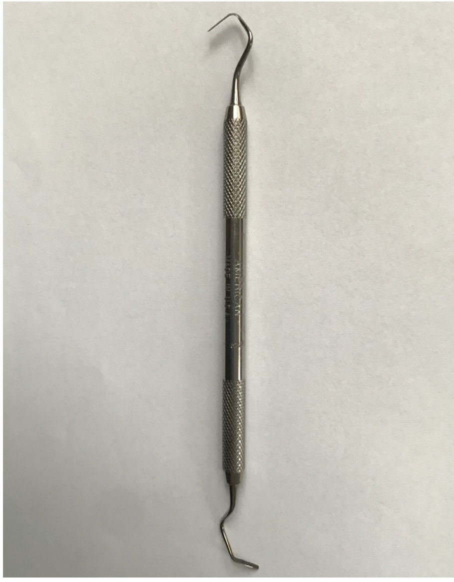

***Figure 1**. Spiral-shaped dental probe*

The chemical composition of meat was studied by the moisture content according to DSTU ISO 1442:2005 "Meat and meat products. Method for determining the moisture content" [10], fat – according to DSTU ISO 1443:2005 "Meat and meat products. Method for determining the total fat content" [11]. The mass fraction of dry matter, protein, ash, and caloric content of meat was determined by the methods described by P.V. Zhitenko and others [12]. Snails of the species *Helix pomatia* collected after rain or early in the morning, *Helix aspersa maxima* and *Helix aspersa muller* they were obtained from the farm "snail 2016" (Ukraine). To calculate the caloric content of meat, you need to know the quantitative content of fats, proteins and carbohydrates in it. The authors of the article used the coefficients of energy value of food substances, which are provided in Table 1.

***Table 1**. Coefficients of energy value of food substances*

Food substances	Coefficient, kcal/g
Proteins	4.0
Fats	9.0
Carbohydrates "by difference"	4.0

To determine carbohydrates "by difference", the amount of moisture, protein, fat and ash is subtracted from 100% of the product. The energy value (X, kcal) is equal to the sum of these components, i.e.:

$$X=4.0\text{x}B+4.0\text{x}C+9\text{x}D$$

where 4.0; 4.0; 9.0 are the coefficients of energy value, respectively: proteins, carbohydrates and fats, kcal/g; B is the amount of protein, g, C is the amount of fat, g, D is the amount of carbohydrates, g.

To determine the energy value in kilojoules, the resulting number of kilocalories is multiplied by 4.184. Determination of fat in meat was carried out by extraction, according to the method described in DSTU ISO 1443:2005 "meat and meat products. Method for determining the total fat content" [11]. The mass fraction of fat (X) was determined as a percentage by the formula (1):

$$X_2 = \frac{(m_2 - m_1) \times 100}{m} \quad (1)$$

where m – mass of the sample taken for analysis, g; m_1 – weight of the extraction flask with pieces of porcelain, g; m_2 – mass of the extraction flask with pieces of porcelain with fat after drying, g.

Calculations were performed with errors of ±0.1%. The final test result was taken as the arithmetic mean value of the results of two parallel definitions, the permissible difference between which should not exceed 0.5% when performing analyses in the same laboratory.

The study of moisture content was carried out by drying according to DSTU ISO 1442:2005 "Meat and meat products. Method for determining the moisture content" [10]. The mass fraction of moisture (X) as a percentage was determined by the formula (2):

$$X = \frac{(m_1 - m_2) \times 100}{m_1 \times m_0} \quad (2)$$

where m_0 – weight of bux with sand and stick, g; m_1 – weight of bux with sand, stick and suspension, g; m_2 – weight of bux with sand, stick and suspension after drying, g.

The final result was taken as the arithmetic mean of two parallel definitions. The difference between the results of parallel definitions should not exceed 0.5%. The final result was calculated with an error of up to 0.1%.

RESULTS AND DISCUSSION

Chemical composition of frozen and boiled meat of various types of snails

At the first stage, it was frozen meat of snails that were selected in early summer was studied. The results of the chemical composition of frozen meat of various snail species are presented in Table 2. The results of Table 2 show that the average sample of frozen snail meat *H. pomatia* icontains a higher amount of dry matter, namely protein, fat and carbohydrates, and is more energetically valuable compared to the other two samples.

At the second stage of research, after cooking meat and forming an average sample of each snail species from it, the chemical composition of snail meat was determined, which is shown in Table 3.

***Table 2**. Chemical composition of frozen meat of different types of snails*

Indicator	Samples			M±m
	1 (*H. pomatia*)	2 (*H. aspersa maxima*)	3 (*H. aspersa muller*)	
1. Moisture, %	78.2	79.7	80.1	79.33±0.58
2. Dry substance, % of which:	21.8	20.3	19.9	20.67±0.58
– protein	13.3	12.7	12.3	12.77±0.29
– fat	0.2	0.1	0.1	0.13±0.03
– carbohydrates	6.3	5.6	5.2	5.7±0.32
– ash	2.0	1.9	2.3	2.07±0.12
3. Energy value, in: kcal/100 g	80.2	74.1	70.9	75.07±2.73
kJ/100 g	335.3	309.7	296.3	313.77±11.44

***Table 3**. Chemical composition of boiled meat of different types of snails*

Indicator	Samples			M±m
	1 (*H. pomatia*)	2 (*H. aspersa maxima*)	3 (*H. aspersa muller*)	
1. Moisture, %	71.5	72.1	72.5	72.03±0.29
2. Dry substance, including % of which:	28.5	27.9	27.5	27.97±0.29
– protein	23.4	22.7	22.4	22.83±0.3
– fat	0.3	0.2	0.2	0.23±0.03
– carbohydrates	1.9	2.4	1.9	2.07±0.17
– ash	2.9	2.6	3.0	2.83±0.12
3. Energy value, in: kcal/100 g	103.9	102.2	99.0	101.7±1.44
kJ/100 g	434.3	427.2	413.8	425.1±6.01

Analysis of the results obtained in Table 3 showed that the chemical composition, namely: moisture content, protein, fat, carbohydrates, ash and energy value (in kcal/100 g) in snail meat of three species – *Helix aspersa maxima, Helix aspersa muller, Helix pomatia* don't differ significantly from each other. If we take into account the indicator of energy value in kJ/100 g, then the most nutritious was the meat of grape snails and amounted to 434.3 kJ/100 g, and the least – the meat of snails of the species *Helix aspersa muller* – 413.8 kJ/100 g.

Comparing the data of frozen and boiled meat of different types of snails, which are shown in Tables 2 and 3, it can be seen that after heat treatment, the amount of dry matter increased by 1.35%, protein – 1.79%, fat – 1.77%, ash – 1.37% and energy value – by 1.35%.

Comparative characteristics of the nutritional value of frozen snail meat

Snail meat differs in its nutritional value not only among different animal species, but also during the periods of their vital activity. Therefore, it became necessary to conduct a study to determine the nutritional value of snail meat during the period of their most active life, when products are obtained from them. For the first sample, snails were taken in early summer, and the second – at the end. The research results are presented in Table 4.

***Table 4**. Comparative characteristics of the nutritional value of frozen snail meat during their possible consumption*

Indicator	Type of snails					
	H. pomatia		*H. aspersa maxima*		*H. aspersa muller*	
	1 sample	2 sample	1 sample	2 sample	1 sample	2 sample
1. Moisture, %	78.2	78.0	79.7	77.8	80.1	77.8
2. Dry matter, including % of which:	21.8	22.0	20.3	22.2	19.9	22.2
– protein	13.3	9.6	12.7	9.4	12.3	9.2
– fat	0.2	0.7	0.1	0.6	0.1	0.6
– carbohydrates	2.0	10.7	1.9	11.0	2.3	11.3
– ash	6.3	1.0	5.6	1.2	5.2	1.1
3. Energy value, in: kcal/100 g	80.2	87.5	74.1	87.0	70.9	87.4
kJ/100 g	335.3	366.3	309.7	364.2	296.3	365.8

The data shown in Table 4 indicate that the nutritional value of snail meat in early and late summer is different. Thus, the indicators of dry matter, fat, carbohydrates and energy value increased, while moisture, protein and ash – on the contrary – decreased. The increase in the content of carbohydrates and fats is obviously conditioned upon the preparation of snails for the winter period and the use of these substances in metabolic processes in an anabiotic state. Data on the composition of snail meat at different periods of their possible consumption are shown in diagrams (Fig. 2, 3, and 4).

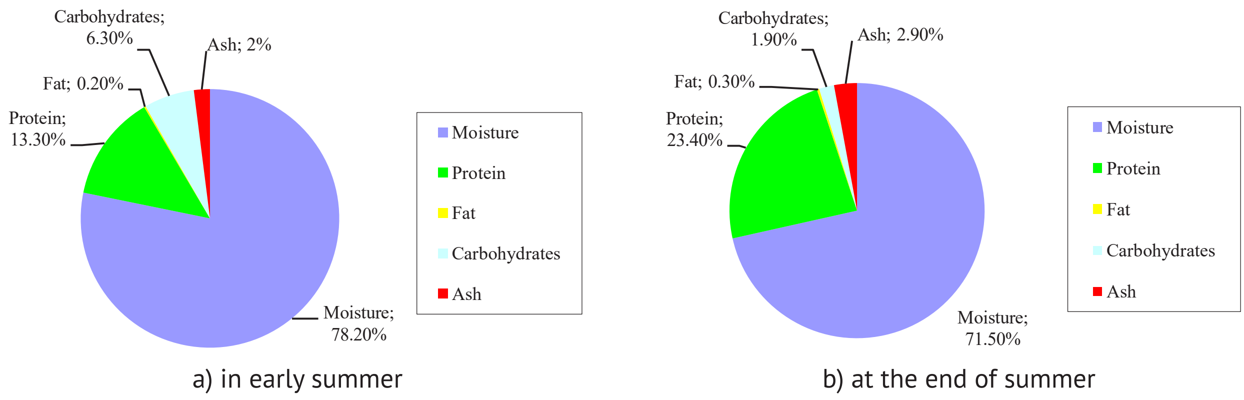

***Figure 2**. Composition of snail meat H. pomatia in different periods of life activity*

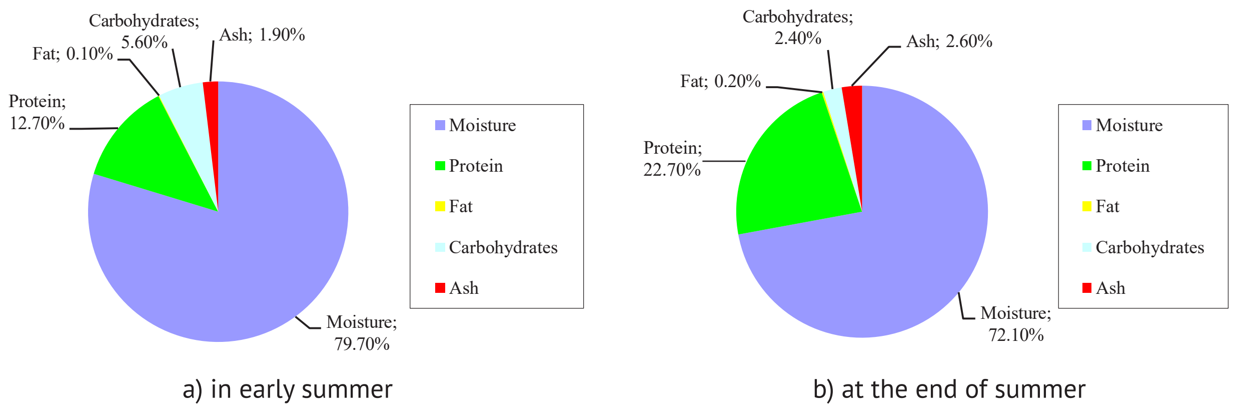

***Figure 3**. Composition of snail meat H. aspersa maxima in different periods of life activity*

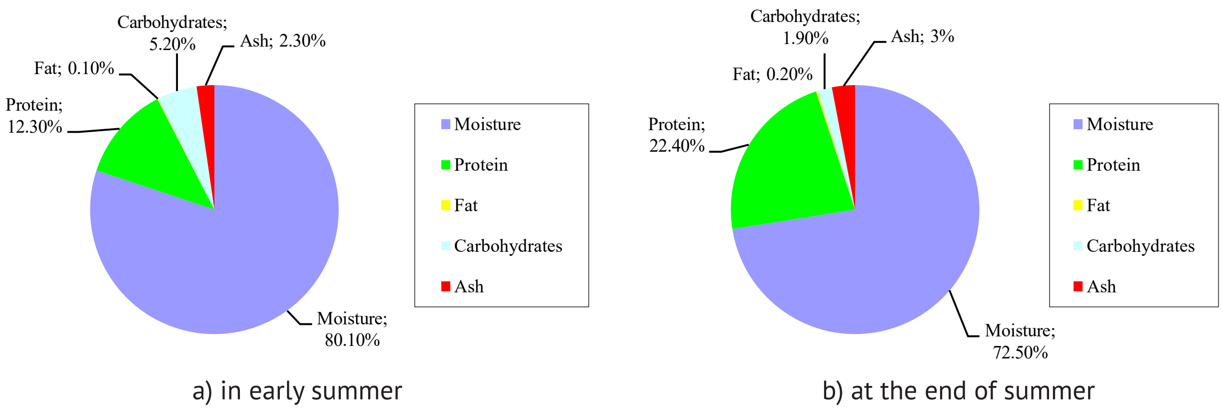

***Figure 4**. Composition of snail meat H. aspersa muller in different periods of life activity*

Protein is the most valuable component of meat, which makes up 95% of all nitrogenous substances in the body. In terms of amino acid composition, they are closest to the "ideal" animal proteins, since they contain all essential amino acids in optimal amounts and ratios. After heat treatment of snail meat, it was found that out of 27.97% of dry matter, 81.6% is protein, 0.8% (on average) [13].

When determining the nutritional and biological value of snails, it is necessary to consider the conditions of their cultivation. Artificially grown snails have a lower biological value than naturally grown snails, and the differences are explained by the strength of their shells, meat yield, and chemical composition. In the meat of snails of the natural population *Helix pomatia* contains 3.0% more protein than snails *Helix aspersa maxima* and 4.27% more than snails *Helix aspersa muller*. That is, if necessary, snails of the natural population can be used as a source of protein nutrition [14].

Comparative studies of snail meat with meat of other animal species

The nutritional properties of any meat are conditioned upon the presence of proteins and fats in it. Comparative studies of snail meat with meat of other animal species showed that in terms of nutritional and energy value, they can be compared with pork, beef, lamb, horse meat, rabbit meat. These types of meat contain from 40% to 75% moisture, from 14% to 23% protein, from 2% to 22% fat. At that time, snail meat contains from 77.8% to 80.1% moisture, from 9.2% to 13.3% protein, from 0.1% to 0.7% fat. The difference in meat composition depends primarily on the type of snails and the period of their consumption [15-17]. When comparing the data on the chemical composition and caloric content of snail meat with other types of meat of farm animals and poultry, it turned out that it is closest to chicken meat. Chicken meat contains 20.4% protein and 2.3% fat, while snail meat contains 22.8% protein and 0.2% fat [1].

The nutritional value and caloric content of farm animal meat depends on the type of meat, breed, age and fatness of the animals. Young animals have a lower caloric content of meat compared to adults, because their meat contains more moisture and protein, and less fat. Animal proteins are absorbed better by humans than vegetable proteins. And to meet the needs of the body with meat proteins and the need for them is less than vegetable. If we are talking about snail meat, then the nutritional value and caloric content, according to the authors, depends again on the period of their consumption and the type of snails.

A number of scientists have studied that the meat of farm animals contains from 1.1% to 40% fat. Pork has the highest fat content – 37%, beef – 23%, Lamb – 26%. Less fat-rich rabbit meat – 11%, etc. The digestibility of fats depends on their melting point. The most refractory is lamb fat, which is digested by 85%, then beef fat, which is digested by 94% and pork fat – by 97%. These properties of meat fats are associated with the presence of saturated and unsaturated fatty acids in the composition. Lamb fat contains more saturated fatty acids than pork or beef fat, so it is more refractory. Fat improves the taste of meat, increases its nutritional value. During our research, it was found that snail meat contains almost no fat and is only 0.7%. This indicates that this type of meat can be classified as dietary, as it contains traces of fat. The caloric content of snail meat is up to 87.5 kcal/100 g – these data also indicate that the meat of all three types of snails is dietary [8; 18; 19].

If you compare the protein indicators in the meat of different animal species, then snail meat can be compared with beef. In snails, its indicator reaches 13.3%, and in beef 14.3% [15]. The chemical composition of snail meat is determined by the quality of the environment in which they stay for the entire period of life. It is not constant, but is subject to minor fluctuations that depend on the time of year, environmental conditions, their physiological state, etc.

The use of mussel meat is also very similar in terms of promising direction of increasing the volume of non-traditional meat and in terms of nutritional indicators. Mussel meat contains: moisture – 80-81%, protein – 10-11%, fat – 1.3-1.5%, carbohydrates – 3.5-4%, while snail meat contains: moisture – 79.3%, protein – 12.8%, fat – 0.1% and carbohydrates – 5.7% (average data for three types of snails). Thus, snail meat and mussel meat differ significantly only in terms of fat and carbohydrates. Snail meat contains less fat and more protein, compared to mussel meat – this indicates a high nutritional value of snail meat [19; 20].

In terms of their environmental friendliness, snails are considered environmentally friendly animals compared to agricultural ones. Artificial snails are kept in the field from April to October, and snails of the natural population are generally kept in natural living conditions every year. This suggests that snails do not consume hormones and antibiotics, and are not kept in cramped stalls or farms, unlike farm animals.

When justifying the general conclusion about the nutritional value of snail meat and comparing the results obtained during the experiment with the data of other scientists who studied the nutritional properties of farm animal meat, it was found that the moisture content of snail meat is close to mussel meat, and the protein content is close to beef. And in terms of fat content, it is not similar to any type of meat. The content of carbohydrates and ash in meat, today, remains a little-studied issue. If you analyse non-traditional types of meat, snail meat is similar to mussel meat, but differs in terms of fat and carbohydrates.

CONCLUSIONS

The composition of boiled meat of snail species is determined: *Helix aspersa maxima*, *Helix aspersa muller*, *Helix pomatia,* namely, the following indicators: moisture, dry matter (protein, fat, carbohydrates and ash), as well as its energy value. The highest rates were found in the meat of snails in the natural population – *Helix pomatia,* except for moisture, carbohydrates, and ash. The meat of the same snail species is rich in protein and reaches 82.1% of the dry matter. All three experimental snail species have the lowest fat content of all the indicators studied, and on average this indicator was 0.23±0.03%.

So, on average, boiled meat of the above – mentioned snail species contains moisture – 72.03±0.29%, and dry matter – 27.97±0.29%. Of the dry matter indicators, protein accounts for an average of 22.83±0.3% for all three snail species, and the snail is the most enriched with this nutrient *Helix pomatia* and it is 23.4%. When studying the chemical composition of raw and boiled snail meat, we found that boiled meat is 14.2% more energetically valuable than raw meat, both in kcal/100 g and in kJ/100 g.

We consider it necessary to make histological studies of snails in different periods as a promising area of further research: hibernation, after hibernation and during the active period of their vital activity.

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Визначення поживних властивостей м'яса равликів та його порівняльний аналіз з іншими видами тварин

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Анотація. В Україні, в умовах сьогодення, підвищений інтерес викликають равлики, що широко використовуються в їжу в ряді європейських країн. Протягом кількох останніх років відбувається інтенсивна заготівля цього виду молюсків з метою його переробки та експорту за кордон. Проте даних щодо поживних властивостей м'яса равликів не так багато, а в Україні таких відомостей практично немає. Мета цього дослідження полягає у визначенні хімічного складу (волога, суха речовина та енергетична цінність) сирого та вареного м'яса харчових равликів *Helix aspersa maxima*, *Helix aspersa muller*, *Helix pomatia* та проведенні їх порівняльного аналізу між собою з іншими видами м'яса. Показники поживних властивостей визначали згідно з методиками. Вміст вологи та жиру визначали за ДСТУ ISO 1442:2005; ДСТУ ISO 1443:2005 відповідно. Масову частку сухої речовини, білку, золи та калорійність м'яса визначали за методиками, що описані П.В. Житенко та інші. Порівняльний аналіз м'яса равликів з іншими видами тварин проводили на основі літературних джерел. При дослідженні авторами було встановлено, що в середньому у равликів видів *Helix aspersa maxima*, *Helix aspersa muller*, *Helix pomatia* міститься вологи – 72,03±0,29 % та сухої речовини – 27,97±0,29 %, з якої: білку – 22,83±0,3 %, жиру – 0,23±0,03 %, вуглеводів – 2,07±0,17 %. Визначено, що показники вологи, сухої речовини, білку, жиру, вуглеводів, золи та енергетичної цінності у равликів всіх трьох видів, що були взяті у дослід, між собою суттєво не відрізнялися. Водночас проба вареного м'яса равликів *Helix pomatia* має вищі показники хімічного складу порівняно з іншими двома видами равликів, а саме: сухої речовини (28,5 %), білку (23,4 %), жиру (0,3 %) та енергетично цінніше (103,9 кКал/100г). Порівнюючи отримані дані щодо вивчення хімічного складу сирого та вареного м'яса цих же видів равликів, було з'ясовано, що варене м'ясо на 14,2 % енергетично цінніше за сире, як у кКал/100 г, так і в кДж/100 г. Перспективним напрямом подальших досліджень вважаємо визначення змін органів на клітинному рівні, тобто проведення гістологічних досліджень, враховуючи різні періоди: сплячка, після сплячки та в активний період їх життєдіяльності

Ключові слова: хімічний склад, равлик *Helix aspersa maxima*, равлик *Helix aspersa muller*, равлик *Helix pomatia*, термічна обробка, калорійність

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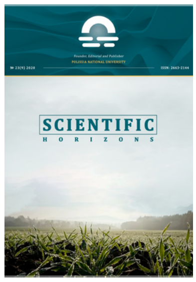

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Efficiency of Microfertilizer Oracle Multicomplex in Corn Cultivation Technology

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Abstract. In recent years, the use of all types of fertilizers has sharply decreased, which negatively affected the state of the agroecosystem, its stability and constancy, therefore, it is extremely important to replenish nutrients, including microelements, to maintain the stability of yields. The increasing attention of scientists and industrialists deserves the question of the use of micronutrient fertilizers in the plant nutrition system, as an important element of the technology of growing crops. It is especially important to study the various forms, types and timing of their introduction. The article presents the research results for 2019-2021 according to the effect of microfertilizer Oracle multicomplex (1.5 l/ha) applied foliarly during the development phases of plants of the mid-early hybrid Orzhitsa 237 MB (VVSN 13-15, VVSN 16-18, VVSN 59) against the background of mineral nutrition – $N_{150}P_{90}K_{90}$. It has been established that on gray forest surface-gley soils of the Western Forest-Steppe zone, a high grain yield of the mid-early corn hybrid (FAO 200-299) of the Orzhitsa 237 MV ripeness group was provided both by favorable weather conditions and by the influence of the Oracle multicomplex. Foliar application of the Oracle multicomplex microfertilizer in the phase BBCH 13-15 (3-5 leaves) increased the yield increase versus control (without micronutrient fertilization) by 0.82 t/ha, by meeting the needs of plants of this period in available forms of phosphorus, nitrogen, zinc, when panicle axes were laid on the tops of the shoots, and lateral apical meristems (future cobs) formed in the leaf axils. The highest yield by 1.19 t/ha was obtained with foliar application of micronutrient fertilizer in the phase of 6-8 leaves (VVSN 16-18). In this phase, panicle flowers, pollen grains in the stamens, the number of ears and grains in a row were laid, therefore, the content of S, Ca, Mg, Mn, Zn in the fertilizer positively influenced the formation of the reproductive organs of maize plants. Under the influence of micronutrient fertility introduced into the phase of full panic appearance (VVSN 59), blooming and pollution of maize effectively taken place, which ensured an increase in grain yield – 1.27 t/ha. The difference in this indicator between the VVSN 16-18 and VVSN 59 phases was unreliable (0.09 t/ha). Balanced nutrition of plants with macroelements ($N_{150}P_{90}K_{90}$ with a gradual introduction of nitrogen) and micro – Mn, Cu, Zn, Fe, Co, S, Mo contributed to the formation of a 55-59 g higher weight of 1000 grains. The total yield of the coarse and medium grain fractions was 91.5-92.1%, the fine one decreased by 30.6%

Keywords: hybrid, FAO, ripeness group, yield, weight of 1000 grains, fractional composition

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INTRODUCTION

The modern strategy for the development of the agro-industrial complex of Ukraine is characterised by high knowledge intensity, in which the stabilisation of grain production, while improving the agrotechnological process of cultivation, is of great importance [1; 2]. Intensive cultivation technologies are based on the widespread use of mineral fertilizers and pesticides, but their uncontrolled use is economically unjustified and environmentally dangerous. Therefore, the search for alternative means of influencing the development of yield and product quality has been gaining more and more attention of researchers in recent years. Promising in this direction may be the introduction of microfertilizers into production, which in low doses can increase the potential of biological productivity of plants within the normal range of the genotype response, enhance their adaptive ability to environmental stress factors [3; 4].

Conditioned upon dynamic changes in environmental and technological situations and to reduce the pressure of environmental stressors on plant agrocenoses, including with great opportunities to use the achievements of domestic breeding, the need for systematic changes in cultivated hybrids in the direction of their greater adaptation to local conditions, ensuring a higher level of yield (10-15 t/ha) and stability over the years, preserving material resources, reducing the use of plant protection products and their impact on the environment and increasing the share of use of natural sources, in particular weather factors and soil nutrients [5-7].

Weather conditions in the Western forest-steppe zone have changed in the direction of warming in recent years. A higher sum of effective temperatures and sufficient moisture supply contribute to the cultivation of niche crops, in particular hybrids of early-maturing corn (FAO 150-199) and medium-early (FAO 200-299) ripeness groups, but low natural soil fertility does not always allow you to get a programmed crop. It is important to observe effective agricultural measures in the cultivation technology, of which the plant nutrition system accounts for up to 50% [8-10].

The basis of such technologies is optimisation of the level of nitrogen nutrition due to differential application by stages of organogenesis against the background of sufficient supply of phosphorus and potassium in combination with microfertilizers, growth stimulants, and retardant protection. Of particular importance is the use of microfertilizers in cases where the cultivation technology does not correspond to the genetic capabilities of the hybrid to ensure a sufficient degree of reliability and protection of the genotype from the adverse effects of biotic and abiotic environmental factors, which does not allow us to fully realise the potential capabilities of plants. The role of microfertilizers is to activate physiological processes in the plant, which is positively manifested in ensuring the maximum biological yield [11; 12].

Effect of trace elements on growth the development, quantitative and qualitative productivity of crops depends on the presence in the soil, which in turn is explained by factors of soil formation and determine the processes of solubility and precipitation of substances, migration, accumulation and redistribution in the soil profile. The most important are six trace elements-B, Mn, Cu, Zn, Co, Mo, which make up 0.01-0.001% per dry substance. However, plants absorb a small amount of them from the soil and only those that are in a mobile, easily accessible form, and inaccessible gross reserves can only be available after undergoing complex microbiological processes involving humic acids and root secretions. Therefore, the gross content of soil trace elements does not reflect the real picture of plant availability, and in the form of inorganic salts, they are available in very small quantities and mainly on acidic soils, only Molybdenum is absorbed by plants on slightly alkaline soils [13-15].

Today, production is offered a number of microfertilizers that stimulate seed germination, regulate growth processes, increase resistance to diseases, reduce crop losses, but the effectiveness of their action is different and this requires scientific justification and practical recommendations [16-18]. The natural soil fertility of the Western forest – steppe is estimated at 38 points, while the average for Ukraine is 55, that is, low, which provides 1.5-1.8 t/ha of grain products. Therefore, optimisation of corn plant nutrition elements at the expense of basic and additional nutrition is an extremely urgent issue that requires appropriate justification for the conditions of the region.

Research purpose it consisted in establishing the effectiveness of the use of microfertilizer Oracle multicomplex, introduced foliar in different phases of development on the productivity of corn in the soil and climatic conditions of the Western forest-steppe of Ukraine.

MATERIALS AND METHODS

The experiments were laid down in the crop rotation of the Department of seed production and seed studies of the Institute of Agriculture of the Carpathian region of the National Academy of Sciences. The object of research was a medium – early hybrid of corn – Orzhitsa 237 MV (originator-state institution Institute of grain crops of the National Academy of Sciences, Dnipro) and complex universal microfertilizer – Oracle multicomplex (manufacturer – "Dolyna"). The application rate is 1.5 l/ha. The composition of microfertilizers includes the main elements of nutrition (NPK) and trace elements: Mn, Cu, Zn, Fe, Co, S, Mo, B, which are in chelated form. As a chelating agent, ethidronic acid (HEDP) is used, which is able to form highly resistant chelates with metals, and when it decomposes, compounds that are easily digestible by plants are formed. The total area of the sown area is 60 m^2, accounting – 50 m^2. The repetition is threefold, and the placement of options is systematic.

Agrotechnics of growing corn included its predecessor – winter rapeseed, the sowing period is optimal

(I decade of May), the seeding rate is 70 thousand similar to s./ha. Mineral nutrition background – $N_{150}P_{90}K_{90}$. Fungicidal mordant-Avicenna (0.5 l/t, d.r. – tebuconazole, 50 g/l + prochlorase, 250 g/l + cresoxime-methyl, 50 g/l). Herbicide-Adengo (0.5 l/ha, d.r. – isokzaflutol, 225 g/l + thiencarbazone-methyl, 90 g/l + ciprosulfamide, 150 g/l). Insecticide: salvo (1.2 l/ha, d.r. – chlorpyrifos, 500 g/l + cypermethrin, 50 g/l).

With the help of biometric and morphological diagnostics and phenological observations, changes in plant growth and development associated with the formation of organs – leaves, stems, cob (method of State Variety testing of agricultural crops, 2001) were established [19]. Crop accounting was carried out by direct combining of experimental sites, followed by weighing and recalculating the obtained data for standard grain humidity. Statistical data processing – by the method of variance analysis (Excel, Statistica 6.0) according to B.O. Dospekhov [20].

RESULTS AND DISCUSSION

Complex universal microfertilizer, when applied foliar, had a positive effect on the growth and development of corn, as can be seen from Figure 1.

***Figure 1**. General view of corn sowing for the introduction of microfertilizers Oracle multicomplex*
***Sources**: photo provided by the authors of the article*

Investigating the level of directed regulation of physiological processes in the plant body under the influence of the proposed nutrition system, which included microfertilizer Oracle multicomplex at a rate of 1.5 l/ha and the level of mineral nutrition $N_{150}P_{90}K_{90}$ with the gradual introduction of nitrogen in the phases of VVSN 13-15; 16-18; 59, the authors established reliable increases in the grain yield of the orzhitsa hybrid of 237 MV (Fig. 2).

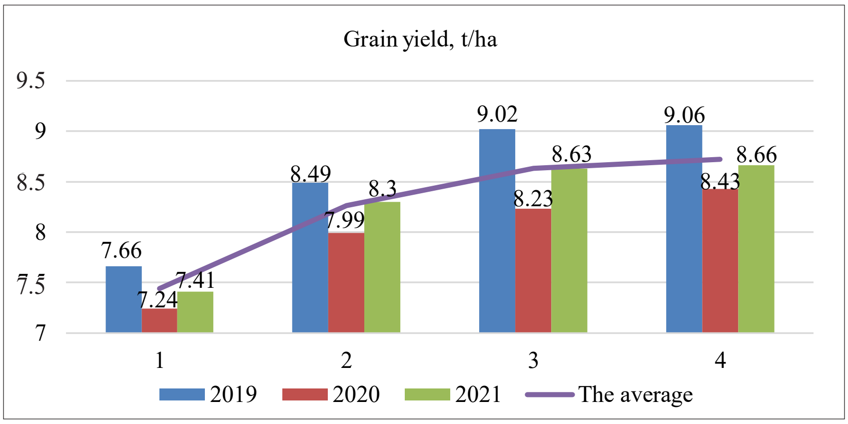

***Figure 2**. Corn grain yield depending on foliar application of microfertilizer Oracle multicomplex (2019-2021), t/ha*
***Note**: 1 – without micronutrient fertilization (control), 2 – BBCH 13-15 (3-5 leaves), 3 – BBCH 16-18 (6-8 leaves), 4 – BBCH 59 (full appearance of the panicle). Hybrid corn – Orzhitsa 237 MV, mineral nutrition background – $N_{150}P_{90}K_{90}$*

It was found that the level of grain yield of the hybrid significantly varied over the years of research. The highest grain yield was obtained in favorable weather conditions in 2019. In the control (without microfertilizers), this indicator was 7.66 t/ha and increased to 9.06 t/ha during the VVSN 59 application phase (complete panicle appearance). The lowest yield was recorded in 2020 – 7.24-8.43 t/ha. The average yield in the control (without microfertilizers) was 7.44 t/ha when applied to the VVSN 13-15 phase (3-5 leaves) significantly increased by 0.82 t/ha ($Nir_{0.05}$=0.17-0.30). It was in this phase that the formation of vegetative parts of the stem was completed, panicle axes were laid at the top of the shoot, and lateral apical meristems (future heads) were formed in the leaf axils. Microfertilizer, providing the need for available forms of phosphorus, nitrogen, and zinc during this period, had a positive effect on plant productivity.

Large increases in control were obtained with foliar application of Oracle multicomplex in the phase of VVSN 16-18 (6-8 leaves) – 1.19 t/ha. This phase coincides with differentiation of panicle flowers, the formation of pollen grains in stamens, cobs and grains in a row, so providing an optimal level of mineral nutrition and trace elements: S, Ca, Mg, Mn, Zn was extremely effective. Later, foliar application of microfertilizers in the VVSN 59 phase (complete appearance of panicles), when the growth of staminate filaments in the panicle, ovary columns of the ear, the formation of germ sacs took place, weather factors and microelements were greatly influenced, which affected photosynthetic productivity (Mg, Mn), water consumption (Zn), fertility (B). Under their influence, corn was effectively blooming and pollinated, so the increase in grain yield was 1.27 t/ha. The difference in this indicator between the VVSN 16-18 and VVSN 59 phases was unreliable (0.09 t/ha).

A balanced level of nutrition of corn plants with macro- and microelements contributed to the formation of a high mass of 1000 grains (Fig. 3). This indicator is genetically determined, but it can change under the influence of weather conditions, research years and microfertilizer application phases. In the experiments conducted by the authors, the mass of 1000 grains in 2019 was in the range of 356 g (control – without microfertilizers) – 421 g for introduction into the VVSN 59 phase (complete appearance of panicles). Compared to the control variant, significant gains were: 39-65 g (2019), 35-55 g (2020) and 41-58 g (2021) for NIR_{05}=16, 10, 11 g. The average mass index ranged from 346 to 405 g, with a difference between 39-59 g.

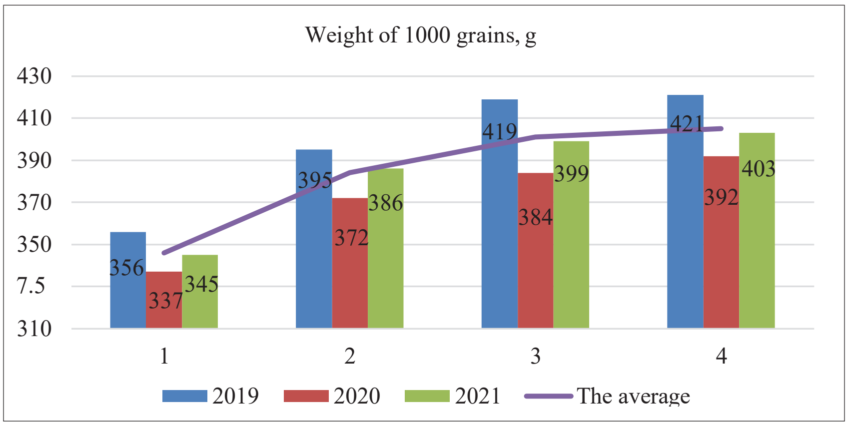

***Figure 3**. Weight of 1000 corn grains depending on foliar application of microfertilizer Oracle multicomplex (2019-2021), g*

***Note**: 1 – without micronutrient fertilization (control), 2 – BBCH 13-15 (3-5 leaves), 3 – BBCH 16-18 (6-8 leaves), 4 – BBCH 59 (full appearance of the panicle). Hybrid corn – Orzhitsa 237 MV, mineral nutrition background – $N_{150}P_{90}K_{90}$*

When determining the yield of grain fractions: large (9-10 mm), medium (7-8 mm), and small (5-6 mm), it was found that in the control, the average for years of research, the yield of small fractions was 38.5%, medium – 44.1%, large – 17.4% (Table 1).

***Table 1**. Fractional composition of corn grain depending on foliar application of microfertilizer Oracle multicomplex (2019-2021), mm*

Microfertilizer application phases	Year 2019			2020			2021			Average		
	Large (9-10)	Average (7-8)	Small (5-6)	Large (9-10)	Average (7-8)	Small (5-6)	Large (9-10)	Average (7-8)	Small (5-6)	Large (9-10)	Average (7-8)	Small (5-6)
Without microfertilizer (control)	18.1	36.6	45.3	17.1	42.5	40.4	16.2	45.4	38.4	17.4	44.1	38.5
VVSN 13-15 (3-5 sheets)	31.5	48.2	20.3	29.8	44.7	25.5	26.3	50.1	23.6	29.2	47.7	23.1
VVSN 16-18 (6-8 sheets)	39.0	56.1	4.9	34.3	55.5	10.2	32.0	59.3	8.7	35.1	57.0	7.9
VVSN 59 (full appearance of panicles)	36.8	55.4	7.8	33.5	57.4	9.1	31.8	59.6	8.6	34.0	57.5	8.5

***Note**: hybrid corn – Orzhitsa 237 MV, mineral nutrition background – $N_{150}P_{90}K_{90}$*

Foliar application of Oracle multicomplex microfertilizer in the VVSN 13-15 phase (3-5 maize leaves) affected the redistribution of these fractions in the direction of increasing large (29.2%) and medium (47.7%) and decreasing small (23.1%). The highest total yield of large and medium grain fractions (92.1%) and the smallest small (7.9%) was obtained from the introduction of microfertilizers in the VVSN 16-18 phase (6-8 leaves), for the introduction of VVSN 59 phase (complete appearance of panicles), respectively – 91.5 and 8.5%.

The data obtained by US confirm the scientific publications of a number of scientists around the world that depending on the need of corn plants for certain elements of nutrition that are insufficient in soil types, with different systems of basic mineral nutrition and the direction of corn use, the increase in grain yield and quality is significant [21; 22]. Thus, Polish researchers have determined that when higher potassium standards are applied to corn, the content of zinc (Zn) in the soil, and especially nickel (Ni), increases, and when nitrogen is applied, the content of manganese (Mn), chromium (Cr), nickel (Ni) and cadmium (Cd) increases, and lead (Pb) decreases [23]. In the soil and climatic conditions of Belarus, the best fertilizer system for growing corn for silage is organomineral with foliar use of zinc-containing microfertilizers [24]. According to studies conducted in the southern agricultural zone of the Amur region in the experimental field of the Far Eastern State agrarian university, it was found that foliar application of microfertilizers has a more effective effect on the accumulation of dry matter in corn than seed treatment. The greatest effect was shown by the variant with the use of cobalt in seed treatment and spraying of plants [25]. In southern Bulgaria, foliar application of Microfertilizer Amalgerol in the 4-6-leaf phase against the background of mineral nutrition of plants (200 kg/ha DW) contributed to an increase in corn grain yield by 31% [26].

Our research on the high efficiency of foliar feeding with micronutrients in easily accessible form, in particular with the balanced microfertilizer Oracle multicomplex, confirms the scientific developments of the Ternopil State Agricultural Experimental Station of Institute of Feed Research and Agriculture of Podillya [27].

CONCLUSIONS

Based on the obtained three-year data, it can be stated that in the conditions of the Western forest-steppe, on Gray forest surface-ogled soils, for a combination of the main mineral nutrition of plants in the norm of $N_{150}P_{90}K_{90}$ with the gradual introduction of nitrogen and additional foliar top dressing of plants with microfertilizer Oracle multicomplex at a rate of 1.5 l/ha in the phase of VVSN 16-18 and VVSN 59, the realization of the genetic potential of the medium – early hybrid Orzhitsa 237 MV was the highest – 8.63-8.72 t/ha.

The highest grain yield was obtained in favorable weather conditions in 2019 – 7.66-9.06 t/ha, and the lowest in 2020 – 7.24-8.43 t/ha. The average yield in the control (excluding microfertilizers) was 7.44 and was significantly higher by 0.82-1.28 t/ha when applying microfertilizers. Providing the need of plants for available forms of nutrients by development phases, microfertilizer had a positive effect on the formation of generative organs.

When microfertilizers were applied in the VVSN 16-18 and VVSN 59 phases, the mass of 1000 grains increased by 55-59 G, the total yield of large and medium grain fractions was 91.5-92.1%, and small ones decreased by 30.6%.

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Ефективність мікродобрива оракул мультикомплекс в технології вирощування кукурудзи

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Анотація. За останні роки обсяги застосування всіх видів добрив різко зменшилися, що негативно позначилося на стані агроекосистеми її стійкості і сталості, тому надзвичайно важливим є поповнення елементів живлення, зокрема мікроелементів для збереження стабільності урожаїв. Все більшої уваги науковців і виробничників заслуговує питання застосування мікродобрив у системі живлення рослин, як важливий елемент технології вирощування культур. Особливо важливим є вивчення різних форм, видів і строків їх внесення. У статті наведено результати досліджень за 2019–2021 рр. з впливу мікродобрива оракул мультикомплекс (1,5 л/га), внесеного позакоренево у фази розвитку рослин середньораннього гібриду Оржиця 237 МВ (ВВСН 13–15, ВВСН 16–18, ВВСН 59) на фоні мінерального живлення – $N_{150}P_{90}K_{90.}$ Встановлено, що на сірих лісових поверхнево-оглеєних ґрунтах зони Західного Лісостепу, високий урожай зернової продуктивності гібриду кукурудзи середньоранньої (ФАО 200–299) групи стиглості Оржиця 237 МВ, був забезпечений як сприятливими погодними умовами в роки досліджень, так і ефективністю листкової обробки посівів мікродобривом оракул мультикомплекс. Позакореневе внесення мікродобрива Оракул мультикомплекс у фазу ВВСН 13–15 (3–5 листки) збільшувало приріст урожайності до контролю (без мікродобрива) 0,82 т/га, за рахунок забезпечення потреби рослин цього періоду в доступних формах фосфору, азоту, цинку, коли на верхівках пагонів закладалися осі волоті, а в пазухах листків утворювались бічні апікальні меристеми (майбутні качани). Вищу урожайність на 1,19 т/га було отримано за позакореневого внесення мікродобрива в фазу 6–8 листків (ВВСН 16–18). У цій фазі закладалися квітки волоті, пилкові зерна в тичинках, кількість качанів і зерен в ряду, тому вміст у добриві S, Ca, Mg, Mn, Zn позитивно впливав на формування репродуктивних органів рослин кукурудзи. Під впливом мікродобрива, внесеного у фазу повної появи волоті (ВВСН 59), ефективно проходило цвітіння та запилення кукурудзи, що забезпечило приріст урожайності зерна – 1,27 т/га. Недостовірною (0,09 т/га) була різниця за даним показником між фазами ВВСН 16–18 і ВВСН 59. Збалансоване живлення рослин макроелементами ($N_{150}P_{90}K_{90}$ з поетапним внесенням азоту) і мікро- – Mn, Cu, Zn, Fe, Co, S, Mo сприяло формуванню вищої на 55–59 г маси 1000 зерен. Сумарний вихід крупної і середньої фракцій зерна складав 91,5–92,1 %, дрібної зменшувався на 30,6 %

Ключові слова: гібрид, ФАО, група стиглості, урожайність, маса 1000 зерен, фракційний склад

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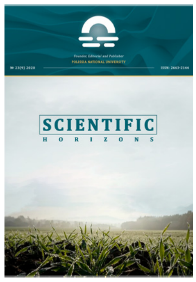

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Effect of Desiccant Application on Pre-Harvest Humidity of Medium-Early Hybrid LG 3258 Corn in Western Forest-Steppe Conditions

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Abstract. The high pre-harvest humidity of corn grain leads to seed injury and considerably increases the cost of growing technology. The purpose of the study is to establish the effectiveness of using desiccants to reduce the pre-harvest moisture content of grain and determine whether the desiccation of corn crops affects the yield. The following methods were used to achieve this purpose: field – to establish the effect of desiccation on corn yield, laboratory – to determine the moisture content in grain, statistical – for mathematical processing of experiment results. A field experiment that examined the timing of desiccation and the norms of desiccant use involving Roundup Max and Reglon Super preparations was conducted. Hybrid corn – LG 3258, FAO 250, medium-early. According to the results of the study, the use of desiccants reduced the pre-harvest moisture content of corn grain in all variants of the experiment. Weather conditions had a considerable impact on the decrease in grain humidity. Thus, in 2018 and 2019, the desiccation decreased the pre-harvest moisture content of grain by 6.4-8.0%, and in 2020 – by 4.0-5.3% with the treatment of corn plants in the black dot phase with Roundup Max at a rate of 3.2 l/ha. The use of Reglon Super in the phase of the appearance of a black dot resulted in a decrease in humidity by 5.2-7.8%, depending on the rate of consumption of the drug and the year of study. The treatment with Roundup Max 10 days after the black dot appeared decreased the humidity by 4.0-7.5%, depending on the consumption rate and the year of study. The use of Reglon Super reduced pre-harvest humidity by 4.0-6.5%, depending on the rate of the drug and the year of the study. Treatment of plants in the 40% grain moisture phase was the most effective, which contributed to the formation of 20.1% humidity when using Roundup Max at a rate of 3.2 l/ha. Desiccant treatment of corn crops did not affect the yield in any of the variants of the experiment. According to the results of the study, corn desiccation is an effective technological technique that reduces the pre-harvest moisture content of grain by 4.0-8.0%, depending on the drug, its rate, and weather conditions. The lowest harvesting humidity – 20.1% was obtained in the variant of treating corn with a grain humidity of 40% with Roundup Max at a rate of 3.2 l/ha. The economic assessment showed that the highest net profit was obtained in the Roundup Max 2.4 l/ha treatment option in the black dot phase – UAH 47,491/ha, the profitability level is 165%

Keywords: corn, harvesting humidity, desiccation, pre-harvest drying, yield

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INTRODUCTION

Corn ranks second in terms of gross grain harvest and structure of sown areas. This is a highly productive crop with a wide range of applications, which conditions its demand. During 1990-2020, there had been a tendency in Ukraine to increase the sown area of corn and, accordingly, the gross harvest, according to which Ukraine ranks 6^{th} in the world [1]. Corn cultivation has an essential economic role, as Ukraine ranks third/fourth in the world in terms of supply volumes [2].

An important element of corn cultivation technology is harvesting. It is conducted at a grain humidity of no more than 25-30%. The high moisture content of the grain increases the risk of injury and the level of loss. According to S.V. Krasnienkov et al [3; 4] with the shift of harvesting dates from early to late, the number of dead plants increased from 0.1 to 9.1% and drooping – by 6.8-67.1%, depending on the hybrid. The delay in harvesting dates led to an increase in disease damage by 9.3-23.8%, in particular Fusarium wilt – by 7.9-14.5%, Aspergillosis – 9.0-13.5%, etc. The humidity of corn grain was the lowest when harvesting at optimal times (14.5-19.3%), compared to the early ones (14.4-23.3%), and the delay in harvesting times contributed to an increase in grain moisture (16.3-20.8%).

Injured seeds have reduced germination, viability, they are worse stored, and prone to pathogens. Corn is most susceptible to injury among cereals. Therefore, it is optimal to harvest it at a grain humidity of 12-22% [5-7]. The pre-harvest humidity of corn is considerably influenced by the ripeness group, weather conditions, and individual characteristics of the hybrid such as the type of grain, the thickness and consistency of the rod, and the density of seed laying, the number of wrappers, their thickness and density, the slope of the cobs after physiological ripeness. According to V. Palamarchuk and O. Kovalenko [8] foliar fertilisation increased pre-harvest moisture of corn by 0.47-5.47% compared to the control. The lowest possible pre-harvest humidity of grain would reduce the cost of drying the grain at which the reduction of 1% moisture consumes 1.6-3.4 kg of fuel, which is especially true with today's increase in fuel prices [9].

It was established that the average daily moisture transfer rate is 0.8-1.2% at a grain humidity of 35-40%, 0.5-0.7% at 30-35%, and 0.3-0.4% at a grain humidity of 25-30% under favourable weather conditions. Cool, humid weather considerably hinders the moisture transfer of grain [10-12]. The use of desiccants can ensure uniform ripening of grain and the ability to harvest in a short time, which prepares the field for subsequent crops. An additional advantage of desiccation is weed control and reduced grain drying costs. This technological technique is widely used on such crops as soy, rapeseed, sunflower [13-15].

For desiccation, preparations based on diquat, glyphosate, and glufosinate ammonium are mainly used, which have different mechanisms of action. It is important to choose the right desiccation time. The use of desiccants before the onset of the physiological ripeness of grain can negatively affect the yield. In hybrids of corn of the early-maturing and medium-maturing groups, an indicator of the onset of physiological ripeness is the development of a "black dot" at the place of attachment of the seed, which indicates that the accumulation of plastic substances is completed. In hybrids of the mid-late group, the signal for desiccation is the drying of 2-3 upper leaves.

Very few studies have been conducted on the use of desiccants on corn. In China, the use of diquat reduced the moisture content of corn grains by 2.01-2.44% [16]. In the conditions of the Russian Federation, the use of desiccants 2 weeks before harvesting decreased the moisture content of corn grain by 3.1-5.6%. Desiccation did not affect the level of corn yield [17; 18]. According to the study by E. Ivanova [19], desiccation at a grain humidity of 40% contributed to a decrease in pre-harvest humidity by 4-5%. According to US researchers, the use of sodium chlorate accelerated the possibility of harvesting corn for 1-3 weeks [20].

However, the conducted studies do not consider the group of ripeness of the hybrid, the terms and rates of the drug use. Climatic conditions also considerably affect the pre-harvest humidity of corn, so it is important to examine the effectiveness of using desiccants in the conditions of the western forest-steppe of Ukraine. Desiccation of corn crops can be an effective measure to reduce the pre-harvest moisture content of grain and have economic feasibility, especially in modern economic conditions, when the cost of drying grain is a major part of the total cost of growing technology; thus, this issue requires detailed investigation.

The purpose of the study is to determine the effectiveness of using desiccants to reduce the pre-harvest humidity of LG 3258 hybrid corn in the conditions of the Western Forest-Steppe.

MATERIALS AND METHODS

Field research was conducted in the Research and Production Centre "Podillia" of Podilskyi State Agrarian Technical University during 2018-2020. The soil of the experimental site is typical chernozem, characterised by the following agrochemical indicators: humus content – 3.27%, easily hydrolysed nitrogen (according to Kornfield) – 116 mg/kg of soil, mobile phosphorus compounds (according to Chirikov) – 95 mg/kg of soil, potassium – 87 mg/kg of soil, pH – 6.5.

The cultivation technology is typical for the region. Its predecessor is winter cereals. After collecting the predecessor, disking was performed at 10-12 cm. Plowing was conducted at 26-28 cm in November. Mineral fertilisers were applied under fallow plowing according to the variants of the experiment. Potassium chloride (potassium content – 60%) was used from potash fertilisers, and ammophos (phosphorus content – 52%) was used from phosphorous fertilisers. Nitrogen fertilisers were applied in the spring. The fertiliser rate is $N_{120}P_{60}K_{100}$. In the spring, moisture was closed, pre-sowing cultivation and nitrogen fertilisers were applied, of which 50% of the rate was urea (46% nitrogen) and 50% ammonium nitrate (34.4% nitrogen).

Hybrid LG 3258 (FAO 250), mid-early, originator company – Limagrain. The total area of the experimental plot is 40 m^2, and the accounting area is 32 m^2. Sowing took place in the third decade of April with a Monosem NG Plus 8 seeder, focusing on temperature indicators. Row spacing is 70 cm wide and seed embedding depth is 6 cm. The seeding rate is 90 thousand seed/ha. The stocking density was 80,000 plants/ha. Hybrid LG 3258 (FAO 250), medium-early, originator – Limagrain Europe. Seeds of category F1 comply with DSTU 2240-93 [21] and are treated by the manufacturer with the following active ingredients: clothianidin + thiram + fludioxonil + metalaxyl M.

Weed protection included the application of herbicides Primextra TZ Gold SC (S-Metolachlor – 312.5 g/l + Terbuthylazine – 187.5 g/l) – 4.0 l/ha before germination and Maister (foramsulfuron 300 g/kg + Iodosulfuron 20 g/kg + Isoxadifen-ethyl 300 g/kg) – 0.15 kg/ha in the phase of 5 leaves. Pest protection – Rimon Fast (novaluron, 50 g/l + bifenthrin, 50 g/l) – 0.5 l/ha in the ejection phase.

Spraying of plants was conducted when a "black dot" appeared – a dark layer at the seed attachment point, and 10 days after the black dot using a satchel sprayer. Roundup Max (450 g/l of glyphosate in acid equivalent) was used to treat plants at a rate of 2.4 l/ha and 3.2 l/ha, Reglon Super (150 g/l of diquat ion) at a rate of 2.0 and 3.0 l/ha. Harvesting, crop accounting, and humidity determination were conducted using a Haldrup C-85 combine. The economic efficiency of the cultivation technology was established using the calculation method.

Climatic conditions during 2018-2020 differed from the long-term average values (Table 1). The average annual temperature in 2018 was higher by 2.3°C, and in 2019 and 2020 – by 2.9°C from the long-term average temperature. Precipitation was also higher than the long-term average. Notably, the nature of precipitation distribution was uneven – dry periods were replaced by heavy downpours.

***Table 1**. Distribution of precipitation and air temperature over the years under study*

Year	Months												Amount for the year
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Precipitation distribution, mm													
L.A.*	27	27	27	48	66	84	85	68	50	40	38	32	592
2018	23	34	62	16	31	113	118	23	21	31	33	59	564
2019	43	23	19	49	139	198	47	26	11	14	21	28	617
2020	14	36	27	20	70	155	39	31	120	62	10	36	620
Average monthly temperatures, °C													
L.A.*	-5.3	-3.8	1.1	7.8	14.4	17.2	19.2	18.5	14.2	8.7	2.2	-2.5	7.6
2018	-1.2	-2.8	-0.2	13.9	17.8	19.7	20.3	21.6	16.1	11.0	2.2	-1.6	9.7
2019	-3.4	1.7	5.5	10.1	15.1	21.8	19.8	21.1	16.0	10.1	6.8	1.7	10.5
2020	-0.3	2.3	5.5	9.3	12.7	20.0	20.0	21.4	17.0	12.7	4.3	1.4	10.5

***Note**: * – long-term averages*

RESULTS AND DISCUSSION

The harvesting moisture content of corn grain depended on the climatic conditions of the studied year. September 2020 was characterised by an excess of the long-term average precipitation rate, which affected the humidity of corn grain, which was 29.2%. On average, over the years under study on the control variant, the pre-harvest moisture content of corn grain was 27.7% (Table 2). The introduction of desiccants at a grain humidity of 40% contributed to the greatest decrease in the harvesting humidity of corn. When using Roundup Max at a rate of 2.4 l/ha, the humidity was 20.6%, which is 7.1% less than the control. When the drug rate was increased to 3.2 l/ha, the humidity decreased to 20.1%, which is 7.6% less than the control. The use of Reglon Super at a rate of 2.0 l/ha reduced the moisture content of corn grain to 20.8%, which is 6.9 less than the control. When 3.2 l/ha of Reglon Super was applied, the moisture content was 20.4%, which is 7.3% less than the control. Spraying plants in the black dot phase and 10 days after the black dot was slightly less effective. Treatment of corn with Roundup Max 2.4 l/ha reduced the humidity of corn grain to 21.2%, and with an increase in the rate to 3.2 l/ha – 20.9%. When Reglon was applied at the rate of 2.0 l/ha in the black dot phase, the grain moisture was 21.3%, and when applying 3.0 l/ha – 21.0%, which is 6.4 and 6.7% less than the control. The smallest decrease in grain moisture was obtained in the option of applying desiccants 10 days after the black dot.

Table 2. *Harvesting humidity of corn depending on the use of desiccants, %*

Application period	Drug	2018	2019	2020	Average	± to control, %
	1. Control	26.4	27.5	29.2	27.7	–
40% grain moisture	2. Roundup Max 2.4 l/ha	19.1	19.5	23.2	20.6	-7.1
	3. Roundup Max 3.2 l/ha	18.3	19.0	23.1	20.1	-7.6
	4. Reglon 2.0 l/ha	19.1	19.8	23.4	20.8	-6.9
	5. Reglon 3.0 l/ha	18.8	19.1	23.2	20.4	-7.3
Black dot	6. Roundup Max 2.4 l/ha	19.2	20.0	24.4	21.2	-6.5
	7. Roundup Max 3.2 l/ha	19.2	19.5	23.9	20.9	-6.8
	8. Reglon 2.0 l/ha	19.3	20.5	24.2	21.3	-6.4
	9. Reglon 3.0 l/ha	18.6	20.2	24.0	21.0	-6.7
10 days after the black dot	10. Roundup Max 2.4 l/ha	19.5	20.9	25.2	21.9	-5.8
	11. Roundup Max 3.2 l/ha	18.9	20.7	25.0	21.5	-6.2
	12. Reglon 2.0 l/ha	20.0	21.1	25.2	22.1	-5.6
	13. Reglon 3.0 l/ha	19.9	20.3	25.0	21.7	-6.0

Thus, when using Roundup Max 2.4 l/ha, humidity was 21.9%, and when applying 3.0 l/ha – 21.5%, which is 5.8 and 6.2% less than the control. The introduction of Reglon Super at a rate of 2.0 l/ha reduced the moisture content to 22.1%, and at a rate of 3.0 l/ha – 21.7%, which is less than the control by 5.6 and 6.0%. The use of desiccants in the cultivation of corn dries the vegetative mass of the plant, which promotes faster physical evaporation of moisture in the grain, which is more intense at higher temperatures. Similar data are observed in a number of studies by Chinese and Russian researchers, in which the decrease in moisture content in corn grain was 2.01-5.6% [17-20].

According to the results of the study, the effect of desiccation depends to a greater extent on the timing of application of the drug (Table 3). In the variants of using desiccants at a corn grain humidity of 40%, grain losses in the amount of 0.17-0.35 t/ha of grain were observed, depending on the drug, rate, and year of the study. When using Roundup Max at a grain humidity of 40%, the average yield was 10.67 t/ha, which is 0.22 t/ha less than the control option – 10.89 t/ha. An increase in the rate of the drug to 3.2 l/ha contributed to an increase in losses by 0.25 t/ha, the yield was 10.63 t/ha (Fig. 1). Corn treatment with Reglon at a rate of 2.0 l/ha reduced the yield to 10.61 t/ha, which is 0.28 t/ha less than the control, and the use of 3.0 l/ha decreased the yield to 10.58 t/ha, which is 0.30 t/ha less than the control. Desiccation at a grain moisture content of 40% reduces the grain yield of corn by stopping photosynthesis, synthesis, and metabolism, artificially accelerating the end of the growing season.

Table 3. *Corn yield depending on the use of desiccants, t/ha*

Application period	Drug	2018	2019	2020	Average	± to control	
						t/ha	%
	1. Control	10.55	11.33	10.78	10.89	–	–
40% grain moisture	2. Roundup Max 2.4 l/ha	10.27	11.16	10.58	10.67	-0.22	-2.0
	3. Roundup Max 3.2 l/ha	10.24	11.12	10.54	10.63	-0.25	-2.3
	4. Reglon 2.0 l/ha	10.22	11.08	10.52	10.61	-0.28	-2.6
	5. Reglon 3.0 l/ha	10.20	11.05	10.50	10.58	-0.30	-2.8
Black dot	6. Roundup Max 2.4 l/ha	10.54	11.32	10.77	10.88	-0.01	-0.1
	7. Roundup Max 3.2 l/ha	10.54	11.32	10.76	10.87	-0.01	-0.1
	8. Reglon 2.0 l/ha	10.53	11.31	10.76	10.87	-0.02	-0.2
	9. Reglon 3.0 l/ha	10.53	11.32	10.76	10.87	-0.02	-0.2

Table 3, Continued

Application period	Drug	2018	2019	2020	Average	± to control t/ha	± to control %
10 days after the black dot	10. Roundup Max 2.4 l/ha	10.55	11.32	10.79	10.89	0.00	0.0
	11. Roundup Max 3.2 l/ha	10.54	11.34	10.79	10.89	0.00	0.0
	12. Reglon 2.0 l/ha	10.54	11.33	10.77	10.88	-0.01	-0.1
	13. Reglon 3.0 l/ha	10.56	11.32	10.78	10.89	0.00	0.0
$HIP_{0,5}$ t/ha	2018	A = 0.10; B = 0.11; AB = 0.11					
	2019	A = 0.15; B = 0.12; AB = 0.12					
	2020	A = 0.12; B = 0.10; AB = 0.10					

Spraying plants in the black dot phase and 10 days after the black dot had little effect on yield (Fig. 1) since the development of a dark layer at the site of seed attachment means that by this time the process of accumulation of assimilates is completed. The desiccation during this period decreased yield by 0-0.02 t/ha of corn grain, which is not statistically proven.

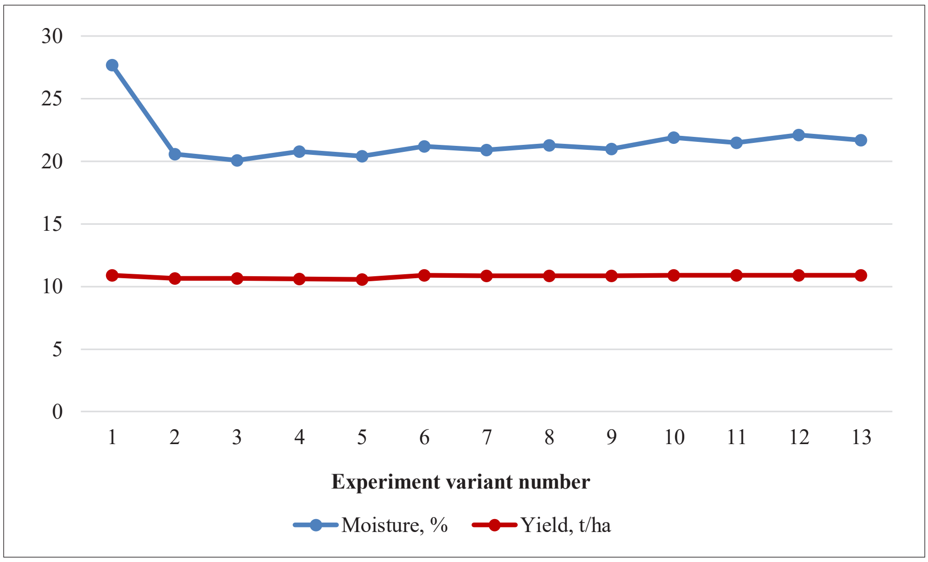

***Figure 1**. Dynamics of moisture and yield of corn under the use of desiccants*

Data on the impact of desiccation on the yield level vary. According to studies by E. Alcantara and D. Wyse [22], the use of glyphosate did not affect yields and had little effect on reducing humidity in high humidity conditions. Other studies also indicate a slight effect on yield. According to A. Volkov, L. Prokhorova and M. Sivandaev, desiccation in the phase of full ripeness of corn reduced the yield by 0.05-0.09 t/ha, depending on the drug and the year under study [23]. L. Zhao et al. [24] report that the effect of glyphosate on yield depends on the hybrid. The study established that the treatment of corn with glyphosate slightly reduces the yield and does not affect the quality indicators.

For a comprehensive assessment of the studied elements of corn cultivation technology, economic efficiency indicators were calculated (Table 4).

***Table 4**. Economic efficiency of using desiccants in corn cultivation, 2018-2020*

	Option	Yield, t/ha	Cost of products with 1 ha, UAH	Expenses per 1 ha, UAH	Prime cost of 1 tonne, UAH	Conditionally net profit from 1 ha, UAH	Profitability level, %
	1. Control	10.89	76230	31571	2899	44659	141
40% grain moisture	2. Roundup Max 2.4 l/ha	10.67	74690	28340	2656	46350	164
	3. Roundup Max 3.2 l/ha	10.63	74410	28215	2654	46195	164
	4. Reglon Super 2.0 l/ha	10.61	74270	28404	2677	45866	161
	5. Reglon Super 3.0 l/ha	10.58	74060	28403	2685	45657	161

Table 4, Continued

	Option	Yield, t/ha	Cost of products with 1 ha, UAH	Expenses per 1 ha, UAH	Prime cost of 1 tonne, UAH	Conditionally net profit from 1 ha, UAH	Profitability level, %
Black dot	6. Roundup Max 2.4 l/ha	10.89	76160	28739	2639	47491	165
	7. Roundup Max 3.2 l/ha	10.88	76090	28727	2640	47433	165
	8. Reglon Super 2.0 l/ha	10.87	76090	28765	2646	47325	165
	9. Reglon Super 3.0 l/ha	10.87	76090	28822	2651	47269	164
10 days after b.d.	10. Roundup Max 2.4 l/ha	10.89	76230	29121	2674	47109	162
	11. Roundup Max 3.2 l/ha	10.89	76160	29057	2668	47173	162
	12. Reglon Super 2.0 l/ha	10.88	76160	29203	2684	46957	161
	13. Reglon Super 3.0 l/ha	10.88	76160	29206	2684	46954	161

Additional spraying and desiccation are cost-effective compared to control. According to Table 4, production costs per 1 ha decreased by 2365-3356 UAH, respectively, the prime cost of 1 t/ha decreased by 214-259 UAH due to the reduction of grain drying costs. Desiccation allows getting 998-2832 UAH/ha more of conditionally net profit.

The smallest increase in net profit was in the options of applying desiccants at 40% humidity of corn grain due to a decrease in yield. The greatest increase in conditional net profit was obtained with the use of desiccants in the black dot phase, where treatments have little effect on yield and reduce humidity by 6.5-6.8%, and the economic efficiency is almost the same regardless of the drug and the rate of its application.

CONCLUSIONS

Roundup Max and Reglon Super both affected the pre-harvest moisture content of corn grains. Weather conditions of the year had a considerable impact on the pre-harvest humidity of grain, compared to the drug and its consumption rate. Desiccation had a positive effect on the pre-harvest moisture content of corn in all variants of the experiment. Desiccant treatments were most effective at a grain moisture content of 40%, the least effective was the treatment 10 days after the onset of the black dot. The lowest grain moisture of 20.1% of corn was obtained when applying Roundup Max at the rate of 3.2 l/ha in the variant of plant treatment at a humidity of 40%. This allows harvesting and preparing the field for subsequent crops in optimal time and reducing the cost of drying grain.

The timing of treatments is found to be important when using chemical dehumidifiers. Desiccation at a corn grain humidity of 40% reduced the yield by 0.17-0.35 t/ha, depending on the drug, its rate, and the year of the study. Spraying in the black dot phase and 10 days after the black dot had little effect on yield – 0-0.02 t/ha less than the control variant. The use of desiccants in corn cultivation technology is cost-effective. The largest net profit was obtained with the Roundup Max 2.4 l/ha treatment option in the black dot phase – UAH 47,491/ha, the profitability level is 165%.

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Вплив застосування десикантів на передзбиральну вологість кукурудзи середньораннього гібриду LG 3258 в умовах Західного Лісостепу

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Анотація. Висока передзбиральна вологість зерна кукурудзи призводить до травматизації насіння та значно збільшує витрати у технології вирощування. Метою досліджень було встановити ефективність застосування десикантів для зниження передзбиральної вологості зерна та визначити чи впливає проведення десикації посівів кукурудзи на врожайність. Для досягнення мети були використані такі методи: польовий – для визначення впливу проведення десикації на врожайність кукурудзи, лабораторний – для визначення вмісту вологи у зерні, статистичний – для математичної обробки результатів досліду. Проведено польовий дослід, у якому були вивчені строки проведення десикації та норми застосування десикантів, з використанням препаратів Раундап Макс і Реглон Супер. Гібрид кукурудзи – ЛГ 3258, ФАО 250, середньоранній. За результатами досліджень встановлено, що застосування десикантів знижувало передзбиральну вологість зерна кукурудзи в усіх варіантах досліду. На зниження вологості зерна вагомий вплив мали погодні умови. Так, у 2018 та 2019 рр. за допомогою десикації передзбиральна вологість зерна знизилася на 6,4–8,0 %, а у 2020 р. – на 4,0–5,3 % при обробці рослин кукурудзи у фазі чорної точки препаратом Раундап Макс у нормі 3,2 л/га. При застосуванні Реглону Супер у фазі появи чорної точки спостерігали зниження вологості на 5,2–7,8 % залежно від норми витрати препарату та року досліджень. У варіантах обробки через 10 днів після чорної точки препаратом Раундап Макс вологість знизилася на 4,0–7,5 % залежно від норми витрати та року досліджень. Використання Реглону Супер знижувало передзбиральну вологість на 4,0–6,5 % в залежності від норми препарату та року досліджень. Обробка рослин у фазі 40 % вологості зерна була найефективнішою, що сприяло формуванню вологості 20,1 % при застосуванні Раундап Макс у нормі 3,2 л/га. Проведення обробки десикантами посівів кукурудзи не мало впливу на врожайність у жодному з варіантів досліду. За отриманими результатами дослідження було встановлено, що проведення десикації кукурудзи є ефективним технологічним прийомом, що дозволяє знизити передзбиральну вологість зерна на 4,0–8,0 % залежно від препарату, його норми та погодних умов. Найнижчу збиральну вологість – 20,1 % отримали у варіанті обробки кукурудзи при вологості зерна 40 % препаратом Раундап Макс в нормі 3,2 л/га. Економічна оцінка показала, що найбільший чистий прибуток отримали у варіанті обробки препаратом Раундап Макс 2,4 л/га у фазі чорної точки – 47491 грн/га, рівень рентабельності становить 165 %

Ключові слова: кукурудза, збиральна вологість, десикація, переджнивне підсушування, врожайність

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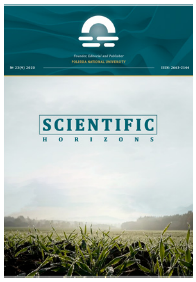

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Total Water Consumption and Evaporation of Winter Wheat in the Irrigation Zone of Southern Ukraine

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Abstract. The most important element in the development of the irrigation regime of agricultural crops is the total water consumption or/and the amount of water that plants need during the growing season to obtain the planned crop in specific natural conditions while optimising all technological processes. The purpose of the study is to determine the features of total water consumption and average daily evaporation of winter wheat plants depending on the natural moisture supply of growing years, irrigation regimes, and groundwater level in the irrigation zone of southern Ukraine. In the course of the study, generally accepted methods were used: system approach and systems analysis, monographic, analysis and synthesis, abstract-logical, historical, field research, statistical and economic-mathematical, etc. The highest indicators of total water consumption were observed in the average weather conditions and amounted to 4,263 m^3/ha in the 2-metre layer of soil, in wet years characterised by moderate temperatures, high humidity, and a considerable number of days with precipitation, the average water consumption from this soil layer was 3,993 m^3/ha. In dry years, which were characterised by hot weather with low humidity and low precipitation, the total water consumption was the lowest and amounted to 3685 m^3/ha. The reduction of the growing season occurs in late June – early July when high air temperatures and low humidity are observed, which is the main reason for the decrease in the total water consumption of irrigated winter wheat. Analysis of data on the use of moisture from different soil layers indicates that during the autumn growing season and during the wintering of plants water reserves in the deep layers are replenished. In general, during the growing season of winter wheat, considering the winter period, the field of this crop consumes an average of 5.2 thousand m^3 of water during irrigation over 12 years. Observation of the average daily evaporation of winter wheat plants in conditions of natural and artificial irrigation indicates that it has the form of a parabola, the maximum mark of which falls on the interphase period of earing – the beginning of milky ripeness of grain

Keywords: irrigation water, average daily evaporation, groundwater level, irrigation mode

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INTRODUCTION

The most important element in shaping the irrigation regime of crops is the total water consumption or the amount of water needed by plants during the growing season to obtain the planned yield in specific natural conditions with all technological processes optimised. Total water consumption by crops is an indicator of plant needs for the entire growing season, while total evaporation relates to some of its segments. They consist of water consumption for plant transpiration, evaporation from the soil surface, and the development of biological mass. Different plant requirements for the amount of water needed for optimal growth and production processes and high yields are the result of their evolutionary development under the influence of varying climatic conditions.

Numerous studies have shown that the strongest regulatory factors of total water consumption are climatic conditions of the growing zone, weather during the growing season, biological characteristics of crop varieties and, above all, the duration of the growing season, plant moisture provision, etc. [1-3]. The loss of soil moisture for the transpiration of plants and evaporation from the soil surface during certain periods of the growing season is called total evaporation in reclamation terminology [3]. The rate of the crop total evaporation is not a constant value and varies during the growing season depending on the rate of growth and plant development, weather conditions, soil water regime, and other factors [4; 5]. As a rule, at the beginning of the growing season, the crops consume a small amount of moisture, which is mainly conditioned by evaporation from the soil surface.

In the steppe zone, the water consumption of plants depends largely on weather conditions. On non-irrigated lands, there is a constant dependence of the total water consumption reduction on wet or dry years, which is conditioned by different temperatures and precipitation during the growing season. According to scientific institutions in the Southern regions, the water consumption of rain-fed winter wheat, which is necessary for the development of a high yield, averages 70% of the optimal values, and in dry years it is 50-60% [6]. Some studies on the water consumption by irrigated winter wheat also show that it is proportionally dependent on cool and dry years [7; 8]. According to researchers, in a particular agro-climatic region where the crop grows in the optimal water regime with high agro-technical techniques, the total water consumption depends primarily on the radiation balance of the ground air and the soil surface. In very dry years, the total water consumption under irrigation is much higher than under moderate weather conditions [9].

The purpose of the study is to establish rates of water consumption by winter wheat plants depending on the conditions of natural and artificial irrigation.

MATERIALS AND METHODS

The experimental part of the study was performed on irrigated lands of the Institute of Irrigated Farming NAAS (IIF NAAS), located on the right bank of the Dnipro, the Dnipro district of Kherson, in the Ingulets irrigation system area. The soil of the plots under study is dark chestnut, medium loamy, slightly saline based on carbonate aeolian soil, which is typical for the irrigated zone of southern Ukraine. To determine the content of relevant elements of natural soil fertility in the spring from a layer of 0-60 cm using the envelope method, samples were taken every 10 cm and sent to the agrochemical laboratory where the following parameters were determined by the current state standards of Ukraine. The content of humus in the arable layer is 2.2%, that of total nitrogen is 0.17%, mobile phosphorus and exchangeable potassium – 30 and 300 mg/kg of soil, respectively [10-12].

Experimental studies were conducted during 2009-2015 using generally accepted research methods for irrigation conditions in Southern Ukraine. In particular, general research methods (analysis, synthesis, observation, comparison, measurement, etc.), special (field, laboratory-field, laboratory, certified generally accepted scientific methods, and DSTU), mathematical-statistical and computational-comparative. To determine the indicators of total and daily water consumption, soil samples were taken every 10 cm to a depth of 2 m at the beginning and end of the growing season and during the main phases of growth and development to establish soil moisture [13; 14].

In a metre-long soil layer, the lowest moisture content (LMC) is 21.3%, wilting moisture (WM) is 9.5% of dry soil weight, texture density is 1.41 t/m^3, pH of the aqueous extract of the arable soil layer is 6.8-7.2. Groundwater lies at a depth of 15-17 m and has virtually no effect on the water-air regime of the active moisture exchange zone.

The materials of the Kherson agrometeorological station located on the territory of the experimental field were used to characterise the weather conditions in the years under study. Agricultural techniques in the experiments corresponded to the technology of growing winter wheat in the South of Ukraine, the requirements for research methods and guidelines for potatoes cultivation; mathematical processing of experimental data was conducted according to generally accepted methods [13-15].

RESULTS AND DISCUSSION

According to the long-term studies of the characteristics of water consumption of irrigated winter wheat under different weather conditions, the following results were obtained (Table 1).

***Table 1**. Total water consumption by winter wheat during the spring-summer vegetation period depending on weather conditions, m³/ha*

Years by weather conditions and their number	Soil layers			
	0-50	0-100	0-150	0-200
Wet (12 years)	3.543	3.847	3.941	3.993
Average (4 years)	3.764	4.088	4.178	4.263
Dry (6 years)	2.916	3.445	3.567	3.685
On average for 22 years	3.396	3.782	3.882	3.958
LSD_{05}, m^3/ ha	150	167	168	188

The highest values of total water consumption were observed under the average weather conditions and amounted to 4,263 m^3/ha in a 2-metre soil layer in wet years characterised by moderate temperatures, high humidity, and a considerable number of days with rainfall. The average water consumption from this soil layer was 3,993 m^3/ha. In dry years which were characterised by hot weather, low humidity, and low rainfall, the total water consumption was the lowest and amounted to 3685 m^3/ha. These data were obtained from the option in which vegetative waterings were prescribed at the optimum humidity for average loamy dark chestnut soil – 70% LMC.

Admittedly, different years with varying weather conditions (12, 4, and 6) may cause some errors in determining the total water consumption but it can not affect the results. The reason for the decrease in the total water consumption of winter wheat in dry years with optimal irrigation is a considerable shortening in the duration of spring-summer vegetation period.

It was noted that the period of spring and summer vegetation and winter wheat ripening was shortened by 8-14 days, compared to the average. The shortening of the growing season occurred in late June-early July during which there are high air temperatures and low humidity, which is the main reason for the decrease in total water consumption by irrigated winter wheat. These experimental data allow analysing the processes of moisture consumption from different soil layers in years that differ substantially in weather conditions. In all years, the main process of moisture consumption takes place in the 1st metre of the soil layer. Moisture from the 2nd metre is used more intensively (240 m^3/ha) in dry years.

Upon analysing the results of the long-term study on winter wheat irrigation in different regions of the Ukrainian steppe, it can be concluded that the total water consumption is influenced by moisture provision, mineral nutrition, certain agronomic techniques, and weather conditions. Therewith, attention is focused on the proportional dependence of the wheat total water consumption on the irrigation regime, which is one of the strongest regulatory factors in providing plants with moisture.

There are two major periods in winter wheat development and moisture consumption: the first one is from sprouting to vegetation stoppage in connection with the onset of winter; the second one is from the spring vegetation renewal to the grain ripening. The study established that the total evaporation of winter wheat, depending on the soil layer, is: 533-608 m^3 per hectare in the period from sprouting to vegetation stoppage, 566-874 from vegetation stoppage to spring revival, 3,605-4,111 m^3 per hectare from spring revival to full ripeness (Table 2).

***Table 2**. Water consumption by the winter wheat in the interphase growing periods with optimal irrigation, m³/ha (average for 12 years)*

Soil layer, cm	Period				LSD_{05}
	Sprouting-vegetation stoppage	Vegetation stoppage-spring revival	Spring revival-grain ripeness	Total moisture consumption	
0-50	608	874	3.605	5.087	122
0-100	561	779	3.931	5.271	121
0-150	533	672	4.046	5.251	125
0-200	554	566	4.111	5.231	116

Accordingly, the following pattern is observed: in the autumn and winter periods the highest water consumption takes place in the soil layers of 0-50 centimetres. This is conditioned by the fact that during these periods part of the water from the upper layers replenishes its reserves in the deeper layers.

The average amount of precipitation by periods during the studied years: sprouting-vegetation stoppage – 674 m^3/ha, vegetation stoppage-spring revival – 988 m^3/ha, spring revival-full grain ripeness – 1,852 m^3/ha, that is, from sprouting to full grain ripeness – mm 3,524 m^3/ha (Table 3).

***Table 3**. Water consumption by the winter wheat in the interphase growing periods with optimal irrigation, m^3/ha (average for 2009-2020)*

Soil layer, cm	Interphase period and values							
	Sprouting-vegetation stoppage		Vegetation stoppage-spring revival		Spring revival-full grain ripeness		Total for vegetation period	
	Rainfall	Evaporation	Rainfall	Evaporation	Rainfall	Evaporation	Rainfall	Evaporation
0-50	674	608	998	874	1.852	3.605	3.524	5.087
50-100		-47		-95		326		184
100-150		-28		-107		115		-20
150-200		21		-106		65		-20

Analysis of data on moisture consumption from different soil layers shows that in the autumn vegetation period and during plant wintering water reserves in deep layers are replenished. The above can be observed from the total water consumption values which decrease from the soil layer of 0-50 cm to the layer of 0-200 cm. During the spring-summer vegetation, on the contrary, the total water consumption values in these layers increase. Such data indicate that in spring and summer the plants use water mainly from the soil layer of one metre. Therefore, all calculations concerning the total plant evaporation should be made considering the values relating to the soil layer of 0-100 cm.

A comparison of the total water consumption by a winter wheat field and the amount of precipitation during the period from sprouting to full grain ripeness allows establishing the moisture deficit, which must be compensated by irrigation. According to data on moisture consumption from a metre layer of soil, it is 1,747 m^3/ha. On average over the years under study, the irrigation rate was 1,380 m^3/ha.

The materials given in the table allow determining the specific weight of moisture consumed in the given periods. They show that during the wintering period the winter wheat field lost about 566 m^3/ha of water (according to the values from the soil layer of 0-200 cm), and the amount of precipitation during the same period averaged 998 m^3/ha over 12 years. Thus, during the winter period, the winter wheat field accumulates about 430 m^3/ha of soil moisture. During the period of spring and summer growth, the disparity between water consumption (used mainly for the development of the crop) and the amount of precipitation is considerable and amounts, on average, to 1,753-2,259 m^3/ha, and in most years the shortage of available moisture should be eliminated by vegetative watering.

In general, during the winter wheat vegetation period (considering the winter period), the irrigated field of this crop consumes an average of about 5.2 thousand m^3 of water over 12 years, which necessitates a careful approach to irrigation in the Southern Steppe.

A similar analysis is made for the 22-year period (1999-2020). The data obtained show that during the period from sprouting to spring vegetation revival, the field of winter wheat consumes, on average, 1,175 m^3/ha of water from the 2-metre soil layer, and the total water consumption during the spring-summer vegetation period is 3,734 m^3/ha. Thus, on the average, a field of winter wheat in the south of Ukraine at the optimal irrigation regime requires about 4,900 m^3/ha of water for a high yield (6.0-6.5 t/ha and more), a great part of it is supplied by moisture-storing and vegetative watering.

Monitoring of the average daily evaporation of winter wheat plants at natural and artificial watering shows that it has the form of a parabola, its maximum value coincides with the interphase period of earing – the beginning of milky ripeness and averages 59.3 m^3/ha over 12 years under the optimal irrigation regime and 35.2 m^3/ha without irrigation (Table 4).

***Table 4**. Average daily evaporation of irrigated winter wheat during the spring-summer growing season, m^3/ha (average for 12 years)*

Interphase period	Average daily evaporation	
	No watering	Optimal irrigation regime
Spring growth renewal – stem elongation	20.3	23.5
Stem elongation – earing	30.9	42.4
Earing – grain milky ripeness start	35.2	59.3
Grain milky ripeness start – grain full ripeness	13.1	30.5

Immediately after plant revival and before the phase of stem elongation and from milky and to full ripeness, the average daily evaporation is minor and averages 23.5-30.5 m^3/ha under irrigation conditions and 20.3-13.1 m^3/ha with no irrigation, respectively. Based on long-term observations of the dynamics of moisture consumption by winter wheat plants from a metre-long soil layer under the optimal irrigation regime, the total and average daily evaporation of winter wheat over the decades of spring-summer vegetation was calculated. These data were systematised in accordance with different weather conditions and specific evaporation rates were determined (Table 5).

***Table 5**. Total (E) and average daily ($\bar{E}$) evaporation of winter wheat under different weather conditions, m^3/ha*

Month	10-day period	Wet (6 years of monitoring)		Average (5 years of monitoring)		Wet (4 years of monitoring)	
		E	$\bar{E}$	E	$\bar{E}$	E	$\bar{E}$
March	2	–	–	180	18.0	200	20.0
	3	227	20.6	239	21.7	263	23.9
April	1	230	23.0	214	21.4	315	31.5
	2	312	31.2	276	27.6	276	27.6
	3	370	37.0	328	32.8	351	35.1
May	1	363	36.3	340	34.0	445	44.5
	2	365	36.5	352	35.2	51.2	51.2
	3	484	44.0	549	49.9	495	45.0
June	1	510	51.0	560	56.0	420	42.0
	2	390	39.0	344	34.4	322	32.2
	3	335	33.5	236	23.6	335	33.5
July	1	276	27.6	241	24.1	327	32.7
	2	316	31.6	257	25.7	–	–

These data allow tracing the dynamics of moisture absorption by winter wheat under optimal moisture conditions during the spring-summer growing season, considering weather differences. The data show that in dry years the maximum water consumption by winter wheat plants is observed in the second ten-day period of May, and in wet and medium years it shifts to the first ten-day period of June. In addition, these data help to establish the beginning and the end of the winter wheat growing season, depending on the weather conditions of the spring and summer vegetation period. Most importantly, these data can be used for setting the timing and rates of vegetative irrigation.

One of the urgent problems of irrigated farming is that groundwaters can lie on different levels, sometimes exceeding 3 m. They have a considerable impact not only on soil-forming processes but also affect plant water regimes. In this regard, a series of field experiments to establish the average daily evaporation of crops in areas with close levels of low-mineralised groundwater were conducted (Fig. 1).

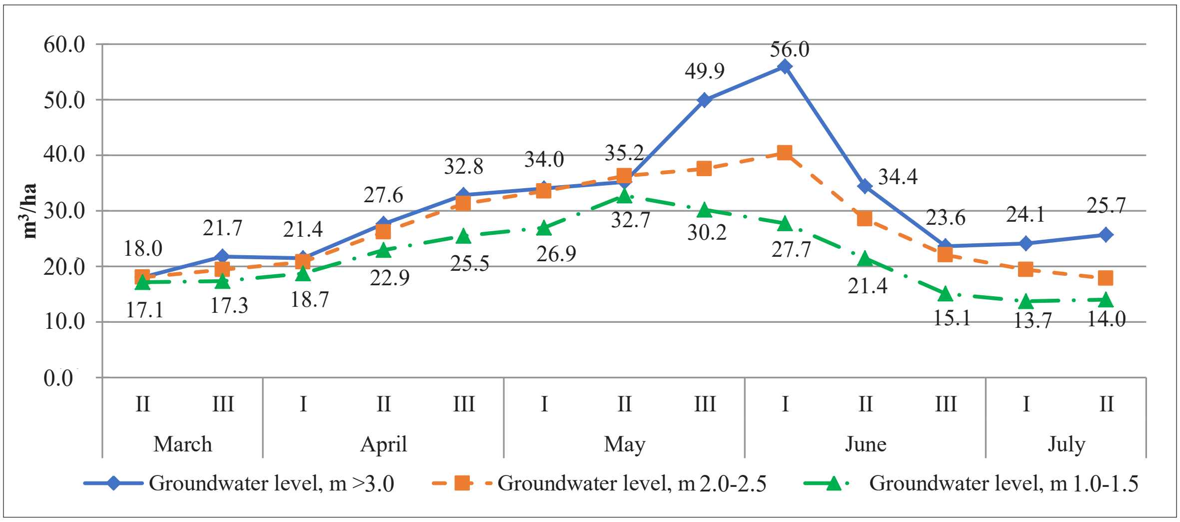

***Figure 1**. Average daily evaporation of winter wheat depending on the groundwater level, m^3/ha*

It has been established that the average daily values of crop evaporation at a groundwater level of more than 3 m and not more than 2 m are almost the same from the second decade of March to the second decade of May and range from 18.0 to 36.3 m^3/ha. From the 3rd ten-day period of May to the 2nd ten-day period of June, the average daily evaporation of winter wheat at a level deeper than 3 metres increases considerably compared to other levels and reaches its maximum (49.9-56.0 m^3/ha), in the 3rd ten-day period of May – 1st ten-day period of June at the level of 2-2.5 m, the average daily evaporation of plants does not exceed 37.5-40.4 m^3/ha. The average daily evaporation of plants at groundwater levels not deeper than 1.5-1 m is completely different. Due to the use of moisture directly from the water level, it decreases substantially and reaches its maximum in the 2nd ten-day period of May – 32.7 m^3/ha, which is almost 2 times lower compared to the groundwater occurrence deeper than 3 m.

The results obtained correlate with the materials obtained by researchers in different natural and climatic zones; thus, according to research at the Kansas Research Station (USA), over 3 years of observations, the average daily evaporation of winter wheat was: autumn (after sowing, October) – 17.5 m^3/ha, winter (November – February) – 7.5 m^3/ha, to tillering (March – April) – 22.4, from tillering to tubing (May 1-15) – 40.0, from tubing to flowering (May 15-28) – 62.2, from flowering to milky ripeness (May 28 – June 6) – 87.0, from milky to waxy ripeness (June 6-13) – 75.0 and from wax to full maturity (June 13-28) – 37.4 m^3/ha [16].

Similar results were obtained at the Volga Research Institute of Irrigated Agriculture. According to studies under the optimal irrigation regime (water-charging irrigation and vegetation at a soil moisture content of 80% HB), the total and average daily evaporation for the interphase periods was: seedlings – the beginning of steady cooling – 606 and 16.9 m^3/ha, the beginning of spring regrowth tubing – 620 and 21 m^3/ha, tubing – earing – 1063 and 52.9 m^3/ha, earing – milky ripeness of grain – 1605 and 65.2 m^3/ha, dairy – full ripeness of grain – 798 and 35.9 m^3/ha, respectively [17].

On average, for 5 years under study at the Rostov Regional Research and Reclamation Station, the total and average daily evaporation during the growing season was: sowing – the beginning of tillering – 390 and 17.0 m^3/ha, autumn tillering – 560 and 20.0 m^3/ha, spring tillering – 805 and 35.0 m^3/ha, tube output – 1350 and 45.0 m^3/ha, earing – grain development 585 and 45.0 m^3/ha, milky ripeness – 760 and 40.0 m^3/ha, wax ripeness – 350 and 23.0 m^3/ha [18].

CONCLUSIONS

In general, the field of winter wheat during irrigation consumes an average of about 5.2 thousand m^3 of water for vegetation, considering the winter period. Analysis of data on the use of moisture from different soil layers indicates that during the autumn growing season and during the wintering of plants water reserves in the deep layers are replenished. During the spring and summer vegetation, on the contrary, the total water consumption in these layers increases. Such data indicate that in spring and summer the plants use water mainly from a metre layer of soil. Therefore, in all calculations, it is better to consider the indicators in the soil layer of 0-100 cm for the total evaporation of plants.

A comparison of the total water consumption of the winter wheat field and the amount of precipitation for the period from germination to full ripeness of the grain indicates the moisture deficit, which must be compensated by vegetative irrigation. According to data on moisture consumption from a metre layer of soil, it is 1,747 m^3/ha. On average over the years under study, the irrigation rate was 1,380 m^3/ha.

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Сумарне водоспоживання та випаровування озимої пшениці в зоні зрошення півдня України

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Анотація. Найважливішим елементом при формуванні режиму зрошення сільськогосподарських культур є сумарне водоспоживання або/та кількість води, яка необхідна рослинам протягом вегетаційного періоду для отримання запланованого врожаю в конкретних природних умовах при оптимізації всіх технологічних процесів. Метою досліджень є визначення особливостей сумарного водоспоживання та середньодобового випаровування рослин пшениці озимої залежно від природньої вологозабезпеченості років вирощування, режимів зрошення та рівня ґрунтових вод у зоні зрошення півдня України. У ході дослідження використовувалися загальноприйняті методи: системного підходу та системного аналізу, монографічний, аналізу і синтезу, абстрактно-логічний, історичний, методи польових досліджень, статистичні та економіко-математичні методи тощо. Найвищі показники сумарного водоспоживання спостерігалися у середні за погодними умовами роки і становили у 2-метровому шарі ґрунту 4263 м^3/га, у вологі роки, які характеризувалися помірними температурами, високою вологістю повітря і значною кількістю днів з опадами, середній показник водоспоживання з цього шару ґрунту дорівнював 3993 м^3/га. У посушливі роки, які відрізнялися спекотливою погодою з низькою вологістю повітря і невеликою кількістю опадів, сумарне водоспоживання було найменшим і склало 3685 м^3/га. Скорочення вегетаційного періоду відбувається наприкінці червня – на початку липня, коли спостерігаються високі температури повітря і низька його вологість, що і є основною причиною зменшення показників сумарного водоспоживання зрошуваної пшениці озимої. Аналіз даних використання вологи з різних шарів ґрунту свідчить про те, що в осінній період вегетації, а також під час зимівлі рослин, проходить поповнення запасів води у глибоких шарах. Загалом за вегетацію пшениці озимої, враховуючи і зимовий період, поле цієї культури при зрошенні витрачає в середньому за 12 років близько 5,2 тисяч кубічних метрів води. Спостереження за показниками середньодобового випаровування рослин пшениці озимої в умовах природного та штучного зволоження свідчить про те, що воно має форму параболи, максимальна позначка якої припадає на міжфазний період колосіння – початок молочної стиглості зерна

Ключові слова: поливна вода, середньодобове випаровування, рівень підґрунтових вод, режим зрошення

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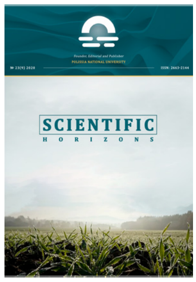

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Influence of Climate Changes on Hydrothermal Regime of Dark Gray Podzolized Soil of Western Forest Steppe

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Abstract. Thermal properties of soil are important conditions that determine the nature and intensity of soil processes, but the features of the formation of thermal and water regimes of dark gray podzolized soil of the Ukrainian Forest Steppe are insufficiently studied. The purpose of the presented materials is to highlight the dynamics of the annual course of temperature and humidity of the air and dark gray podzolized soil to determine the peculiarities of the formation of its hydrothermal regime in modern agro-climatic conditions of the Forest Steppe zone. The study of soil temperature was carried out during 2008-2019 in the Rivne region using generally accepted standards and methods (DSTU ISO 11464-2007, DSTU ISO 11465-2001, DSTU B B.2.1-17:2009, DSTU B B.2.1-25:2009). Surface air temperature observations throughout the study period indicate an increase in average annual temperature, and five-year averages of the sum of effective air temperatures above 10°C show tends to increase. The study of the relationship between the temperature of the surface air layer and dark gray soil in the Rivne region confirmed that the correlation of these indicators is linear. Analyzing the dynamics of temperature indicators, it should be noted a significant increase in maximum soil temperatures, due to which there is an increase in average annual temperatures. Detailing of soil warming indicators according to the data of ten years showed that during 2008-2017 the soils warmed up much more than in the average during the whole period of meteorological observations. According to the accepted classification, the studied soils belong to the seasonally freezing type, moderately warm subtype and genus with medium heat supply. The results obtained during the study allow to justify changes in the hydrothermal conditions of dark gray podzolized soil and determine the needs for corrective measures in crop production to maintain sustainable yields and ensure enhanced fertility reproduction

Keywords: global warming, air temperature, soil temperature, soil warming index, sum of temperatures, moisture supply, CO_2 emissions

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INRODUCTION

Soil temperature and its thermal properties are important conditions that determine the nature and intensity of soil processes, including synthesis, destruction of substances, biodynamic of soil [1; 2]. C.A. Aliev noted that the increase in soil temperature leads to the accelerated of rock decay, increases the intensity of chemical and biological processes occurring in the soil cover [3]. Later this was the development of work of O.H. Chuian and L.N. Karaulova, which emphasized the determining influence of general climatic conditions of the territory on formation of physical and chemical properties of zonal soils and their oxidation-recovery, living and other modes [4].

Since the beginning of the XXI century, much of the attention of scientists is directed at studying the manifestations of so-called "global warming" or global climate change. In this context, research of hydrothermal regime of soils has gained new relevance and new faces, in particular – a separate section has become the study of processes of transformation of organic substance and associated emission of greenhouse gases [5]. According to this, in studying the role of the temperature factor in the soil processes it is possible to allocate a classical period, under which the general regularities of the course of soil processes were substantiated depending on temperature conditions and degree of soil moisture [6-8] and the modern period, the main tasks of which were the study of the extent and speed of changes in the general agro-climatic conditions of territories [9], as well as the reaction of field crops to these changes. The latter aspect was studied in a rather deep way in the world scientific community, so Carlos Garcia described in detail not only the important role of soil in the carbon cycle, but also its reaction to the change of CO_2 in the atmosphere [10], similar conclusions follow from R. Chauhan [11] and D. Uprety in their work [12] noted the importance of taking into account the actual agro-climatic parameters of the territory when planning technological approaches to field crops cultivation, as the latter are sharply reacting to climate changes.

A significant number of researches are carried out concerning formation of temperature regime of soils of the boreal forest with limited thermal resources, in which dried peat [13-15] and mulch podzolized soils [16-18] are researched. The above articles are informative for understanding of the orientation of the ground processes and general regularities of the soil reaction on climatic changes, but not presented for the forest-steppe soils. So N. Koronatova in her work [15] highlighted the modern hydrothermal regime of boggy soil, and S. Veremeenko based on general methodological approaches to soil management of Polesia under different conditions of their thermal supply. Preliminary studies have found that the soils are sufficiently dynamic to react to the increase of warming, and thus changes not only the speed of the biochemical processes, but also, in some cases, their direction [17].

Some works focus on the study of the black soil area [4], but they can also be applied to the forest-steppe zone only partially because of significant differences in the structure and composition of soils, in particular – in times smaller content of organic substances. Thus, at the present stage of the law-making and peculiarities of the formation of thermal, water regimes of the dark-gray podzolized soil of the forest-steppe of Ukraine are not studied enough. The issues of changing elements of their hydrothermal regime in the context of climate change, which have been evident over the past 10-15 years, are particularly urgent.

The purpose of the study was to study dynamics of the annual course of temperature and humidity of air and dark gray podzolized light loamy soil to determine the peculiarities of formation of its hydrothermal regime. The expected result is the determination of actual parameters of heat and moisture supply of the territory, which was investigated as the basis for planning further measures on rational use of available soil resources.

MATERIALS AND METHODS

The study of temperature conditions of dark-gray podzolized soil in 2008-2019 was carried out on the territory of Rivne region (Western Forest Steppe of Ukraine) on the research field of the Department of agricultural chemistry, soil science and arable farming of the National University of Water Economy and Nature Management. Location of the site: 50°35'59.9"N 26°19'33.1"E. Before placing the experimental site, three main soil sections and a number of brackets were laid for the determination of general genetic peculiarities of the soil and its local differences. According to the results of the research it was found that the available soil type is dark gray podzolized light loamy, zonal for the Western forest-steppe of Ukraine. The content of humus 1.4-1.45%, the power of humus-eluvial horizon up to 30 cm, the reaction of soil solution is subacid.

All field observations on the research site were performed in accordance with the current standards and methods of agrometeorological and soil observations (DSTU ISO 11464-2007 [19], DSTU ISO 11465-2001 [20]) and in accordance with [21]. In the warm season the soil temperature was measured with the help of mercury thermometers, which were installed at the depth 5, 10, 20, 30, 40, 50, 80, 100 cm, measuring accuracy 0.1°C. For monitoring of temperature on small (5, 10, 20 cm) depths were used the Savinov elbow thermometer, for other depth – soil thermometers. During the winter period the observations lasted until the beginning of soil freezing, in some years it was possible to carry out twelve-month studies.

Soil moisture was determined by a thermostatic-weight method every decade; samples were taken in the field for the eighth day of the decade after 10 cm to the meter depth (DSTU B. 2.1-17:2009 [22]). Drying of selected samples was carried out to a constant mass at a temperature of 105 degrees. After 6 hours of drying, the cooling in the desiccator and the first weighing was performed, after which the drying time was repeated for 1.5 hours. In case of significant differences between the indicators, carried out further drying for an hour.

The precipitation was measured with the help of the field pluviometer M-99 at a height of 250 cm above the ground level, accounting was carried out with accuracy up to 1 mm. The depth of seasonal freezing and defrosting – the field cryopedometer (DSTU B.V. 2.1-25:2009 [23]). Since during the past 15 years the temperatures of the winter period in some years of soil freezing were not significantly increased. Laboratory researches were carried out on the basis of department of agricultural chemistry, soil studies and arable farming with the use of certified and tested in the established order equipment. The site where the accounting devices were laid is open, flat. Plant of grass, natural for forest-steppe zone.

Also, as source materials were used logs of archive data of multi-year meteorological observations of Rivne Regional Center of Hydrometeorology. The partial data are present for the period from 1945, the full list of indicators is available for the period from 1987. The data digitization for the further statistical processing full rows of observation data were used, without the use of a sample. Statistical processing of data obtained from field and laboratory observations was carried out with the use of commonly accepted methods, with the help of Microsoft Excel, Statgraphics Centurion, Statistica.

RESULTS AND DISCUSSION

Atmospherical temperature and rainfall amount

According to the Ukrainian Hydrometeorological Center of climatic norms, the average annual air temperature in the Rivne region should be 7.0°C, the temperature amplitude is small, typical for a moderate continental climate. The average temperature of the coldest month (January) is set at -5.4°C, July – 17.8°C. The transition through zero mark and fast warm air begins in the middle of March, from September there is a cooling, reverse transition to sub-zero temperature in November. However, according to the observations on the temperature of the ground air layer during the entire investigated period for 1945-2019, the growth of the average annual temperature is noted (Fig. 1).

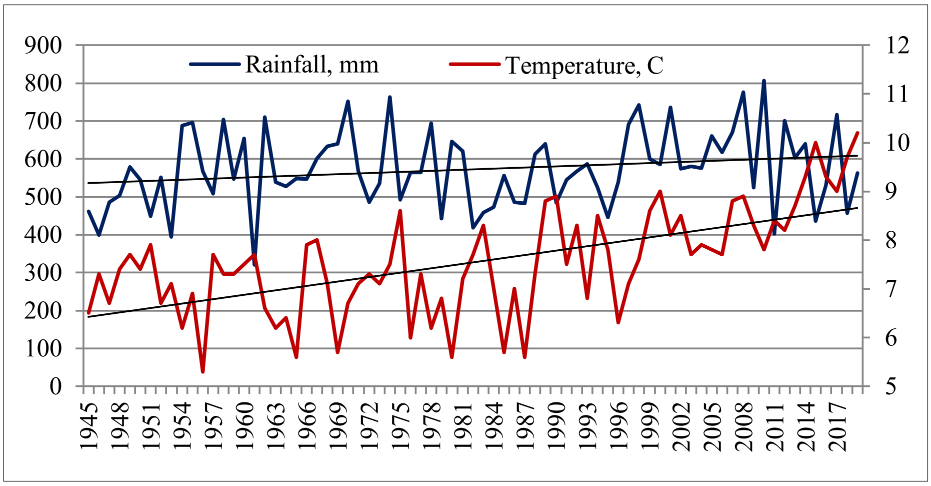

***Figure 1**. Average annual temperature of air (T) and amount of rainfall (R) on the meteorological station of Rivne (according to the Rivne Center of Hydrometeorology)*

The trend growth of the indicator for the period 1986-2019 is about 1.8°C and is formed mainly due to the warm period of the year (period of effective temperatures).

At the same time, the sharp rise in temperatures after 2005, which was also noted by other authors [24]. However, the figures are much higher than the average on the planet, and according to the National Oceanic and Atmospheric Research Administration of the United States (NOAA), the region to which Ukraine belongs, has one of the highest rates of temperature growth in the world, which is approximately 3.5 times higher than in the average on the planet [25].

The five-year average shows that effective temperatures above 10°C vary in the range of 800-1200 degrees. At the same time, throughout the period the trend toward the increase of this indicator is clearly highlighted (Fig. 2). Most of the annual amount is formed during June-August. The maximum number of effective temperatures is recorded annually in July; an excess increase is formed mainly during July-August. In 2012, the record value of 1428°C was reached, subsequently exceeded 1500°C and continues to grow. With the increase in the threshold, the percentage increase in annual amounts increases, so if the sum of temperatures is higher than 5°C recently than the average multi-year figure by 16%, the same amounts above 10, 15°C exceed the average values by 23 and 39% respectively. This indicates that the rise in the average temperature of the warm air, which was discussed above, is due to the rise in high temperatures in the warmest months (July-August). The duration of the warm season in autumn is also increased.

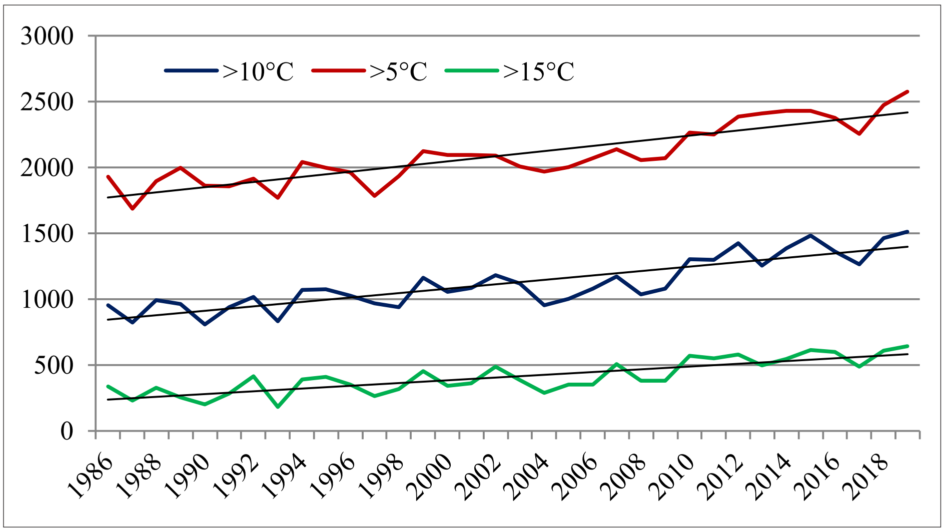

***Figure 2**. Sum of effective temperatures, 1986-2019*

Analysis of the number of precipitations according to the observations, during 1945-2019 shows a significant variation in both the number and distribution of precipitations during the year. On average, for the whole period of observation there were 577 mm of precipitation per year, but during the year their distribution did not always correspond to the standard dynamics. In the winter and spring months of precipitation was less normal, in the summer-autumn period there was a reversal trend. The annual rainfall dynamics has been growing (Fig. 1). To similar conclusions came in their researches M. Barabash and O. Tatarchuk [26]. In this case, from the point of view of influence on the soil cover of increase of heat supply has a more significant influence, than a mineral growth of precipitations. Moreover, preliminary studies of the effect of warming on evaporation of moisture from soil [9] have shown that the increase in soil moisture loss can occur at a higher rate in relation to the increase in humidity as a result of rising precipitation.

Moisture and soil temperature

The above mentioned regularity is confirmed by the deposits of moisture data during the warm period in layer 0-20 and 0-50 cm. In the spring there will be a clear increase in the deposits of moisture in both explored soil horizons (Fig. 3).

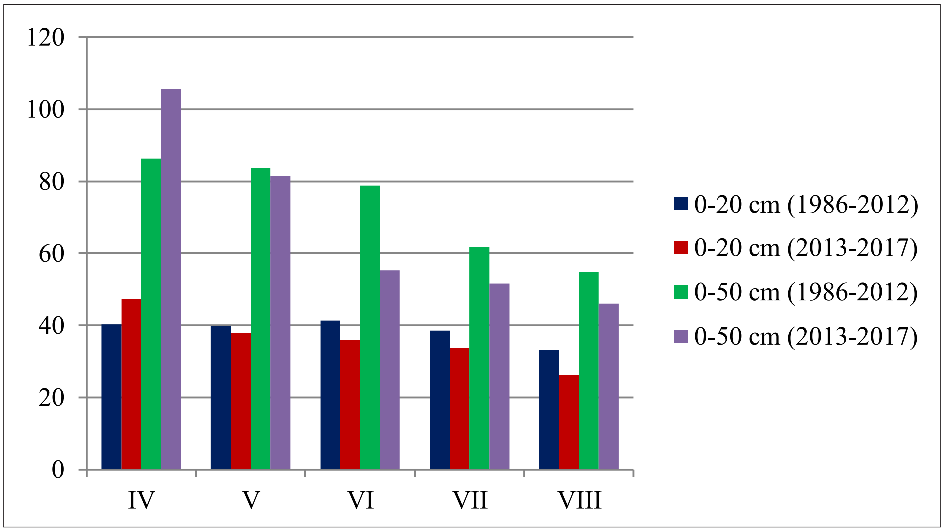

***Figure 3**. Comparison of deposits of moisture in layers 0-20 and 0-50 cm for periods 1986-2012 and 2013-2017, mm*

Despite the higher deposits of moisture at the beginning of vegetation, in May the average amount of available moisture is less than the many years' norm, which can be explained by more intensive water evaporation due to better heat supply. During the summer period, the trend is only increasing. The data received generally correlate with data received in other regions [24; 26]. Thus, the trend toward changes in the general agroclimatic conditions is similar for the regions of the country, but their intensity is very varied. Based on the average data, the graph of availability of dark gray soil by moisture is presented in Figure 4.

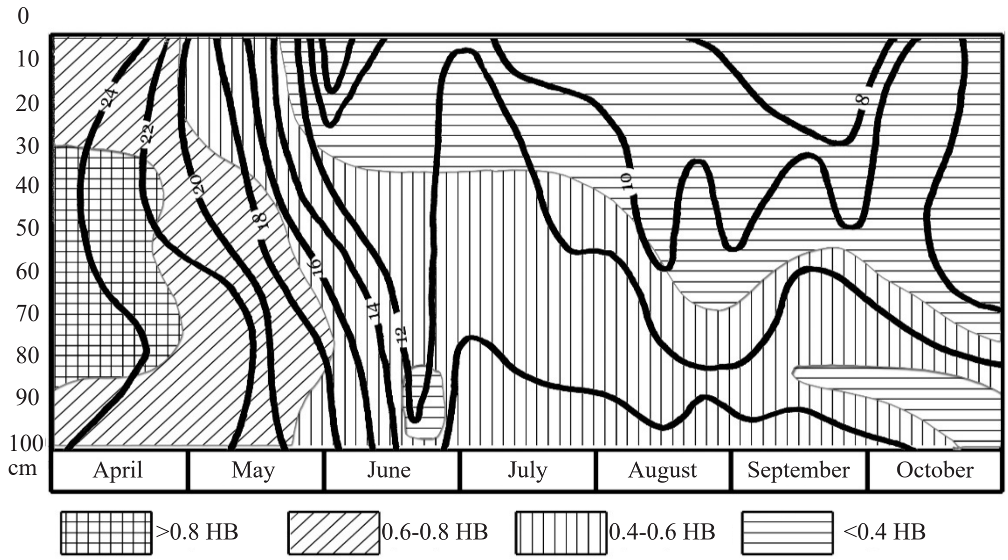

***Figure 4**. Water availability of dark gray podzolized soil, averaged data*

Monitoring of air temperature and precipitation during 2008-2019 showed that the average annual temperature during all years significantly exceeded the long-term norm, while the main increase was formed due to the warm period of the year (May-September). The study of dependence between the temperature of the ground air layer and dark gray soil in conditions of Rivne region confirmed that correlation of these indicators is linear.

The annual cycle of soil temperature completely repeats the cycle of air temperature. The rise in soil temperature is observed in March, reaching the maximum in July month, in August begins to cool down the top soil, annual minimum in late January – the first half of February. In order to determine the general trends of the long-term course of the dark gray soil temperature, processing of the database of the Rivne Center of Hydrometeorology for 1986-2019 was carried out the data of decades' temperature of dark gray soil on the depths of 5, 10, 15 and 20 cm. The average increase in the temperature of the top soil during the warm period is 2.1°C, which is much more than the similar indicator for the air temperature. This regularity confirms that the rise in surface soil temperatures occurs at a much higher rate relative to the established rates of so-called global warming, the determining benchmark for which is the temperature of the surface air.

The analysis of the annual cycle of soil temperature showed that the temperature is above +10°C in the top soil in the second-third decade of April. The isotherme of 10°C falls annually below 100 cm already in early May. Temperature +15°C at a depth of 20 cm comes in the second decade. In the years with delays in heat in the spring, the soil can be heated for 10-15 days later. In May, hot surfaces continue and heat migration is intensified down the soil profile, at a depth of 50 cm reach temperatures above 15°C, at a meter depth – up to 13°C. June is marked by the continued warming of deep soils and stabilization of surface horizon temperatures at 20-22°C. July is considered the warmest month, on the surface of temperature can pass a threshold of 30°C, on the depth of the horizon fixed average monthly temperature of 22.8°C, the soil is warmed up to 20 degrees below 50 cm, to 17.7°C at a depth of 100 cm. In August, heat is extended to the depth, while the surface layers begin to cool. The reverse transition through a 10°C threshold in the top soil occurs in mid-October, deeper effective temperatures are stored until the end of the month. During the active heating, the temperature difference in the depths of 5 and 20 cm is 3.5-4.0°C, in the summer period 2.0-3.0°C, and gradually decreases with the beginning of cooling. The oscillation of temperature maximums at that is shown even more strongly than on the surface. The delay of spring heating in comparison with the surface is 18-20 days, as against 5 cm depth – 12-15 days. The ground is heated above 10°C from May to October. The depth of penetration of temperatures above 15°C is from 100 to 150 cm and more depending on the conditions of the year. The temperature of the top soil in the summer does not exceed 22...24°C. Isopleth +18°C, reaches the maximum mark of 90...100 cm in early August, +20°C – in July passes at a depth of 30 cm. Thus, during the vegetation period in the soil profile prevail temperatures of 10...22°C. Temperatures above 22°C can be observed only in the layer 0...10 cm. The cooling takes place in September-October, the temperature in the top soil quickly decreases and in the second decade of October falls below +10°C, and by the middle of November does not exceed 3...4°C. The cooling dynamic follows the dynamics of the surface horizon with a slight delay. The annual temperature stroke at a depth of 50 cm has a number of features. Spring heating is more generalized and less dependent on short-term weather conditions of a given year, but penetration of high amplitude allows to better detect years with atypical strong spring and summer heating (2010, 2012), and the suspension of temperature maximums is well shown tendency to delay autumn cooling. The dynamics of the annual temperature circle at a depth of 100 cm is illustrated by the delay in heat at a depth, at a time when the surface layers actively give it. The years with early spring heating (2008) are clearly shown, the trend is better to extend the period of active temperatures in autumn. The long period of research shows that vegetation is stopped in the first-second decade of November. During the monitoring period, there is a noticeable tendency to decrease the depth of freezing, so if according to the average data of the hydrometeorological center in 1985-1989 the maximum depth was 68.2 cm, the average – 39 cm, then over the last five years these indicators have fallen to 18.4 and 8 cm respectively (Fig. 5).

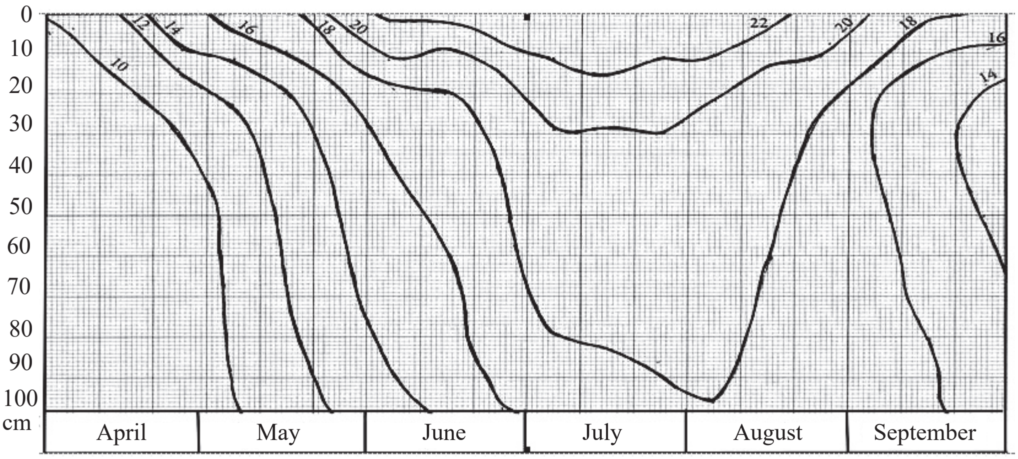

***Figure 5**. Thermoisoplethes of dark gray podzolized soil, averaged data*

The general circle of soil temperature is fully in line with the classical substantiation [6], but the presence of a number of obvious differences, which is probably the result of the development of climate changes of the XXI century. In particular, the absolute values of temperatures in the soil profile are increased, the penetration depth of thermal insulation is greater, the period of maintenance of high temperatures in the top soil and at the depth is prolonged, which creates conditions for prolongation of vegetation period of winter crops in autumn, and possibly requires correction of the terms of their dropping. Such a tendency with high probability can be scaled on adjacent agro-climatic zones, taking into account the same direction of the climatic factors [24; 27].

Changes in soil heating

Analyzing the dynamics of temperature indicators, it is necessary to note a significant increase in temperature maximums, due to which growth of average values of annual temperatures is observed. Soil heating is an integral process, which depends not only on global factors, but also on many factors and conditions of local character – meso- and micro-relief, nature of the underlaying layer, type and method of soil use, etc. That is why the soil warming index, proposed V. Dimo [6], is an important indicator in the assessment of the heat supply of soils. It represents the ratio of the sum of effective soil temperatures above 10 degrees at a depth of 20 cm to the equivalent sum of effective air temperatures. The details of this indicator according to ten years showed that during 2008-2017 the soils were heated much more strongly than in the average for the whole period of meteorological observations (Table 1).

***Table 1**. Calculation of soil warming index*

Year	The sum of effective soil temperatures>10°C at a depth of 20 cm, °C	The sum of effective air temperatures >10°C, °C	Soil warming index	The sum of effective soil temperatures >15°C at a depth of 20 cm, °C	The sum of effective air temperatures >15°C, °C	Soil warming index
2008	2993	2656	1.13	2377	1868	1.27
2009	2780	2735	1.02	2231	1978	1.13
2010	3322	2804	1.18	3107	1771	1.75
2011	3193	2718	1.17	2845	2254	1.26
2012	3859	3128	1.23	3635	2179	1.67
2013	3387	2890	1.17	2964	2063	1.43
2014	3754	3074	1.22	3369	2276	1.48
2015	3865	2995	1.29	3487	2468	1.41
2016	3491	2896	1.20	3006	2312	1.30
2017	3652	3167	1.15	3291	2443	1.35
Average	3429.6	2906.3	1.176	3031.2	2161.2	1.405

First of all, it should be noted that the value of the indicator of the soil warming index during all years above the unit, that is, even at the depth of the top soil of the investigated soil is characterized by higher temperatures than air. The absolute values of the soil warming index vary from 1.02 to 1.29, reaching the maximum values in 2012 and 2015. At the same time, if you compare the dynamics of the index with the dynamics of the initial parameters, it is easy to notice that the soil warming index reproduces the dynamics of the course of the soil temperatures, while the air temperature does not make a serious impact.

The results of statistical analysis showed that the total correlation between the soil warming index and the initial parameters is 99.21% at standard and absolute accuracy, respectively, 0.0179 and 0.019. The regression equation of the water absorbing capacity dependence on the initial parameters (1) can be defined as:

$$Soil\ warming\ index = 1.14932 + 0.000776816 \times \text{Тп} - 0.000901762 \times \text{Тв} \quad (1)$$

where Тп and Тв are the sum of soil temperatures more than 10°C (at a depth of 20 cm) and air.

Similar to its nature is also the indicator of soil warming index proposed by S.I. Veremeenko [15]. It represents the ratio of soil temperatures to air temperatures, but the threshold value is higher and is 15°C, which allows to estimate the change in the temperature regime of the soil in the area of high temperatures. This is especially relevant in conditions of sharp increase of summer temperature maximums. During 2008-2017, the Veremeenko index ranged from 1.13 to 1.75. Note that the maximum values were observed in 2012 and 2010 and were caused by abnormally strong warming of the soil cover, while the sum of air temperatures were close to the norm. In 2010, the amount of soil temperature for the first time recorded is higher than 3000°C, the year was considered extremely hot. However, already in 2012 the indicator exceeded 3500°C, at high, but far not record, the sum of air temperatures 2179 degrees (Table 1). It is worth noting that relative deviations of the sum of effective soil temperatures (-21.4 ... +28,0%) is much higher than similar fluctuations of air temperatures (-11.9...+12.1%). In addition, if you compare the variation of the sum of temperatures above 10 and above 15°C, then immediately noticeable increase of fluctuations with the increase of the threshold value. This regularity clearly indicates that the existing changes in the temperature regime of dark gray soil are particularly acute in a period of high temperatures, which can significantly affect the growth of many traditional crops, especially against a background of lack of precipitations in the same period.

In recent years, average decades' air temperatures have exceeded 30°C, and in some days were fixed temperatures above 35°C. And if at a depth of 20 cm the soil, according to the calculations, is heated by 50-87% stronger, then on the surface of temperature could reach critical for the development of plants, causing drought, accelerated mineral erosion of organic substance, evaporation and general soil degradation. According to the proposed S.I. Veremeenko (1997) classification, investigated soils belong to seasonal-intermediate type, moderately warm sub-type and type with average heat supply (annual amount of soil temperatures within 2400-3000°C), but change of agro-climatic conditions of the territory was reflected on their taxonomic position. According to the archive data of the first jumps in the amount of annual soil temperatures to the area with good heat supply observed in 1995 and in the period 1999-2002, and since 2005 a complete transition has taken place. A significant deviation can be considered only 2009 years, when the sum of temperatures was 2780 degrees. At that 3859°C in 2012 get already in zone of sufficient heat supply (Fig. 6).

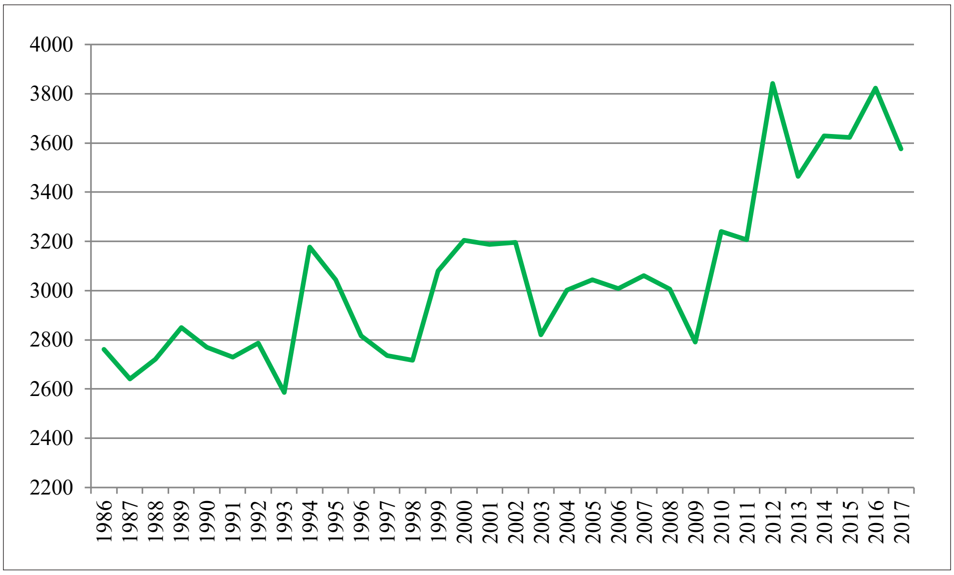

Figure 6. *Change of the annual sum of soil temperatures above 10°C*

In subsequent years, the sum of temperatures is stable in the zone of sufficient heat supply, the average for the period of 2013-2017 indicator is 3629.8 degrees. From the point of view of the typification of hydrothermal regime for S.I. Veremeyenko [9], a classic dark gray podzolized soil belongs to the optimal group with medium heat supply against the background of periodically flushing regime.

CONCLUSIONS

Climatic changes in the territory of the Western forest-steppe led to increase of air temperatures throughout the year, and during the warm period in particular. At the same time, annual amounts of effective air temperatures above +5, +10 and +15°C. A characteristic increase in relative temperature rise with a threshold increase from +5 to +15 degrees. The changes have also affected the moisture regime, in particular, the annual amount of precipitations has a slight increase, which in other equal conditions would lead to better maintenance of moisture. However, it is necessary to take into account the parallel increase in heat supply of the territory, which inevitably leads to an increase in evaporation of moisture. At the same time, the uneven distribution of precipitation has increased significantly during the year – long periods of heavy rainfall and periods of heavy rainfall have appeared, which creates additional risks for agriculture.

The observations made by the authors also showed that despite the growth of spring deposits of moisture, in the summer period soil often moves to critical values and in general there is a tendency to decrease the supply of plants by moisture at this time, which is critical for growing. In the complex with the above mentioned changes of heat supply there is a potential danger of shift of hydrothermal regime of investigated soil from group optimal in group satisfactory, with sufficient supply of thermal resources and insufficient moisture supply and, as a result, strengthening processes of transformation of mineral part and organic substance of soil.

It was found that on the territory, which was researched, changes in the main climate-forming indicators – average annual air temperature, sum of effective air temperatures, amount of precipitations are actively shown. In addition to quantitative changes, changes in heat and moisture distribution are also shown throughout the year. In the complex this led to changes in the soil thermal maintenance – increase of the available heat resource, increase of maximum temperature values, decrease of freezing depth and height of snow cover, and, as a result, – change of classification position of the territory according to the indicator of hydrothermal regime.

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Вплив кліматичних змін на гідротермічний режим темно-сірого опідзоленого ґрунту Західного Лісостепу

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Анотація. Теплові властивості ґрунту є важливими умовами, що визначають характер і інтенсивність ґрунтових процесів, однак закономірності та особливості формування теплового, водного режимів темно-сірого опідзоленого ґрунту Лісостепу України вивчені недостатньо. Метою представлених матеріалів є висвітлення динаміки річного ходу температури і вологості повітря та темно-сірого опідзоленого легкосуглинкового ґрунту для визначення особливостей формування його гідротермічного режиму в сучасних агрокліматичних умовах зони Лісостепу. Вивчення температурного режиму ґрунту проводилося протягом 2008–2019 рр. на території Рівненської області із використанням загальноприйнятих стандартів і методик (ДСТУ ISO 11464-2007, ДСТУ ISO 11465-2001, ДСТУ Б В.2.1-17:2009, ДСТУ Б В.2.1-25:2009). Дані спостережень за температурою приземного шару повітря протягом усього досліджуваного періоду вказують на зростання середньої річної температури, також усереднені по п'ятиріччям дані показують, що суми ефективних температур повітря вище 10°С мають тенденцію до збільшення. Аналіз кількості опадів протягом 1945–2019 рр. вказує, що багаторічна динаміка річної суми опадів має зростаючий тренд. Дослідження залежності між температурою приземного шару повітря і темно-сірого ґрунту в умовах Рівненської області підтвердило, що кореляція цих показників має лінійний характер. Аналізуючи динаміку температурних показників, слід зазначити істотне підвищення максимальних температур ґрунту, за рахунок яких і спостерігається зростання середніх значень річних температур. Деталізація показників прогрівання ґрунту за даними десяти років показала, що протягом 2008–2017 рр. ґрунти прогрівалися значно сильніше, ніж у середньому за весь період метеорологічних спостережень. Згідно із прийнятою класифікацією досліджувані ґрунти належать до сезоннопромерзаючого типу, помірно теплого підтипу і роду з середнім тепло забезпеченням. Отримані при виконанні дослідження результати дозволяють обґрунтувати зміни гідротермічних умов темно-сірого опідзоленого ґрунту та визначити необхідність запровадження коригуючи засобів у рослинництві для підтримання сталих врожаїв і забезпечення розширеного відтворення родючості

Ключові слова: глобальне потепління, температура повітря, температура ґрунту, індекс прогрівання грунтів, сума температур, волого забезпечення, емісія CO_2

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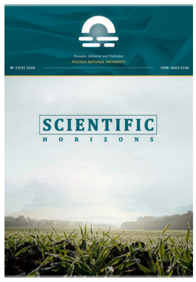

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Ukraine's Agrarian Sector in the Conditions of COVID-19 Distribution and Restrictive Quarantine Measures: Methodological Principles of Empirical Evaluation

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Abstract. Conditioned upon the negative impact of pandemic restrictions explained by the spread of COVID-19 disease, the global economy is declining, which has led to real risks and threats to the development of the Ukrainian agricultural sector. Identifying these risks and threats, assessing the impact of the spread of the COVID-19 pandemic and the quarantine measures introduced in response to the agricultural sector is an important problem of agricultural policy that requires maximum efforts to solve it. The purpose of the article is to summarise the methodological basis for assessing the impact of restrictive quarantine measures 2020-2021 related to the spread of the COVID-19 pandemic for the agricultural sector of the Ukrainian economy, to substantiate the basis for determining criteria and indicators of impact and to carry out their empirical measurement. Analysis and synthesis, induction and deduction, analogy and comparison are used to generalise the theoretical and methodological aspects of the study. To diagnose the dynamics of economic indicators, economic and statistical methods are used in analytical studies. A number of techniques of abstract-logical tools made it possible to formulate intermediate and final conclusions. Methodological foundations, scientific, methodological and practical approaches to assessing the impact of restrictive quarantine measures 2020-2021 related to the spread of the COVID-19 pandemic for the agricultural sector of the Ukrainian economy have been improved by substantiating the optimal research tools, identifying the most informative indicators and indicators. It is proved that from the standpoint of an integrated approach, all indicators that are a measure of the impact of the spread of COVID-19 and restrictive quarantine measures on the development of the agricultural sector should be considered in accordance with the target segments for assessing changes at the macro and micro levels. In particular: macroeconomic trends in business efficiency; entrepreneurial activity; foreign economic activity; social and labour relations; finance and investment, state support, etc. The analysis showed that the progressive development of agriculture in Ukraine during 2020 explained by quarantine restrictions demonstrated structural, economic and financial effects (results) of a downward nature. Promising areas for further research in this direction should include the development of a set of strategic measures to minimize risks for the agricultural sector of Ukraine during and after the end of the COVID-19 pandemic

Keywords: agricultural sector, COVID-19 pandemic, quarantine restrictive measures, external shocks, internal factors of influence, assessment method

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INTRODUCTION

The downturn in the global economy caused by the spread of the COVID-19 pandemic has led to significant changes in all spheres of life and economic activity, including the agricultural sector. Compared to the previous global crisis, in the situation of the spread of the COVID-19 pandemic, countries are responding relatively quickly, trying to limit the negative consequences for the usual consumer standards of living and working, and slow down the economic downturn. Since in agriculture the economic process of reproduction of production is closely intertwined with natural (biological) processes, the restrictive measures introduced by central or local authorities in response to the spread of the COVID-19 pandemic, especially adversely affect the productive employment of peasants, the budgets of rural households, the functioning of the social sphere of rural territories, etc. This pressure is significantly increased conditioned upon a variety of objective and subjective factors, the imperfection of the institutional environment and the uniqueness of the rural way of life.

The impact of the crisis on the economy will depend on the duration of the emergency, the rigidity of restrictive measures and control over their compliance, the stability of the economy, social orders and other characteristics of the country, as well as on the effectiveness of compensation measures for all segments of the population, enterprises, institutions and organizations [1].

The agricultural sector of Ukraine has been affected by restrictions related to the spread of the COVID-19 pandemic and the introduction of quarantine measures, both at the global and national levels. In particular, external shocks include the following: restrictions on trade transactions between states, restrictive measures on the movement of goods, the closure of certain global agri-food markets, and so on. Internal factors of influence are: restrictive measures for the sale of seasonal products, the movement of goods, the closure of local retail and wholesale food markets, the removal from work of infected workers or workers who have been in contact with infected people, changes in consumer sentiment and the structure of the consumer basket, a decrease in effective demand, especially socially vulnerable segments of the population, a reduction in production volumes from suppliers of resources for agriculture, an increase in prices for means of production and raw materials, a depreciation of the national currency, and so on.

So, for example, in Ukraine, quarantine restrictions caused by coronavirus disease did not affect large agricultural holding companies and did not actually affect the level of their capitalization. At the same time, a significant number of small and medium-sized farms suffered significant losses. The closure of food markets in March-May 2020 deprived small agricultural producers of the opportunity to sell their grown products. To a large extent, this problem is explained by the fact that about 85% of early vegetables, herbs and berries are sold through local agri-food markets. One of the restrictive measures in the framework of the lockdown imposed by the government was their complete closure, which lasted for several months and provoked a problem with the sale of grown products. Many farmers suffered huge losses as a result of such actions. In addition, in some regions of the country, especially in rural areas, there was a restriction of public access to food resources and a decrease in the range of available goods, which affected food security. At the same time, large retail chains, taking advantage of the situation, which was accompanied by temporary panic and partial uncertainty, resorted to raising food prices. As a result, there was a permanent decrease in consumer demand from the population, which affected the change in the structure of agricultural production and its sale. To a large extent, this was the reason that the growth rate of prices for agri-food products in Ukraine during April-May 2020 exceeded the same growth rate in the EU countries by 20-30% [2].

Researchers [2] note that the situation that developed as a result of quarantine restrictions was accompanied by a deterioration in the level of food security of the population, the destruction of agri-food chains, the aggravation of social tension in society, the mass curtailment of small and micro businesses, the growth of shadowing of agri-food markets, which negatively affected the provision of anti-epidemic control in this area, provoked a galloping increase in food prices in retail chains and an uncontrolled increase in their imports.

Assessing the impact of the spread of COVID-19 and restrictive quarantine measures on the development of the agricultural sector of Ukraine requires balanced and reasonable methodological approaches to its study. As noted by V.V. Nechyporenko [3], the research methodology is a system of concepts of basic principles, methods, means of studying the object and implementing a creative idea in the form of a program (algorithm), ways to know the truth and achieve the goal. Its effectiveness is manifested by confirming or refuting the hypothesis put forward and solving a scientific and practical problem. Ukrainian and foreign scientists are currently conducting active research on the development, systematisation, testing and improvement of the entire set of methods and techniques for studying this problem.

Notably, in the practice of management and economic analysis, quite often methods, approaches, algorithms, evaluation models, etc. differ too much from each other. The variety of existing methods for assessing the impact of the spread of COVID-19 and restrictive quarantine measures on the development of the agricultural sector and their differences in methods, approaches and indicators are explained by the following: the variety of assessment goals that require relevant approaches; the compliance of individual methods only with certain stages or research tasks; the use of both statistical and expert indicators in the evaluation process; the use of the expert assessment method to determine the weight coefficients of partial indicators in integrated assessment systems; problems associated with the lack of necessary statistical data for a long period of time; difficulties in evaluating processes conditioned upon the overload of the indicator system; the complexity of choosing the object of research for comparison, and so on.

In general, determining the most appropriate methodology is now often recognised as one of the most difficult problems in assessing phenomena and processes in socio-economic systems. An additional difficulty lies in the fact that the evaluation method must be universal, positioning, informative and accessible to use.

Purpose of the article there is a generalisation of methodological bases for assessing the impact of restrictive quarantine measures 2020-2021 related to the spread of the COVID-19 pandemic for the agricultural sector of the Ukrainian economy, justification of methodological approaches to determining criteria and indicators of impact and implementation of their empirical measurement. The purpose of the study provides for the implementation of such *tasks*:

– to summarise the methodological foundations for studying the impact of the spread of the COVID-19 pandemic and restrictive quarantine measures on the development of the agricultural sector;

– to develop methodological approaches to assessing the impact of quarantine measures and the spread of COVID-19 on the development and functioning of the agricultural sector of Ukraine with the definition of the most informative indicators and indicators;

– to assess the impact of COVID-19 quarantine measures on the functioning of the agricultural sector of Ukraine.

LITERATURE REVIEW

Despite the fact that the COVID-19 pandemic is a fairly new phenomenon, however, its research has become a priority for many scientists, both foreign and Ukrainian. There are quite a lot of approaches to research here. Thus, according to Fan, Jamison and Summers [4], the COVID-19 pandemic causes direct and indirect losses of added value. Barua [5], using a standard macroeconomic model, demonstrated that the COVID-19 outbreak can seriously damage global supply chains, as well as cause a significant negative economic impact.

H.M.M. Taqi and colleagues [6] based on the analysis of literature sources and their own observations highlight the following results of the spread of the COVID-19 pandemic and quarantine measures to the economy: cancellation of orders from brands and retailers; reduction of production and non-fulfillment of orders; slow shipments and inconsistent delivery, inflated delivery costs; excessive inventory; job cuts; disruption of international logistics, slowing down financial calculations.

The authors of the study "Commodity Market Prospects: the impact of COVID-19" [7] draw attention to the impact of quarantine measures on the price situation in the agricultural market. The deep global economic shocks caused by COVID-19 affect producers' cash flows and financial liquidity conditioned upon limited production capacity, limited market access, loss of remittances, lack of employment, and unexpected medical expenses [8].

In particular, it is noted that in Africa, the greatest negative impact was felt by farms. Thus, the restriction of the movement of people explained by the spread of the COVID-19 pandemic led to a shortage of labor in farms; the decrease in crop yields was the result of a violation of access to agricultural resources (seeds, fertilizers, veterinary materials, feed). Disruptions in logistics, processing and market access have negatively affected the value creation of agricultural products. Labour shortages because of stay-at-home policies have affected food production and processing, especially in labour-intensive meat processing plants. Restrictions on public transport stopped most of the campaigns, and the rest of them were forced to reduce their activity, and organisations had to adapt to physical distancing. The slowdown in overall logistics has negatively affected food safety and quality. The closure of many informal markets in urban and suburban areas to avoid crowding has disrupted food supply systems, especially for fresh produce such as meat, eggs and milk. This affected the structure of consumer demand. For livestock breeders, there is a loss of income from the sale of livestock and products (milk, butter, eggs), which led to a general decrease in the purchasing power of households [9].

As an important aspect of the methodology for assessing the impact of the spread of COVID-19 and restrictive quarantine measures on the development of the agricultural sector, the lack of unified analysis indicators should be noted. However, scientists are working fruitfully to determine them. Specialists of the Economic Development Agency PPV Knowledge Networks regarding approaches to assessment at the sector level identified the following key indicators: production, shortage of raw materials for production; supply and demand for products, price conditions, sales volumes of manufactured products, excess of finished products in stock, waiting times and payment terms for goods and services, availability of frozen contracts; liquidity – availability of financial resources to repay debts to suppliers, to pay wages, taxes, rent, loan repayment, accounts receivable, staff employment, etc [10]. The expediency of including in the system of indicators those that characterize food security (prices, demand, production, sales, consumption, availability of food products, food habits (types of diet, daily consumption of certain products, number of meals per day, etc.) is justified by A.E. Obayelu, O.A. Obayelu, K.K. Bolarinwa, and R.A. Oyeyinka [11].

Specialists of the public organization "Center for Applied Research" in cooperation with "Economic truth", as indicators suggested using indicators of revenue, the number of contracts and clients, the volume of services provided [12]. The main purpose of the search was to obtain information from the owners and top management of Ukrainian companies on the transformation of operating activities, expected risks due to the re-introduction of lockdown by conducting structured in-depth interviews.

Assessment of the impact of the pandemic and restrictive measures on the agricultural market by D. Varshne, D. Roy, and J. Meenakshi is suggested by determining differences (DiID-in-difference) and differential results between high and low load points. At the same time, data on the daily dynamics of wholesale prices for agri-food products and their supply on the market were analysed [13].

G. Gregorioa and R. Ancog argue that the restrictions caused by COVID-19 have affected the supply of labour, which in turn has affected overall agricultural production and sector performance. Therefore, in their study to assess the impact of the spread of the coronavirus pandemic and restrictive quarantine measures on agricultural development, they calculated the relative change in agricultural production and the share of industry GDP in the country's economy. In particular, the data collected and used in the analysis included (a) employment in agriculture, (B) the volume of production of the basic sectors of the agricultural sector, (C) the share of agriculture, forestry and fisheries in GDP (in US dollars) [14].

Another important aspect of the methodology for studying the impact of the spread of COVID-19 and restrictive quarantine measures on the state and development of Agriculture is the identification of related objects of analysis. UN analysts have paid considerable attention to this segment of analytical work in their research [15]. In particular, they identified three levels of analysis: macro, meso, and micro. The assessment was aimed at studying the direct and indirect impact of the pandemic on micro, small and medium-sized enterprises, employment levels, living conditions, means for normal life, and autonomy in decision-making for women and men. At the same time, considering the type of settlement (urban, rural), age, gender, in all regions of Ukraine with an emphasis on identifying gender adaptation opportunities for each topic/sector. The researchers studied the impact of restrictive measures on international trade, production volumes, the labour market and employment in certain sectors of the economy, inflation, the exchange rate, GDP, unemployment, current account, public debt and foreign exchange reserves of the country [15].

Despite the existence of a number of scientific papers covering the diverse aspects of the impact of the COVID-19 pandemic caused by the Sars-CoV-2 coronavirus and the restrictive measures it causes, new, unprecedented problems are now emerging to ensure the stable functioning and development of the Ukrainian agricultural sector. More thorough research is needed to identify the degree of impact of quarantine restrictive measures on economic and foreign economic activity in the agricultural sector. This is necessary to develop in the future a targeted, effective and targeted state policy aimed at increasing the competitiveness of the agricultural sector, ensuring a stable position of Ukraine in the world market of agri-food products, ensuring the socio-economic development of the country in the context of a pandemic, transforming development problems into competitive advantages.

MATERIALS AND METHODS

The theoretical provisions of the study are based on the works of Ukrainian and foreign scientists who justify the impact of the COVID-19 pandemic on the agricultural sector. The methodological basis of the study is a systematic approach to the study of the studied phenomena and processes and a dialectical method of cognition, which allowed us to comprehensively consider the processes associated with the impact of the spread of the COVID-19 pandemic and quarantine measures on the agricultural sector of Ukraine. The methods of abstract-logical method, analysis and synthesis, induction and deduction, analogy and comparison are used to generalise the theoretical and empirical aspects of the study.

The study uses a mixed approach, which includes institutional norms for the introduction of quarantine measures by the state on the territory of Ukraine during the COVID-19 pandemic, including indicators for determining complex (general) and partial (personalised) indicators of the state of the problem under study with structuring partial indicators into a wider range of indicators available in the system of statistical observations in the period being evaluated. From the standpoint of an integrated approach, all indicators that are a measure of the impact of the spread of COVID-19 and restrictive quarantine measures on the development of the agricultural sector of Ukraine were considered in accordance with the target segments for assessing changes at the macro and micro levels. In particular, such as: macroeconomic trends in business efficiency; entrepreneurial activity; foreign economic activity; social and labour relations; finance and investment, state support, etc.

The collection of statistical information and the formation of the database cover: the GDP of Agriculture of Ukraine and its share in the total GDP of the country, capital investment in the agricultural sector and the share of the industry in the total volumes of capital investment, the volume of production of agricultural products, including livestock and crop production, labor productivity, consumer price indices, sales price indices of agricultural products, the total index of expenditures on agricultural products, export and import of agri-food products, Foreign Trade Balance, foreign direct investment in agriculture of Ukraine, the exchange rate, the number of employed rural population, employment level and unemployment rate of rural population, the number of people employed in agriculture of Ukraine, wages in the agricultural sector, total expenses on average per month per household in rural areas, the share of expenses for food, utilities, healthcare, the number of enterprises that carried out agricultural activities, including farmers, financial results of management, the level of profitability and other macroeconomic indicators.

To diagnose the dynamics of economic indicators, analytical research uses economic and statistical methods (comparative analysis, average and relative values, grouping, trend analysis, graphical method, index, coefficient analysis, and others). Calculation of absolute and relative indicators is necessary to determine the current state of affairs in the industry, the dynamics of changes, and establish certain relationships, such as identity, similarity, or difference between the characteristics of the processes and phenomena under study. The graphical method was used to summarise statistical data, analyze them, and study complex relationships between socio-economic phenomena and processes in the movement of dynamics indicators. A number of techniques of abstract-logical tools made it possible to formulate intermediate and final conclusions and proposals. The reliability of the obtained results and conclusions is confirmed by calculations using statistical observations and testing.

The information base of the study is: data from the State Statistics Service of Ukraine, the State Employment Service, the National Bank of Ukraine, legislative and regulatory legal acts for their implementation; scientific publications. The study period covers 2019-2021.

RESULTS AND DISCUSSION

Methodological bases for studying the impact of the spread of COVID-19 and restrictive quarantine measures on the development of the agricultural sector of Ukraine

Assessment of the impact of the spread of COVID-19 and restrictive quarantine measures on the state and development of the agricultural sector should be based on the following principles: legality, complexity, consistency, compliance with national interests, prevention of unfair competition, parity of development of economic entities, promotion of innovation, sustainable rural development, balance of interests of stakeholders, social responsibility and control, improving the standard of living of the population, etc. These principles determine the interaction and relationships of subjects (households, agricultural enterprises, personal farms, individual entrepreneurs, state institutions and organizations, non-state institutions), directions and measures for implementing these assessment results.

From all the objects worked out during the study, it becomes clear that in economics and practice today there is no single approach to measuring the impact of the spread of COVID-19 and restrictive quarantine measures on the state and development of the agricultural sector. There is also no single standpoint in the scientific community on the list of indicators that should be used to conduct such an assessment. And whether it is worth calculating a certain complex aggregated Index, whether it is enough to use a set of individual indicators in certain areas of intelligence.

Establishing work on assessing the impact of quarantine measures and the spread of COVID-19 on the development and functioning of the agricultural sector of Ukraine requires first of all justification of methodological approaches and development of tools for conducting such an assessment. When assessing the impact of quarantine measures and the spread of COVID-19 on the development and functioning of the agricultural sector, we suggest the following algorithm (Fig. 1). This algorithm is universal in nature, it is advisable to use it to assess the impact of quarantine measures and the spread of COVID-19 on the development and functioning of various sectors of the economy and make decisions to support the development of the agricultural sector of Ukraine.

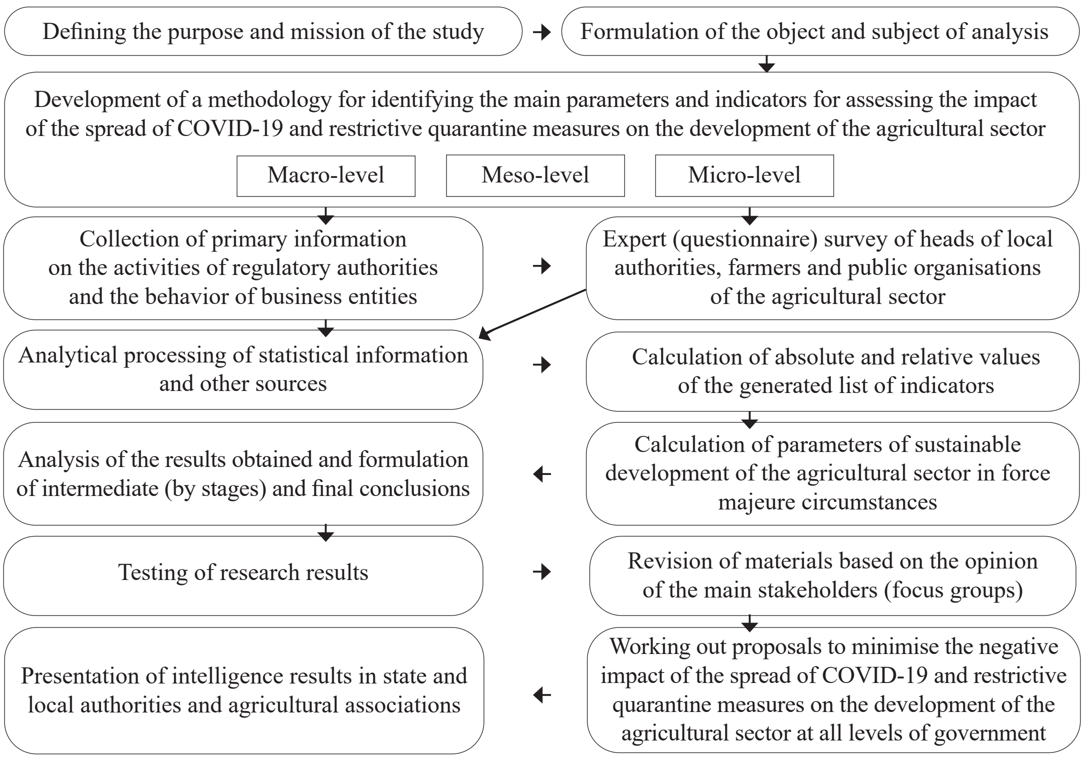

***Figure 1**. Structural and logical scheme for assessing the impact of the spread of COVID-19 and restrictive quarantine measures on the development of the agricultural sector*

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

Considering that assessing the impact of quarantine measures is a complex multi-factor task, which boils down to identifying and interpreting a set of indicators that characterize various aspects of the industry under study, the issue of forming a relevant system for measuring risks and ways to eliminate them or mitigate destructive consequences is updated. The accuracy and reliability of the selected indicators ensure the adequacy of the entire proposed algorithm in general. Hence, only a rationally selected assessment method, a well-formed system of indicators and a rational organisation of the process can provide an objective analysis and identification of true changes associated with force majeure circumstances.

According to the authors of the article, it is most justified, from the standpoint of an integrated approach, to consider indicators that are a measure of the impact of the spread of COVID-19 and restrictive quarantine measures on the development of the agricultural sector in two planes: at the macro- and micro-levels. Methodological approaches to determining criteria (indicators) and indicators for assessing the impact of the spread of COVID-19 and restrictive quarantine measures on the development of the agricultural sector are summarised in Figure 2. The methodological design of the study of the impact of the spread of COVID-19 and restrictive quarantine measures on the development of the agricultural sector of Ukraine is built in accordance with the target segments of assessment of changes, in particular: macroeconomic trends in business efficiency; entrepreneurial activity; foreign economic activity; social and labour relations; finance and investment, state support, etc. The system of suggested indicators allows us to comprehensively characterise the state of each of the subsystems of the agricultural sector.

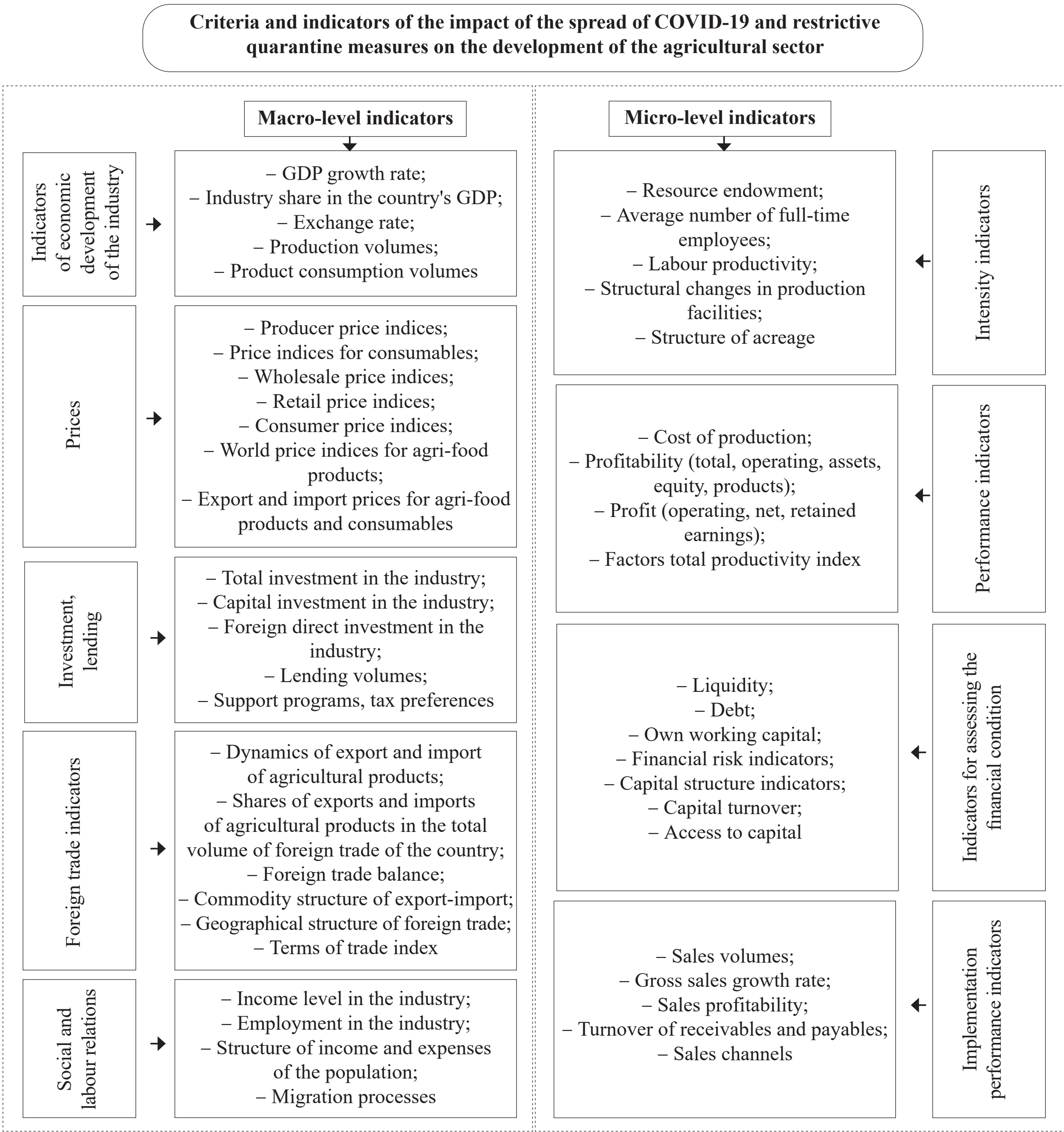

***Figure 2**. Criteria and indicators for assessing the impact of the spread of COVID-19 and restrictive quarantine measures on the development of the agricultural sector*

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

Empirical assessment of the impact of COVID-19 and quarantine restrictive measures on the agricultural sector of Ukraine

Macroeconomic trends in economic efficiency. The development of the industry is expressed by the level and dynamics of its share in the country's GDP. This is a complex indicator that reflects the processes of social reproduction occurring in a particular industry and technologically related activities. At the same time, the impact of the state's economic policy on the development of the industry and expected and unexpected risks for commodity producers is also important. The value of this indicator is considered by investors when making decisions about starting a business and investing in a particular industry, which also characterizes the level of its attractiveness in terms of payback periods, future risks, product sales markets and competitiveness. It is positively evaluated with dynamic growth. In 2020 compared to 2019, Ukraine's agricultural GDP, expressed in actual prices, increased by 8.9%. However, if we analyse the value of the industry's GDP, expressed in constant prices in 2016, the opposite trend can be traced – there was a decrease of 11.5% (Table 1). At the same time, the share of agriculture in the GDP of the country's economy as a whole decreased by 0.8% points, if we consider quarterly dynamics (Fig. 3). This decrease is caused by violations in the work of logistics infrastructure, in particular transport, including the organization of export of agricultural products.

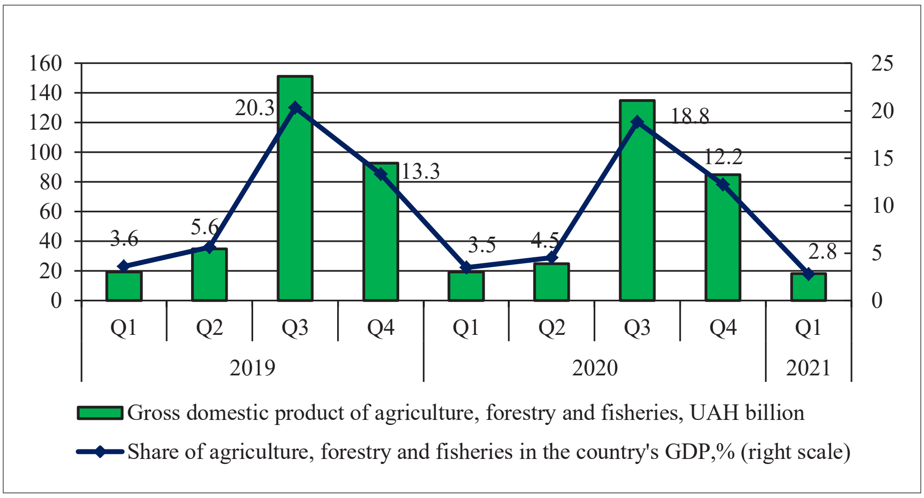

***Figure 3**. GDP of Agriculture, Forestry and Fisheries of Ukraine, 2019-2021 (in constant prices in 2016)*
***Source**: formed by the authors according to the state statistics service of Ukraine [16]*

Ensuring the effective functioning and development of the agricultural sector of Ukraine requires significant investments, both in infrastructure and production itself. Capital investments are funds allocated for the reproduction of fixed assets, expansion, reconstruction and modernisation of enterprises, implementation of technical and technological progress in the industry, construction of social and cultural facilities, design work, etc. Capital investment serves as a basic parameter of the reproduction process, which determines the possibilities of structural reforms and sustainable long-term economic and social development of the industry. They are positively evaluated when growing in dynamics. However, according to the analysis, the total volume of capital investment in agriculture in Ukraine has steadily declined. Thus, for the period 2019-2020, the volume of capital investments decreased by 34.5%, and similar trends continue in 2021 (Table 1, Fig. 4).

***Table 1**. Key macroeconomic, socio-economic and financial indicators of Agriculture in Ukraine, 2019-2021*

Indicator	Units	Years, periods					2020 to 2019	Q1 2021 to Q1 2019
		Q1 2019	2019	Q1 2020	2020	Q1 2021		
Agricultural GDP	billion UAH	24.4	356.6	24.0	388.4	28.3	108.9%	116.0%
Share of industry GDP in the country's total GDP	%	3.0	9.0	2.8	9.3	2.8	0.3 p.p.*	-0.2 p.p
Agricultural GDP (*in constant prices in 2016*)	billion UAH	19.4	298.1	19.1	263.9	18.2	88.5%	93.8%
Capital investment	billion UAH	11	55	7	36	9	65.5%	81.82%
Share of the industry in total capital investments	%	10.1	9.5	9.2	8.7	11.2	-0.8 p.p.	1.1 p.p.
Production of agricultural products (*in constant prices in 2016)*	billion UAH	–	681	–	612	–	89.9%	–

Table 1, Continued

Indicator	Units	Years, periods					2020 to 2019	Q1 2021 to Q1 2019
		Q1 2019	2019	Q1 2020	2020	Q1 2021		
Including crop production	billion UAH	–	539	–	473	–	87.8%	–
Animal husbandry	billion UAH	–	142	–	139	–	97.9%	–
Production of gross output per 1 employed in agriculture (labor productivity)	thousand UAH	–	929	–	857	–	92.2%	–
Consumer price indices (*by the corresponding period of the previous year)*	%	108.9	107.9	102.6	102.7	107.4	-5.2 p.p.	-1.5 p.p
Agricultural sales price indices (*by the corresponding period of the previous year)*	%	101.3	92.4	92.7	119.2	165.1	26.8 p.p.	63.8 p.p
Aggregate index of agricultural production costs (*by the corresponding period of the previous year)*	%	105.5	93.4	92.7	118.5	130.4	25.1 p.p.	24.9 p.p
Export of agri-food products	million US dollars	5,343	22,144	5,643	22,179	4,997	100.2%	93.5%
Export of agri-food products	million US dollars	1,434	5,736	1,686	6,498	1,724	113.3%	120.2%
Foreign trade balance	million US dollars	3,909	16,408	3,955	15,681	3,276	95.6%	83.8%
Foreign investment	million US dollars	-36.5	587.2	-9.8	444.9	-7.7	75.8%	21.1%
Exchange rate	UAH/USD	27.30	25.84	25.04	26.96	27.97	104.3%	102.5%
Rural employment	thousand people	5,027.4	5,205.7	5,141.7	4,968.3	4,810.9	95.4%	95.7%
Rural employment rate	%	47.2	48.9	48.8	47.1	46.1	-1.8 p.p.	-1.1 p.p
Rural unemployment rate	%	10.4	8.6	9.4	10.3	11.5	1.7 p.p.	1.1 p.p.
Number of people employed in agriculture	thousand people	–	3,010	–	2,721	–	90.4%	–
Average salary in agriculture	UAH	7,782	8,738	8,947	9,734	1,0058	111.4%	129.2%
The ratio of the average wage in agriculture to the average in the economy	%	76.0	83.2	78.2	84.0	73.4	0.8 p.p.	-2.6 p.p
Total expenses on average per month per household in rural areas	UAH	7,379.4	–	7,464.9	–	8,705.7	–	118.0%
Share of spending on food and non-alcoholic beverages	%	39.1	–	42.0	–	38.4	–	-0.7 p.p
Share of utility costs	%	19.3	–	16.8	–	19.5	–	0.2 p.p.
Share of health care costs	%	5.4	–	5.4	–	5.7	–	0.3 p.p.
Number of enterprises engaged in agricultural activities	units	–	48,504	–	47,523	–	98.0%	–
including farms	units	–	32,452	–	31,851	–	98.1%	–
Financial results before tax	billion UAH	–	93.6	–	81.6	–	87.2%	–
Net profit	billion UAH	–	92.9	–	81.0	–	87.2%	–
Level of profitability of operating activities	%	–	19.8	–	19.0	–	-0.8 p.p	–
Level of profitability of all activities	%	–	16.6	–	13.9	–	-2.7 p.p	–

Note*: * p. p. - percentage points*
Source*: calculated by the authors according to the state statistics service of Ukraine [16]*

A representative indicator for analysing trends in the development of the agricultural sector during the period of quarantine measures is the dynamics of growth rates and the structure of gross agricultural output. These indicators indicate the stability of production, the ability of producers to use comparative and competitive advantages, including "scale effect", the ability to adequately respond to price volatility and the variability of the agri-food market. They characterise labor productivity per 1 employee and the land intensity of production of the main crops. According to statistics, in 2020 in Ukraine there was a significant decrease in agricultural production – by 9.1%, including in crop production – by 12.2, animal husbandry – by 2.1%, while labor productivity decreased by 7.8% (Table 1).

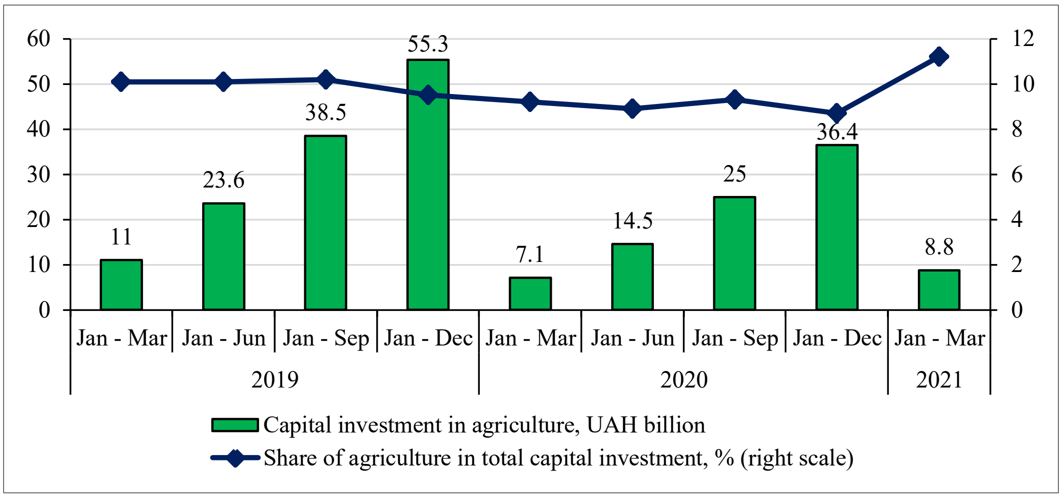

***Figure 4**. Capital investments in agriculture of Ukraine, 2019-2021*
***Source**: formed by the authors according to the state statistics service of Ukraine [16]*

This resulted in the spread of the COVID-19 pandemic and quarantine measures on the foreign economic activity of the agricultural sector of Ukraine. The agricultural sector of Ukraine is largely a raw material and export industry, so its effectiveness significantly depends on the foreign economic situation on world markets. As it is known, with the spread of the COVID-19 pandemic and the introduction of quarantine measures at the global level, it has undergone significant changes. In particular, conditioned upon the rupture of logistics chains between individual companies, non-fulfillment of contracts, restrictions on trade transactions between states, restrictive measures on the movement of goods, the closure of agri-food markets, and so on. Uncertainty in agri-food markets and the general economic downturn have put foreign trade revenues at risk.

As can be seen from Table 1, the volume of exports of agri-food products in 2020 compared to 2019 remained virtually unchanged-an increase of only 0.2% or 35 million dollars. While in 2015-2019, the average annual export growth rate was 11.2%, and in 2019 – 19.0% [16]. The opposite trend was observed in the import sector. In 2020, the volume of imports of agri-food products increased by 13.3% compared to the previous 2019. And this is at a time when in the previous 2015-2019 the average annual growth rate of imports was 8.0%, and in 2019 it decreased by 7.6%. An increase in imports and a slowdown in exports led to a significant deterioration in the foreign trade balance of agri-food products – for the first time in the last decade, the foreign trade balance decreased, although it remained positive (Table 1, Fig. 5).

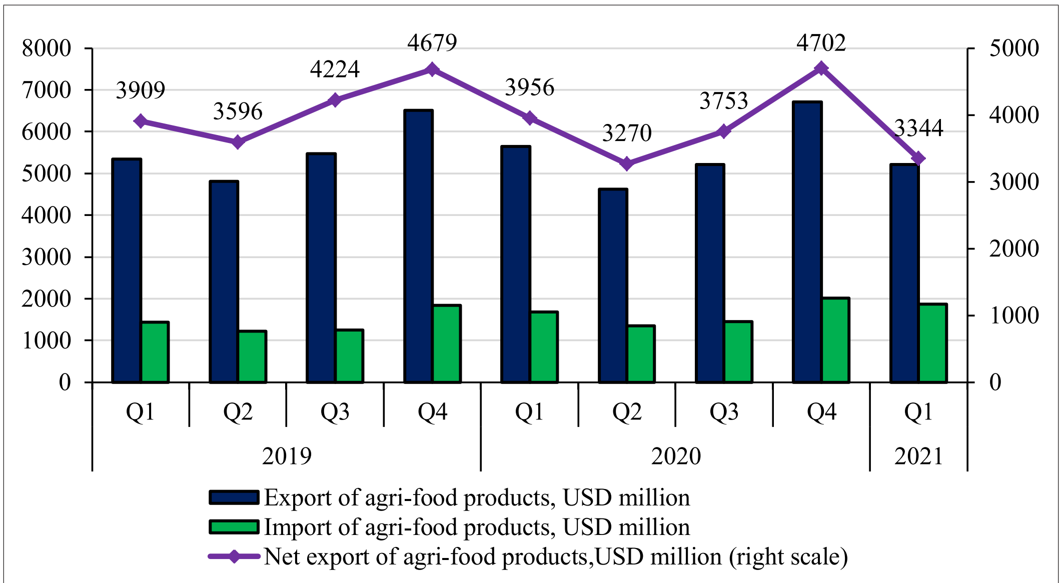

***Figure 5**. Foreign trade in agri-food products of Ukraine, 2019-2021*
***Source**: formed by the authors according to the state statistics service of Ukraine [16]*

In the future, such trends will have a negative impact, namely, a decrease in the competitiveness of Ukrainian companies' products, their loss of market share, which, in turn, will lead to even worse long – term consequences, such as a decrease in production and sales volumes, a drop in income, a shortage of working capital for current needs and resources for innovative expanded reproduction, mass dismissal of employees, and so on.

The recovery of the global economy in late 2020 – early 2021, the revival of international trade and sectoral factors led to an increase in prices in the world's commodity markets. Thus, according to the Food and Agriculture Organization of the United Nations (FAO), the average value of the FAO Food Price Index (FFPI) in September 2021 was 130.0 points, which is 1.5 points (1.2%) higher than in August and 32.1 points (32.8%) higher than in the same period last year. The increase in the value is mainly conditioned upon the increase in prices for most cereals (the average value of the FAO grain Price Index in September 2021 was 132.5 points, which is 2.6 points (2%) higher than in August and 28.5 points (27.3%) higher than in September 2020) and for vegetable oils (the average value of the FAO Vegetable Oil Price Index in September was 168.6 points, which is 2.9 points (1.7%) higher than in the previous month and almost 60% higher for the same period last year). Prices for dairy products and sugar also increased, while the meat price index remained almost at the same level (Fig. 6).

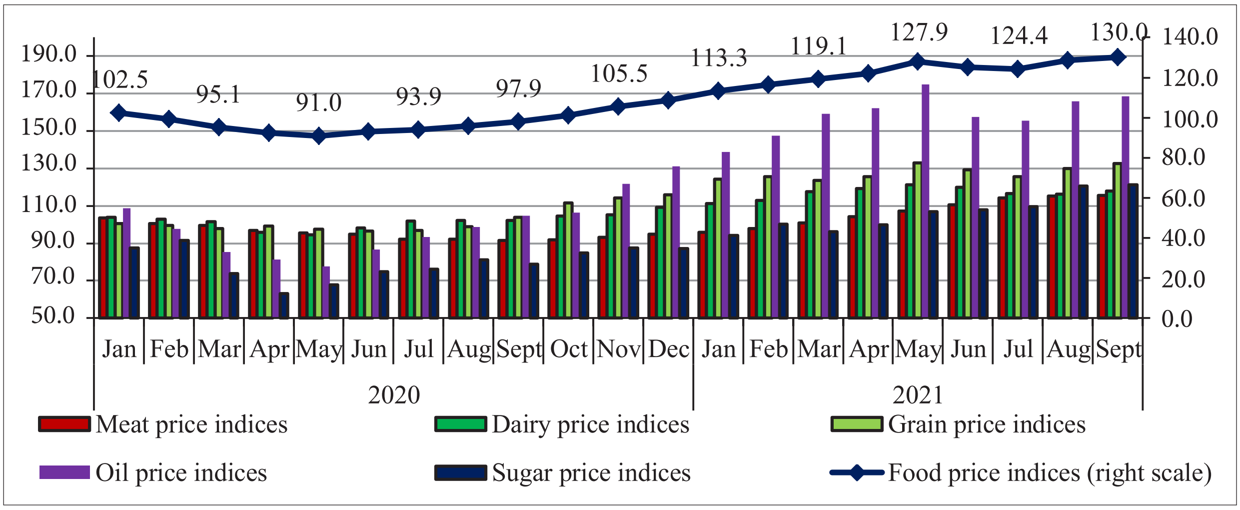

***Figure 6**. Nominal food price index, 2020-2021*
***Source**: formed by the authors according to FAO data [17]*

This is a favorable factor for Ukrainian agricultural exports. High prices essentially remained the main driver of export revenue growth. Wheat prices rose due to adverse weather conditions and low yields in exporting countries, corn-due to the high demand of livestock and bioethanol production, sunflower oil – explained by a decrease in stocks (Fig. 7).

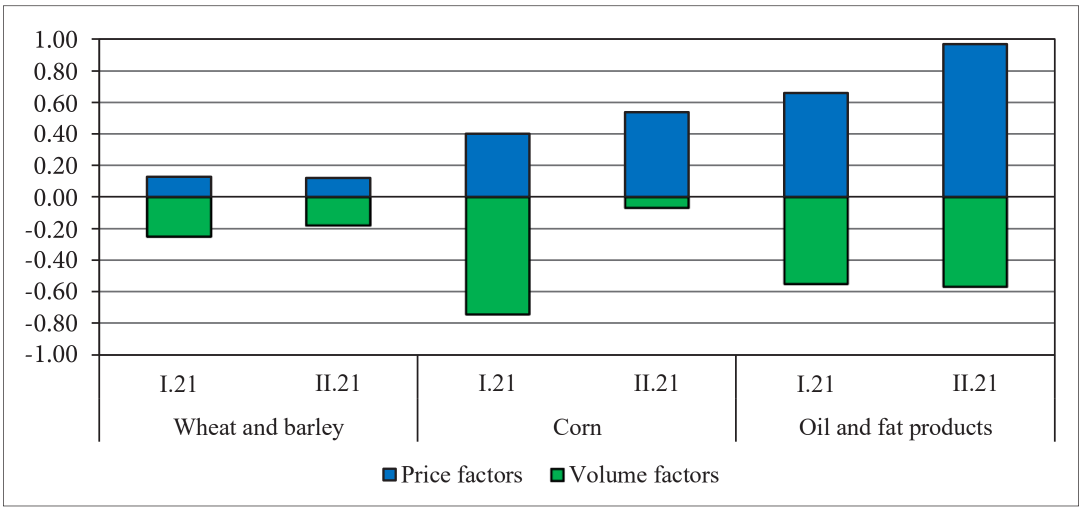

***Figure 7**. Absolute annual change in prices and export volumes for certain agri-food products, 2021, USD billion*
***Source**: formed by the authors according to the state statistics service of Ukraine [16]*

One of the most effective tools for the development of the agricultural sector is foreign investment. The volume of Foreign Direct Investment (FDI) in the industry is a sign of its attractiveness, as it indicates absolute and comparative advantages that investors cannot get in other countries. Foreign investment contributes to modernisation, provides access to modern technologies not only in production, but also in management, which serves as an important factor in the development of market forms of management and the introduction of modern methods of conducting agricultural business; sales of products and their promotion to new foreign markets; meet the need for means of production, equipment for in-depth processing of raw materials and its marketing. Foreign investment, if used effectively, can provide the necessary scale and pace of structural adjustment of Agriculture, which will make it possible to join the global value chains and take its rightful place in the international system of division of labour. The current situation in the context of the growing new wave of the coronavirus pandemic does not contribute to this. For the period 2019-2021, the volume of FDI to agriculture in Ukraine was insignificant. Their share in total FDI volumes in Ukraine was only 1.1-1.7%. Moreover, during the analysed period, their amount decreased by almost 24.2%, which indicates a significant outflow of foreign capital from the industry (Table 1).

The forecast of experts that in the context of the coronavirus pandemic, the volume of FDI in the agricultural sector will grow conditoned upon the fact that this sector is the most stable and less vulnerable to this type of shock compared to other industries (tourism, transportation, hotel and restaurant business, mass event industry, etc.) – did not come true. Therefore, it is advisable to conclude that the main reason for the lack of strategic foreign investment is the unfavorable investment climate in Ukraine, frequent changes in legislation and under-reformed judicial reform. In particular, because of this, there is still uncertainty about further cooperation on the part of investors who have already invested their funds in agriculture in Ukraine. According to Table 1, 150.0 USD million was withdrawn from the industry in the period 2019-2021. Therefore, experts' forecasts that the opening of market turnover of rights to agricultural land plots will give a green light to investment, in the short term, turned out to be somewhat exaggerated.

Impact of the spread of the COVID-19 pandemic and quarantine measures on the labour market, employment and income level of the rural population of Ukraine. The data in Table 1 show that in the first quarters of three consecutive years (2019-2021), the number of employed rural population decreased, which in 2021 amounted to 4810.9 thousand people, or 216.5 thousand less compared to 2019, and compared to the previous year – by 330.8 thousand people. The least popular in the rural labour market were people aged 15-29 years – the reduction in this category of employees amounted to 159.7 thousand people, or 73.8% of the total number of dismissed employees. As you know, the risk group for the possibility of COVID-19 was people aged 60 years and older, so the number of employees in this age category decreased by almost 28 thousand, which is 13% (Fig. 8).

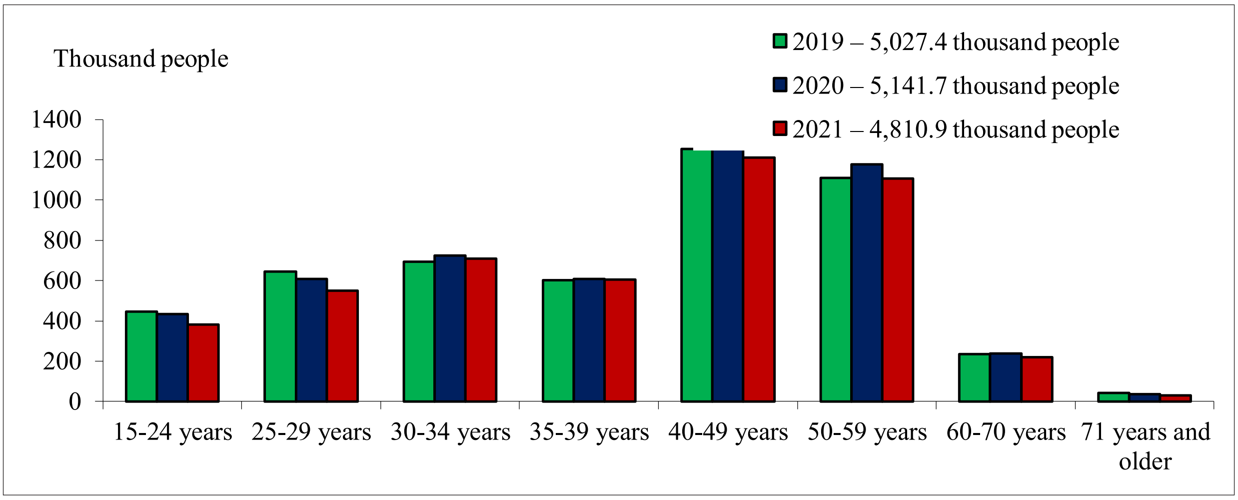

Figure 8*. Employment of the rural population of Ukraine by age group in January-March 2019-2021, thousand people*
Source*: formed by the authors according to the state statistics service of Ukraine [16].*

The release of employees from enterprises, institutions and organisations in the agricultural sector, including due to COVID-19, led to a significant increase in unemployment in 2020-2021. In particular, the unemployment rate of the rural population increased by 2.9% points from 8.6% in 2019 to 11.5% in the first quarter of 2021.

An important marker of the impact of quarantine restrictions on rural residents is their income and the extent of poverty. As of March 2021, the average monthly salary in agriculture of Ukraine in the equivalent of full employment was UAH 10,058.0, which is on average UAH 3,554.0 less than the average salary in the Ukrainian economy, and UAH 4,063 less than in industry for the specified period. As of March 2021, wages in agriculture were only 73.9% and 67.1% of their level in the country's economy and Industry, respectively (Fig. 9).

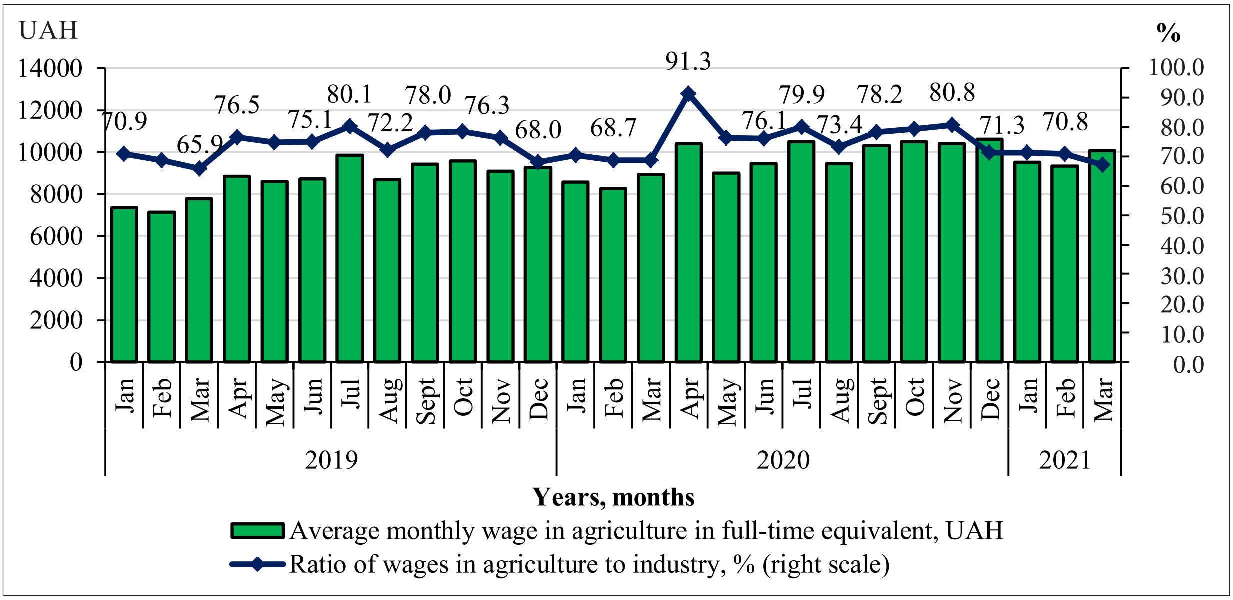

***Figure 9**. Dynamics of wages in agriculture of Ukraine, per full-time employee, 2019-2021*
***Source**: formed by the authors according to the state statistics service of Ukraine [16]*

According to the state statistics service of Ukraine, the share of the population whose average per capita equivalent total income per month is lower than the average level of total income in the first half of 2020 compared to the previous year increased by 0.3% points and amounted to 58.4% [16]. Similar trends are observed in relation to the intersection of the so-called "red lines" – the legally established and actual subsistence minimum, they also increased by 0.6 and 1.7% points, respectively. Total expenditures of the rural population for the analysed period 2019-2021 increased by 18.0%. In the total expenditures of rural households, food and non – alcoholic beverages account for 38.4%, utilities – 19.5%, and healthcare – 5.7% (Table 1).

Trends in the development of entrepreneurial activity in agriculture in Ukraine. It is worth noting that the spread of COVID-19 has affected the activities of the agricultural business, namely – on the activity and efficiency of enterprises. In accordance with the dynamics of statistical estimates of the number of economic formations, we note their decrease in 2020 compared to 2019, while in previous years there was an increase. In particular, according to the results of 2020, the number of enterprises engaged in agricultural activities decreased by 981 units or by 2%. Of these, the number of farms decreased by 601 units (Table 1).

The analysis showed that the state of agriculture in Ukraine in 2020 conditioned upon quarantine restrictions showed a deterioration in structural, economic and financial indicators. In particular, net profit for 2020 decreased by 12.8% compared to 2019. The level of profitability of operating activities decreased by 0.8% points to 19.0%, and the profitability of all activities of agricultural enterprises – by 2.7% points to 13.9% (Table 1, Fig. 10).

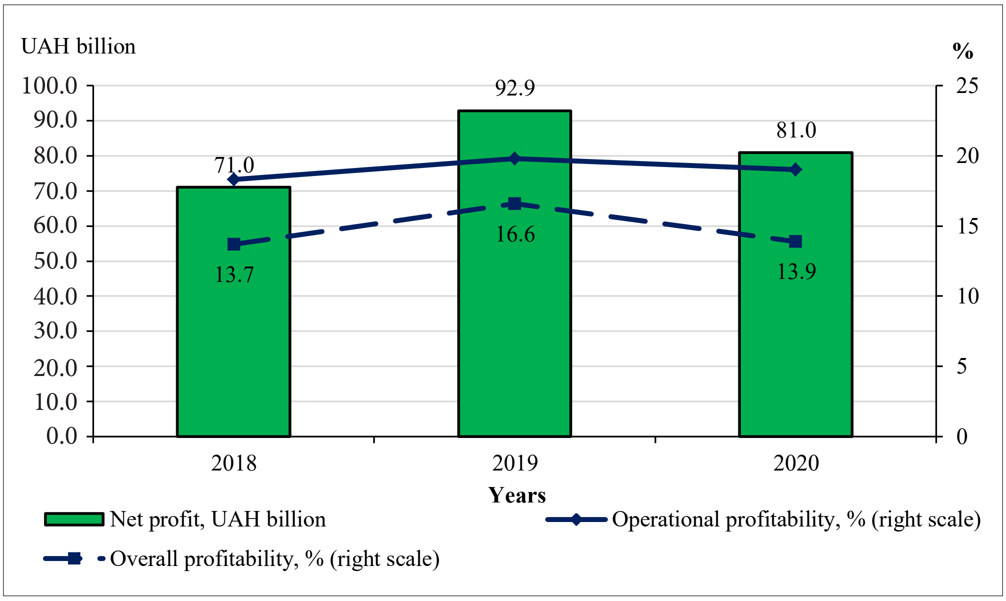

***Figure 10**. Results of agricultural enterprises' activities in Ukraine, 2018-2020*
***Source**: formed by the authors according to the state statistics service of Ukraine [16]*

In 2020, under the influence of quarantine restrictions, the resulting resource usage indicators significantly worsened compared to the previous year 2019. We believe that the largest losses, both financial and image, were suffered by micro-, small and medium-sized agricultural assets of farmers who are focused on the production of niche products. Experience shows that almost half of the products (45.6% in 2019 and 46.1% in 2020) are produced by private farms (OSG) and small producers (44.1% and 44.9% of crop production, 51.0% and 50.2% of livestock production, respectively). However, these products are mainly aimed at the domestic consumer, whom they generally satisfy in terms of "price – quality" items and are sold at local food markets, public catering establishments (restaurants, cafes). Spring and summer 2020, spring 2021 conditioned upon the introduction of restrictive measures in response to the spread of COVID-19 retail and wholesale markets, public catering establishments that are the main sales channels, especially fruit and vegetable, early berries, greens and meat and dairy products by these categories of producers, were closed in almost all regions of Ukraine. Since this happened during the period of harvesting early vegetables and herbs, in fact, the products of Ukrainian producers were forced out of the domestic market by import supplies. Ukrainian farmers suffered significant losses, and the state did not offer them appropriate compensation.

The Cabinet of Ministers of Ukraine tried to ease external pressure on businesses and households by providing some benefits and discounts, as well as minimum wage compensation for employers. In particular, the Law of Ukraine "On Amendments to the Tax Code of Ukraine and Other Laws of Ukraine Regarding Taxpayer Support for the Period of Implementation of Measures Aimed at Preventing the Occurrence and Spread of Coronavirus Disease (COVID-19)" No. 533-IX of March 17, 2020 [18], provided for the exemption of agricultural producers from paying for land in the period from March 1 to April 30, 2020 (land tax and rent for land plots of state and municipal ownership) for land plots that are owned or used, including on the terms of lease, individuals or legal entities and are used by them in economic activities. According to the Law of Ukraine [18] for the periods from March 1 to March 31 and from April 1 to April 30, 2020, members of farms were temporarily exempt from calculating, calculating and paying a single contribution to mandatory state social insurance, if they do not belong to persons subject to insurance on other grounds. This saved money in the amount of UAH 2,078.12 for each member of the farm.

The volume of tax preferences from the application of agricultural enterprises that pay a single tax of group 4 in 2020 almost tripled the corresponding indicator in 2019. In particular, in 2020, the volume of tax preferences for this category of enterprises amounted to UAH 23.04 billion against UAH 8.23 billion in 2019, while direct budget support remained almost at the same level: UAH 4.3 and 4.0 billion, respectively [19]. The predominant amount of benefits was received by producers of crop products. Thus, explained by the opportunity to pay a single tax of Group 4, agricultural enterprises received tax "savings" in the amount of more than UAH 17.5 billion only for three crops – wheat, corn and sunflower, which are the most common in cultivation (18.2%, 20.3 and 19.1% of crop production, respectively) [16]. These opportunities were mainly used by medium and large companies. Measures to support the vital activity of small and medium-sized agricultural businesses in the context of the coronavirus pandemic were insufficient.

CONCLUSIONS

Based on the results of the study it is advisable to draw the following conclusions:

1. In economics and practice, there is currently no scientifically based and methodologically verified approach to measuring the impact of the spread of COVID-19 and restrictive quarantine measures on the development of the agricultural sector. It is proved that the methodological basis of the study can be an approach that includes institutional norms for the introduction of quarantine measures by the state on the territory of Ukraine during the COVID-19 pandemic, as well as indicators for determining complex (general) and partial (personalised) indicators.

2. It is proved that from the standpoint of an integrated approach, all indicators that are a measure of the impact of the spread of COVID-19 and restrictive quarantine measures on the development of the agricultural sector should be considered in two planes: at the macro and micro levels. The methodological design of the study of the impact of the spread of COVID-19 and restrictive quarantine measures on the development of the agricultural sector of Ukraine in the study is built in accordance with the target segments of the assessment of changes, in particular: macroeconomic trends in business efficiency; entrepreneurial activity; foreign economic activity; social and labour relations; finance and investment, state support, etc.

3. The analysis showed that the progressive development of Agriculture in Ukraine during 2020 explained by quarantine restrictions demonstrated the structural, economic and financial effects of the descending plan. In particular, agricultural GDP, expressed in constant prices in 2016, decreased in 2020 p. by 11.5% compared to 2019. There was a significant decrease in agricultural production – by 9.1%, labour productivity decreased by 7.8%. The volume of imports of final consumption goods increased by 13.3%. Total capital investment in agriculture for the period 2019-2020 decreased by 34.5%, foreign direct investment decreased by 24.2%.

As a result of the introduction of two All-Ukrainian lockdowns in 2020-2021, the number of employed rural population decreased by 7%. The unemployment rate for this period also increased by 1.7% points, or to 11.5%. The number of people employed directly in agriculture in Ukraine decreased by 9.6%. for the period 2019-2020. There is a significant differentiation of incomes between rural and non-rural population, increasing poverty and social insecurity of self-employed. As a result, the general well-being of rural households has deteriorated, poverty has increased, and the problem of food affordability has worsened for some groups of population.

4. It should be noted, however, that there is no reason to claim that such a deterioration in the performance of the agricultural sector is due solely to the spread of the COVID-19 pandemic and related restrictive measures. After all, 2020 turned out to be a difficult year for agricultural producers. The crisis situation coincided in time and space with unfavorable weather: a low-snow winter, cold and rainless spring, which slowed down the growing season of plants, the need to re-sow; the transfer of the harvest period to later periods; the drought, which led to a decrease in yield and even to a complete loss of crops in the southern regions of Ukraine.

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Аграрний сектор України в умовах поширення COVID-19 та обмежувальних карантинних заходів: методологічні засади емпіричного оцінювання

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Анотація. Внаслідок негативного впливу пандемічних обмежень через поширення захворювання COVID-19 відбувається спад світової економіки, що спричинило наявність реальних ризиків і загроз розвитку українського аграрного сектору. Визначення цих ризиків і загроз, оцінювання впливу чинників поширення пандемії COVID-19 та запроваджених у відповідь карантинних заходів на аграрний сектор є важливою проблемою аграрної політики, що потребує спрямування максимуму зусиль на своє вирішення. Метою статті є узагальнити методологічні основи оцінювання впливу обмежувальних карантинних заходів 2020–2021 рр., пов'язаних з поширенням пандемії COVID-19, для аграрного сектору економіки України, обґрунтувати засади визначення критеріїв та індикаторів впливу та здійснити їх емпіричне вимірювання. При узагальненні теоретичних і методичних аспектів дослідження використано аналіз і синтез, індукцію й дедукцію, аналогію та порівняння. З метою діагностики динаміки економічних показників в аналітичних дослідженнях застосовано економіко-статистичні методи. Низка прийомів абстрактно-логічного інструментарію дозволили сформулювати проміжні й прикінцеві висновки. Удосконалено методологічні засади, науково-методичні та практичні підходи до оцінювання впливу обмежувальних карантинних заходів 2020–2021 рр., пов'язаних з поширенням пандемії COVID-19, для аграрного сектору економіки України шляхом обґрунтування оптимального інструментарію дослідження, виокремлення найінформативніших показників та індикаторів. Обґрунтовано, що з позицій комплексного підходу всі показники, які є мірилом впливу поширення COVID-19 та обмежувальних карантинних заходів на розвиток аграрного сектору, доцільно розглядати у відповідності до цільових сегментів оцінки змін на макро- і мікрорівнях. Зокрема: макроекономічні тенденції ефективності господарювання; підприємницька активність; зовнішньоекономічна діяльність; соціально-трудові відносини; фінанси та інвестиції, державна підтримка тощо. Проведений аналіз показав, що поступальний розвиток сільського господарства України протягом 2020 р. у зв'язку з карантинними обмеженнями демонстрував структурні, економічні й фінансові ефекти (результати) низхідного характеру. Перспективними напрямами подальших наукових розвідок у цьому напрямі слід вказати розробку комплексу стратегічних заходів щодо мінімізації ризиків для аграрного сектору України під час та після завершення пандемії COVID-19

Ключові слова: аграрний сектор, пандемія COVID-19, карантинні обмежувальні заходи, зовнішні шоки, внутрішні чинники впливу, метод оцінювання

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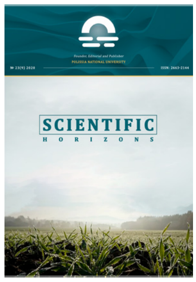

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Methods of Valuation of Ecosystem Assets and their Assimilation Services

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Abstract. An urgent problem of the modern world is the degradation of ecosystems, which requires a radically new approach to assessing and ensuring further, cost-effective use of their potential. However, the value assessment of ecosystem assets (capital) that provide assimilation and other, in particular, oxygen-producing, services to territorial communities has not yet been conducted. It is proved that if ecosystem assets are recognised as the property of territorial communities and the latter are granted the right to dispose of their property (ecosystem assets), the problem of valuation of such assets becomes a priority task. The purpose of the study is to compare scientific approaches to the valuation of ecosystem assets and develop a method for evaluating them, considering the ecosystem services that they provide to territorial communities during their life cycle. The study involves general scientific methods of economic studies and specific ones. The essential features of methods for evaluating a natural resource object are determined, which are the assessment methodology and financial and economic tools used for its practical implementation. Based on this, the analysis is conducted and the substantive features of the method of discounting cash flows (rent valuation method), cost, market prices, hedonistic pricing (price advantages), transport costs, conditional survey method, etc. are established. It is proved that these methods do not meet the requirements of value-market assessment and do not allow for an adequate assessment of the assimilation potential of ecosystems. An ecosystem asset should be considered from the standpoint of environmental safety, so the assessment methods should be different. In view of the above, the most optimal method is proposed: the value of ecosystem assets is determined by the value of the entire complex of assimilation and oxygen-producing services provided by them for their entire life cycle. The author's method was tested on the example of poplar alley, which is part of Taras Shevchenko Boulevard, located in Kyiv

Keywords: evaluation methods, cost, the object of evaluation, territorial communities, poplars, assimilation and oxygen production services

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INTRODUCTION

The problems that have been accumulating in Ukraine in the environmental sphere for a long time have a nationwide scale and require fundamental official recognition, serious attention, and further solution from society. The seriousness and importance of this issue are evidenced by the fact that it is one of the priorities of the President of Ukraine, who by Decree of March 23, 2021, No. 111/2021 put into effect the decision of the National Security and Defense Council of Ukraine "On Challenges and Threats to the National Security of Ukraine in the Environmental Sphere and Priority Measures to Neutralise Them" [1], which encouraged researchers and civil servants to join the discussion and strengthen the investigation of this area. The head of the All-Ukrainian Ecological League T. Tymochko notes that "environmental security is recognised as an important component of national security of Ukraine" [2].

Therewith, the problems in the field of environmental protection (EP) that humanity is currently facing constantly generate new challenges and necessitate new scientific approaches to ensure interaction between ecosystems, on the one hand, and the population, on the other. In the current market conditions, the question of revising or even developing a new approach to evaluating the interaction mentioned above arises. The formulation of such a problem and its solution are highly relevant for modern Ukraine, which is explained by a number of circumstances: historical indifference to environmental issues, environmentally outdated technologies, inadequately low environmental taxes, chronic budget deficit, and, as a result, the financial inability to provide environmental programmes, including relevant studies, lack of political will to fundamentally resolutely change the situation in this area. This problem is becoming even more relevant, considering the decentralisation transformations in Ukraine. In the Constitution of Ukraine [3]: Articles 142 and 143; in the Civil Code of Ukraine [4]: Art. 319 (p. 1, 5), Art. 324 (p. 1, 2, 3); in the Law of Ukraine "On Local Self-Government in Ukraine" [5]: Art. 26 (p. 24, 35, 36, 37), Art. 27 (p. 2, 5), Art. 28, Art. 33 (a): p. 1, 2, 3), Art. 60 (p. 1) – local communities have the right to own property belonging to them. In particular, Article 142 of the Constitution of Ukraine stipulates: "The material and financial basis of local self-government is movable and immovable property, revenues of local budgets, other funds, land, natural resources owned by territorial communities of villages, towns, cities, districts in cities, and objects of their common property managed by district and regional councils" [3]. According to the provisions of the Constitution of Ukraine [3], The Civil Code of Ukraine [4], the law of Ukraine "On Local Self-Government in Ukraine" [5], it is established that the owner possesses, uses, disposes of their property at their own discretion.

Consequently, natural resources are the property of territorial communities, and their owner has the right to dispose of them considering their (the owner's) economic and other interests. To have such an opportunity (to dispose of their own property to obtain a certain economic benefit), the owner must evaluate it, that is, make a value assessment of the property (assets) belonging to them. In assessing the value of the owner's assets, their potential ability to be useful to the owner – to provide the owner with acceptable living conditions should be considered. This utility of ecosystem assets is conditioned by the fact that they generate ecosystem services, including the assimilation potential of such assets. However, as summarised in the official report of the international company for the promotion of environmental and socially responsible development ECODIT LLC (Virginia, USA) [6, p. 15], no serious systematic assessments of ecosystem services have been conducted in Ukraine, so such a gap in information on the cost of ecosystem services necessitates developments in this area.

Ecosystem services, including assimilation and oxygen production services, often cannot be evaluated using the most common monetary method. Such valuation methods have existed for a long time [7-9], and they are used to determine the value of natural resources that are valued as a commodity (admittedly, this is how everything that is valuable should be valued in a market economy). The assimilation potential of ecosystems is quite different, and the classical market approach is not quite appropriate in this case. Nevertheless, the current methods of evaluating it do not consider this, and, consequently, the current methods cannot adequately assess it. The main disadvantage of this approach is that its practical use does not allow comprehensively assessing the ecosystem: these methods [10-13] do not cover all aspects of the interaction between the ecosystem and consumers of ecosystem services – territorial communities of villages, towns, cities, districts in cities, etc.

For that reason, a need appeared to find a fundamentally new approach along with the task to develop and implement new methods that would be aimed at assessing ecosystems (and their assimilation potential) as objects that ensure the life of people from a comprehensive standpoint of environmental safety. From this position, it is necessary to find the assessment methodology that should be used to assess ecosystem assets from the standpoint of environmental safety, as an object that provides a range of ecosystem services to the population. Thus, the value of these ecosystem assets is determined by the value of the entire complex of assimilation and oxygen-producing services provided by them for their entire life cycle.

In the modern world, which is currently globalising, the issue of developing common approaches and rules, considering the assimilation potential of ecosystems, becomes more acute. This challenge is also very relevant for Ukraine, which focuses on civilised European standards and implements the latest approaches in nature management to ensure the interests of the population of territorial communities. Therefore, it is advisable to perform a cost assessment of the assimilation potential of ecosystems as an asset of territorial communities, including united ones, and other ecosystem services that contribute to improving EP to preserve local ecosystems in the context of decentralisation of power.

The purpose of the study is to develop the author's method for assessing ecosystem assets that provide assimilation and oxygen-producing services to territorial communities based on the analysis of methods of valuation of natural resources and structuring of their substantive features.

LITERATURE REVIEW

A review of the specialised literature shows that there are successful examples of economic assessment of ecosystem services within the framework of international and national economic mechanisms for solving environmental issues. "Identification and evaluation of ecosystem services, and consequently the development of economic and institutional mechanisms for paying for these services, are extremely important in this context. The concept of ecosystem services has been recognised in national environmental policies and legislation in many countries. Activities are being intensified on a wide range of issues related to ecosystem services, including their assessment, identification of potential sellers and buyers and compensation mechanisms, and the development of markets for these services" [8, p. 3].

For a long time, researchers have been attempting to develop an economic assessment of ecosystems, their components, and services from various positions. Thus, V.M. Zakharov and D.M. Clark conducted an integrated assessment of the health of ecosystems and their individual species [14]; T.I. Makeeva and G.N. Nikonova assessed the anthropogenic load on the territory according to the indicators of plant development stability [15]; O.A. Neverova performed a bioecological assessment of air pollution by the condition of woody plants [16]. Some researchers study bioresources as components of ecosystems. In particular, M.A. Magomedova and K.A. Kasimova examined the properties of poplars and their use in monitoring EP [17]; K.M.Kinzerskaya and N.V. Vyvodtsev investigated the ecological and biological characteristics of Populus suaveolens in conditions of environmental pollution [18]. However, while in Ukraine these issues are just beginning to receive state and professional attention, for example, "in the US, urban plantations are assessed in terms of their potential for air purification, flood protection, and increasing the value of nearby real estate" [10]. Serious attention from the governments of the United States, Germany, Australia, Japan, Spain, The Netherlands, Switzerland, Norway, Finland, Sweden, Denmark, and the United Kingdom to projects in the field of efficient use of ecosystem assets and increasing funding, in particular, forestry, is noted in [8, p. 94-95].

From the standpoint of ensuring environmentally sound human behaviour, on the example of fisheries, C.E. Hunter and M. Lauer [19] explore the value of ecosystem services, emphasising the importance in natural fisheries of mastering and developing unique ecosystem services for the supply of goods (fish resources) that people receive from nature (ocean). In [20], Japanese researchers prove the feasibility of involving municipalities in ecosystem management and propose appropriate official state measures. The need for systematic development of national parks in China and the role of local communities in this, the reform of environmental policy and practice based on these principles, are discussed in [21]. Environmental initiatives in the field of managing local ecosystem services in the format of public activities of the Brazilian population are presented in [22]. It is proposed to conduct seminar cycles in rural areas of Costa Rica to introduce the latest mechanisms (as the authors of the alternative methodology for interaction with ecosystem services discuss) on the interest of local communities in solving territorial ecosystem issues and overall improvement of environmental protection activities at the local level [23]. The importance of examining ecosystem services in the modern world is also evidenced by the holding of official events in the format of conferences, webinars, etc. under the auspices of international organisations [24]. Similar studies are conducted in Russia [25].

Therefore, in the modern world, increased attention is drawn to the mechanisms for developing socio-economic relations in the sphere of consumption of ecosystem services by local communities, which, as mentioned above, is also relevant for Ukrainian society. In general, the assessment of ecosystem assets should take place considering the fact that they are the object of a specific market [26]: "the mechanism for forming ecosystem services markets is one of the modern innovative scientific and methodological approaches, the essence of which is to create new markets that would redistribute financial flows in favour of organisations and enterprises that preserve ecosystems and biodiversity".

MATERIALS AND METHODS

Both general scientific methods of economic studies and specific ones were used to conduct the study. The research materials were the best practices of researchers in the field of assessing the value of natural resources as ecosystem assets. A content analysis of researchers' scientific positions on the definition of these categories was applied to examine the essence of ecosystem assets and their value assessment, which allowed formulating a new vision of their essence and substantive features as objects of the study. The theoretical investigation of the essence of the value of ecosystem assets was based on the concept of the predominance of essence over form, which allowed determining the need to apply the price concept of consumer utility. The concept of consumer utility in relation to ecosystem assets means evaluating them in terms of their benefits to consumers, which are territorial communities.

Four methods of valuation of ecosystem services are used: the method of direct market valuation; methods of indirect market valuation; the method of conditional valuation; the method of group valuation. The direct market valuation is currently more well-known and familiar to modern pricing, as it is primarily focused on modern market conditions. From the standpoint of direct market valuation, natural resources are a commodity that can be sold or leased, etc., but it does not consider a great number of aspects that are not directly related to the market environment. All methods of cost assessment are aimed at achieving one goal – determining the value of the object, but their economic essence differs in that each of them is based on its individual methodological approach and diverse financial and economic tools.

Financial and economic tools, which are somewhat specific in a particular valuation method, should be used to perform the valuation of an object. For example, if the cost method is considered, then these tools are expenses; as for the method of discounting cash flows, they are the discount rate, net cash flow, and the term of discounting; in the method of futures contracts – other tools. Financial and economic tools can also be the initial data for calculation. The actual process of discounting cash flows can be an economic tool, and the initial data is the discount rate, cash flow, and the period of its discounting. To compare these methods, classical methods of analysis and synthesis, logical comprehension, and segmentation by their substantive features were used.

In the course of the study, systematic and integrated approaches are used, which is conditioned by the systemic and diverse nature of both ecosystem assets and the composition of the ecosystem services that generate these assets. In contrast to the current estimates of the value of such assets, the use of systematic and integrated approaches allows considering the entire range of ecosystem services that ecosystem assets provide to territorial communities, including assimilation and oxygen production.

The development of a valuation of ecosystem assets involves the use of analytical and calculation methods and the use of appropriate formalised procedures. The long period of functioning in the useful state of the studied ecosystem assets has necessitated calculations with discounting of the cost of ecosystem services that are remote and somewhat "extended" in time. Forecast calculations of the value of ecosystem assets should consider the probabilistic nature of the impact of objective and subjective factors that individually or in combination affect the studied cost indicators. Therefore, they are evaluated using classical methods of financial risk management theory, in particular probability theory and the pragmatic risk method (Hurwitz method). The scientific and logical substantiation was applied to develop proposals for changing environmental taxation in the context of accounting for the value of ecosystem assets in tax norms.

RESULTS AND DISCUSSION

Methodological approaches to identifying and evaluating ecosystem assets of territorial communities

In the context of Ukraine's strategic progress in the EU, appropriate innovations are being introduced to preserve ecosystems and ensure the competitiveness of Ukrainian enterprises. In Ukraine, theoretical, methodological, and methodological approaches to the valuation of easily vulnerable ecosystems, ecosystem assets of territorial communities, ecosystem services, ecosystem capital that provides ecosystem (including assimilation and oxygen production) services to the population have begun to be developed at the academic level, which is a considerable shift, albeit belated compared to economically developed countries. Today, the valuation of ecosystem assets can become an effective tool for making informed management decisions for their rational use and preservation of ecosystems.

The object of valuation is an ecosystem asset (capital) that provides assimilation and oxygen-producing services to territorial communities. Based on the price theory of utility, it is necessary to determine the essence of ecosystem services to assess ecosystem assets: "ecosystem services should be defined as economic benefits that economic entities receive from the use of existing ecosystem functions, and those developed as a result of generation, restoration, support, regulation of ecosystem processes" [8, p. 12]. Therefore, the economic (cost) assessment of ecosystem capital should be conducted by determining the cost of ecosystem services that it is capable of providing to society (territorial communities) during its life cycle.

The proposed methodology is based on the cost of ecosystem services, with an ecosystem asset having value as long as it provides environmental services to the population. Therefore, the essence and substantive features of the method are as follows: an object (ecosystem asset) is evaluated through the cost of ecosystem services, as long as it has the ability to provide them. It is advisable to specifically consider a simple example: if the forest absorbs CO_2 and emits O_2, it provides ecosystem services (assimilation and oxygen production), that is, as an ecosystem asset, performs certain functions.

Notably, an ecosystem asset (capital) is also capable of assimilating harmful substances and improving EP. Therefore, it is necessary not only to assess the assimilation potential of ecosystems but also to consider it comprehensively, that is, for example, to assess the release of oxygen by plants, which should also be included in the ecosystem services of these ecosystem assets. This corresponds to the principle of complexity because, from the standpoint of environmental safety, ecosystems should be evaluated as an object that ensures the life of the population by providing the latter with a set of ecosystem services.

Based on this, the following, relatively more capacious, definition of the object to be assessed (ie which is the object of valuation) is formulated: ecosystem asset (capital), which provides assimilation and oxygen production services to the population is a set of natural resources, which, in close cooperation with each other, are capable of providing ecosystem services to the population (including local communities): capturing and absorbing harmful emissions, enterprise and household emissions, digesting waste (ie assimilation services), emitting oxygen into the atmosphere, etc. The assimilation potential of ecosystems is a component of an ecosystem asset (capital) that provides ecosystem services to the population. Ecosystem capital can include the sea, forest, and other ecosystems. For a brief explanation, some good examples can be provided: a tree simultaneously absorbs greenhouse gases (CO_2 and others) and at the same time releases oxygen; sewage is dumped into the sea, and it digests them.

The following substantive features of methods and parameters for assessing ecosystem assets of territorial communities are determined (systematised list) based on these positions:

1) the property-legal feature, i.e., ecosystem assets and assimilation potential of ecosystems is the property of territorial communities, which should be assessed; that is, the feature is a property right;

2) a feature according to the "polluter pays" principle: methods for assessing ecosystem assets and the assimilation potential of ecosystems should be based on the "polluter pays" principle (that is, considering the fact that, for example, someone would pollute the lake, etc.);

3) a feature in accordance with the principle of preserving ecosystems and their assimilation potential for future generations (especially today, this applies to forests that are mercilessly cut down in Ukraine, so the assessment of forest ecosystems should be based on this feature);

4) assessment of all components of ecosystems, including bioresources that are living organisms;

5) a substantive feature of the efficiency of using ecosystems, that is, in market conditions, it is advisable to determine how effectively ecosystems are exploited by territorial communities.

Analysis of methods for assessing ecosystem assets of territorial communities and determining their substantive features

To analyse the methods and their substantive features, their classification is conducted, their essence is investigated, and the possibilities of practical use are determined (Table 1). A comprehensive analysis of methods for assessing both ecosystem services and the assimilation potential of ecosystems was conducted in the following areas: the economic essence and target orientation of methods for assessing ecosystem assets; the substantive features of existing methods for estimating ecosystem assets of territorial communities and the assimilation potential of ecosystems; the fundamental methodology and tools (financial and economic tools); the disadvantages of these methods of assessment and the possibility of their elimination to improve the accuracy of calculations; the level of acceptability of assessment methods for their application in Ukraine; the differences of methods from each other and their adaptation to market conditions of application.

***Table 1**. Substantive features of methods and parameters of assessment of natural resources and determination of possibilities of their use for valuation of ecosystem asset (capital), which provides ecosystem services to territorial communities*

No.	Method for evaluating natural resources	Substantive features of the method (methodology and financial and economic tools)	Possibility of use
	1. Market (marketing) methods *(economic),* in which the methodology is to estimate the expected income		
1.1.	Market price method	Income, market prices, prices for goods and services on domestic and global markets (tools)	–
1.2	Shadow price method	Revenue, shadow prices – market prices adjusted for transfers, market failures, and policies (tools)	–
1.3	Rent method (rent estimation method or cash flow discounting method)	Income, rent (tools). Economic rent – the price or rent paid for the use of natural goods, the number of which is limited	It is possible, but not in all cases because the term of use of soil or aquatic ecosystems can be 1000 years or even endless
1.4	Cadastral method	Income, cadastres (tools); methodology: a regulatory assessment of their value based on the possibility of generating income from the use of these resources	–
1.5	Method of production functions	Revenue, production functions (tools); methodology – modelling changes in economic results depending on the contribution of resources and functions	–

Table 1, Continued

No.	Method for evaluating natural resources	Substantive features of the method (methodology and financial and economic tools)	Possibility of use
***2. Cost methods** (economic),* in which the methodology is to determine the amount of costs for the maintenance of goods rather than the evaluation of the goods themselves, in the absence of markets for goods, services, and benefits			
2.1	Replacement cost method	Replacement costs (tools). The replacement cost method determines the cost of artificially replacing goods and services in the ecosystem	+
2.2	Recovery cost method	Reproduction costs (tools)	+
2.3	Relocation cost method	Relocation costs (tools); the relocation cost method determines the cost of relocating objects	–
2.4	Preventive cost method	Preventive costs (tools); methodology: identification of the costs of damage prevention, degradation of environmental services	(Partially) possible (to assess potential damage, but not to assess the usefulness of environmental services)
2.5	Averted damage method	Damage prevention costs (tools)	Possible (the same as 2.4)
***3. Comparative methods** (economic)*, in which the methodology is the use of one or more methods based on the comparison of this natural resource with similar already estimated			
3.1	Method of analogies	Analogies (tools)	–
3.2.	Product replacement method	Replacement of products (tools); methodology: information about the relationship between a product that does not have a market and a product that has a market is used	–
***4. Methods of conditional assessment** (sociological)*, in which the methodology lies in conducting various types of sociological surveys, among which one of the main is the concept of willingness to pay and the method of transport and travel costs			
4.1	Subjective preference method (willingness to pay)	Subjective preferences (tools); methodology: the subjective value estimation method involves constructing a hypothetical market to identify consumer preferences	–
4.2	The method of transport and travel costs	Travel expenses (tools); methodology: the willingness to pay for environmental benefits located in a particular place is evaluated based on information about the time and money spent on visiting that place	–
4.3	Hedonistic pricing method	Hedonistic pricing (tools); methodology: assessment of environmental goods at real estate or labour market prices	It is impossible to apply it to avoid inefficient management decisions in modern conditions

***Source**: developed according to [10-13]*

A) Table 1 shows that the most optimal methods for assessing the ecosystem assets of territorial communities in modern conditions are ***cost methods***: replacement cost method and recovery cost method. The essential features of *the cost method* are a determination of the cost of cleaning atmospheric air, water, and soil; the cost of protecting public health; the cost of restoring disturbed territories if the ecosystem is vulnerable, depleted, and ceases to self-clean and provide waste assimilation services, etc.

The assessment of ecosystem assets of territorial communities should be conducted using other methods than the assessment of natural resources, because they are not a commodity that can be sold or bought, donated, leased, etc., so if the use of more effective methods is not possible, the method of preventive costs or the method of averted damage should be applied. It should be noted that the consideration of only possible losses from any negative changes in the environment substantially limits the value of ecosystem assets because in this case the positive (useful) influence of the latter on the territorial community is not considered at all (which violates the principle of systematic consideration of the ecosystem that provides ecosystem services).

B) ***Market methods*** cannot be used for such an assessment. *The market price method* has market prices as substantive features, that is, it considers only monetary indicators set by the market and ignores an important component of ecosystem services, which is assimilation potential.

However, in some cases, the method of discounting cash flows can be used, but it is advisable to carefully determine the term of use of soil or aquatic ecosystems because such a period can be 1000 years or even endless. Since this method is quite widely used for assessing natural resources, an analysis was conducted, and substantive features of *the cash flow discounting method (rent valuation method)* were determined. Thus, the economic essence of the cash flow discounting method is to bring future receipts (net cash flows without taxes and fees) to the present point of time (at the valuation date, i.e., to date) by discounting.

The calculation for determining the value of ecosystem assets of territorial communities using the method of discounting cash flows can be the most accurate and most acceptable if this refers to a natural resource as a commodity, but it cannot be applied to assess the assimilation potential of ecosystems, because the essential features (tools) of this method are annual net cash flow, discount rate, and discount period. To apply this method, it is necessary to determine the term of use of ecosystems or their services, or ecosystem capital that provides environmental services to the population, or the assimilation potential of ecosystems. There is a specific period for the extraction of minerals or the use of forest resources, for example, a license for the use of mineral resources is granted for 20 years. When using forest resources, it is advisable to know the time when the crowns close, etc. In other words, it is known on a planned basis for what period it is worth discounting cash flows. However, it is not possible to estimate the absorption of carbon dioxide (CO_2) and oxygen release.

The cash flow capitalisation method is not suitable for making such estimates.

C) ***Comparative methods***: evaluation should not be used in this case.

D) ***Conditional evaluation methods*** cannot be used either. For example, *hedonistic pricing method (price advantages)* has a different set of tools. Its substantive features are that environmental benefits are evaluated at the prices of the real estate market or the labour market [12, p. 92]. In other words, the ecosystem assets of territorial communities can be evaluated using this assessment method. However, in the current economic conditions of Ukraine, the use of the hedonistic method can lead to an insufficiently accurate assessment of ecosystems and the adoption of inefficient management decisions. With regard to assessing the assimilation potential of ecosystems using this method, it is worth noting that there are no relevant specific opportunities or examples.

Essential features of the *method of transport and travel costs* are transportation costs, vacation expenses, etc.; therefore, applying this approach is also quite problematic. There is also a conditional survey method and others, but they would not allow for an accurate assessment of the assimilation potential of ecosystems. Therewith, Ukraine has been using existing methods for estimating land, forests and other isolated natural resources for many years, but it is incorrect or even impossible to estimate the value of ecosystems or ecosystem services on these grounds because they are designed to assess a natural resource as a commodity, not as an object that ensures the life of people from the standpoint of environmental safety, which digests harmful emissions (and releases oxygen), discharges into reservoirs, waste.

The above refers to the practical use of mainly market-based or cost-based pricing methods, despite the fact that, as noted above, this is not an adequate approach to evaluating ecosystem assets that generate and provide ecosystem services to consumers. Ecosystems meet the needs of the population, that is, they ensure the life of people from the standpoint of environmental safety, hence the methodology should be different. Collectively, land, water, forests form ecosystems, but the value of the system of objects can not become the value of the ecosystem, and it is advisable to develop fundamentally new methodological approaches to assessing the ecosystem as an object that ensures human life, using new financial and economic instruments [27].

However, there are still attempts to use valuation methods from classical economic theory to evaluate ecosystems or their services exclusively as goods that can be sold, bought, rented, exchanged, bequeathed, etc. [10-13]. However, it is impossible to adapt such methods to assess the assimilation potential of ecosystems or other ecosystem services, because it is necessary to evaluate an ecosystem asset (capital) as an object that provides environmental services: absorption, neutralisation, digestion, etc. It should be emphasised that completely different methods of assessing the ecosystem are needed (in relation to which the author's attempt was made) because an ecosystem is a set of living organisms that have adapted to living together in a certain habitat, forming a single whole with it. It is substantiated that the practical implementation of the valuation of such assets should be based on the theory of utility. However, such a value estimate cannot be complete in relation to an ecosystem as an object that provides environmental services. As noted above, plants not only absorb and retain CO_2, but they also release oxygen. Therefore, it is necessary to determine the cost of working with the assimilation potential of ecosystems and the cost of oxygen production by the ecosystem. The cost of oxygen can be estimated, for example, as the cost of its production using oxygen separation plants or other methods.

Substantiation of the author's methodology for estimating the value of ecosystem assets

The analysis of existing methods of estimating the value of ecosystem assets allowed assessing their feasibility in practice and substantiating the scientific basis for changing the prevailing price concept in science in estimating the value of these assets. This refers to the fact that in economics two classical price theories coexist: cost and marginal utility (value). Upon comparing the views of modern supporters of "cost" and "value" approaches to price formation, O.O. Orlov and Ye.H. Riasnykh note that modern authors are clearly divided into two camps – some assert that prices should be formed based on costs, and others that the basis of pricing should be "value", but emphasise that the "cost" is predominant in practice [28, p. 35]. Other researchers also cover this [29, p. 255].

I. Homyn wrote about the dualism of pricing and the possibility of comparing the exchange value of goods and its usefulness [30, p. 44]:

$$Pu=C \qquad (1)$$

where Pu – physical utility of goods; C – exchange value of goods.

The inadequacy of market methods for valuing ecosystem assets is compared to "market failures", and the inaccuracy of conventional methods of valuing eco resources is that they are mainly based on consumer prices of these resources, the cost of their use, for which it is necessary to know their market price. Evidently, this approach considers only a small part of the real value of natural goods, since the market does not know how to adequately assess them. In this regard, the concept of common economic value is widely used in the world, which allows approaching the assessment of biological resources more comprehensively, considering not only direct resource but also assimilation functions, natural services, and the "cost of consumption" [31, p. 120-121].

In this sense, it is worth noting that an ecosystem asset should be considered from the standpoint of eco-safety, so the methods of its assessment should be based on the theory of consumer utility. An ecosystem asset is not an ordinary market commodity, but it has consumer utility, so the utility theory is suitable for its assessment, which is what further study is based on. The utility of an ecosystem asset lies in the fact that it naturally generates ecosystem services for consumers (the population).

Thus, the essential feature of such a method would be that the ecosystem asset (capital) is valued for the entire period of its existence through the value of ecosystem services it provides (as opposed to the assessment of natural resources as a commodity). Given that the assessment must take place over the entire period when an ecosystem asset provides its services to consumers (and such a period can be measured in tens of years), the methodology of this assessment requires the use of the discounting method mentioned above. This would allow evaluating future ecosystem services at the time of valuing the ecosystem asset.

For a fairly long period of time, during which the ecosystem asset is assessed, in addition to discounting the value of ecosystem services, it is also necessary to consider the risks and any negative deviations in the processes of consumption of ecosystem services. Notably, the above refers to objective and subjective factors influencing the ability of ecosystem assets to generate ecosystem services for consumers. The natural, climatic, and weather conditions of the functioning of these assets are considered to be objective influencing factors, while the decisions and actions of state institutions, regulatory authorities, including even consumers of such services, to be subjective. The subjectivity of such influence is conditioned by the fact that these entities may have their own interests and goals, which do not always coincide with the conditions for ensuring the rational use of the potential of ecosystem assets.

Therefore, it is necessary to consider the risk of consumers not receiving the desired ecosystem services, which makes it necessary to appropriately adjust the approach to assessing ecosystem services and apply a certain risk factor. Methodically, this is ensured by using the theory of risk management and predicting the level of shortfall in ecosystem services over a certain period of time. The importance of the risk factor is enhanced both by the relatively long period of study of ecosystem assets and the existing objective uncertainty of their functioning.

Development of the author's methodology for evaluating assimilation and oxygen-producing services of forest ecosystems

The above scientific basis for assessing ecosystem assets is implemented in this study using the example of forest assets. The evaluation procedure is developed on the above-mentioned scientific and theoretical provisions: application of the price concept of consumer utility; consideration of the life cycle period of an ecosystem asset; assessment of the fair value of ecosystem services as a result of the functioning of an ecosystem asset; discounting of the specified cost of ecosystem services, considering a fairly considerable period of functioning of an ecosystem asset. I.K. Bystryakov and D.V. Klynovyi also wrote about the need for discounting within the ecosystem capital assessment procedure [32], but their formulas have gross errors from an economic standpoint, so it is impossible to focus on their methodology; forecasting and appropriate calculation of emergencies (that is, the risk of not receiving ecosystem services for of both objective and subjective reasons); consideration of the specific assimilation properties of particular ecosystems.

The cost of an ecosystem forest asset from an ecological and economic standpoint consists of the cost of assimilation and oxygen-producing services of forest ecosystems. The following substantive features of the assessment method are considered to perform a cost assessment of ecosystem capital (in this case, forests) that provides ecosystem services to the population:

– years required for forest growth;

– the annual ability of trees to absorb CO_2 (to calculate this indicator, it is advisable to multiply the number of years required for forest growth by the amount of CO_2 absorption per year and the cost of quotas for greenhouse gas emissions into the atmosphere);

– the tree simultaneously absorbs co_2 and releases oxygen;

– bushes absorb less CO_2 compared to trees, they emit less oxygen, so differentiation in calculations is necessary;

– the cost of oxygen production is determined based on data on the operation of converter oxygen separation plants, etc.; and other methods can be used to determine the cost of oxygen production.

It is necessary to calculate the costs associated with the absorption of CO_2 and the costs associated with oxygen production; that way the methodology for estimating the ecosystem capital that provides environmental services to the population considers the cost of greenhouse gas absorption (CO_2 and others) plus the cost of releasing oxygen. Consequently, properly selected methods of cost assessment of the assimilation potential of ecosystems would allow for an adequate cost assessment and contribute to maintaining a balance between the man-made load and the recovery potential of ecosystems.

The author's method of determining the value of forest ecosystem assets (plants) of territorial communities that provide assimilation services to society is based on the price concept of utility; and their value is determined by the cost of ecosystem services that he (ecosystem asset) provides to society throughout its life cycle. One of the author's methodological approaches to valuing the assimilation potential (AP) of ecosystems as an asset of local communities is to determine the "work" of AP forest ecosystems or plants, which can be indicated in the form of formula (2):

$$C_{ASfe} = \sum_{1}^{n} \frac{1}{(1+i_t)^t} \cdot (M_{CO_2})_t \cdot (C_{CO_2})_t \cdot S_{fe} \cdot (C_p)_t \cdot C_{pr} \quad (2)$$

where C_{ASfe} – the cost of assimilation services (work of assimilation potential) of forest ecosystems for the entire period of functioning of the forest ecosystem, UAH.; $(Mco_2)_t$ – mass of carbon dioxide emissions (CO_2), which is absorbed by plants per year t, t/ha/year; $(Cco_2)_t$ – cost of carbon dioxide (CO_2) per year t, determined based on the price of quotas for carbon dioxide emissions, UAH/tonne; S_{fe} – area of the forest ecosystem, ha; i_t – discount index for the year t; t – year of the life cycle of plants in the forest ecosystem (trees, undergrowth, grass tier), years; $(C_p)_t$ – coefficient of emergencies (risk of shortfall in ecosystem services) in the year t of the life cycle of plants of the forest ecosystem (trees, undergrowth, grass tier), determined by the expert method of predicting the influence of objective and subjective factors on the efficiency of the functioning of the forest ecosystem; C_{pr} – coefficient that characterises the assimilation properties of natural areas where ecosystems are located, such as forest-steppe, mixed forests, etc.

The author's method of determining the value of forest (plant) ecosystem assets of territorial communities that provide oxygen-producing services to the population is based on the cost of these services. In turn, the cost of oxygen-producing services of forest ecosystems (plants) can be determined by the formula (3):

$$C_{OSfe} = \sum_{1}^{n} \frac{1}{(1+i_t)^t} \cdot (M_{O_2})_t \cdot (C_{O_2})_t \cdot S_{fe} \cdot (C_p)_t \quad (3)$$

where C_{OSfe} – the cost of oxygen-producing services of the forest ecosystem for the entire period of its operation, UAH; $(Mo_2)_t$ – oxygen volume (O_2), which is released per year t from 1 ha of plantings surface, t/ha/year; $(Co_2)_t$ – the cost of oxygen (O_2) per year t, is determined: either 1) based on the price of quotas for carbon dioxide emissions; 2) according to data on the implementation of natural photosynthesis – planting and conservation of forests; 3) according to the passport data of the operation of an air separation plant in metallurgical production, in coke chemistry, medicine; or 4) according to the passport data of the operation of an installation for artificial photosynthesis), UAH/tonne. On this basis, the total cost estimate of the forest ecosystem C_{fe} equals (4):

$$C_{fe} = C_{ASfe} + C_{OSfe} = \sum_1^n \frac{1}{(1+i_t)^t} \cdot (\mathrm{M}_{CO_2})_t \cdot (C_{CO_2})_t \cdot \\ \cdot S_{fe} \cdot (C_\mathrm{p})_t \cdot C_{pr} + \sum_1^n \frac{1}{(1+i_t)^t} \cdot (\mathrm{M}_{O_2})_t \cdot (C_{O_2})_t \cdot \\ \cdot S_{fe} \cdot (C_\mathrm{p})_t \quad (4)$$

Practice and prospects of introduction of the author's methodological approach to the assessment of the ecosystem asset of territorial communities

Testing of the developed methodology was conducted on the example of poplar alley, which is part of Taras Shevchenko Boulevard, located in Kyiv. The properties of poplars and other plants are analysed to perform a correct cost assessment of the assimilation potential of green spaces. Green spaces use their functions to purify, moisten, and enrich the soil and air, change the temperature and radiation regime, and reduce noise and wind strength.

It is advisable to pay special attention to various types of poplar (for example, *Populus suaveolens*) because they are leading in the purification of air among trees. Due to their cleaning properties, poplar plantings restrain toxic fumes and gases, preventing them from spreading. These trees are able to neutralise and absorb harmful compounds from the soil and air. The essential role of this tree is evidenced by the following statements of experts: due to the active photosynthetic apparatus, poplars process a huge amount of carbon dioxide and emit a lot of oxygen [18], and one poplar produces as much oxygen per season as one person needs per year [33]. Such properties of poplars determined the field of assessing the assimilation potential for these trees.

For the development of this method of assessing ecosystem capital that provides environmental services, a cost assessment of the assimilation potential (capital) of an individual ecosystem was conducted using the example of the poplar alley on Kyiv's Taras Shevchenko Boulevard.

If in rural areas in most of the territory of Ukraine there are green spaces that provide relatively clean air, in cities and mining regions the number of forest and park ecosystems is insufficient, so the air there is polluted. In Kyiv, from Khreschatyk Street to Victory Square in the middle of Taras Shevchenko Boulevard, there is the poplar alley with a length of 1.8 km and an area of 3.0 ha.

550 poplars grow on Taras Shevchenko Boulevard in Kyiv. Poplar alley is a park ecosystem and an ecosystem asset of the territorial community of the Shevchenko district of the city, which is confirmed by the memorial sign installed by the state – "State nature monument of local importance".

The boulevard was built as a city street in the 1830s. Simultaneously with the construction of the building of the University of Kyiv on the neighbouring Volodymyrska Street, an alley was planted in the middle of the street – first chestnuts, then, from the 1840s, poplars. By the decision of the Executive Committee of the City Council of March 20, 1972, No. 363 Taras Shevchenko Boulevard was included in the list of territories and objects of the nature reserve fund of Ukraine as a botanical monument of nature of local importance. The length of the poplar alley on the boulevard is about 1.5 km.

The following data and assumptions were used to calculate the cost of assimilation services of the poplar alley of Taras Shevchenko Boulevard:

– mass of carbon dioxide emissions absorbed by poplars of the poplar alley of Taras Shevchenko Boulevard in Kyiv, 40.0 t/ha/year;

– the cost of quotas for carbon dioxide emissions, UAH/tonne – 30 EUR [34];

– the area of poplar plantations in the poplar alley of Taras Shevchenko Boulevard in Kyiv – 3.0 hectares;

– the life cycle of poplars is more than 40 years (poplars can live for an average of 60 years, but in the city – much less; in Kyiv, poplars are often cut down and new ones are planted immediately);

– the discount rate (or, synonymously, capitalisation) "should be set, considering the existing experience of assessing natural resources, primarily the World Bank, in relation to the social rate of return on investment (SRRI – Social Rate of Return on Investment). According to the recommendations of this institution, the capitalisation ratio for developed countries is at least 4%, for developing countries, – a maximum of 7-9% [32, p. 51]. The value of this coefficient is substantiated by the level of the inflation index, which, according to the forecast of economic and social development of Ukraine for 2022-2024 [35], respectively by years, is: 2022 – 7.2%, 2023 – 6.0%, 2024 year – 5.2%, average – 6.13%; the average coefficient of 0.0613 (this value, apparently, meets the modern requirements of the World Bank) is taken in this paper for further calculations. Notably, similar studies of the economic assessment of forest ecosystems in regulating the composition of atmospheric air (using the discounting method) have been conducted before: for example, [36], but the authors of this study chose bank percentage, which cannot be considered scientifically correct in relation to assessing the value of ecosystems or their services because it is not an investment project, the effectiveness of which must be compared with an alternative option for bank depositing funds or some other. The use of ecosystem potential and the provision of services to consumers by ecosystems has prevailing environmental and social effects, not purely economic ones. This gives grounds to assert that the discount rate for ongoing study does not require the inclusion of alternative profitable components in its composition;

– the coefficient that characterises the assimilation properties of an ecosystem (forest-steppe), according to various sources, differs slightly in its value. Thus, according to Appendix A DBN B. 2.2-12:2019 [37, p. 127], the northern (and most) part of Kyiv is located in the zone of mixed forests (polissia) (I), and the southern (smaller) part of the city is located in the forest-steppe zone (III). According to some geographical maps, the northern part of Kyiv belongs to the zone of mixed forests. The entire city of Kyiv is located in the forest-steppe zone. Since the city has much less greenery than the outside of the city, the coefficient was used for the city of Kyiv as for the forest steppe. Based on this, this coefficient is calculated by O.M. Sukhina by determining the correlation coefficients for considering the assimilation properties of ecosystems (as a component of the author's economised classification of assimilation services of ecosystems of Ukraine) [38; 39] and is equal to K_{vl}=1.060;

– the risk factor for non-receipt of ecosystem services, as noted, is established by an expert method of predicting the impact of factors on the efficiency of the forest ecosystem. The Hurwitz risk assessment method is used to determine it, which allows establishing a balance between cases of extreme optimism and cases of extreme pessimism regarding the development of the studied events in the future, involving the optimism coefficient. This coefficient takes values from zero to one and shows the degree of the propensity of the decision-making expert to optimism or pessimism; it is recommended not to be guided by extreme optimism or extreme pessimism, but to take some average result [40, p. 41]. Given that there are certain hopes for an optimistic development of events in connection with the increased attention to the problems under study on the part of officials, researchers, and the international community, it is worth assuming and possibly accepting this coefficient at the level of 0.8.

In addition to assimilation services, forest ecosystems also provide oxygen-producing services. A similar method is used to determine the cost of oxygen-producing services of the poplar alley of Taras Shevchenko Boulevard in Kyiv, for which the following data were used: oxygen volume (O_2), which is released per 1 year from 1 ha of poplar plantings surface, $(Mo_2)_t$=33.6 t/ha/year; cost of oxygen $(Co_2)_t$=1 362,9 UAH/tonne.

In the study [41], the cost of oxygen was determined by various methods of its production: using an installation for artificial photosynthesis, based on the price (sales) of quotas for CO_2 emissions, using natural photosynthesis – planting and conservation of forests and using an air separation plant in metallurgical production, in coke chemistry, medicine.

This study focuses on a method based on the implementation of CO_2 emission quotas. Thus, the Russian power engineer V. Boldyrev [42] noted back in 2001: "If industrialised countries are willing to pay 10 USD for one "over-limit" tonne of CO_2, and 0.727 tonnes of oxygen are formed when this tonne is decomposed, these countries are willing to pay 13.8 USD (10/0.727) for the production of a tonne of atmospheric oxygen by "green lungs".

Then, if the cost of carbon dioxide (CO_2) quotas is 30 EUR/t in the EU, 1 tonne of atmospheric oxygen is 41.3 EUR (30/0.727). As of November 7, 2021, the euro exchange rate is UAH 30.2, then 1 tonne of atmospheric oxygen would be UAH 1,247.26. However, to assess the value of the assimilation potential of ecosystems in the summer of 2021, the euro exchange rate against the hryvnia was used – 33 UAH, so this figure will be focused on in these calculations. Then the cost of 1 tonne of oxygen would be 1,362.9 UAH. That is, the determination of the cost of assimilation services of ecosystem assets of territorial communities and the cost of their oxygen-producing services is conducted based on the price of quotas for CO_2 emissions, that is, using a single method.

For comparison, it is advisable to substantiate the determination of the cost of oxygen based on determining the cost of forest planting. In addition, the value of the discount coefficient is taken in calculations for the entire period (for all years) of the functioning of the forest ecosystem, that is: i_t = *and* = 0.0613; and environmental services for this period (in any year) are equal to those defined above the average annual, i.e.: $(M_{CO2})_t = M_{CO2}$ and $(M_{O2})_t = M_{O2}$. The averaging of the volume of environmental services for a fairly long period determines the use of annuity discounting their value. Formula 4 can then be changed to consider the current annuity value factor as follows:

$$C_{fe} = \sum_1^n \frac{1}{(1+i_t)^t} \cdot (\mathrm{M}_{CO_2})_t \cdot (C_{CO_2})_t \cdot S_{fe} \cdot (C_\mathrm{p})_t \cdot C_{pr} + \sum_1^n \frac{1}{(1+i_t)^t} \cdot (\mathrm{M}_{O_2})_t \cdot (C_{O_2})_t \cdot S_{fe} \cdot (C_\mathrm{p})_t = \\ = \left(1 - \frac{1}{(1+i)^n}\right) / i \cdot S_{fe} \cdot C_p \cdot (M_{CO_2} \cdot C_{CO_2} \cdot C_{pr} + \mathrm{M}_{O_2} \cdot C_{O_2}) \quad (5)$$

The results of calculations of the alley's oxygen production services are:

$$C_{fe} = \left(1 - \frac{1}{(1+0.0613)^{40}}\right)/0.0613 \cdot 3.0 \cdot 0.8 \cdot (40.0 \cdot 990.0 \cdot 1.060 + 33.6 \cdot 1362.9) = 3128103 \text{ UAH, or}$$

3128.1 thousand UAH

The cost of services of the herbaceous tier of poplar alley of Taras Shevchenko Boulevard in Kyiv was estimated in a similar way, for which the following data were used:

– mass of carbon dioxide emissions absorbed by the herbaceous tier, 0.6 t/ha/year [43, p. 13];

– the cost of quotas for carbon dioxide emissions, UAH/t – 30 EUR [34], i.e., 990.0 UAH/t;

– the area of the herbaceous tier of poplar alley Taras Shevchenko Boulevard in Kyiv is 3.0 hectares;

– the life cycle of a herbaceous tier can be 30 years or more;

– the coefficient that characterises the assimilation properties of an ecosystem (forest-steppe) is 1.060.

Under these conditions, the cost of assimilation services of the herbaceous tier of poplar alley is $(C_{fe})_{he}$:

$$(\mathrm{C}_{fe})_{he} = \left(1 - \frac{1}{(1 = 0.0613)^{30}}\right) /0.0613 \cdot 0.6 \cdot 990.0 \cdot 3.0 \cdot 1.060 = 25576 \text{ UAH, or 25.6 thousand UAH}$$

Thus, the total cost estimate of assimilation and oxygen production services of poplar alley (together with its herbaceous tier) of Taras Shevchenko Boulevard in Kyiv is 3153.7 thousand UAH (3128.1 thousand UAH + + 25.6 thousand UAH).

The valuation of an ecosystem asset (capital) that provides environmental services would contribute to a sound reform of environmental tax legislation, since the environmental payment or environmental tax act as compensation for the ecosystem services used. The Tax Code of Ukraine on Environmental Tax states the following provisions of Article 242 "Object and Base of Taxation" [44]:

242.1. The object and base of taxation is:

242.1.1. volumes and types of pollutants released into the atmospheric air by stationary sources;

242.1.2. volumes and types of pollutants discharged directly into water bodies;

242.1.3. volumes and types (classes) of disposed waste, except for volumes and types (classes) of waste as secondary raw materials placed on the territories (objects) of business entities.

As noted above, unfortunately, in Ukraine there is no connection between the amount of environmental tax and the cost of ecosystem services (which is asserted with confident responsibility), and the rates of this tax are introduced without any economic substantiation, which is absolutely unacceptable. Therefore, it is necessary to reform environmental taxation in Ukraine, which should be based on establishing a correlation (relationship) between the cost of ecosystem services and the amount of environmental tax, since there are much more effective and efficient environmental payments or taxes in the world and the government itself decides: who and how to pay for the use of environmental services – to the state or territorial communities. In addition, it is advisable to pay more attention to the conservation of ecosystems in the mining regions [45] and areas of military operations.

CONCLUSIONS

The object of valuation is an ecosystem asset that provides environmental services to the population, and its component is the assimilation potential of ecosystems. It is advisable to establish the cost of such an object by determining the cost of its services. The paper evaluates all currently known approaches to assessing the value of ecosystem assets, which were divided into four groups: marketing methods, in which the methodology is the assessment of expected income; cost methods, based on determining the size of costs to support goods, rather than on evaluating the goods themselves in the absence of markets for goods, services, and benefits; comparative methods, which provide for comparing a natural resource with similar ones already estimated; methods of conditional assessment (sociological), the basis of which is to conduct various kinds of sociological surveys, for example, the concept of willingness to pay and the method of transport and travel costs.

The analysis conducted in this paper determines the advantages and disadvantages of these methods, and the possibilities of their practical application. The most correct available methods are cost-effective, but their adequacy is not absolute. Profitable valuation methods narrow the interpretation of natural resources to a commodity, comparative, and sociological ones, they are not correct and practically unsuitable for performing a cost assessment of the object under study. Other methods are even more unsuitable for determining the sought value because they fundamentally ignore the very essence of the object of valuation. Whereas the essence is that the value of an asset should be determined by the cost (equal to the cost) of ecosystem services that it provides to society during its life cycle; only the costs associated with the provision of environmental services should be considered.

The proposed method of estimating the value of ecosystem assets is based on: the application of the price concept of consumer utility; consideration of the period of the life cycle of the ecosystem asset; estimation of the fair value of ecosystem services as a result of the functioning of the ecosystem asset; discounting of the specified value of ecosystem services, given the rather considerable period of operation of the ecosystem asset; forecasting and calculation of emergencies (ie the risk of not receiving ecosystem services for objective and subjective reasons); consideration of the specific assimilation properties of specific ecosystems.

The method was tested on the example of a separate ecosystem – the poplar alley of Kyiv's Taras Shevchenko Boulevard, the assimilation potential of which was measured along with oxygen-producing services of this ecosystem. The assessment was conducted for trees and the herbaceous tier of poplar alley. The total cost of this ecosystem is set at UAH 3.15 million.

In the future, it is advisable to create a systematic list of methods for assessing ecosystems and ecosystem services, including the assimilation potential of ecosystems, which should indicate the methods that are closest to the economic realities of Ukraine. Rationally selected methods of valuing ecosystem capital should be applied to all territorial communities of districts, oblasts, etc., which would help improve the ownership structure and maintain the balance between man-made load and regenerative potential of ecosystems in terms of ecological and economic development of local communities.

The valuation of an ecosystem asset is performed to determine the economically sound amount of future environmental rent payments, to ensure consistency between the value of ecosystem services and the size of the environmental tax that currently compensates ecosystem services used, and to determine payments for ecosystem services. In other words, the assessment of ecosystem assets should become the basis for substantiating environmental tax rates and the amount of environmental rent payments based on determining the amount of environmental rent.

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Методи вартісного оцінювання екосистемних активів та їх асиміляційних послуг

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Анотація. Актуальною проблемою сучасного світу є деградація екосистем, що потребує кардинально нового підходу до оцінювання і забезпечення подальшого, економічно ефективного, використання їх потенціалу. Однак наразі ще не здійснювалось вартісного оцінювання екосистемних активів (капіталу), які надають асиміляційні та інші, зокрема, киснепродукуючі, послуги територіальним громадам. Обґрунтовано, що за умови визнання екосистемних активів власністю територіальних громад і для надання останнім права розпоряджатися своїм майном (екосистемними активами) проблема вартісного оцінювання таких активів стає першочерговою задачею. Метою статті є порівняльний аналіз наукових підходів щодо вартісного оцінювання екосистемних активів і розробка методу їх оцінки із урахуванням екосистемних послуг, які вони надають протягом свого життєвого циклу територіальним громадам. Для наукової розробки використані як загальнонаукові методи економічних досліджень, так і специфічні. Визначено сутнісні ознаки методів оцінки природно-ресурсного об'єкту, якими є методологія оцінки та фінансово-економічні інструменти, що застосовуються для практичної її реалізації. На базі цього здійснено аналіз і визначено змістовні ознаки методу дисконтування грошових потоків (методу рентної оцінки), витратного, ринкових цін, гедоністичного ціноутворення (цінових переваг), транспортно-шляхових витрат, умовно-опитувальний метод та інші. Доведено, що названі методи не відповідають вимогам вартісно-ринкового оцінювання і не дозволяють здійснити адекватну оцінку асиміляційного потенціалу екосистем. Екосистемний актив повинен розглядатися з точки зору екологічної безпеки, тому й методи оцінювання повинні бути іншими. З урахуванням цього запропоновано найбільш оптимальний метод: вартість екосистемних активів визначається вартістю всього комплексу наданих ними асиміляційних та киснепродукуючих послуг за весь їх життєвий цикл. Авторська методика апробована на прикладі алеї тополь, яка є складовою бульвару Тараса Шевченка, розташованої в місті Києві

Ключові слова: методи оцінки, вартість, об'єкт оцінювання, територіальні громади, тополі, асиміляційні та киснепродукуючі послуги

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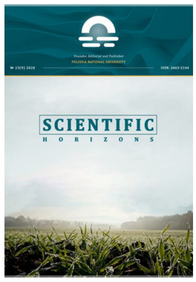

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Empirical Study of Convergent-Divergent Trends in Innovation EU Countries Development

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Abstract. The article is devoted to the problem of disproportionate innovation development in the European Union and the impact of these processes on economic growth. The aim of the work is an empirical study of the unevenness and asymmetry of innovation spending in the EU and analysis of convergent-divergent trends in this area. The results of recent research show a desire to strengthen cooperation in the field of innovation, which changes the situation in a positive direction and proves the signs of convergence of innovation, and they are most pronounced in the least developed regions of Europe. The urgency of solving this scientific problem is that the internal convergence of the European Union in the field of policy to support research, development and innovation is one of the strategic goals of the association. Models based on the concept of convergence have become a methodological tool for determining the asymmetry of development. The study was conducted on the basis of analysis of statistical data of 28 European Union countries for the period 2008-2019. The article presents the results of an empirical analysis of the asymmetry of innovative development of EU countries in terms of research and development. It is established that there is a shift towards increasing the share of R&D expenditures in GDP. Convergent tendencies in terms of development asymmetry, σ-convergence and β-convergence are revealed. The study empirically confirms and theoretically proves that the reduction of differentiation and convergence of countries is manifested in increased funding for innovation in countries lagging behind in these parameters. The practical significance of the results of the study lies in the possibility of their use to assess the effectiveness of innovation policy in the European Union

Keywords: innovation development, R&D expenditures, rapprochement, disproportion, asymmetry, European integration

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INTRODUCTION

Globalisation trends in the world economy determine the innovation processes taking to a whole new level. Globalisation covers all stages of the innovation process – from basic research to the commercialisation of innovation. Close interaction of national innovation potentials, joint research by scientific communities of different countries, implementation of international innovation programs allow to achieve more significant results of innovation activities and open new opportunities in R&D (research and development) field.

The current policy of the European Union economic development, taking into account these trends, provides for the countries unification into an innovation union in which the stimulation of innovation development processes gets to the supranational level. However, the strengthening of integration processes, including in the field of scientific and technical cooperation, often gives rise to the so-called dissociation paradox. The paradox of dissociation is a manifestation of two opposite tendencies coexistence: to the economic space unification, on the one hand, and to its heterogenisation, on the other [1; 2]. The reason for this process is that countries that are close in some parametres tend to unite with each other. However, further expansion of integration associations such as the EU (European Union), the inclusion of national economies with a significant gap in levels of economic development, the state of national innovation systems, the dominance of different technological systems in the economy lead to increased heterogeneity and disintegration. Uneven development of the EU countries in the field of innovation is primarily associated with different amounts of R&D expenditures and the difference in goals and directions of their application.

In order to converge parameters and reduce disparities in the innovation development of the EU member states in 2002, the Council of Europe announced a course to create a single European research area, taking into account the EU enlargement, increasing the share of R&D expenditures in the EU to 3% of GDP (Gross Domestic Product); increasing the financing rate of innovation activities at the expense of private sector; increasing the level of vertical and horizontal coordination of innovation policy [3]. In this context, it is important to study the asymmetry of certain aspects of innovation development of the European Union countries and identify trends in its dynamics (convergent or divergent).

Problems of innovation development of the EU are a topic to study by many scientists. A study of innovation effect on the economic dynamics of European countries, conducted by V. Medeiros, C. Marques, A.R. Galvao, and V. Braga [4] show that gross domestic expenditure on R&D per capita is positively related to economic development indicators. At the same time, the countries of Northern Europe (Finland, the Netherlands, Norway, and Sweden) show better results in terms of innovation and entrepreneurship than the countries of Southern Europe (Spain, Greece, Italy and Portugal). The study of the existence and effectiveness of regional innovation systems in European countries by A. Rodriguez-Poz and R. Crescenzi [5] is aimed at analysing the relationship between investment in research and development, patents, and economic growth. Scientists have obtained results on the existence of intercountry disparities in the creation of new knowledge which affects the rate of economic growth in some regions.

The purpose of the study is an empirical study of the inequality and asymmetry of innovation expenditures in the EU countries and analysis of convergent-divergent trends in this area.

LITERATURE REVIEW

Internal convergence of the European Union in the field of policy to support research, development and innovation is one of the strategic goals of the association. This question has been of concern to scientists for a long time. Moreover, the results of comparing the EU countries in terms of innovation due to external and internal factors are various in different periods of the study. The study of the processes of innovation convergence in European countries by analysing the relative changes in the innovation situation at the beginning of the 21st century [6] showed that there were no significant changes in the process of convergence in the innovation sector. This was due to progress in a number of countries with a high level of innovation while countries with relatively worse starting positions did not improve significantly. In particular, these are the countries that joined the European Union as a result of its enlargement. Further research [7] points to the convergence of the innovation potential of the EU member states in 2004-2008, but under the influence of the economic crisis of 2008, the differences intensified. Countries with lower levels of development have suffered more from the crisis, so the disparities in innovation opportunities have increased, which required the development of new innovation policies. It was assumed that the implementation of such a policy should contribute to convergence in the level of innovation development. However, the results of the analysis conducted [8] by the σ- and β-convergence method showed significant differences in the innovation potential between the highly innovative northern and less developed southern part of the European Union. According to researchers, this fact significantly limits economic growth. The study of the development asymmetry of certain aspects of innovation potential, in particular, R&D expenditure in terms of three sectors – government, business and higher education – has shown increased convergence in this area [9]. It was established that the main driver of convergence for the EU-15 was the business sector and for the EU-13 – government expenditure. However, these trends have worsened as a result of the financial and economic crisis.

The study of M. Voinarenko [10] shows a significant level of differentiation of factors and results of regional innovation in the countries of the European Union. Leaders of technological development at the regional level in almost all sectors of high technology are the most advanced economies (Germany, Britain, France, Sweden, the Netherlands). The revealed positive dynamics of convergence as a result of reducing the gap between peripheral regions and leaders of innovative development is characterised as unsatisfactory which requires further improvement of regional and scientific and technical policy of the EU.

Using the data of the Framework Program of the European Union, E. Erdil, I. Akçomak, U. Cetinkaya [11] found that the desire to strengthen cooperation in the innovation sphere changes the dynamics towards the positive direction and proved the signs of innovation convergence, and they are most pronounced in the least developed regions of Europe.

P. Bednář and M. Halásková [12] in their research conclude that, despite the fact that Western Europe is a world leader in innovation among OECD countries, the distribution of innovation development indicators is not uniform across regions. Scientists note the existence of a general spatial divergence in innovation efficiency and R&D expenditures along with local convergent trends at the level of several regions.

W. Baumol, R. Nelson, and E. Wolff concluded that some countries may form a kind of dynamic "convergence clubs" based on the implementation of common policies. According to them, such a "club" includes industrialised countries and countries with transformational economies only which have the necessary potential for convergence [13].

Analysis of the convergence of innovation activity in European countries in terms of regional R&D expenditure, conducted by C. Barrios, E. Flores, M. Martínez [14] in the period of 2002-2012, confirmed the hypothesis of convergence in the form of "innovation clubs" creation. Club convergence envisages that different economies do not have a common growth trajectory for all, but a common among the group (cluster) close in terms of entry level of development and other characteristics. Thus, cluster (club) convergence envisages the grouping of countries into homogeneous clusters within which the rate of convergence significantly exceeds the corresponding figure for the entire sample [15].

Asymmetry of European countries innovation development is also noted in the studies of K. Koschatzky, T. Stahlecker, H. Kroll, M. Graffenberger [16]. A. Biurrun [17] explains the growth of internal inequality by the world economy turbulence and the consequences of the crisis in developed countries. The scientist proves that the positive general evolution of reducing inequality and technological progress in Europe is not a linear process. As a result of this, the relevance of structural and institutional transformations in the European region is growing.

Complex and unresolved problem of disproportionate innovation development in the European Union and the impact of these processes on economic growth indicators require additional research in this area.

MATERIALS AND METHODS

The study of convergence of innovation activity in European countries in terms of regional R&D expenditure in the article is carried out in the following logical sequence: study of the dynamics and structure of R&D expenditure in the EU countries; analysis of asymmetry indicators of innovation development; σ- and β-convergence evaluation; formulation of conclusions on the existence of convergent-divergent relations between the EU countries. The asymmetry of economic systems development is considered as inequality and disproportion and its increase or decrease is explained by divergence and convergence of development, respectively. The founders of the convergence theory, American scientists R. Barro and X. Sala-i-Martin [18] formulated two convergence concepts:

1) the concept of σ-convergence is observed when the variance of development indicators tends to decrease, ie there is a convergence in time of the levels of development of economic entities;

2) the concept of β-convergence occurs when less developed territories have higher rates of economic growth than more developed ones as a result of which in the long run there is a level convergence of economic development of territories.

These concepts are not equivalent as β-convergence indicates the existence of a long-term tendency to converge levels of economic development, while random shocks can lead to short-term growth of interregional differences and, consequently, σ-convergence [19].

The methodological approach to the study of interregional and intercountry disparities involves the use of appropriate mathematical tools. To determine the asymmetry of development in the study, a statistical apparatus using such indicators as the magnitude of variation, the coefficient of variation, the magnitude of regional disparities, standard deviation, oscillation, asymmetry and excess. The analysis of convergent-divergent dynamics (σ-convergence) was performed on the basis of variation index calculation.

The variation coefficient for determining σ-convergence (quantitative homogeneity of a set of objects) was determined by the formula:

$$K_{var} = \frac{\sigma}{\bar{y}} = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \bar{y})^2}}{\bar{y}} \quad (1)$$

where y_i is the level of R&D expenditure in country i; $(\bar{y})$ – average level per capita; n – number of countries; σ – standard deviation of y values.

This indicator is considered both in statics to analyse the differences that occur at a particular time and in dynamics – to determine changes in the characteristics of a set of objects. The increase in the indicator value in the dynamics indicates a general divergence trend among countries [15].

β-convergence characterises the situation when countries with a low level of the studied indicator have higher rates of economic growth than countries with its low level. Thus, in the long run there is an equalisation of levels of economic development [20].

To determine β-convergence, an econometric apparatus was used the application of which is based on the construction of regression models of expenditure and rate indicators. The study was conducted on the basis of analysis of statistical data analysis of 28 countries of the European Union for the period of 2008-2019.

RESULTS AND DISCUSSION

The European Union continues to develop a knowledge-based economy. The impetus to launch the innovation development strategy was the lag in the EU's economic growth from the United States which appeared in the 1990s. To a large extent, these trends were due to the insufficiently rapid technological development of the European Union, low rates of innovation, unsatisfactory level of funding in this area. As a result of the EU enlargement, the new members introduced negative characteristics of their own innovation systems, increased the disproportion of scientific and technological development. In view of this, overcoming differences and inequalities in the implementation of innovation processes and the realisation of scientific and technological potential of European countries has become one of the important tasks in the formation of integration cooperation.

The national innovation policy is most vividly characterised by the volume and financing directions of the scientific and technical sphere. Forms of research and development funding in the European Union differ depending on the nature of innovation: basic research and projects of national importance are funded entirely from the state budget, applied research – on a different basis. Research institutions conducting basic research receive basic financial support as institutions. Currently, 2.14% of GDP is spent on R&D in the EU, while in the US – 2.64%, Japan – 3.04%, with the share of the private sector in innovation financing in the US is 68.2%, in the EU – 66.4% [21].

Recently, there have been changes in the implementation of the innovation development strategy. Some countries have increased R&D expenditures or refused to reduce them which in general had a positive effect on the dynamics of innovation expenditures in the whole association (Fig. 1).

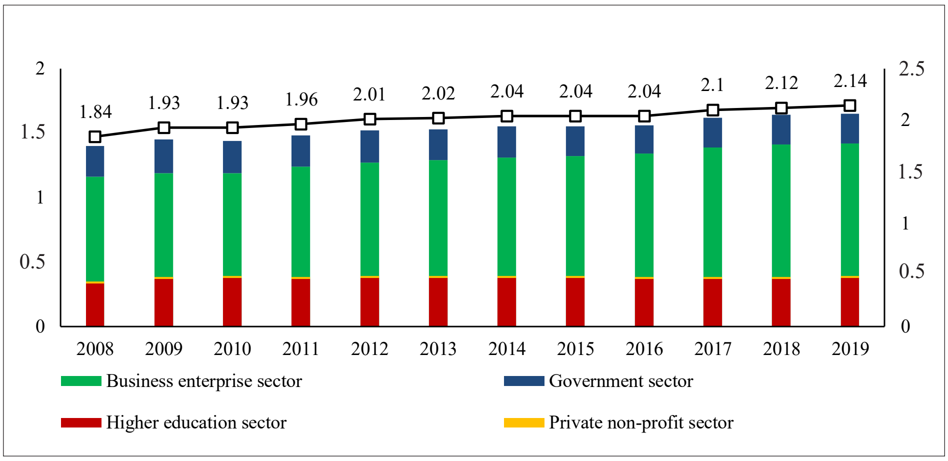

***Figure 1**. Dynamics and structure of R&D expenditures in the EU-28 countries in 2008-2019, % of GDP*
***Source**: developed by the authors based on Eurostat Database, 2020 [21]*

The shift towards increasing the share of R&D expenditures in GDP was due to the consistent implementation of the European Economic Development Strategy "Europe 2020: a strategy for smart, sustainable and inclusive growth" which provided for high intellectual, sustainable and inclusive economic growth. This strategy contained a targeted initiative "Innovation Union" among the goals of which can be identified: increasing the innovation efficiency within the innovation association, as well as increasing the competitiveness and protection of the interests of innovation; integrating countries should implement a national innovation policy that is in line with the common innovation policy developed at the supranational level during integration [22]. The implementation of programs to stimulate innovation was also aimed at leveling the interregional characteristics of innovation development. The most common methods of regional development disparities evaluation involve the use of two methods: determining the discrepancy between the most prosperous and most problematic regions (scope of regional disparities) and estimate of the deviation range of regional indicators relative to their average value (using the variation coefficient) [23]. More detailed system of indicators is considered to be necessarily used for analysis. The dynamics study of these indicators will determine the type of innovation development:

asymmetric, harmonious and neutral. In this case, asymmetric (disharmonious) is a type of regional development for a certain period during which the regions that have a relative advantage of one or another indicator at the beginning of the period, then increase it, and regions that have a relative lag, increase it. In contrast, symmetrical (harmonious) is a type of regional development in which the gap in the level of regional indicators is reducing. With the neutral type of development, the ratio of regional indicators during the period remains unchanged [24].

An empirical study based on Eurostat data for 2008-2021 revealed the effectiveness of the policy to reduce asymmetry among the EU countries in terms of expenditures on research and development (Table 1).

***Table 1**. Indicator's dynamics of innovation development asymmetry in the EU countries in 2008-2019*

Time period (year)	Maximum	Minimum	Average value	Scope of variation	Coefficient of non-uniformity	Scope of regional disparities	Mean linear deviation	Mean square deviation	Dispersion	Coefficient of oscillation,%	Coefficient of variation,%	Coefficient of asymmetry	Excess
2008	3.54	0.39	1.43	3.15	9.08	2.2	0.69	0.88	0.77	219.79	61.22	0.95	0.26
2009	3.73	0.44	1.50	3.29	8.48	2.2	0.74	0.92	0.85	219.80	61.56	0.83	0.003
2010	3.71	0.44	1.51	3.27	8.43	2.17	0.71	0.89	0.79	216.71	58.91	0.79	-0.13
2011	3.62	0.45	1.58	3.17	8.04	2.01	0.75	0.89	0.8	201.18	56.71	0.61	-0.64
2012	3.40	0.44	1.60	2.96	7.73	1.85	0.76	0.89	0.79	184.59	55.39	0.57	-0.9
2013	3.27	0.39	1.61	2.88	8.38	1.79	0.75	0.88	0.77	178.80	54.49	0.52	-0.96
2014	3.15	0.38	1.60	2.77	8.29	1.73	0.73	0.85	0.72	173.05	53.14	0.55	-0.98
2015	3.22	0.48	1.61	2.74	6.71	1.7	0.72	0.83	0.69	170.11	51.58	0.62	-0.86
2016	3.25	0.44	1.55	2.81	7.39	1.82	0.74	0.86	0.75	181.71	55.89	0.68	-0.79
2017	3.36	0.50	1.58	2.86	6.72	1.81	0.72	0.85	0.73	181.26	54.13	0.68	-0.72
2018	3.32	0.50	1.62	2.82	6.64	1.74	0.72	0.85	0.72	173.81	52.16	0.66	-0.75
2019	3.40	0.48	1.65	2.92	7.08	1.77	0.73	0.87	0.75	176.51	52.49	0.62	-0.78
2019 to 2008, %	96.1	123.1	115.4	92.7	78.0	80.5	105.8	98.9	97.4	80.3	85.7	65.3	96.1

***Source**: developed by the authors based on Eurostat Database, 2020 [21]*

The obtained results of the spatial-dynamic estimate of the coefficients of uneven development confirm the disproportion presence. There is a tendency to reduce the asymmetry, though the differences remain significant. The value of variation coefficient – one of the most significant asymmetry indicators is quite high and exceeds 50% throughout the 12-year period. This indicates the presence of significant heterogeneity of the population and high variation level. The analysis of the asymmetry coefficient dynamics showed that the distribution of countries by the level of R&D expenditures is characterised by right-sided asymmetry (the indicator is positive), so most countries have a value of the studied parameter below average. Negative value of excess rate throughout the study period means that there is no so-called "core" which slightly varies, i.e., the countries concentration around the average value is insignificant.

Dynamics of absolute variation indicators – average linear deviation, standard deviation, variation magnitude have a slight tendency to decrease. The conclusion to the significant degree of variation of the studied parameter during the whole period confirms the value of the oscillation coefficient which varied in the range of 219.79-176.51 but the amplitude of oscillations relative to the average value decreases.

The analysis results give grounds to hypothesise the existence of convergent trends in the studied characteristics of innovation development. To confirm this conclusion, σ-convergence which is defined as the decrease over time of the variation indicator (inequality, differentiation) of development of regions (countries), is going to be estimated. In addition to the variation indicator, such an indicator as the standard deviation is going to be used (Fig. 2).

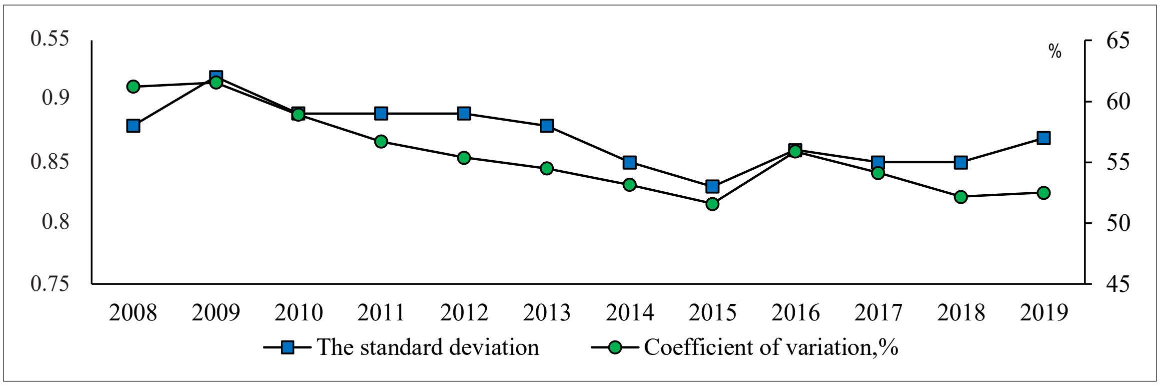

***Figure 2**. Intercountry σ-convergence in terms of R&D expenditures in the EU countries in 2008-2019*
***Source**: developed by the authors based on Eurostat Database, 2020 [21]*

The dynamics of both analysed indicators allows to draw conclusions about the tendency of gradual increase in convergence but the variation indicator is considered to be more informative because it does not depend on the dimension and scale of variables. The polarisation of the EU countries due to the implementation of a consistent innovation policy is declining as evidenced by the reduction of the variation coefficient by 8.73% points.

However, the reduction of regional development asymetry cannot be unambiguously interpreted as a positive shift. It may be caused by the deterioration of indicators in highly developed countries, thereby leading to approximation the indicators of countries with low levels of research parameters. Such smoothing is undesired for the development of the integration association as a whole. In order to formulate final conclusions, it is necessary to establish the presence of β-convergence for which the econometric apparatus was used and a regression model was built in which the dependent variable is the growth rate of innovation funding, and independent – entry level indicator. This will allow evaluating the dynamics of differentiation based on the pace of development of individual EU countries (study period – 12 years) (Fig. 3).

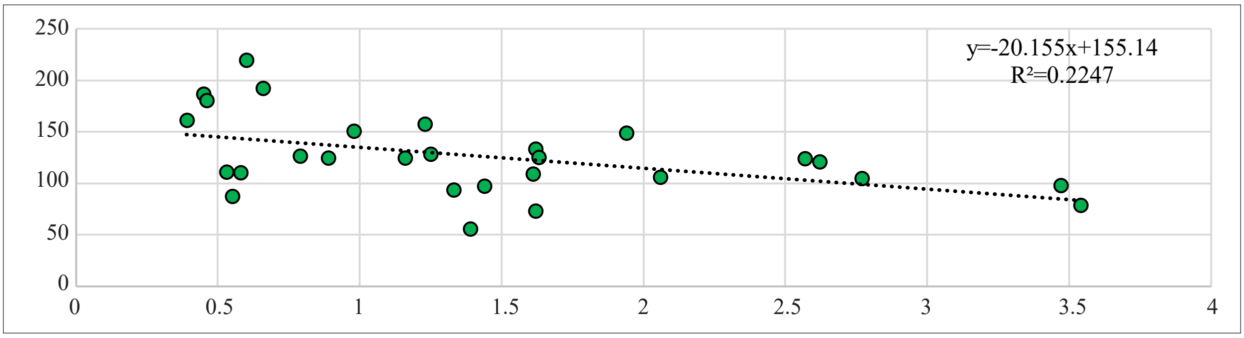

***Figure 3**. Absolute β-convergence of R&D expenditures dynamics in the EU in 2008-2019*
***Sources**: developed by the authors based on Eurostat Database, 2020 [21]*

According to the convergence hypothesis, if a country (region) economy is initially away from the position of stable equilibrium, its growth rate will be higher than in the economy that is closer to it [16]. The hypothesis of β-convergence is confirmed by the negative regression coefficient, with a positive value a divergence is observed. The statistical significance of the regression coefficients of the constructed model is confirmed, Fisher's criterion is actually larger than the tabular criterion (F-criterion$_{factual}$ = 7.5348, F-criterion$_{tabular}$ (1.26) = 4.23). The negative value of the regression equation coefficient (-20,155) allows to conclude that countries lagging in terms of innovation financing have higher rates of increasing innovation expenditures which in the long run implies a convergence of the innovation development level of countries within the EU.

CONCLUSIONS

In summary, it should be noted that the unevenness and disproportion of regional parameters of innovation development has a significant impact on economy efficiency as differences lead to conflicts between regions (countries). The results of the conducted study of the innovation expenditures asymmetry and the study of convergent-divergent relations between the countries of the European Union to summarize that the countries are converging.

Convergent trends are observed in terms of development asymmetry and σ-convergence. The hypothesis of the existence of absolute β-convergence of the dynamics of R&D expenditures in the EU countries was confirmed by the results of building a regression model of the dependence of entry and tempo indicators. The catching-up effect is manifested in the increase of innovation financing indicators in the countries lagging in these parameters. The tendency to reduce differentiation and rapprochement of countries in this context indicates the existence of a coherent innovation policy which proves its effectiveness in practice. In the long run, adherence to such a vector of development will allow the European Union to gain the status of a leader in research and innovation and ensure high rates of economic growth on an innovation basis.

Funding for R&D expenditure in the European Union will undoubtedly be affected by the UK's secession from the association. This, in turn, may change the trends identified as a result of the study. The nature analysis of this effect will determine the directions for further research.

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Емпіричне дослідження конвергентно-дивергентних тенденцій інноваційного розвитку країн ЄС

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Анотація. Стаття присвячена розгляду проблеми диспропорційності інноваційного розвитку в країнах Європейського Союзу та впливу даних процесів на показники економічного зростання. Метою роботи є емпіричне дослідження нерівномірності та асиметричності здійснення інноваційних витрат у країнах ЄС та аналіз конвергентно-дивергентних тенденцій у цій сфері. Результати останніх досліджень виявляють прагнення до посилення співпраці в інноваційній сфері, що змінює ситуацію в позитивному напрямку та доводять наявність ознак конвергенції інновацій, причому найбільше вони проявляються в найменш розвинених регіонах Європи. Актуальність вирішення даної наукової проблеми полягає в тому, що внутрішнє зближення країн Європейського Союзу у сфері політики підтримки досліджень, розробок та інновацій є однією зі стратегічних цілей асоціації. Методичним інструментарієм для визначення асиметричності розвитку стали моделі, які засновані на концепції конвергенції. Дослідження проводилось на основі аналізу статистичних даних 28 країн Європейського Союзу за часовий період 2008–2019 рр. У статті представлено результати емпіричного аналізу асиметричності інноваційного розвитку країн ЄС за показником витрат на дослідження та розробки. Встановлено, що відбувається зрушення в бік збільшення частки витрат на НДДКР у ВВП. Виявлено конвергентні тенденції за показниками асиметричності розвитку, σ-конвергенції та β-конвергенції. Дослідження емпірично підтверджує та теоретично доводить, що скорочення диференціації та зближення країн проявляється в підвищенні показників фінансування інновацій в країнах, що відстають за цими параметрами. Практичне значення результатів проведеного дослідження полягає у можливості їх використання для оцінки дієвості інноваційної політики в країнах Європейського Союзу

Ключові слова: інноваційний розвиток, витрати на НДДКР, зближення, диспропорційність, асиметрія, євроінтеграція

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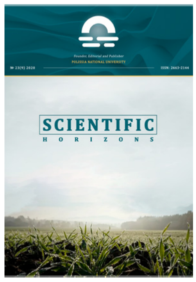

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Sustainable Economic Development of Ukraine through the Agro-Sector Growth

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Abstract. The urgency of the research forms the complex of agricultural sector productivity problems, employment level reduction problems, low wages level, and land productivity reduction. The article is devoted to searching for agrarian sector development directions, which promotes steady economic development based on identified problems. The research aims to develop proposals for solving the main agro-sector problems, which contribute to sustainable economic growth. The article develops the methodology of analysis and uses statistical analysis, probability theory, and generally scientific methods of knowledge. The study brings evidence of the leading hypotheses proposed and the table in the "problem-solution" format. It is proved that the agriculture of Ukraine has a heavy influence on the economy and employment. Agriculture is characterised by instability, low wages, and increased land for growing plant products, while livestock farming is in decline. The following methods are used to solve the problems: market transformation on finished food-product, diversification of production, de-shadowing of the sector, agriculture automation increase, land reform controlling, stimulating farming state programmes. The originality of this study lies in the authors' sustainable development analysis methodology through the agricultural sector growth. The practical significance of the study lies in the possibility of implementing recommendations at the macro- and microeconomic levels. A further research field forms the automation processes in agriculture available to small and medium-sized farmers

Keywords: agriculture, automation, employment, land reform, export

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INTRODUCTION

For decades, Ukraine has been a key supplier of agro-industrial raw materials worldwide. But despite its enormous agro-industrial potential, Ukraine is not on the course to sustainable development. Moreover, for several decades Ukraine has turned from an industrial country into a backward one [1]. In these conditions, the sustainable development idea remains more an ideology than a research-to-practice concept. The Ukrainian literature compares sustainable economic development to the "philosopher's stone" that economists, country leaders, and citizens strive for [2]. The sustainable development strategy for today exists, it is formally developed, and the national policy makes decisions strives to implement it. The sustainable development concept is formed on three pillars: ecology, economy, employment [3-5]. Admittedly, the agricultural sector plays an indispensable role in meeting humanity's essential need – food. Still, it is also the component of strategic development. But beyond that, it is also crucial in sustainable economic development because it is a critical element in the economy, labour market, and resource potential.

According to the latest United Nations (UN) data, over the next 30 years, the world population will grow from the current 7.3 to 9.7 billion people, while food consumption on the planet, according to various estimates [6], will increase by 60-100%. In such circumstances, Ukraine may become a key player in the food supply. Being Europe's second-largest country, Ukraine accumulates a tenth of the world's black soil reserves, and 72.1% of the area consists of agricultural land. Agriculture now generates about 11% of Ukraine's GDP (gross domestic product) and about 17% of jobs, and farming exports nearly tripled between 2010 and 2020, reaching about 59% of the country's total exports [7]. Ukraine is currently one of the largest exporters of grain crops globally. However, these apparent successes trap Ukrainian farmers, who use only cheap raw materials to produce inefficiently. During 2015-2020, Ukraine's agricultural sector grew thanks to a 1.9-fold increase in sunflower production, a 1.7-fold increase in grains and legumes. But despite this, according to Food and Agriculture Organisation of the United Nations [8], Ukraine's land-use efficiency in terms of average grain crop yields is half what the United States of America and Western European countries have.

As a result, Ukrainian agrarians receive twice or thrice less revenue per hectare than their Western colleagues in terms of money. The main reasons are weak production technology and low added value of raw materials. Thus, unproductive agriculture, outdated technologies, the decline in employment, and land fertility do not allow the agricultural sector to become an essential component of sustainable economic development, which forms the main problem under study. Therefore, the relevance of this paper is to find the development vectors of the agro-sector, which contributes to the sustainable economic development of Ukraine. Considering the main determinants of sustainable economic development are economic infrastructure, population welfare, and ecology, the agricultural sector also affects these components of sustainable development.

Thus, *the purpose of this study* is to develop proposals to solve the primary agricultural sector problems that contribute to sustainable economic development.

To achieve the purpose, it is necessary to solve the following *tasks*: to justify the dependence of the economy's sustainable development on the agricultural sector's development; to identify the main agricultural development issues; to determine the agricultural sector's importance in employing the population; to determine the capital investment in technology for the development of the agricultural sector; to investigate the current state of agricultural land in Ukraine; to develop and substantiate the main development vectors of the agro-industrial sector to increase economic sustainability.

LITERATURE REVIEW

The sustainable development issues in Ukraine have been the subject of research and discussion by scientists, politicians, practitioners, and public members since 1992. But these studies and discussions consider various aspects of this complex issue [2]. According to most modern researchers, innovation and technological support are the main drivers of sustainable development [4; 9; 10]. Such a development strategy is also applied to the agricultural sector, namely the agricultural industry in Azerbaijan [11]. In addition, critical strategic vectors for the country's sustainable development are land fertility preservation [12] and effective management. To date, the food market in Ukraine is unstable, and the agricultural business environment is unfavourable for sustainable development, especially in the livestock industry [13; 14]. Under such conditions, most Ukrainian researchers, scientists, and experts believe that the agricultural sector requires structural changes. Therewith, there are three sustainable development models of agro-industry in world practices, which partly take place in Ukraine.

The first model is the Japanese and Chinese, under which a farmer works on small plots of land (up to 2 ha). Such farms are similar in Ukraine. Therefore, they can be considered as small businesses. The second model, the European one, is built on 10-150 hectares farms. The analogue of such formations in Ukraine is farming. The third model, American, where the size of farms is considerable, is in the range of 1-2 thousand hectares. Agricultural holdings represent such farms in Ukraine, and they cultivate more than half of the agricultural land [15]. The main issue of agricultural development in Ukraine is that being the primary industry that provides jobs for the rural population, it is necessary to stimulate the importance of the first two models. But it is also essential to stimulate the third model, which can introduce expensive technologies of agribusiness automation, increasing agricultural production volume. Moreover, land reform, which Ukraine passed in 2021, while formally aimed at developing small and medium-sized farms, constitutes a regulatory framework for developing agricultural holding. In turn, big businesses will push out small and medium businesses, which may become the basis not for sustainable economic development but for a solid crisis.

Notably, the model of economic formations alone will not provide the growth of economic indicators, social development and will not improve the environmental situation in the country. It requires a comprehensive application of changes in the development of competitive agrarian production so that the agricultural sector can provide state food security and good living standards for the population [16]. Therewith, it is impossible to solve the problem with land reform alone; it is necessary to change both the agricultural industry management concept and the national policy to support agribusiness. Researchers have sufficiently investigated the issue [13; 17; 18], considered individual agricultural industry problems. But the general problem of agro-industrial development in the sustainable economic development context is understudied, which forms the originality of this study. For the first time, the study developed a methodology for the sustainable development analysis, which is based on four determinants: economic, social, environmental, and technological.

MATERIALS AND METHODS

The empirical analysis of this study is carried out based on the State Statistics Service of Ukraine statistical data [7]. In addition, to highlight the main problems, many expert opinions on the main problems and the methods of their solution were investigated. Finally, the application of general scientific cognitive methods allows confirming the united development concept of agriculture based on the current state and problems under study. The development vectors are chosen considering sustainable economic growth, which balances technical, economic, social, and ecological development. Through the grouping of information, data for the current state analysis of the agro-industrial sector and its importance in economic development are obtained. The synthesis of facts and information published by agricultural experts allows identifying and summarising the main problems and finding alternative solutions in the scientific literature. The inductive method is used to find problems based on the analysis results, and the deductive way – to find solutions to these problems. The study is based on four hypotheses, which form the main tasks and objectives as follows:

– hypothesis 1: agriculture has considerable importance in the economy and is a sustainable development tool;

– hypothesis 2: the unsustainable development of agriculture is determined by the asynchrony of agricultural production;

– hypothesis 3: employment in the agricultural sector is decisive for sustainable economic development;

– hypothesis 4: the capital investment growth in agriculture contributes to the productivity growth of the sector.

To prove these hypotheses, the authors apply the methodology developed based on the strategy for Ukraine's sustainable development until 2030 [19] and the concepts of sustainable development based on economic, social, and environmental development. But given the intensifying interest in the technological component of the agro-sector, authors of this paper allocate technology as the fourth important determinant, which stands apart from the economy because it affects not only the production but also the employment structure and the environment. Statistical and mathematical analysis methods are used to conduct empirical research. Horizontal and vertical analysis allows determining the dynamics and structures of agro-industrial development. Regression analysis (particularly the Pearson coefficient) defines the relationship between the indicators and demonstrates which factors influence the research object. Its high value, more than 0.9, indicates the close relationship, which allows concluding on the mutual influence of certain phenomena on each other. The negative value indicates a direct proportional impact of indicators; the value less than 0.3 suggests that the indicators are practically unrelated. The method of probability theory (the standard deviation) is used to analyse the synchronicity of agroindustrial production. It shows the average deviation of indicators for a certain period compared to the average indicator for the period under study. The variation coefficient was applied to demonstrate this value not in monetary values but as a percentage.

RESULTS AND DISCUSSION

In the empirical study of sustainable economic development, authors will determine the agricultural production value in the total country's added value. According to the State Statistics Service of Ukraine data [7], the total value added in 2020 was 145.5 bn, while the agricultural production added value was 15.7 bn (Table 1).

***Table 1**. Added value of agricultural production in Ukraine*

Indicators	2015	2017	2018	2019	2020	Pearson's coefficient
Gross value added, $mln	74,752	91,192	108,168	144,372	145,546	0.99
Gross value added of agriculture, $mln	10,611	10,993	12,939	15,045	15,726	
% of gross value added	14.2	12.1	12.0	10.4	10.8	

***Note**: The statistics data are converted into dollars using the dollar exchange rate as of January 1 of the understudy year*
***Source**: Ministry of Finance of Ukraine (2021) [20]; State Statistics Service of Ukraine (2021) [7]*

According to Table 1, the agricultural production share in the economy has decreased by 3.4% over the last five years, which is a rather considerable indicator, demonstrating a gradual loss of agricultural importance in the economy. However, in 2019 there was a rapid increase in value added – by 33%. Therewith, the increase in the agricultural production value was only 16%, which indicates the asynchronous development of agriculture and the economy, and the activation of other economic sectors in 2019. But in 2020, value-added growth across all industries was 0.8%, while the agribusiness sector grew by 4.5%. Moreover, the Pearson coefficient, which demonstrates the close relationship between agribusiness and the economy, is quite strong – 0.99. Thus, the hypothesis can be confirmed that even despite the instability of the agro-industrial sector, it is still an essential component of Ukraine's sustainable development. But the agricultural industry's importance in the country's GDP gradually gives way to other economic sectors. Here authors will consider the reasons for the uneven agricultural production. For this, one should analyse the agrarian production structure and calculate the average statistical deviation and the coefficient of variation, which demonstrate the production uniformity for five years (Table 2).

***Table 2**. Agricultural production structure of Ukraine*

Indicator	2015	2017	2018	2019	2020	Standard deviation, mln	Coefficient of variation, %
Plant growing, $mln	20,045	17,397	18,973	22,730	19,165	1,963	10
Cereals and legumes, $mln	8,557	7,197	8,087	10,115	8,412	1,059	12
Technical crops, $mln	6,605	6,055	6,831	8,221	6,574	814	12
Potatoes, vegetable, and melon food, $mln	3,422	2,895	2,900	3,281	3,193	235	7
Fruit and berry crops, grapes, $mln	655	517	614	615	543	57	10
Fodder crops, $mln	447	347	347	364	329	46	13
Other crop products, $mln	359	386	195	135	114	127	53
Livestock, $mln	6,364	5,084	5,088	6,003	5,617	563	10
Farm animals (breeding), $mln	3,104	2,529	2,602	3,129	2,972	283	10
Milk, $mln	2,094	1,660	1,606	1,813	1,668	198	11
Eggs, $mln	863	653	671	817	760	91	12
Wool, $mln	2	2	2	2	2	0	18
Other livestock products, $mln	300	240	207	242	216	37	15

***Note**: The statistics data are converted into dollars using the dollar exchange rate as of January 1 of the understudy year*
***Source**: [7; 19]*

According to Table 2, it can be seen that plant products have an advantage in agriculture. As of the year, plant products form 77.3% of all agricultural production. In its turn, the most considerable indicators are grain and leguminous plants production – 34% of total farm production, technical crops – 27%, potatoes, and vegetables – 13%. Among livestock products, meat production prevails – 12%, dairy products – 7%. The dynamics of all types of production characterised by instability. The highest instability level is in wool production (the variation coefficient is 18%), feed crops – 13%, grains, industrial crops – 12%, eggs – 12%. Since grain production and technical crops are essential in agriculture, it can be stated that the deviation from the average of 12% is quite a considerable factor, which determines the agricultural production asynchrony. But the particular instability of the agro-industrial sector can be determined not by production but by the export of products. Therefore, the export dynamics of agricultural products can be compared with the general export indicators in the country as follows (Table 3).

***Table 3**. Agricultural exports*

Indicators	2015	2017	2018	2019	2020
Export, $mln	14,563	17,757	18,612	22,144	22,179
Agriculture export, $mln	8,795	10,324	11,097	14,192	13,071
Livestock products, $mln	823	1,109	1,211	1,277	1,188
Crop production, $mln	7,971	9,216	9,886	12,915	11,883
% of livestock exports	5.7	6.2	6.5	5.8	5.4
% of crop exports	54.7	51.9	53.1	58.3	53.6
% agriculture exports	60.4	58.1	59.6	64.1	58.9

***Note**: The statistics data are converted into dollars using the dollar exchange rate as of January 1 of the year under study*
***Source**: [7; 19]*

Table 3 demonstrates that vegetation products dominate exports. As of 2020, $11.8 billion of plant products were exported, and 2019 was more productive as the value was $12.9 billion. Livestock products exports account for 5.4% of total exports, and plant products – 53.6%. Overall, agribusiness exports account for 58.9% of total exports. But this indicator is not characterised by stability, which is clearly presented in Figure 1.

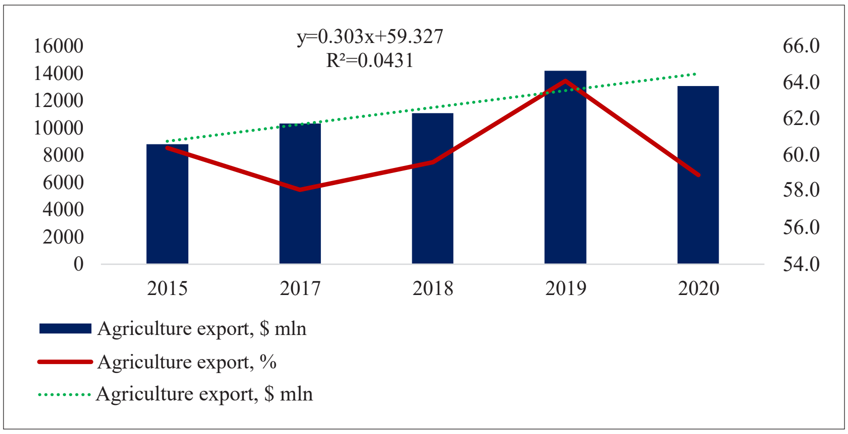

Figure 1. *Agricultural export dynamics and its share in total export in Ukraine*

Figure 1 demonstrates that the approximation coefficient is 0.04, which indicates a severe instability affecting the total export indicator and, as a result, the country's economic development. Thus, the hypothesis that the asynchrony of agricultural product supply considerably impacts the economy can be confirmed. Still, a greater level of asynchrony is recorded in exports rather than in production, which is associated with the competitive market features. Sustainable economic development is a concept that determines several components, not only the development of the economy. In particular, an essential sustainable development element is the population's well-being, which is expressed by the possibility of having a stable job and getting a high wage. Below the study considers these indicators in Table 4.

Table 4. *Employment in agriculture in Ukraine*

Indicators	2015	2017	2018	2019	2020	Pearson's coefficient
Employed population, thousand people	16,443.2	16,156.4	16,360.9	16,578.3	15,915.3	0.92
Employed in agriculture, thousand people	2,870.6	2,860.7	2,937.6	3,010.4	2,721.2	
Employees, thousand people	5,930	5,844	599.5	6,369.6	6,213.7	-0.14
Employees in agriculture, thousand people	569.4	558.1	545.7	535	499.9	
% of employment in agriculture	17.5	17.7	18.0	18.2	17.1	
% of employed workers in agriculture	9.6	9.5	91.0	8.4	8.0	

Source: *[7]*

The Table 4 demonstrates that agriculture employs 17.1% of the country's population, which is quite a high indicator, confirming this industry's importance for population employment. In particular, it is essential for rural employment, which comprises entrepreneurs and owners of the agricultural business. Importance of the hired employees is much less in the employment rate of hired employees – 8%. Employment dynamics analysis indicates an uneven performance; in particular, the highest number of employed people was in 2019 – 3 million people, and in 2020 – about 9% of people lost their jobs. In general, however, the decline in employment in agriculture is logical, as the automation level of agricultural processes increases every year. The high correlation level between total employment and employment in agriculture at the level of 0.92 confirms the sector's importance in employment, thereby supporting Hypothesis 3. Present-day agriculture in Ukraine is not an economic sector that can provide a sufficient wage level. The average monthly wage in the agricultural sector was $469.3 in 2020 (Table 5). However, in 5 years, the wages level in agriculture increased 2.5 times, which influenced the populations interest towards work in this industry.

Table 5. Average wages in agriculture in Ukraine

Indicators	2015	2017	2018	2019	2020
Average monthly salary, $	185.6	257.4	317.7	442.9	469.3
Average monthly salary in agriculture, $	146.4	219.5	270.9	373.7	395.0
% of average wages in agriculture	78.9	85.3	85.2	84.4	84.2

Source: *[7; 19]*

According to 2020 data, the average agricultural wage of people is 84.2% of the national average wage. Meanwhile, the peak of wage growth in agriculture was observed in 2017-2018, after which the wage level in agriculture declined compared to other economic sectors. At present, agriculture automation is considered the cornerstone of its future development, as lower labour costs lead to lower production costs, which allows signing more export contracts (Table 6).

Table 6. Capital investments in agriculture in Ukraine

Indicators	2015	2017	2018	2019	2020	Pearson's coefficient
Total capital investment, $mln	12,085	16,249	20,743	26,328	20,575	0.79
Capital investments in agriculture, $mln	1,334	2,328	2,369	2,495	2,052	
% of capital investment in agriculture	11.0	14.3	11.4	9.5	10.0	

Source: *[7; 19]*

Table 6 demonstrates that $2 billion was invested in agriculture in 2020, accounting for 10% of all capital investment in the country. However, the investment indicator in agriculture has an unstable trend; in particular, capital investment in the industry is disproportionate to production, as indicated in Figure 2.

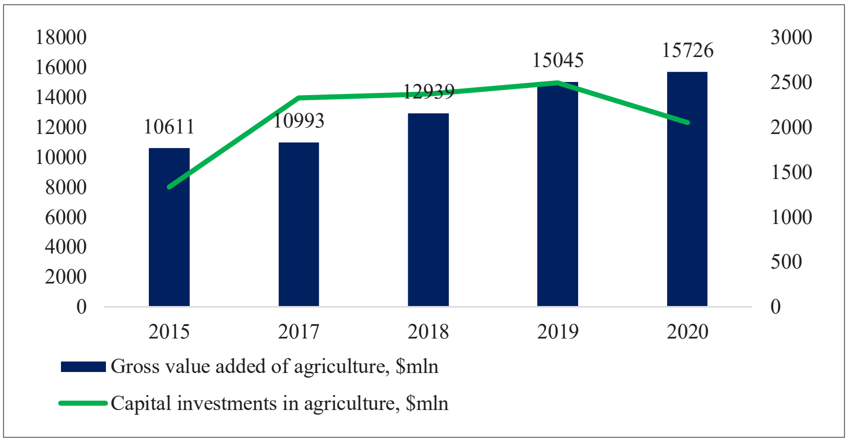

Figure 2*. Comparison of capital investments in agriculture and its production*

The Pearson coefficient for these indicators is 0.47. Thus, the hypothesis that capital investment increases agricultural productivity is not confirmed. It is because capital renewal occurs through the purchase of machinery, which does not affect the production volume, but rather reduces the production cost. The environmental component is an essential part of sustainable development. Its main task is to form a national policy that will ensure the use of the country's resources in the long term (Table 7).

Table 7. Agricultural land components of Ukraine

Indicators	2015	2016	2017	2018	2019
Agricultural land, thousand hectares	41,507.9	41,504.9	41,489.3	41,329	41,310.9
Arable, thousand hectares	32,541.3	32,543.4	32,544.3	32,698.5	32,757.3
Hayfields, thousand hectares	2,406.4	2,402.9	2,399.4	2,294.4	2,283.9
Pastures, thousand hectares	5,434.1	5,430.9	5,421.5	5,282.6	5,250.3
Fallows, thousand hectares	233.7	230.6	229.3	190.5	166.7
Perennial plantings, thousand hectares	892.4	897.1	894.8	863	852.7

Source: *[7; 19]*

According to the study results, it is clear that the agro-industrial land is exploited less every year. As a result, less and less land is used for hayfields; the cultivated area increases. Thus, the study identified a set of problems, which allows proposing solutions. Firstly, authors summarise the data in Table 8.

***Table 8**. Agricultural sector problems and methods of their solution to ensure sustainable development*

Problem	→	Solution
The importance of agro-industry in the economy is decreasing	→	Increase of production not only of raw materials but also of finished products; agro-sector de-shadowing
Unstable production processes	→	Increasing automation of production processes; production diversification
Decreasing employment in agriculture	→	Incentives for small and medium-sized farmers; land reform and control of its implementation
Low wages	→	Improving skills through the automation of processes, which increases wages
Insufficient level of capital investment	→	Financing of small and medium-sized businesses
Decrease in the land fertility	→	Land reform and control over its implementation

***Source**: authors' development*

Based on the results presented in Table 1, the agribusiness industry's importance in the economy is gradually decreasing. Despite this, according to the Minister of Agrarian Policy and Industry of Ukraine [21], the current indicators are not maximum. Agro-industry can work much more productively and has massive potential for growth. To bring this agriculture to a new level, it is necessary to develop industry by raw materials production and the finished food-product production. A vital part of sustainable development is also the shadowing of agriculture. According to experts, 30-40% of the land is cultivated without paying taxes. The scheme for forming such a market makes provision for the land received for personal development to be leased [22]. Based on the results presented in Table 2, there is empirical evidence that agricultural production is unstable. Yu. Kuznetsova [23] and S.E. Pogodiaev [24] consider the agricultural production stability through the lens of eliminating sharp declines and fluctuations year by year with minimal adverse effects. The following sustainability criteria meet these definitions: growth in production; uniform production flow without interruptions by years; provision of planned yields under any weather conditions; provision of planned gross yields; the ability of agricultural systems to withstand adverse weather conditions; ability to diversify production [18].

Directing the agricultural management policy to solve the problem in this area will stabilise the farm production and form its sustainable importance in the country's economic development. An essential component in solving this problem is the production process automation, which will improve logistics, information collection, data processing, and company activities simulation depending on weather conditions. Some experts believe that the launch of the agricultural land market is an influential factor in the near Ukrainian reality. Evidently, Ukraine's place in the global food market will only increase [25]. Other experts, on the contrary, believe that the launch of the market will create non-competitive conditions for small and medium-sized farming. In particular, this is due to the following reasons:

– small farmers do not have enough finances to purchase land, and bank lending provides a rate of 12% – which further aggravates the problem;

– there are problems with the documentation of land through the high cost of notary services; consequently, many lands are not properly registered, which creates the issue of land grabbing and raiding [26].

To solve the issue, it is necessary to create conditions to stimulate the purchase of land by small farmers [27], which can be solved with the help of the Partial Credit Guarantee Fund in agriculture [28]. In addition, securitisation, which allows lenders to convert illiquid assets into liquid, profitable securities, is now considered an alternative financing tool. Such a system aims to reduce risks for agribusiness creditors, but in the definitive version, the benefits are accrued to the agribusiness producer [29]. Analysis of employment in agriculture confirms the sector's importance for population employment, especially the rural population, but the employment rate of people in agriculture is decreasing every year. Digitalisation of all agricultural production processes is recognised as the future trend. McKinsey [30] estimates that by 2030, the number of farming jobs in developed countries will decrease by 15-35% due to automation. It is possible that the industry could go without human resources at all. For example, in 2017, an experimental farm in Britain managed to grow and harvest crops with no human involvement [31].

Combine harvesters already know how to work the fields without drivers, and programmes have been trained to make the best decisions on agricultural operations. Signals from sensors about soil chemistry, wind, sun intensity, moisture, operations per square meter of field, plant parasites, and diseases are collected and processed using unique algorithms. As a result, the farmer receives recommendations on fertilisers, pesticides, personnel work quality, the necessary work plan, yield estimates, and even best prices for contracting. The farmer's approved decisions then go to the input of the self-directed farming equipment software. The entire workforce is connected into a single system where each worker's work and corresponding financial results are visible. The workforce of the agricultural sector can be formed not by low-skilled personnel but, on the contrary, highly qualified in the field of intelligent technology, which with the use of their developments and robotics, can bring the agricultural industry to a new level. It will also change the salary level in the industry, which is going to be higher than the usual IT (information technology)-sector wages. If today the agricultural worker's wage level is 84% of the average one, it will be ten times higher with automation of processes. Practice in Britain has shown that this is already a reality, and farming is increasingly like a computer game [31]. A study by the World Economic Forum [32] points to a list of technologies that will shape the future of the agribusiness sector over the next 12 years. Each development will bring tremendous benefits to farmers globally:

– produce condition monitoring technologies that will save 20 million tonnes of food from loss;

– mobile services will create $200 billion in profits and reduce drinking water losses by 100 billion cubic metres;

– big data analytics will create over $70 billion in profits for farmers and increase production by 150 million tonnes;

– Internet-of-Things for supply chain tracking will reduce production losses by 35 million tonnes;

– blockchain for record-keeping will reduce production losses by 30 million tonnes;

– precision agriculture will reduce costs by $100 billion, increase production by 300 million tonnes, and reduce water use by 180 billion cubic feet;

– alternative energy would create $100 billion in profits, add 530 million tonnes of production, and reduce water use by 250 BCF;

– genetically modified foods, biologically active technology, and land quality management would generate $250 billion in profits for farmers.

But such a future is unrealistic for economic conditions in the short term. According to well-known researchers O. Prysyazhnyuk and M. Plotnikova [33], the availability of natural and labour resources, significant intellectual potential, real financial capabilities of the state, and a favourable foreign economic environment provide the conditions necessary for sustainable development agricultural development. The authors believe that a high employment level in agriculture is an important aspect of the country's sustainable development. At the current development stage, it is necessary to ensure an increase in production, which will contribute to improving the level and life quality of the population [34]. Thus, the main state development dilemma arises, which can take one of the following two routes: by automating agriculture, increasing its productivity but also reducing the level of employment, or by maintaining and increasing the level of rural employment by encouraging the development of small and medium-sized businesses. Today, automated control of agricultural processes occurs only on 3% of the land, and such technologies are used only by large agricultural holdings. It is necessary to create affordable financing for farmers to bring these technologies to a more progressive level. Future research will aim to find a harmonious solution to the agricultural sector development through the automation of processes, but not to the detriment of employment.

CONCLUSIONS

According to the study results, it is possible to determine the main development directions of the agro-industry sector in the context of sustainable development based on current problems. Despite the agricultural sector instability, defined by the current state analysis result, it is still an essential sustainable development component. But the importance of agro-industry in the country's GDP gradually gives way to other economic sectors. To solve this problem, it is necessary to redirect the agricultural strategy from raw material to finished product production. Also, it will be essential to establish control over land use in this context and introduce tools for the sector's de-shadowing. Agricultural production is characterised by unstable production. The most unstable sectors are wool. The production of cereals and industrial crops is also characterised by asynchrony. To solve the problem, it is necessary to bring production to a new technological level and implement diversification strategies to smooth out productivity jumps.

Agriculture is essential in employment, mainly rural work, but it is characterised by a gradual decline in labour use due to production process automation. To date, the labour cost in the agricultural sector is below the average wage in Ukraine. To solve this problem, it is necessary to have a mechanism to stimulate industry automation by financing small and medium-sized farming and controlling the land reform so that the rural population develops agriculture rather than transferring land to large agricultural holdings. Today, experts insist that IT and agribusiness uniting is essential for agricultural development, so capital investments in agribusiness are insufficient. However, the current situation shows that capital investments do not contribute to industry development. To change the situation, state funding programmes, which will ease the acquisition of new technologies by large agricultural holdings and medium and small farmers, are needed. The environmental issue of devastation and decreasing land fertility is solved by land reform controlling, particularly ensuring that land is not leased out on a short-term basis but is carefully used as a long-term asset that contributes to sustainable economic development. The research's practical value lies in the possibility of implementing the recommendations at the macro and microeconomic levels. Further research forms the automation processes in agriculture that small and medium-sized farmers can access.

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Сталий економічний розвиток України крізь зростання сільськогосподарського сектора

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Анотація. Актуальність дослідження зумовлена комплексом невирішених досі проблем продуктивності агропромислового сектора, зниженням рівня зайнятості, низьким рівнем заробітної платні та зниженням продуктивності землі. Стаття присвячена пошуку напрямів розвитку агропромислового сектору, які пропонуватимуть сталі рішення, базуючись на зазначених проблемах. Мета статті полягає в розробці рішення основних проблем аграрного сектору, які сприятимуть його довгостроковому сталому розвитку. У статті розробляється методологія аналізу та використовуються статистичний аналіз, теорія ймовірності та загальні методи наукового пізнання. У статті висунуто низку гіпотез, пов'язаних з розвитком аграрного сектору, та наведено таблицю у форматі «проблема-рішення». Доведено, що сільське господарство України знаходиться під сильним впливом економіки та зайнятості населення. Сільське господарство характеризується нестабільністю, низьким рівнем заробітної платні та збільшенням площі земель, відведених під рослинництво з одночасним зменшенням площі земель для тваринництва. Запропоновано такі методи для вирішення зазначених проблем: трансформація ринків готових продуктів харчування, диверсифікація виробництва, детінізація сектору, підвищення автоматизації сільського господарства, контроль земельної реформи, державні програми зі стимулювання сільського господарства. Новизна дослідження полягає у розробленій авторами методології аналізу сталого розвитку крізь призму зростання аграрного сектора. Практична цінність дослідження полягає у можливості імплементації рекомендацій на мікро- та макроекономічному рівнях. Подальше вивчення формує автоматизацію процесів у сільськогосподарській галузі, доступну дрібним та середнім фермерам

Ключові слова: сільське господарство, автоматизація, земельна реформа, експорт

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